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Review article

The Effects of Assisted and Resisted Plyometric Training Programs on Vertical Jump Performance in Adults: A Systematic Review and Meta-Analysis

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Abstract
Traditional, assisted and resisted plyometrics are considered to be effective training methods for improving vertical jump performance. The purpose of this systematic review and meta-analysis was to compare effectiveness of traditional, assisted and resisted plyometric methods on vertical jumping ability in adults. Available literature was searched using MEDLINE (via EBSCO), SPORTDiscus (via EBSCO), Scopus and Web of Science databases. The methodological quality of studies was assessed using the PEDro scale. Peer-reviewed studies were accepted only if they met all eligibility criteria: (a) healthy adults mean age > 18 years (b) training program based on plyometric exercises (c) the study reported on vertical jump height for the countermovement jump or drop jump performance. Of the 5092 articles identified, 17 studies were included in the qualitative and quantitative analyses. Both funnel plot analysis and Egger's test ($p = 0.04$) indicated publication bias for the comparison of resisted plyometrics and control condition. No publication bias was found for the other meta-analyses ($p > 0.05$). The effects of the traditional and assisted plyometric methods, when compared with the control condition (a non-plyometric condition), on jump height were moderate (SMD = 0.68, 95% CI 0.37 to 0.99, $p < 0.0001$; SMD = 0.70, 95% CI 0.20 to 1.20, $p = 0.006$, respectively). The effects of the resisted plyometric methods, when compared with the control condition, on a jump height was small (SMD = 0.48, 95% CI 0.17 to 0.79, $p = 0.002$). There were no significant differences between the training effects of the assisted and traditional plyometric interventions on jump height (SMD = 0.62, 95% CI -1.66 to 2.91, $p = 0.59$), nor between the resisted and traditional plyometric training programs (SMD = 0.2, 95% CI -0.19 to 0.23, $p = 0.86$). Traditional, assisted and resisted plyometric methods are effective training modalities for augmenting vertical jump performance in healthy adults. Resisted and assisted plyometric methods are equally effective as the traditional plyometric method in improving vertical jumping ability in healthy adults.

Key words: Plyometric exercise, human physical conditioning, resistance training, lower limb, stretch-shortening cycle, vertical jump.

Introduction

Jumping ability has been considered as fundamental for successful performance in many sports (Sheppard et al., 2008). Depending on the sport, the importance of jumping ability can be affected by the direction of the jump. Considering the tactical nature of jumping activities in team sports like basketball, football (soccer) and volleyball, a vertical jump height is often considered to be critical performance outcome (Sattler et al., 2012). For example, a greater jump height achieved during a jump in basketball produces more favourable condition for shots and rebounds. In volleyball, the achievement of a greater jump height provides a clear advantage in the attack and block actions. Also, several studies have shown a positive association between jumping ability and other motor abilities (Wisløff et al., 2004; Maulder and Cronin, 2005).

The countermovement jump (CMJ) and drop jump (DJ) are reliable and valid for the evaluation of jumping performance (Arteaga et al., 2000; de Villarreal et al., 2009). At this point it is worth noting that both tasks represent different muscle action patterns (Flanagan and Comyns, 2008). The CMJ is classified as slow SSC movements and DJ as fast due to shorter contraction time and a smaller range of motion when compared to CMJ.

Plyometric exercises are widely believed to contribute to positive neuromuscular adaptations to high eccentric forces and corresponding improvements in vertical jumping ability (Markovic 2007; de Villarreal et al., 2009; Stojanović et al., 2017). This training approach is effective due to increase fibre force and contraction velocity (Malisoux et al. 2006). The main mechanism explaining the effects of plyometric exercises is related to a specific muscle performance in the stretch-shortening cycle (SSC). This sequence of concentric (shortening) contraction preceded by the intense eccentric action (stretch) increased force and velocity compared to concentric action alone (Bobbert et al. 1996). The effect of the SSC is due to the storage and utilization of the elastic energy, the stretch reflex and tendon reflex (Bosco et al., 1982; Kawakami et al., 2002). A typical plyometric training includes jumps in place, standing jumps, multiple hops and jumps, bounds and drop jumps (Baechle and Earle, 2008). Jumps in place involve jumping and landing in the same spot. Standing jumps like vertical jumps, jumps over barriers are performed with maximal effort. Multiple hops and jumps involve repeated movements. Bounds are performed in a horizontal direction. Drop jumps consist of jumping off a box, a two-legged landing, and jump upward or to another box immediately after landing.

Assisted and resisted training methods have been adapted from sprint training (Rumpf et al., 2016) as a novel solution in the plyometric regime. Assisted plyometrics usually involve mainly countermovement jumps and drop jumps with the aid of elastic bands or tubing fixed between the body harness and point (e.g. the ceiling of a training

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hall) above the body. This system pulls on an individual upward (Makaruk et al., 2014; Sheppard et al., 2011). There are several types of resisted plyometric exercises that are performed under varied external conditions like water, sand and additional external loads. The most common among them are aquatic plyometrics (Robinson et al., 2004) and plyometric exercises with a weight vest (Khlifa et al., 2010), elastic bands (pulling downward) (Argus et al., 2011) and dumbbells (Markovic et al., 2011). The ground contact time (CT) during a jump is a basic parameter differentiating assisted and resisted methods. Assisted plyometrics provides shorter CT (Tufano et al., 2018), while resisted plyometrics results in longer CT (Dell'Antonio et al., 2016; Makaruk et al., 2010) as compared to the traditional plyometrics.

