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Review article

Effects of Plyometric Jump Training on Vertical Jump Height of Volleyball Players: A Systematic Review with Meta-Analysis of Randomized-Controlled Trial

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Abstract

This meta-analysis aimed to assess the effects of plyometric jump training (PJT) on volleyball players' vertical jump height (VJH), comparing changes with those observed in a matched control group. A literature search in the databases of PubMed, MEDLINE, Web of Science, and SCOPUS was conducted. Only randomized-controlled trials and studies that included a pre-to-post intervention assessment of VJH were included. They involved only healthy volleyball players with no restrictions on age or sex. Data were independently extracted from the included studies by two authors. The Physiotherapy Evidence Database scale was used to assess the risk of bias, and methodological quality, of eligible studies included in the review. From 7,081 records, 14 studies were meta-analysed. A moderate Cohen's *d* effect size (ES = 0.82, p <0.001) was observed for VJH, with moderate heterogeneity (I^2 = 34.4%, p = 0.09) and no publication bias (Egger's test, p = 0.59). Analyses of moderator variables revealed no significant differences for PJT program duration (≤8 vs. >8 weeks, ES = 0.79 vs. 0.87, respectively), frequency (≤2 vs. >2 sessions/week, ES = 0.83 vs. 0.78, respectively), total number of sessions (≤16 vs. >16 sessions, ES = 0.73 vs. 0.92, respectively), sex (female vs. male, ES = 1.3 vs. 0.5, respectively), age (≥19 vs. <19 years of age, ES = 0.89 vs. 0.70, respectively), and volume (>2,000 vs. <2,000 jumps, ES = 0.76 vs. 0.79, respectively). In conclusion, PJT appears to be effective in inducing improvements in volleyball players' VJH. Improvements in VJH may be achieved by both male and female volleyball players, in different age groups, with programs of relatively low volume and frequency. Though PJT seems to be safe for volleyball players, it is recommended that an individualized approach, according to player position, is adopted with some players (e.g. libero) less prepared to sustain PJT loads.

Key words: human physical conditioning; resistance training; stretch-shortening cycle; physical fitness; exercise therapy; team sports.

Introduction

Volleyball is a team sport characterized by periods of short duration (i.e. 3–9 s), high-intensity activities, interspersed with relatively long periods (i.e. 10-20 s) of recovery time (Polglaze and Dawson, 1992). Although the actions performed by players may vary in terms of their individual roles' technical and tactical requirements, common movements include running accelerations and decelerations, jumping, ball-striking, and multidirectional locomotion (Sheppard et al., 2007). Specifically, jump height has previously been shown to be related to performance in volleyball (Ziv and Lidor, 2010). Indeed, scoring actions (i.e., spike, block and serve) are mainly performed while jumping vertically (Sheppard et al., 2007; 2009). Accordingly, with the principle of training specificity in mind, volleyball players should systematically engage in jump-related training programs to improve their performance (Gabbett, 2016). In relation to this, plyometric jump training (PJT) programs have previously demonstrated similar, or even greater, improvements in vertical jump height (VJH) in volleyball players when compared to other types of training practices (Newton et al., 1999; 2006; Ziv and Lidor, 2010).

Because of the demands of volleyball, players regularly incorporate PJT in their training schedules (Silva et al., 2019; Ziv and Lidor, 2010) and several studies have demonstrated the positive effects of this. For example, after six weeks of PJT, VJH was assessed in 14-year-old female volleyball players, with an 11% improvement observed after the intervention (Martel et al., 2005). In addition, an eight-week PJT intervention in ~24-year-old male and female volleyball players showed substantial improvement in VJH (~6%) after training (Behrens et al., 2014). However, despite this, some studies have shown conflicting results (Kristicevic et al., 2016; Leporace et al., 2013; Mroczek et al., 2018; Taube et al., 2012; Voelzke et al.,

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2012) which could be related to small sample sizes. Indeed, PJT studies among volleyball players regularly have used small cohorts, with a mean of 13 participants per study (Ramirez-Campillo et al., 2018a). The problem of underpowered interventions seems common in the PJT literature and a recent scoping review, which included 420 studies, supports this observation with very small sample sizes (~10 participants per study) apparent (Ramirez-Campillo et al., 2020). Accordingly, the problem of underpowered studies may be addressed by conducting a meta-analysis and pooling the results of several studies to increase total statistical power (Liberati et al., 2009). This approach facilitates the drawing of stronger inferences of the effectiveness of PJT in the population of interest.

To our knowledge, there are no meta-analyses that have addressed the effects of PJT on measures of physical fitness in volleyball players and, more specifically, on a measure closely related to sports performance that is VJH. Although several types of jumps are performed during a volleyball match (e.g., spike jump, block jump), muscular power in volleyball players is most commonly assessed through some form of countermovement jump (CMJ) (Laffaye et al., 2014; Silva et al., 2019; Ziv and Lidor, 2010). The CMJ is an appropriate measure of muscular power, requiring utilization of the stretch-shortening cycle (Harman, 2006). The measure also presents a very high test-retest reliability (Slinde et al., 2008), a key issue for meta-analyses (Liberati et al., 2009). Moreover, compared to other jumps (i.e. spike jump) the CMJ is not coordinatively challenging and so changes may reflect physiological, and biomechanical, rather than coordinative, mechanisms, thus allowing an assessment of an athlete's muscle power (Fuchs et al., 2019b). Although a generic jumping test, the CMJ still allows sport-specific patterns to be assessed among volleyball players (Laffaye et al., 2014).

It is noteworthy that a systematic review dealing with the effects of PJT on the measures of physical fitness (i.e., vertical jump; horizontal jump; strength; flexibility; agility/speed) in volleyball players was recently published (Silva et al., 2019). However, data from the included studies was not aggregated for a meta-analysis and the authors included others than randomized-controlled studies (Silva et al., 2019), which could affect the robustness of the research. In addition, no analysis was performed on key moderator variables such as training volume and frequency, intervention duration, or the sex of the volleyball players, among other factors (Fuchs et al., 2019b; Laffaye et al., 2014). This has resulted in a gap in the literature related to the magnitude of the effects of PJT on VJH in volleyball players (Fusar-Poli and Radua, 2018).

Given the above evidence and considering: (i) the greater scientific awareness of the relevance of PJT, evidenced by a 25-fold increase in PJT-related scientific publications from 2000 to 2017 (Ramirez-Campillo et al., 2018a), (ii) the inconsistent findings on the effects of PJT interventions on VJH in volleyball players and (iii) the problem of underpowered studies, this meta-analysis aimed to assess the effects of PJT on volleyball players' VJH, comparing changes with those observed in a matched control group.

Methods

Search strategy

This systematic review and meta-analysis comply with the guidelines of the Cochrane Collaboration (Green and Higgins, 2005). Findings were reported under the Preferred Reporting Items for Systematic Reviews and Meta-Analyses recommendations (PRISMA) (Liberati et al., 2009).

Eligibility criteria

The *a priori* inclusion criteria for this meta-analysis were as follows: i) randomized-controlled studies that incorporated a PJT program of at least 2 weeks duration, and which included lower-body jumping, bounding, or hopping actions that commonly utilize a pre-stretch or countermovement that incites usage of the stretch-shortening cycle (Chu and Myer, 2013; Moran et al., 2018a; Ramirez-Campillo et al., 2018a), ii) cohorts of healthy volleyball players (with no restriction for age or sex) iii) a measure of VJH that was selected based on a logically defensible rationale (Moran et al., 2018a; Turner and Bernard, 2006), most often assessed with some form of CMJ.

Only peer-reviewed articles were included in the meta-analysis. Articles were excluded if they were cross-sectional, a review, or a training-related study that did not focus on the effect of PJT exercise. Also excluded were retrospective/prospective studies, studies in which the use of jump exercises was not clearly described, studies for which only the abstract was available, case reports, non-human investigations, special communications, repeated-bout effect interventions, repeated references, 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, ignoring the detraining period in the analysis. Grey literature sources (e.g., conference proceedings) were also considered if a full-text version was available. Finally, studies that were not published in English were not explored.

Information sources

Two authors systematically searched the databases PubMed, MEDLINE, Web of Science, and SCOPUS for relevant studies up to August 1st, 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" and "OR" was applied. The words "ballistic", "complex", "explosive", "force-velocity", "plyometric", "stretch-shortening cycle", "jump", "training", and "volleyball" were used. Following is an example of a PubMed search: (((((((((("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 "volleyball"[Title/Abstract]) OR "volleyball players"[Title/Abstract]) OR "volleyball/physiology" [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 the initiation of manuscript preparation on October 2nd, 2019. Following the formal systematic searches, additional hand-searches were conducted. In addition, the reference lists of included studies and previous reviews and meta-analyses were examined to detect studies potentially eligible for inclusion.

Study selection

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 this process independently. Potential discrepancies between the two reviewers, concerning study data or characteristics, were resolved by consensus with a third author. The reasons for excluded articles were recorded.

Data collection process

Data were extracted from gathered articles independently by two authors using a custom made Microsoft Excel data matrix (Microsoft Corporation, Redmond, WA, USA).

Data items

VJH was chosen as the main outcome measure for this meta-analysis because of its relevance for volleyball players (Gabbett and Georgieff, 2007; Polglaze and Dawson, 1992; Sheppard et al., 2007; 2009) and high reliability (Slinde et al., 2008).). It is commonly reported as peak jump height (cm) although it may also be reported as power (W), velocity (m.s^{-1}), or in other similar units.

Extracted data also included the following information: year of publication, quality of PJT treatment description, type of control, method of randomization used, and the number of participants per group. In addition, participants' sex, age (years), body mass (kg), height (m), previous experience with PJT (yes/no), and sport level (e.g., professional, amateur) were extracted. Regarding PJT characteristics, extracted data also included the frequency of training (days/week), duration (weeks), level and indicators of intensity (e.g., maximal velocity; submaximal height), jump box height (cm), number of total jumps completed during the intervention, types of jump drills performed, the combination (if applicable) of PJT with another form of training type, rest time between sets (s), rest time between repetitions (s), rest time between sessions (hours), type of jumping surface (e.g., grass), type of progressive PJT overload (e.g, volume-based; technique-based), training period of the year (e.g., in-season), details on the replaced portion of the regular training with PJT (if applicable) and tapering strategy (if applicable). In addition, novel aspects and potential limitations of the studies were recorded for a more comprehensive qualitative appraisal of meta-analysis outcomes in the discussion. A complete description of the aforementioned PJT characteristics has been previously published (Ramirez-Campillo et al., 2018a).