The conception of assisted and resisted methods in a plyometric intervention is based on two general training principles, i.e. specificity and overload (Baechle and Earle, 2008). Specificity aims to produce a high transfer of training exercises to sports performance by emphasizing similar movement patterns, muscle action and contraction velocity to those during sports competition. This idea was used by Makaruk et al. (2010), who found that drop jump training showed a positive tendency for changes in force at peak power during the CMJ test. Therefore, the authors claimed that plyometric training with a weight vest (resisted plyometrics) could be a specific and effective stimulus for athletes who require power production against large resistance, e.g. in shot put. In turn, the overload principle states that disturbance of the homeostasis of the body, including cells, tissues, and organs, is required for effective training adaptation. According to Sheppard et al. (2011), assisted plyometrics could be a novel ‘overloading’ stimulus for the athletes in jumping sports who have a narrow window of adaptation for jumping performance development. This type of plyometric exercises promote an improvement in jumping ability by decreasing an effective mass of a jumper and an increasing peak acceleration during jump due to unloaded condition (Sheppard et al. 2011). Following this observation, they found that a 5-week assisted jumping training allowed young elite male volleyball players to increase jump height for CMJ, while traditional jump training did not provide significant enhancement in jump height. Reducing impact landing forces is the other reason why assisted or resisted plyometric exercises are implemented into the training programs (Argus et al., 2011; Donoghue et al., 2011). Some studies have demonstrated that the aquatic environment (Robinson et al., 2004) or sand (Impellizzeri et al., 2008; Miyama and Nosaka, 2004) induced less muscle damage in comparison to a solid surface. Moreover, research revealed that aquatic- and land-based plyometric training programs provided similar gains in athletic performance (Arazi et al., 2012; Robinson et al., 2004).

Although traditional plyometric training programs have been shown to improve jumping ability in athletes who already achieved of jumping ability (de Villarreal et al., 2009; Stojanović et al., 2017), the use of traditional plyometric training methods may be insufficient for the improvement of jump height (Argus et al. 2011). Several original studies provided evidence that incorporation of the assisted and resisted plyometric methods using non-standard devices (e.g. rubber bands) or environment (e.g., water) during plyometric training programs may pose a more effective approach to enhance jumping ability as compared to the traditional plyometrics in athletes (Argus et al. 2011; Sheppard et al., 2011) and non-athletes (Kibele et al., 2015). Conversely, other studies found greater jumping effects for traditional plyometric method relative to resisted plyometrics in recreationally trained students (McClenton et al., 2008). To our knowledge, no systematic review has been conducted to determine and compare the effects of different plyometric training methods on vertical jumping ability in adults. Clarifying the influence of plyometric training interventions on jump performance in adults appears to be important for three reasons: (i) to determine the effects of traditional, assisted and resisted plyometric training methods as compared to control group (no plyometric training), (ii) to identify if assisted and resisted plyometric methods are more effective than traditional plyometrics and (iii) to provide sport coaches with a critical evaluation of the current plyometric methods concerning sport level. The objective of this systematic review and meta-analysis was to compare the effects of traditional, assisted and resisted plyometric methods on vertical jumping ability in healthy adults.

Methods

Search strategy

This systematic review with meta-analysis was conducted according to the criteria of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement (PRISMA). A literature search was performed using the MEDLINE (via EBSCO), SPORTDiscus (via EBSCO), Scopus and Web of Science Core Collection databases, with no restriction of dates until June 1, 2019 (with an update until February 11, 2020), for peer-reviewed articles published in the English language. The following groups of keyword combined with Boolean operators were used as search terms: (“plyometric*” OR “jump* exercise*” OR “plyometric* training” OR “jump* training” OR “ballistic* training” OR “ballistic* exercise*” OR “power training” OR “explosive training”) AND (“power” OR “reactive strength index” OR “rate of force development” OR “jump* height” OR “countermovement jump” OR “drop jump” OR “depth jump” OR “vertical jump*” OR “center of body mass” OR “flight time” OR “contact time” OR “vertical velocity”). The electronic data search and screening based on titles and abstracts were conducted independently by three authors (MS, MC, and BS). The duplicate articles were rejected. The scanned articles were discussed during the meeting of all the authors and selected for further eligibility assessment.

Inclusion criteria

The inclusion criteria were: (a) healthy adults mean age > 18 years (b) training program based on plyometric exercises, i.e. modalities which utilize the stretch-shortening cycle (e.g., CMJs, DJs, hurdle jumps) (c) the study required to report vertical jump height for the CMJ or DJ performance.

Exclusion criteria

The exclusion criteria were as follows: (a) studies with no randomized design (b) plyometric training program with duration < 4 weeks (c) the study program design based on upper body plyometric exercises (d) studies providing no comparison between traditional plyometrics vs. assisted plyometrics, nor traditional plyometrics vs. resisted plyometrics (e) studies using within-subject design.

Data extraction

The data extraction was undertaken independently by two authors (MC and BS) while the third author (HM) checked the extracted data and made the final study inclusion. Any disagreement was resolved with discussion among reviewers. The following data from the included publications were provided: population (sports level, age and gender), characteristics of plyometric training (sample size, duration, days a week and total jumps) and reported outcomes (CMJ, DJ and muscle damage). Data from graphs were extracted with Meazure® software (version 2.0.1, C Thing software, USA).

Quality assessment

The quality of each study included in this review was assessed using the PEDro (Physiotherapy Evidence Database) quality scale (Moher et al., 2009). The PEDro scale consists of 11 criteria assessing methodological quality of the experimental studies. Each criterion can be rated from 0 to 1 point. For this review, criterion 1 was not included as it comprises external validity. Therefore, a total of 10 points were scored. Points were awarded only when a given criterion was clearly satisfied (Table 1). Ambiguous issues regarding rating points were discussed between the reviewers (HM, MS). Studies with scoring points range 8-10 were considered of "excellent", 6-8 of "good", 4-5 of "fair", and <3 of "poor" quality.