Risk of bias in individual studies

The Physiotherapy Evidence Database (PEDro) scale was used to assess the risk of bias and methodological quality of the included studies. This scale evaluates internal study validity on a scale from 0 (high risk of bias) to 10 (low risk of bias). As in a similar previous PJT meta-analysis (Stojanović et al., 2017), the quality assessment was interpreted as follows: ≤3 = poor quality; 4–5 = moderate quality; 6–10 = high quality. If trials had already been assessed and listed on the PEDro database (or similar sources), their scores were adopted.

Two independent reviewers performed this process and, in the event of a disagreement about the risk of bias, a third reviewer verified the data and executed the final decision on it. Agreement between reviewers was assessed using a Kappa correlation for risk of bias. The agreement rate between reviewers was k=0.82.

Summary measures

Meta-analyses were conducted when at least three studies provided enough data for effect sizes (ES) calculation (Garcia-Hermoso et al., 2019; Moran et al., 2018a; Skrede et al., 2019). Means and standard deviations for a measure of post-intervention VJH (commonly reported as some form of CMJ height) were used to calculate an ES (Cohen's *d*). When data values from a study were not available (Behrens et al., 2014; Maffiuletti et al., 2002), the corresponding author was contacted to provide information. When no response was obtained, software was used to obtain mean and standard deviation values (GetData Graph Digitizer; http://getdata-graph-digitizer.com/index.php) from graphical data.

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 (Deeks et al., 2008) and facilitates analysis while accounting for heterogeneity across studies (Kontopantelis et al., 2013). This approach was used to account for the inaccuracy in the estimate of between-study variance (Hardy and Thompson, 1996). Cohen's *d* ESs are presented alongside 95% confidence intervals (CIs) and interpreted according to sport-related criteria: <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 (Hopkins et al., 2009). In cases in which there was more than one intervention group, the control group was proportionately divided to facilitate comparison across all participants (Higgins et al., 2008). All analyses were carried out using the Comprehensive Meta-Analysis program (version 2; Biostat, Englewood, NJ, USA).

Synthesis of results

To gauge the degree of heterogeneity amongst the included studies, the percentage of total variation across the studies due to heterogeneity (Higgins et al., 2003) was used to calculate the I^2 statistic. This represents the proportion of effects that are due to heterogeneity as opposed to chance (Liberati et al., 2009). Low, moderate, and high levels of heterogeneity correspond to I^2 values of <25%, 25-75%, and >75%, respectively (Higgins and Thompson, 2002;

Higgins et al., 2003). However, these thresholds are considered tentative (Higgins et al., 2003). 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, provide evidence of heterogeneity of intervention effects beyond those attributed to chance (Deeks et al., 2008).

Risk of bias across studies

The risk of bias across studies was assessed using the extended Egger's test (Egger et al., 1997). Sensitivity analyses were conducted to assess the robustness of the summary estimates to determine if a particular study accounted for the heterogeneity. Thus, to examine the effects of each study outcome on the overall findings, results were analyzed with each study deleted from the model once. We acknowledge that other factors, such as differences in trial quality or true study heterogeneity, could produce asymmetry.

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*. The moderator variables of program duration (weeks), training frequency (sessions per week), total number of training sessions and the total number of jumps were chosen based on the accepted influence of such factors on adaptations to exercise (Pescatello et al., 2015), as previously demonstrated in meta-analyses (Moran et al., 2018b; 2019). Participants were divided using a median split (Moran et al., 2017; 2018b; 2019) for PJT duration (≤8weeks vs. >8 weeks), frequency (≤2 sessions/week vs. >2 sessions/week), total number of sessions (≤16 sessions vs. >16 sessions), and total volume of jumps (>2,000 jumps vs. <2,000 jumps). Meta-analyses stratification by each of these factors was performed with a p-value of <0.05 considered as the threshold for statistical significance. Although not considered *a priori*, the sex (female vs. male) and age (≥19 years of age vs. <19 years of age) of the participants in the included studies were also considered for analysis as moderator variables.

Results

Study selection

Figure 1 provides a graphical schematization of the study selection process. Through database searching, 7,081 records were initially identified. From these, duplicates were removed (n = 4,811) before study titles were screened and removed for relevance (n = 1,053). After this, article abstracts were screened for relevance with 797 studies being removed. We then inspected full articles and after applying all inclusion/exclusion criteria, were left with 14 randomized-controlled trials eligible for meta-analysis (Amato et al., 2018; Behrens et al., 2014; Çimenli et al., 2016; Fathi et al., 2019; Gjinovci et al., 2017; Idrizovic et al., 2018; Kamalakkannan et al., 2011; Maffiuletti et al., 2002; Martel et al., 2005; Newton et al., 1999; Pereira et al., 2015; Turgut et al., 2016; Usman and Shenoy, 2015; 2019). These studies comprised of 20 separate experimental groups and 322 participants involved in PJT interventions.

Study characteristics

The characteristics of PJT intervention programs and included participants are displayed in Table 1.

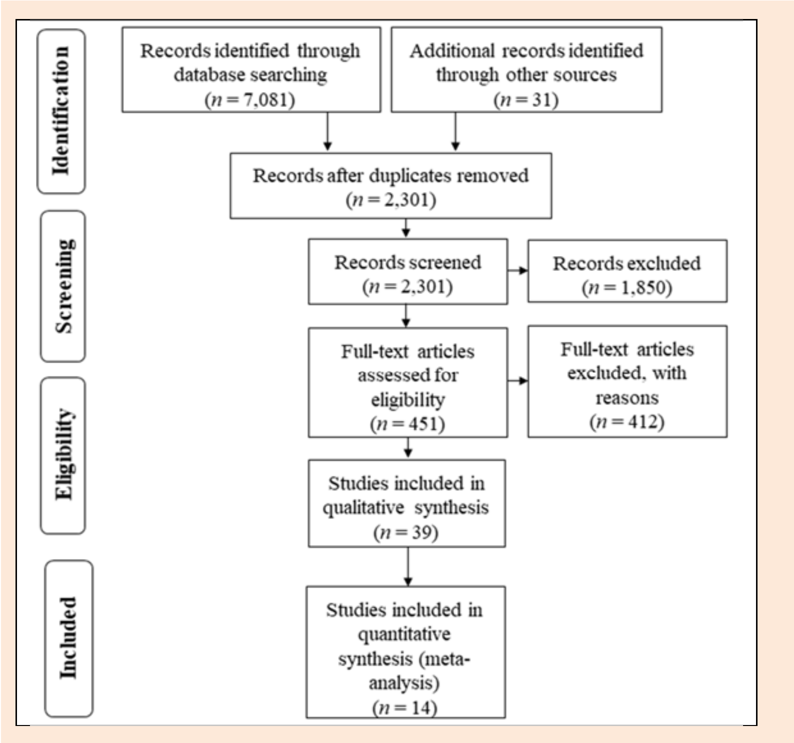


Figure 1. **PRISMA flow diagram.**

Table 1. Characteristics of PJT programs and included participants.

	N	Gender	A	BM	H	SPT	Fitness level*	Test	Freq	Wk	Int	BH	TJ	Type	Comb	RBSE	RBR	RBTS	Surf	PO	TP	R	T
Amato et al., 2018	12	NR	11.6	48.5	156	NR	MOD (>3 y of practice)	CMJ (cm)	2	6	NR	NA	880	Mix	Isometric squat	NR	NR	NR	NR	V	NR	NR	No
Behrens et al., 2014	13	M-F	24	77	183	No	Normal to MOD	CMJ (cm)	2	8	Maximal	40	972	Mix	No	90	4	3	Rigid	V	IS	A	No
Cimenli et al., 2016	12, wood 12, synthetic	M	18 to 24	73.7 83.1	184 185	NR	MOD to high	CMJA with step (cm)	3	8	NR	30 - 70	3,000	Mix	No	120	NR	48 - 72	Wood Synthetic	T, V	PS	NR	No
Fathi et al., 2019	20 (with RT) 20 (without RT)	M	14.7 14.6	68.7 67.9	177 178	No	NR	CMJ (cm)	2	16	Low, MOD and high	30 - 50 30 - 40	576 1,184	Mix	RT No	90	NR	≥48	NR	V, T, I	IS	NR	No
Gjinovci et al., 2017	21	F	21.8	60.8	176	Yes	High	CMJ (cm)	2	12	Low, MOD and high	NR	>924	Mix	No	120 - 240	NR	NR	NR	I, V	NR	A	No
Idrizovic et al., 2018	13	F	16.6	59.4	175	Yes	High	CMJ (cm)	1	12	Low, MOD and high	20 - 60	613	Mix	No	120 - 300	NR	168	Wood	V, T, I	PS	A	No
Kamalakkannan et al., 2011	12, water (with weights) 12, water (without weights)	NR	18 to 20	NR	NR	NR	Normal to MOD	CMJA (cm)	3	12	NR	NR	4,080	Mix	No	30 - 90	NR	NR	Water	V, T	NR	NR	Yes
Maffiuletti et al., 2002	10	M	21.8	80.5	191	NR	MOD	CMJ (cm)	3	4	Maximal	40	600	RBVJ	Electro stimulation	180	NA	NR	NR	No	PS	A	No
Martel et al., 2005	10	F	15	64	167	No	High	CMJA (cm)	2	6	Maximal	61	>138	Mix	No	30	NR	NR	Water	V	PS	A	No
Newton et al., 1999	8	M	19	84	189	Yes	High	CMJA (cm)	2	8	30-80% 1RM	NA	576	Loaded jump squat	No	NR	NR	NR	NR	No	PS	R	No
Pereira et al., 2015	10	F	14.0	52.0	160	No	MOD	CMJ (cm)	2	8	Maximal	NA	2,376	Mix	No	120 - 180	NR	48	NR	V, I	IS	A	No
Turgut et al., 2016	8, weighted jump rope 9, standard jump rope	F	15 14.1	59.4 57.7	166 165	NR	MOD to high	CMJA (W)	3	12	NR	NA	5,490 s	Rope jumps	No	30 , 40, 50, 60 (1:1 work: rest ratio)	NA	NR	NR	V	NR	R	No
Usman and Shenoy, 2019	30, plyo 30, plyo + stretching	M	19.6	66	176	No	MOD	CMJA (cm)	2	8	NR	30 - 80	2,976	Mix	No Stretching	60 - 600	5 -10	NR	NR	No	NR	NR	No
Usman and Shenoy, 2015	30, male 30, female	M F	19.2	66	176	No	MOD	CMJA (cm)	2	8	NR	30 - 80	2,976	Mix	No	60 - 300	5 -10	48 - 120	NR	No	NR	NR	No