Statistical analysis

Meta-analyses were conducted in Review Manager (RevMan5.3, Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). The agreement between reviewers was tested using the Kappa correlation coefficients (Altman, 1991). Coefficients of 0.81–1.00 are generally interpreted as very good, 0.61–0.80 as good, 0.41–0.60 as moderate, 0.21–0.40 as fair and <0.20 as poor (Altman, 1991). In meta-analysis with at least ten studies, a funnel plot and Egger's regression test for funnel plot asymmetry were used to assess publication bias (Egger et al., 1997), which was considered if the $p < 0.05$. Random effects meta-analyses were conducted to determine and compare the effects of traditional, assisted, and resisted plyometrics on jump height. The standard mean difference values (SMD) with a 95% confidence interval (CI) were used to estimate the magnitude of training intervention. The SMD was calculated using the difference between raw mean changes (post minus pre values) in the compared groups that was divided by the post-pooled standard deviation ($SD_{post\text{-}pooled}$). Hedges' adjusted g was applied to give a better estimate in cases of smaller sample sizes (Hedges and Olkin, 2014), using formula 1:

$$\text{(1)}\quad SMD = \frac{\text{Raw mean change}_1 - \text{Raw mean change}_2}{SD_{post-pooled}}\left(1 - \frac{3}{4N-9}\right)$$

where N= the sum of sample sizes, $SD_{post\text{-}pooled}$ was calculated using the formula 2:

$$\text{(2)}\quad SD_{post-pooled} = \sqrt{\frac{(n_1-1)SD_1^2 + (n_2-1)SD_2^2}{n_1+n_2-2}}$$

where SD = standard deviation, n = sample size of groups.

Table 1. PEDro quality rating of included studies.*

Study	Criterion 1	2	3	4	5	6	7	8	9	10	11	PEDro score
Arazi et al., 2012	0	1	0	1	0	0	0	1	1	1	0	5
Arazi et al., 2014	0	1	0	1	0	0	0	1	1	1	1	6
Argus et al., 2011	0	1	0	1	0	0	0	1	1	1	0	5
Impellizzeri et al., 2008	0	1	0	1	0	0	0	1	1	1	1	6
Jurado-Lavanant et al., 2015	0	1	0	1	0	0	0	1	1	1	1	6
Jurado-Lavanant et al., 2017	0	1	0	1	0	0	0	1	1	1	1	6
Khlifa et al., 2010	0	1	0	1	0	0	1	1	1	1	1	7
Kibele et al., 2015	0	1	0	1	0	0	0	0	1	1	1	5
Kobak et al., 2015	1	1	0	1	0	0	0	1	1	1	1	6
Makaruk et al., 2010	0	1	0	1	0	0	0	1	1	1	1	6
Makaruk et al., 2014	0	1	0	1	0	0	0	1	1	1	1	6
Markovic et al., 2011	0	1	0	1	0	0	0	1	1	1	1	6
Markovic et al., 2013	0	1	0	1	0	0	0	1	1	1	1	6
McClenton et al., 2008	0	1	0	1	0	0	0	1	1	1	1	6
Ploeg et al., 2010	0	1	0	1	0	0	0	1	1	1	1	6
Robinson et al., 2004	1	1	0	1	0	0	0	1	1	1	1	6
Stemm and Jacobson, 2007	0	1	0	0	0	0	0	1	1	1	1	5

* PEDro rating criteria (1) eligibility criteria were specified, (2) subjects were randomly allocated to groups, (3) allocation was concealed, (4) the groups were similar at baseline regarding the most important prognostic indicators, (5) there was blinding of all subjects, (6) there was blinding of all therapists who administered the therapy, (7) there was blinding of all assessors who measured at least one key outcome, (8) measures of at least one key outcome were obtained from more than 85 % of the subjects initially allocated to groups, (9) all subjects for whom outcome measures were available received the treatment or control condition as allocated, (10) the results of between-group statistical comparisons are reported for at least one key outcome, (11) the study provides both point measures and measures of variability for at least one key outcome