A: age of subject (years); BH: box height for plyometric drop jumps (cm); BM: body mass (kg); CMJ: countermovement jump; CMJA: countermovement jump with arms; Comb: combined; F: female; Freq: frequency of training (days/week); H: height of participants (cm); Int: intensity of training. For maximal, this involved either maximal effort to achieve maximal height, distance, reactive strength index, velocity, or another marker of intensity; IS: in-season; M: male; MOD: Moderate; N: number of participants; PJT: plyometric jump training; PO: progressive overload, in the form of either volume (i.e., V), intensity (i.e., I), type of drill (i.e., T), or a combination of these; PS: pre-season; R: replacement of habitual training drills with plyometric jump training drills; RBR: rest between repetitions; RBSE: rest between sets and/or exercises; RBTS: rest between training sessions; RBVJ: repeated bilateral vertical jumps; RT: resistance training; SPT: systematic plyometric jump training experience; SSC: stretch-shortening cycle; Surf: surface type; T: tapering; TJ: total plyometric jumps; TP: training period of the season; Type: type of PJT drill. When "Mix" is indicated, this involved a combination of 2 or more of the following jumping drills: vertical, horizontal, bilateral, unilateral, repeated, non-repeated, lateral, cyclic, sport-specific, slow stretch-shortening cycle, fast stretch-shortening cycle; Wk: weeks of training. *Fitness level: 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. 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. Normal, for recreational athletes with <5 training hours per week with sporadic competitions' participation, and for physically active participants and school-age youths regularly involved in physical education classes.

Table 2. **Physiotherapy Evidence Database (PEDro) scale ratings.**

PEDro scale items*	N° 1	N° 2	N° 3	N° 4	N° 5	N° 6	N° 7	N° 8	N° 9	N° 10	N° 11	Total (from a possible maximal of 10)
Amato et al., 2018	1	1	0	1	0	0	0	1	1	0	1	5
Behrens et al., 2014	1	1	0	1	0	0	0	1	0	1	1	5
Cimenli et al., 2016	1	1	0	1	0	0	0	1	1	1	1	6
Fathi et al., 2019	1	1	0	1	0	0	0	1	1	1	1	6
Gjinovci et al., 2017	1	1	0	0	0	0	0	0	1	1	1	4
Idrizovic et al., 2018	1	1	0	1	0	0	0	1	1	1	1	6
Kamalakkannan et al., 2011	0	1	0	1	0	0	0	1	1	1	0	5
Maffiuletti et al., 2002	1	1	0	1	0	0	0	1	1	1	1	6
Martel et al., 2005	0	1	0	1	0	0	0	1	0	1	1	5
Newton et al., 1999	1	1	0	1	0	0	0	1	1	1	1	6
Pereira et al., 2015	0	1	0	1	0	0	0	1	0	1	1	5
Turgut et al., 2016	1	1	0	1	0	0	0	1	1	1	0	5
Usman and Shenoy, 2019	1	1	0	1	0	0	0	1	1	1	0	5
Usman and Shenoy, 2015	0	1	0	1	0	0	0	1	0	1	1	5

*: 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: September, 9, 2019)

Risk of bias within studies

From the studies included in the meta-analysis, nine achieved a quality assessment of 4-5 points, while the remaining five achieved a quality assessment of 6 points (Table 2).

Results of individual studies and synthesis of results

Across all included studies, there was a very large, significant improvement in VJH (ES = 2.079 [95%CI = 1.224-2.935], Z = 4.765, p <0.001). The relative weight of each study in the analysis varied between 3.41% and 5.27%, demonstrating a relatively equal weight distribution. In the sensitivity analysis to assess the robustness of the summary estimates, with each study deleted from the model once, the results remained consistent (i.e., p-value remain <0.05) across all deletions. However, when the results from one research group (Usman and Shenoy, 2015; 2019) were removed from the analysis, the improvement in VJH remained significant (p < 0.001) but the magnitude of the main effect decreased to 'moderate' (ES= 0.822; Figure 2).