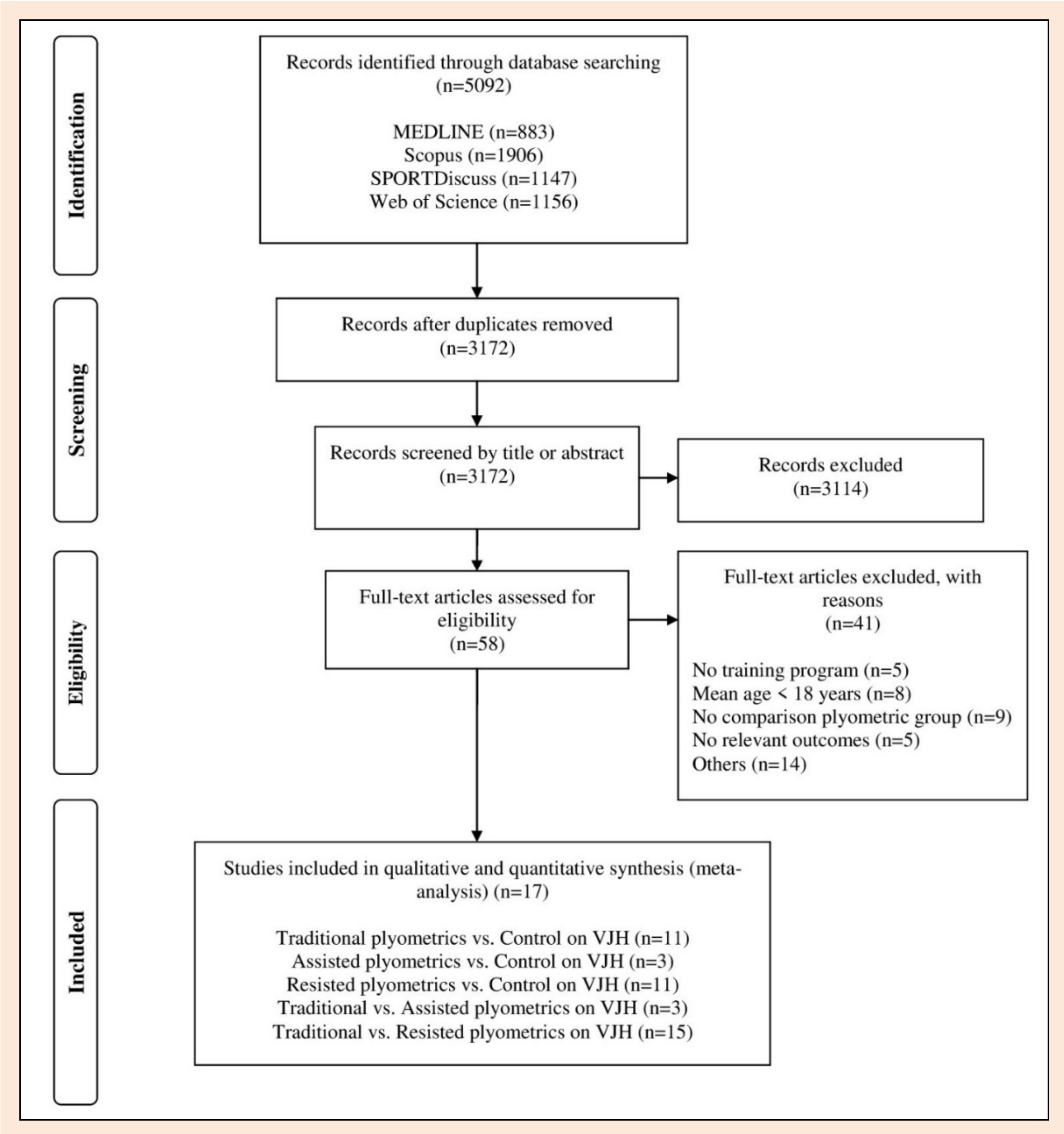

Figure 1. The flow chart of the study selection process. VJH – vertical jump height.

Subgroup analysis was carried out to evaluate the effects of training status on vertical jump performance when plyometric methods were compared. The plyometric training effects on jump performance were interpreted using the following thresholds: trivial (<0.20), small (0.21-0.60), moderate (0.61-1.20) and large (>1.20) (Hopkins et al., 2009). A chi-squared statistic was used to calculate the level of heterogeneity. The I^2 measure was used to describe the percentage of variation across studies. The value of 25%, 50% and 75% were classified as low, moderate and high statistical heterogeneity, respectively (Higgins et al., 2003).

Results

Study selection

A total of 5092 articles were identified in the initial search. Following the exclusion of duplicates and the screening process based on titles and abstracts, 58 studies remained. After the full-text review of remaining studies, 17 articles were met final inclusion criteria. Details of study identification are presented in Figure 1.

Methodological quality

The quality analysis found that all studies were either of good or fair methodological quality (grades 5-7). The mean overall rating was 5.8±0.5. The most common missing criteria were blinding procedures. All included studies scored negative for blinding of the subjects and therapists. Except for one study (Khlifa et al. 2010) they did not specify that the assessors were blinded to group allocation. With one exception (Kibele et al., 2015), all studies fulfil the criteria of the obtained outcome data for at least 85% of subjects initially allocated to groups. Two studies (Arazi et al., 2012; Argus et al., 2011) did not report both point measures and measures of variability for vertical jump performance. In all papers the study groups were similar in the values of the baseline measurements. The rate of agreement between the assessments performed by two reviewers was classified as very high since the Kappa correlation coefficient was 0.92.

Study characteristics

The pooled sample size of 17 studies was 458 subjects (Table 2). The number of participants ranged from 6 to 20 individuals per group. Two studies involved high-level athletes, 3 studies referred to medium-level athletes, while 12 studies involved physically active or untrained individuals. The duration of training programs was as follows: 4 weeks (n = 2 studies), 5 weeks (n = 1 study), 6 weeks (n = 5 studies), 7 weeks (n = 2 studies), 8 weeks (n = 4 studies), 10 weeks (n = 3 studies). The number of training days per week ranged from 2 to 3. Four studies involved the traditional and assisted plyometric methods. Other programs consisted of the traditional and resisted plyometrics, including aquatic (n = 7), sand (n = 2), weight vest (n = 3), dumbbells (n= 1), resistance of elastic bands (n = 3), unstable surface (n=1). The types of plyometric exercises mainly included vertical jumps like countermovement jumps, drop or depth jumps, squat jumps, hops, hurdle jumps, tuck jumps as well as bounds, broad jumps, single-leg jumps, and lunge jumps. The total number of jumps across training programs varied from 144 to 6500 jumps

Table 2. **Systematic review and characteristic of included studies.**

	Population			Plyometric training				Outcomes (pre-post change)		
Study	**Sports level**	**Age (mean ± SD in years)**	**Gender**	**Sample size (n)**	**Duration (weeks)**	**Days a week (duration of session)**	**Type of exercises (jumps in total)**	**CMJ (%)**	**DJ (%)**	**Muscle damage or muscle soreness**
Arazi et al., 2012	Semi-professional basketball players	TP: 18.0 ± 1.4 RP$^{\#}$: 18.0 ± 0.6 C:20.4 ± 0.6	M	TP: 6 RP$^{\#}$: 6 C: 6	8	3 (40 min)	AJs, SJs, SDs (3564)	TP: 29.3% ↑ RP$^{\#}$: 30.4% ↑ C: -1.1%		
Arazi et al., 2014	Healthy men, experienced in plyometrics	TP: 20.5 ± 0.3 RP$^{\$}$: 20.7 ± 0.5	M	TP: 7 RP$^{\$}$: 7	6	2 (35 min)	DJs (1200)	TP: 9.1% ↑ RP$^{\$}$: 8.6% ↑		
Argus, 2011	Professional rugby players	TP: 24 ± 2 RP‡: 23 ± 2 AP: 25 ± 2	M	TP: 8 RP‡: 9 AP: 11	4	2	CMJs (144)	TP: 1.1%**Δ RP‡: 3.7%**▲ AP: 6.2%**▲		
Impellizzeri et al., 2008	Amateur soccer players	25 ± 4	M	TP: 18 RP$^{\$}$: 19	4	3 (15 min warm-up)	VJs, BJs, BRJs, DJs (4500)	TP: 14.6% ↑ RP$^{\$}$: 6.5% ↑		Likert scale (0-6$_{max}$) TP>RP$^{\$}$
Jurado-Lavanant et al., 2015	Healthy and physically active men	21.2 ± 2.9	M	TP: 20 RP$^{\#}$: 20 C: 25	10	2 (35 min)	VJs (6500)		<u>30 cm (box)</u> TP: 7.3% ↑ RP$^{\#}$: 4.8% C: 2.4% <u>50 cm (box)</u> TP: 13.4% ↑ RP$^{\#}$: 3.6% C: 1.6%	CK TP>RP$^{\#}$
Jurado-Lavanant et al., 2017	Physical education students	TP: 20.8 ± 3.1 RP$^{\#}$: 21.8 ± 3.4 C: 20.1 ± 2.2	M	TP: 20 RP$^{\#}$: 20 C: 25	10	2 (35 min)	VJs (6500)	TP: 13.1% ↑ RP$^{\#}$: 14.6% ↑ C: -0.3%		
Khlifa et al., 2010	Elite basketball players	TP: 23.6 ± 0.3 RP$^{\wedge}$: 23.1 ± 0.3 C: 24.2 ± 0.2	M	TP: 9 RP$^{\wedge}$: 9 C: 9	10	2-3 (90 min)	VJs, BJs, BRJs, DJs (11930)	TP: 7.0% ↑ RP$^{\wedge}$: 12.2% ↑ C: 1.8%		
Kibele et al., 2015	Physically active students	TP: 24.1 ± 4.6 RP†: 24.1 ± 3.4	M	TP: 13 RP†: 20	7	2 (40 min)	CMJs, DJs, HJs (1050)	TP: 5.3% RP†: 13.6% ↑		
Kobak et al., 2015	Students	22.5 ± 1.41	M: 21 F: 13	TP: 11 RP$^{\#}$: 12 C: 11	8	2 (60 min)	DJs, SJs, CPs, LJs, TJs, DJs, SLJ (4196)	TP: 10.7% RP$^{\#}$: 13.0% ↑ C: 8.9%		
Makaruk et al., 2010	Students experienced in drop jumps	21.2 ± 1.3	M	TP: 14 RP$^{\wedge}$: 14 C: 14	6	3 (40-45 min)	DJs (660)	TP$^{\&}$: 11.6% ↑ RP$^{\wedge\&}$: 6.1% ↑ C: 2.0%	<u>30 cm (box)</u> TP$^{\&}$: 8.7%↑$^{\pounds}$ RP$^{\wedge\&}$: 2.0%$^{\pounds}$ C: 0.8%	

AP-assisted plyometrics, RP-resisted plyometrics, TP-traditional plyometrics, C-control group (without intervention), $^{\#}$-aquatic, ‡- dumbbells, $^{\$}$-sand, ^-weight vest, , ‡- resistance of the elastic cords, †-unstable surface, BJs-bounds, BRJs-broad jumps, CJs-contrast jumps, CMJs-countermovement jumps, CPs- calf pops, DJs- drop or depth jumps, HJs-hurdle jumps, HPs-hops, JBs-jumps to box, Js-jumps, LJs-lunge jumps, QQJs- quarter quick jumps, Sds- skipping drills, SJs-squat jumps, SLJs-single leg jumps, STLJs-standing long jumps, TJs-tuck jumps, VJs-vertical jumps. **-lack of data regarding significance, $^{\&}$-unpublished data, $^{\pounds}$-form of resisted plyometrics included in meta-analysis, ↑-indicates significant increase, ▲-small effect size, Δ-trivial effect size

Table 2. Continue….

Study	Population			Plyometric training				Outcomes (pre-post change)		
	Sports level	Age (mean ± SD in years)	Gender	Sample size (n)	Duration (weeks)	Days a week (duration of session)	Type of exercises (jumps in total)	CMJ (%)	DJ (%)	Muscle damage or muscle soreness
Makaruk et al., 2014	Collegiate basketball and volleyball players, track and field athletes	TP: 21.7 ± 2.2 AP: 21.3 ± 1.9 C: 20.9 ± 1.8	M	TP: 11 AP: 11 C: 11	5	3	DJs (588)		30 cm (box) TP: 9.0% ↑ AP: 8.4% ↑ C: 0.8% 60 cm (box) TP: 6.0% ↑ AP: 8.5% ↑ C: -0.5%	
Markovic et al., 2011	Physical education students	22 ± 3	M	RP⁑: 12 AP: 10 C: 10	7	3	CMJs (420)	RP⁑: 3.4% ↑ AP: 8.6% ↑ C: 0.6%		
Markovic et al., 2013	Physical education students	23.7 ± 1.7	M	TP: 12 RP^: 11 RP‡: 12 AP: 12 C: 13	8	3	CMJs (1404)	TP: 11.6%↑ RP^: 7.5% ↑ RP‡: 7.2% ↑£ AP: 8.4% ↑ C: 1.0%		
(McClenton et al., 2008)	Recreationally trained students	TP: 21.3 ± 2.0 RP‡: 22.2 ± 2.5 C: 21.5 ± 1.7	M: 14 F: 7	TP: 11 RP‡: 10 C: 10	6	2	DJs, SJs, QQJs, CJs (274-278)	TP: 10.5% ↑ RP‡: 5.3% C: 1.3%		
(Ploeg et al., 2010)	Untrained individuals	M: 21.8 ± 2.3 F: 22.4 ± 3.5	M: 16 F: 23	TP: 8 RP#: 10 C: 10	6	2	HPs, VJs, STLJs, HJs, SLJs, BJs, TJs, JBs (1460)	TP: -2.6% RP#: 0.7% C: 5.9%		
(Robinson et al., 2004)	Physically active women	TP: 20.6 ± 0.6 RP#: 19.8 ± 0.3	F	TP: 15 RP#: 16	8	3 (65 min)	BJs, HPs, Js (3–5 sets of 10–20 reps of 10 drills per training)	TP: 32.5% ↑ RP#: 33.5% ↑		Muscle soreness TP>RP#
(Stemm and Jacobson, 2007)	Physically active men	24 ± 2.5	M	TP: 8 RP#: 7 C: 9	6	2	SJs, HJ, TJs (1620)	TP: 7.8% ↑ RP#: 6.5% ↑ C: 1.5%		

AP-assisted plyometrics, RP-resisted plyometrics, TP-traditional plyometrics, C-control group (without intervention), #-aquatic, ⁑- dumbbells, $-sand, ^-weight vest, , ‡- resistance of the elastic cords, †-unstable surface, BJs-bounds, BRJs-broad jumps, CJs-contrast jumps, CMJs-countermovement jumps, CPs- calf pops, DJs- drop or depth jumps, HJs-hurdle jumps, HPs-hops, JBs-jumps to box, Js-jumps, LJs-lunge jumps, QQJs- quarter quick jumps, Sds- skipping drills, SJs-squat jumps, SLJs-single leg jumps, STLJs-standing long jumps, TJs-tuck jumps, VJs-vertical jumps. **-lack of data regarding significance, &-unpublished data, £-form of resisted plyometrics included in meta-analysis, ↑-indicates significant increase, ▲-small effect size, Δ-trivial effect size