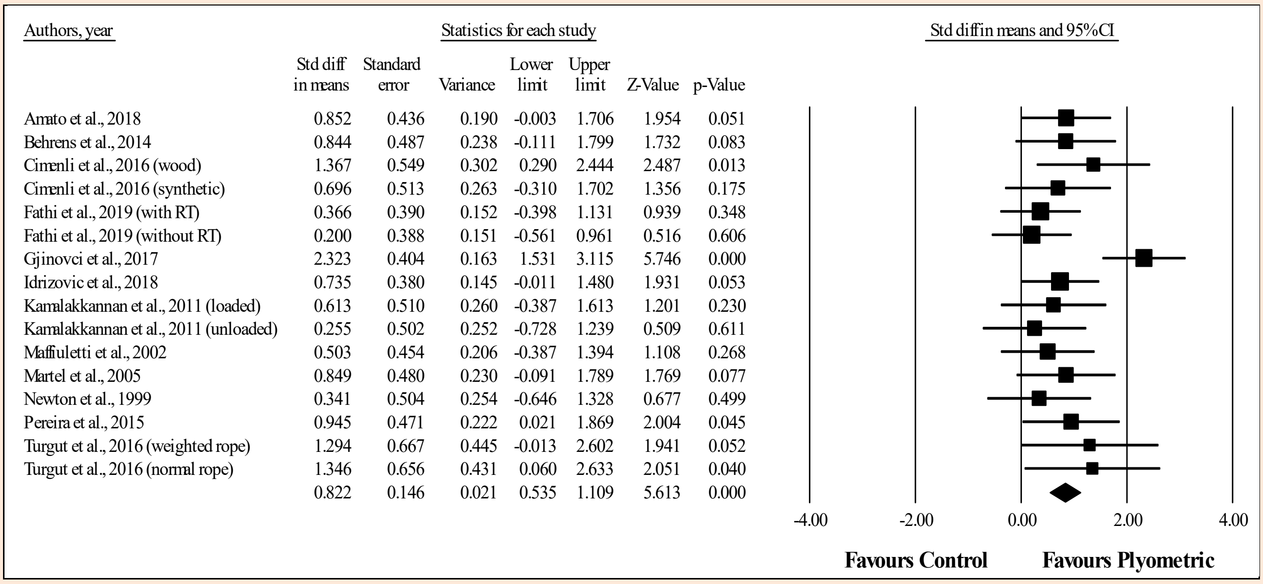
Risk of bias across studies

The percentage of total variation across the studies due to heterogeneity was moderate I^2 (34.4%, p = 0.087), and the Egger test was p = 0.59.

Additional analysis

The effect of moderator variables can be viewed in Table 3. No significant differences were noted for PJT duration (≤8 weeks vs. >8 weeks), frequency (≤2 sessions/week vs. >2 sessions/week), total number of sessions (≤16 sessions vs. >16 sessions), total volume of jumps (>2,000 jumps vs. <2,000 jumps), sex (female vs. male) or age (≥19 years of age vs. <19 years of age).

Regarding adverse effects, none of the studies reported evidence of significant soreness, pain, fatigue, injury, damage, or any other adverse event that resulted in dropouts from the PJT programs.



Authors, year	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Amato et al., 2018	0.852	0.436	0.190	-0.003	1.706	1.954	0.051
Behrens et al., 2014	0.844	0.487	0.238	-0.111	1.799	1.732	0.083
Cimenli et al., 2016 (wood)	1.367	0.549	0.302	0.290	2.444	2.487	0.013
Cimenli et al., 2016 (synthetic)	0.696	0.513	0.263	-0.310	1.702	1.356	0.175
Fathi et al., 2019 (with RT)	0.366	0.390	0.152	-0.398	1.131	0.939	0.348
Fathi et al., 2019 (without RT)	0.200	0.388	0.151	-0.561	0.961	0.516	0.606
Gjinovci et al., 2017	2.323	0.404	0.163	1.531	3.115	5.746	0.000
Idrizovic et al., 2018	0.735	0.380	0.145	-0.011	1.480	1.931	0.053
Kamalakkannan et al., 2011 (loaded)	0.613	0.510	0.260	-0.387	1.613	1.201	0.230
Kamalakkannan et al., 2011 (unloaded)	0.255	0.502	0.252	-0.728	1.239	0.509	0.611
Maffiuletti et al., 2002	0.503	0.454	0.206	-0.387	1.394	1.108	0.268
Martel et al., 2005	0.849	0.480	0.230	-0.091	1.789	1.769	0.077
Newton et al., 1999	0.341	0.504	0.254	-0.646	1.328	0.677	0.499
Pereira et al., 2015	0.945	0.471	0.222	0.021	1.869	2.004	0.045
Turgut et al., 2016 (weighted rope)	1.294	0.667	0.445	-0.013	2.602	1.941	0.052
Turgut et al., 2016 (normal rope)	1.346	0.656	0.431	0.060	2.633	2.051	0.040
	0.822	0.146	0.021	0.535	1.109	5.613	0.000

Figure 2. **Forest plot of increases in vertical jump height (muscular power) in volleyball players participating in plyometric jump training compared to controls.** Values shown are effect sizes with 95% confidence intervals (CI). *Std diff:* standard difference.

Table 3. Effect of moderator variables on vertical jump performance.