Study outcomes

The funnel plot analysis and Egger's regression test indicated publication bias for the comparison of resisted plyometrics and control condition ($p < 0.05$). No publication bias was found for the other meta-analyses ($p > 0.05$). The effects of the traditional and assisted plyometric methods, when compared with the non-plyometric control condition, on jump height were moderate (SMD = 0.68, 95% CI 0.37 to 0.99, $p < 0.0001$; SMD = 0.70, 95% CI 0.20 to 1.20, $p = 0.006$, respectively) (Figure 2-3). The effect of the resisted plyometric methods, when compared with the control condition, on jump height was small (SMD = 0.48, 95% CI 0.17 to 0.79, $p = 0.002$) (Figure 4). Heterogeneity of the effect of the traditional and resisted methods was moderate ($I^2 = 31$-33%) and low for assisted methods ($I^2 = 0\%$).

We did not find any significant difference between the training effects of the assisted and traditional plyometric interventions on a jump height (SMD = 0.62, 95% CI -1.66 to 2.91, $p = 0.59$) (Figure 5). There were also no significant difference between resisted and traditional plyometric training programs (SMD = 0.20, 95% CI -0.19 to 0.23, $p = 0.86$) (Figure 6). The subgroup analysis for training status showed similar non-significant differences ($p = 0.89$) between the training effects of the resisted and traditional methods for athletes and non-athletes (SMD = -0.03, 95% CI -0.57 to 0.52, $p = 0.92$; SMD = 0.02, 95% CI -0.23 to 0.29, $p = 0.90$, respectively). Heterogeneity for the comparisons of the resisted versus traditional plyometric methods and the assisted versus traditional methods was very low ($I^2 = 0\%$). Heterogeneity in the subgroup analysis of athletes was moderate ($I^2 = 33\%$).

Study or Subgroup	Traditional plyometrics Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
(Arazi et al., 2012)	13	6.3	6	-0.5	5.6	6	3.6%	2.09 [0.57, 3.61]
(Jurado-Lavanant et al., 2015)	2.3	5.1	20	0.8	5.2	25	14.4%	0.29 [-0.31, 0.88]
(Jurado-Lavanant et al., 2017)	4.1	5	20	-0.1	4.7	25	13.7%	0.85 [0.24, 1.47]
(Khlifa et al., 2010)	3.1	3.2	9	0.8	1.5	9	7.5%	0.88 [-0.10, 1.86]
(Kobak et al., 2015)	5.3	6.8	11	4.1	5.5	11	9.4%	0.19 [-0.65, 1.02]
(Makaruk et al., 2010)	4.5	4	14	0.3	4	14	10.1%	1.02 [0.22, 1.81]
(Makaruk et al., 2014)	3.5	3.6	11	0.3	4.1	11	8.8%	0.80 [-0.08, 1.67]
(Markovic et al., 2013)	5.1	5.1	12	0.4	5.3	13	9.5%	0.87 [0.05, 1.70]
(McClenton et al., 2008)	5.4	4.1	11	0.5	4.1	10	7.9%	1.15 [0.21, 2.09]
(Ploeg et al., 2010)	-1.3	7	8	2.6	8.5	10	7.9%	-0.47 [-1.42, 0.47]
(Stemm and Jacobson, 2007)	5.3	5.5	8	1	5.7	9	7.3%	0.73 [-0.26, 1.72]
Total (95% CI)			**130**			**143**	**100.0%**	**0.68 [0.37, 0.99]**

Heterogeneity: $Tau^2 = 0.08$; $Chi^2 = 14.40$, df = 10 (P = 0.16); $I^2 = 31\%$
Test for overall effect: Z = 4.33 (P < 0.0001)

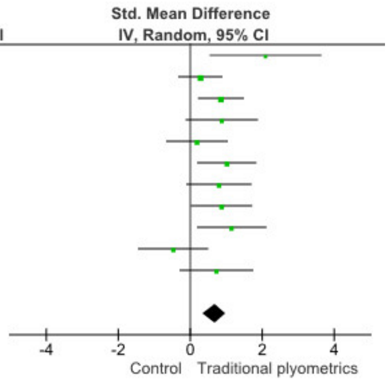

Figure 2. **Forest plot summarizing the effects of traditional plyometrics vs. control on vertical jump height. Data reflects standardized mean differences. CI - confidence intervals.**

Study or Subgroup	Asissted plyometrics Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
(Makaruk et al., 2014)	3.2	4.1	11	0.3	4.1	11	33.0%	0.68 [-0.18, 1.55]
(Markovic et al., 2011)	3.8	4.1	10	0.3	4	10	29.0%	0.83 [-0.09, 1.75]
(Markovic et al., 2013)	3.6	4.7	12	0.4	5.3	13	38.0%	0.62 [-0.19, 1.42]
Total (95% CI)			**33**			**34**	**100.0%**	**0.70 [0.20, 1.20]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.12$, df = 2 (P = 0.94); $I^2 = 0\%$
Test for overall effect: Z = 2.76 (P = 0.006)

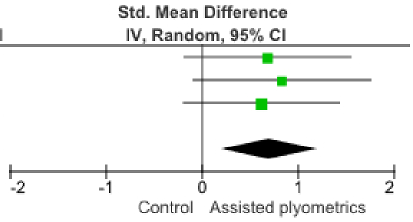

Figure 3. **Forest plot summarizing the effects of assisted plyometrics vs. control on vertical jump height. Data reflects standardized mean differences. CI - confidence intervals.**

Study or Subgroup	Resisted plyometrics Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
(Arazi et al., 2012)	13.5	6	6	-0.5	5.6	6	3.4%	2.23 [0.66, 3.80]
(Jurado-Lavanant et al., 2015)	1.6	4.7	20	0.8	5.2	25	14.0%	0.16 [-0.43, 0.75]
(Jurado-Lavanant et al., 2017)	4.9	9	20	-0.1	4.7	25	13.6%	0.71 [0.10, 1.32]
(Khlifa et al., 2010)	5.3	3.4	9	0.8	1.5	9	6.1%	1.63 [0.53, 2.73]
(Kobak et al., 2015)	6.4	5.4	12	4.1	5.5	11	9.3%	0.41 [-0.42, 1.24]
(Makaruk et al., 2010)	0.7	3.8	14	0.3	4	14	10.8%	0.10 [-0.64, 0.84]
(Markovic et al., 2011)	1.6	4.8	12	0.3	4	10	9.1%	0.28 [-0.56, 1.12]
(Markovic et al., 2013)	3.2	5.5	12	0.4	5.3	13	9.8%	0.50 [-0.30, 1.30]
(McClenton et al., 2008)	3	4.1	10	0.5	4.2	10	8.3%	0.58 [-0.32, 1.48]
(Ploeg et al., 2010)	0.3	6.4	10	2.6	8.5	10	8.6%	-0.29 [-1.18, 0.59]
(Stemm and Jacobson, 2007)	4.5	5.7	7	1	5.7	9	7.0%	0.58 [-0.43, 1.60]
Total (95% CI)			**132**			**142**	**100.0%**	**0.48 [0.17, 0.79]**

Heterogeneity: $Tau^2 = 0.09$; $Chi^2 = 14.87$, df = 10 (P = 0.14); $I^2 = 33\%$
Test for overall effect: Z = 3.06 (P = 0.002)

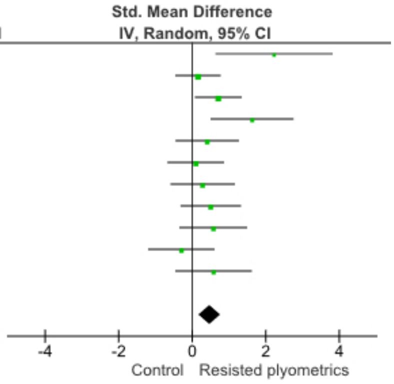

Figure 4. **Forest plot summarizing the effects of resisted plyometrics vs. control on vertical jump height. Data reflects standardized mean differences. CI - confidence intervals.**

Study or Subgroup	Traditional plyometrics Mean	SD	Total	Assisted plyometrics Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
(Argus et al., 2011)	0.5	4.7	8	3.01	7.6	9	26.8%	-0.37 [-1.33, 0.59]
(Makaruk et al., 2014)	3.5	3.6	11	3.2	4.1	11	35.6%	0.07 [-0.76, 0.91]
(Markovic et al., 2013)	5.1	5.1	12	2.7	4.5	12	37.6%	0.48 [-0.33, 1.30]
Total (95% CI)			**31**			**32**	**100.0%**	**0.11 [-0.39, 0.61]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.77$, df = 2 (P = 0.41); $I^2 = 0\%$
Test for overall effect: Z = 0.42 (P = 0.67)

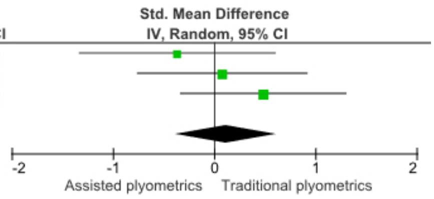

Figure 5. **Forest plot summarizing the effects of traditional vs. assisted plyometrics on vertical jump height. Data reflects standardized mean differences. CI - confidence intervals.**

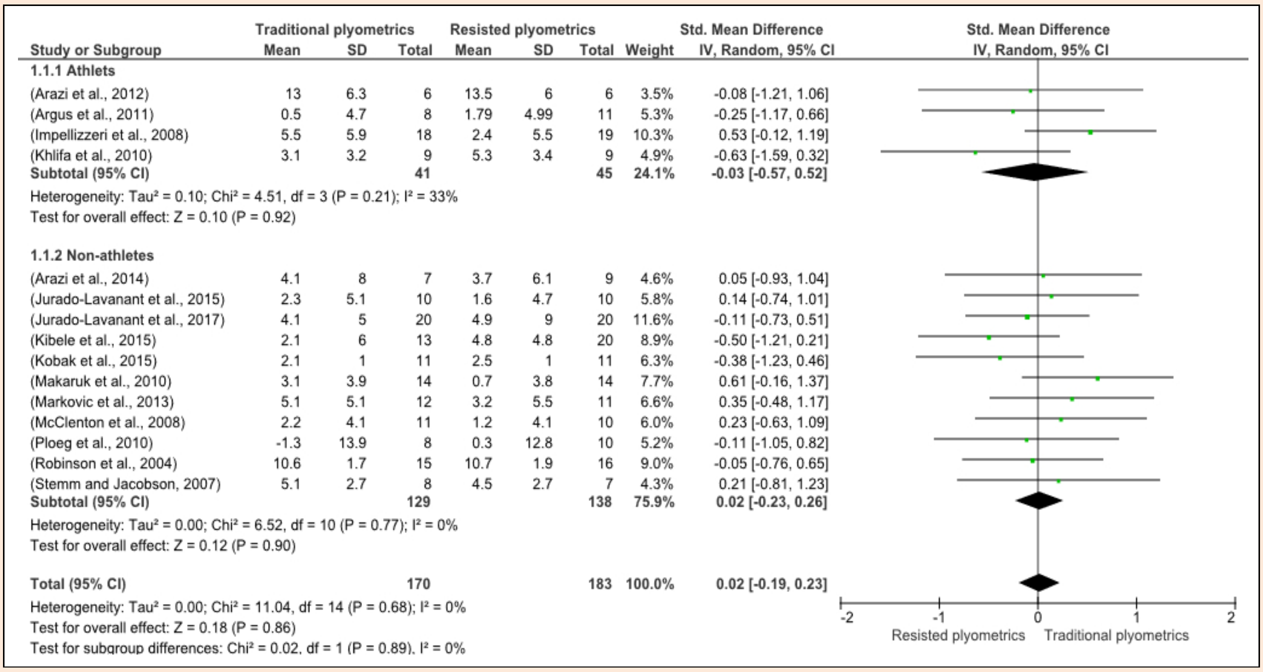

Figure 6. Forest plot summarizing the effects of traditional vs. resisted plyometrics on vertical jump height, including training status (subgroup analysis). Data reflects standardized mean differences. CI - confidence intervals.