Subgroup	Effect size with 95% confidence interval	Effect descriptor	Groups	*n*	Within-group I2 (%)	Within-group p^a	Between-group p^b
≤8 weeks	0.787 (0.452 – 1.122)	Moderate	8	154	0.0	<0.001	0.811
>8 weeks	0.866 (0.314 – 1.418)	Moderate	8	192	65.6	0.002	
≤2 sessions/week	0.832 (0.398 – 1.266)	Moderate	9	229	57.3	<0.001	0.866
>2 sessions/week	0.781 (0.384 – 1.179)	Moderate	7	117	0.0	<0.001	
≤16 sessions	0.730 (0.394 – 1.066)	Moderate	7	148	0.0	<0.001	0.558
>16 sessions	0.916 (0.393 – 1.439)	Moderate	9	198	62.2	0.001	
Female	1.251 (0.696 – 1.807)	Large	6	101	50.1	<0.001	0.164
Male	0.505 (0141 – 0.868)	Small	6	172	0.0	0.006	
≥19 years of age	0.891 (0.362 – 1.421)	Moderate	8	220	59.3	0.001	0.549
<19 years of age	0.703 (0.388 – 1.018)	Moderate	8	102	0.0	<0.001	
>2,000 jumps	0.761 (0.317 – 1-206)	Moderate	5	178	0.0	0.001	0.540
<2,000 jumps	0.785 (0.348 – 1.221)	Moderate	9	127	58.2	<0.001	

[a]: test of null (2-tail), mixed model; [b]: *p*-value, heterogeneity, total between, mixed model.

Discussion

This meta-analysis aimed to assess the effects of PJT on volleyball players' VJH, comparing changes with those observed in matched control groups. To our knowledge, this is the largest and most complete database search conducted so far about the effects of PJT in volleyball players. From records we retrieved, 14 studies were eligible for inclusion in the final analysis. The main finding of this study indicates that PJT improves VJH in volleyball players compared with a control condition (ES = 0.822). This finding complements those from previous reviews (Silva et al., 2019; Ziv and Lidor, 2010) that supported the use of PJT to increase VJH in volleyball players. However, a wide range of magnitudes of VJH improvements was noted among the studies included in this meta-analysis. This may be due to differences between PJT programs (e.g., frequency, duration, total number of PJT sessions) and, indeed, this is partially supported by the moderate level of heterogeneity we observed across the included studies (I^2 = 34.4%). To analyse this possibility, the effects of potential moderator variables were explored in this study.

The analysis of moderator variables revealed that interventions with ≤2 sessions per week and those with >2 sessions per week produced near-equal moderate effects on VJH (ES = 0.781 - 0.832), with no significant differences between the two intervention groups (p = 0.866). Previously, PJT meta-analyses (de Villarreal et al., 2009a; Moran et al., 2019) also observed no significant subgroup differences or correlation for training frequency and vertical jump gains. This may indicate that the content of individual training sessions appears to be more important than the frequency with which those sessions are performed. In support of this finding, one study (Ramirez-Campillo et al., 2018d) contrasted the effect of one vs. two PJT sessions per week, equated for total volume, intensity, and jumping drills, and found similar gains in physical fitness variables, including VJH. Despite this result, current findings must be considered with caution, as a limited number of studies were available for the analysis of the moderator role of PJT frequency. Moreover, such a limited number of studies precluded further analyses regarding the effect of PJT frequency with respect to age and sex. On this, the PJT studies that included either males or females did demonstrate similarly significant increases in VJH, with no significant differences between them; however, a greater magnitude was found in females (ES = 1.3) vs. males (ES = 0.5). Likewise, moderate improvements in VJH were observed among athletes irrespective of age (<19 vs. ≥19 years old; ES = 0.703 – 0.891).

Regarding PJT duration, the current meta-analysis shows that programs of ≤8 weeks demonstrated a moderate effect (ES = 0.787), similar to those that lasted >8 weeks (ES = 0.866), with no significant group differences (*p* = 0.811). Similarly, the total volume of jumps completed during interventions (<2,000 vs. >2,000 jumps) produced comparable significant improvements in VJH (ES = 0.761 - 0.785). Of note, interventions that used <2,000 jumps applied a mean of ~42 jumps per PJT session whereas interventions that used >2,000 jumps applied ~160 jumps per session. Previous meta-analyses concluded that ~50 jumps per session resulted in significant improvements in VJH (de Villarreal et al., 2009b), whereas ~40 jumps per session (de Villarreal et al., 2010), and ~80 jumps per session (Saez de Villarreal et al., 2012) resulted in significant improvements in strength (e.g., 1RM squat and leg press, maximal isometric strength) and sprint performance, respectively. Accordingly, volleyball players may improve VJH with a low to moderate volume of PJT. This may help to avoid excessive PJT loads which could otherwise lead to increased injury risk, especially among females (Brumitt et al., 2016). In this sense, practitioners should carefully assess if they are prescribing too much PJT for their athletes, based on the demands of volleyball, resulting in needless additional training. This is particularly important, considering the high volume of jumps that volleyball players usually perform during technical training sessions and competitions (Garcia-de-Alcaraz et al., 2020).

For the total number of PJT sessions as a moderator variable, our data showed that programs which included ≤16 sessions demonstrated a moderate effect (ES = 0.730), similar to those that included >16 sessions (ES = 0.916), with no significant group differences found (p = 0.558). Although it may be enticing to assume that greater improvements in VJH can be achieved with a greater number of PJT sessions, other key PJT moderator variables must be considered (Ramirez-Campillo et al., 2018a). For instance, PJT intensity has been defined as the training-induced strain delivered to muscles, connective tissue, and joints (Ebben, 2007). In the current meta-analysis, PJT intensity was not precisely reported in eleven of the 20 experimental groups included in the analyses, precluding a robust analysis of this moderator. The lack of detailed reporting of PJT intensity seems to be a common and unfortunate characteristic of the PJT literature (Ramirez-Campillo et al., 2018a). However, preliminary studies have attempted to identify adequate PJT intensities in both young and elite athletes, including volleyball players (Andrade et al., 2017; Ramirez-Campillo et al., 2018b) while anecdotal recommendations of PJT intensities are also available in the literature (Piper and Erdmann, 1998). To date, only a few well-controlled studies (Ramirez-Campillo et al., 2018b; 2019) have examined the potential effects of different PJT intensities on components of physical fitness in athletes and/or physically active subjects and, of note, none of these studies were conducted in volleyball players. Accordingly, the selection of an appropriate jump type in PJT programs (e.g., depth jump vs. CMJ) and intensity level in jump-oriented sports, such as volleyball, remains an unsolved research problem at this stage.

Some potential limitations should be acknowledged in this study. Scientific publications on PJT have considerably increased in number from 2000 to 2017 (Ramirez-Campillo et al., 2018a). Indeed, the output of research during that time is 25 times greater than that in the period up to that point. Despite this, only 14 studies conducted in volleyball players were eligible for this meta-analysis. This relatively low number of randomized-controlled studies is surprising considering that volleyball is an Olympic sport played on a worldwide basis. However, this is not a problem unique to volleyball as over 40% of all PJT studies have failed to incorporate an active or passive control group or randomized samples of participants (Ramirez-Campillo et al., 2018a). Therefore, more effort should be made to overcome such limitations and improve study quality. Methodologically, the dichotomization of continuous data (e.g., ≤8 weeks compared to >8 weeks) with the median split technique could result in residual confounding and reduced statistical power (Altman and Royston, 2006) in the current meta-analyses. In relation to this, the moderator effects of program variables were calculated independently, and not interdependently. The univariate analysis must be interpreted with caution because the parameters of the program were calculated as single factors, irrespective of between-parameter interactions (Moran et al., 2018a).

The lack of adverse responses to PJT is encouraging. Although current evidence points toward the safety of PJT exercise in general, practitioners should take a cautious approach to programming. In addition, the reader must consider the lack of uniformity in the way training programs were prescribed and tested (i.e., potential sources of heterogeneity). For instance, the role of exercise intensity was not considered and would vary by points of contact (single-leg *versus* double-leg drills), speed of motion, height or length of drill, and body mass (Potach and Chu, 2008). Until more focused research is conducted, practitioners are advised to conform to general guidelines in the formulation of PJT programs, according to current scientific evidence, adapting them for their specific target group (Jiménez-Reyes et al., 2017; 2019; Ramirez-Campillo et al., 2018b; 2018c).

Regarding the methodological quality of the included studies in this meta-analysis, although all studies included achieved a moderate to high-quality score, no study scored higher than 6 on the PEDro scale. However, methodological quality was not an inclusion criterion as training studies present inherent challenges in applying practices such as blinding of testers and participants (Bedoya et al., 2015; Johnson et al., 2011; Stojanović et al., 2017). Indeed, from the included studies in this meta-analysis, none complies with the blinding of participants, therapists, or assessors. However, aside from blinding, a PJT scoping review (Ramirez-Campillo et al., 2020) noted several methodological shortcomings from 420 analyzed studies, such as the insufficient description of training interventions. This is in line with the current meta-analysis. For example, PJT intensity was not reported in six out of 14 studies. In the future, researchers are encouraged to be more rigorous in their methodological approach to implementing such reporting (e.g. intensity; PJT drills description) in PJT interventions.

Considering practical applications, current findings suggest that <2,000 jumps (i.e. ~40 jumps per session) or >2,000 jumps (i.e. ~160 jumps per session) as a total training volume offer similar improvements in VJH in volleyball players. In a similar vein, comparable effects were observed with ≤2 or >2 PJT sessions per week. Lower PJT volumes may reduce injury risk while lower PJT frequencies could allow players to devote more time to other key aspects of their preparation, whilst still optimizing adaptations to PJT. Regarding PJT duration, although programs ≤8 weeks demonstrated a similar effect as those >8 weeks, the longest study duration in the meta-analysis was 16 weeks. This period does not necessarily cover the full preparation period in the volleyball seasonal cycle; thus, inferences about longer-term PJT effects are limited at this time. However, it is recommended that long-term approaches consider the monitoring of VJH parallel to changes in jumping strategy as this informs practitioners about biomechanical adaptations that may have affected jump performance (Fuchs et al., 2019a; 2019b). Such monitoring facilitates feedback regarding players' VJH development and could also serve as a method to screen for potential injury risks. Finally, rather than serving as a standalone training modality, PJT should be a component of an integrated approach to athletes' physical development, targeting multiple physical fitness qualities and aligning with the goals of long-term physical development strategies.

Conclusion

In conclusion, PJT appears to be effective in inducing improvements in volleyball players' VJH. Moreover, improvements can be achieved by both sexes from various age groups, with programs of relatively low volume and frequency. Though PJT seems to be safe for volleyball players, it is recommended that an individualized approach according to player position is adopted with some players (e.g. libero) less prepared to sustain PJT loads.

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Key points

- Vertical jump is a key physical ability in volleyball.
- Plyometric jump training programs are effective in improving vertical jump height in volleyball players.
- Improvements can be achieved by both sexes from various age groups, with programs of relatively low volume and frequency.

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