Discussion

The empirical evidence presented in this systematic review and meta-analysis confirmed the effectiveness of traditional, assisted and resisted plyometric training methods on vertical jumping ability when compared with the no plyometric control condition. The results of the systematic review and meta-analysis showed that assisted and resisted plyometric methods are equally effective as traditional plyometric method in improving vertical jumping ability in adults. The subgroup analysis pointed to similar and statistically non-significant training effects for athletes and non-athletes comparing resisted and traditional plyometrics. Overall, this review suggests there is a need for further exploration of factors influencing the effects of plyometric training methods in increasing jumping performance.

The findings of this systematic review extended those of previous reviews (Markovic 2007, de Villarreal et al., 2009; Stojanović et al., 2017) regarding the effects of plyometric training methods on jumping ability and provided preliminary evidence that the assisted and resisted plyometrics are an effective method for vertical jumping ability improvement in healthy young adults. The plyometric training effects were moderate for the traditional and assisted (SMD = 0.68 and SMD = 0.70, respectively) plyometrics and small for the resisted plyometrics (SMD = 0.48) when compared with no plyometric training condition. It is in congruent with the findings of Markovic (2007) and of de Villarreal et al. (2009) who also revealed moderate effects of plyometric intervention. Interestingly, the meta-analysis by Stojanovic et al. (2017) including only female athletes demonstrated moderate, large and very large effects (range SMD = 1.09-3.59) for jump height depending on the type of vertical jump measured. We found very low heterogeneity of the effects for the assisted plyometrics, and a moderate heterogeneity for traditional and resisted methods when compared with control conditions. This may suggest that sources of variability exist in plyometric training of the included studies. It also needs to be highlighted that the heterogeneity of the effects of assisted or resisted vs. traditional plyometrics was very low.

The comparison of training effects of the assisted vs. traditional and resisted vs. traditional plyometric methods revealed similar jumping gains. These findings produce several interesting implications for the theory and practice in plyometric training. First, traditional plyometric method guarantees significant jumping enhancement without using additional equipment (e.g., weight vest, elastic cords) or specific environments (e.g., swimming-pool, sand). Second, the fact that a comparable increase in jumping ability were induced by methods using different underlying mechanisms implies broader spectrum of plyometric exercises in sports training. Based on the previous studies (Makaruk et al., 2010, Makaruk et al., 2014), it was expected that contact time would increase after resisted plyometric training and decrease after assisted training. Accordingly, resisted plyometric methods may be used where ability to generate maximal force for jumping ability enhancement is important (e.g., beach volleyball), while assisted plyometric methods may be included in training when time to produce maximal force for increasing jump height is limited (e.g., defence actions in team sports). Further research is required to test these contentions due to lack of experimental studies addressing this issue directly. Third, a plyometric training is associated with high ground reaction forces during landing (Makaruk and Sacewicz, 2011), potentially resulting in exercise induced muscle damage (Marginson et al., 2005). Thus, to reduce the impact of landing force, non-specific conditions for plyometrics are applied. For example, an aquatic environment produces buoyancy that reduces weight-bearing stress on muscles and joints. Three studies investigating muscle damage or muscle soreness, researchers (Impellizzeri et al., 2008; Jurado-Lavanant et al., 2018; Robinson et al., 2004) found that resisted plyometric methods (two aquatic and one sand plyometrics) had a greater preventive effect than a traditional one. It needs to be highlighted that both methods provided similar jumping performance enhancement.

Considering previous research demonstrating that sport level influenced the effects of plyometric training (de Villarreal et al., 2009), this issue was analysed in the present review. A subgroup analysis of training status showed that athletes and non-athletes had similar responses for resisted plyometrics relative to traditional plyometrics. However, heterogeneity in the athletes group was moderate, while in non-athletes was very low. Moderate level of heterogeneity in athletes may be caused by plying different sports (basketball, rugby, soccer), baseline jump performance and sports experience. Since only two studies (Khlifa et al. 2010, Argus et al., 2011) investigated training effects on the elite athletes and two on semi-professional (Arazi et al., 2012) or amateur athletes performance (Impellizzeri et al., 2008). A moderator analysis for high- and low-level athletes was not performed. Also note that only one study investigated the long-term effects of the assisted and traditional plyometrics on jump height in professional athletes, and one in collegiate athletes.

The results of this review should be interpreted with some limitations. First, a small number of studies limited the ability to draw definite conclusions. Second, some included studies involved relatively small groups in the experiments. Third, meta-analyses conducted in this review used non-plyometric training groups (control) not differing physically active subjects (e.g. controls participating in their regular training program) from non-active subjects (e.g. controls completing only pre- and post-testing). Fourth, the analysed plyometric methods involved different types of equipment and environment. Fifth, 14 of 17 studies lasted less than 10 weeks, while the study (Stojanović et al., 2017) reported that the advantages of plyometric training in jumping performance are greater for interventions of 10 weeks or more. In addition, different plyometric jumps, total number of jumps and the intensity of exercises differ across studies.

Conclusion

This review demonstrates that the traditional, assisted and resisted plyometric methods can be recommended as effective training modalities for augmenting vertical jump performance. To sum up, the assisted and resisted plyometrics are as effective as traditional plyometrics. Therefore, there is no robust evidence to suggest that the traditional plyometric method should be substituted by the assisted and resisted methods in the jump training of adults. Further research with greater sample sizes of athletes is required to examine the effects of assisted and resisted plyometric methods on jumping performance in sports training.

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Key points

- Traditional, assisted and resisted plyometric methods can be recommended as effective training modalities for augmenting vertical jump performance in healthy adults.
- Resisted and assisted plyometric methods are equally effective as traditional plyometric method in improving vertical jumping ability in healthy adults.
- It is suggested that long-term effects of assisted and resisted plyometrics on high-level athletes should be investigated.

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