Olympic weightlifting training improves vertical jump height in sportspeople: a systematic review with meta-analysis

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▸ Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjsports-2015-094951).

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Accepted 5 November 2015
Published Online First 1 December 2015

ABSTRACT

Purpose This systematic review was conducted to evaluate the effect of Olympic weightlifting (OW) on vertical jump (VJ) height compared to a control condition, traditional resistance training and plyometric training.
Methods Five electronic databases were searched using terms related to OW and VJ. Studies needed to include at least one OW exercise, an intervention lasting ≥6 weeks; a comparison group of control, traditional resistance training or plyometric training; and to have measured VJ height. The methodological quality of studies was assessed using the Downs and Black Checklist. Random and fixed effects meta-analyses were performed to pool the results of the included studies and generate a weighted mean effect size (ES).
Results Six studies (seven articles) were included in the meta-analyses and described a total of 232 participants (175 athletes and 57 physical education students) with resistance training experience, aged 19.5±2.2 years. Three studies compared OW versus control; four studies compared OW versus traditional resistance training; and three studies compared OW versus plyometric training. Meta-analyses indicated OW improved VJ height by 7.7% (95% CI 3.4 to 5.4 cm) compared to control (ES=0.62, p=0.03) and by 5.1% (95% CI 2.2 to 3.0 cm) compared to traditional resistance training (ES=0.64 p=0.00004). Change in VJ height was not different for OW versus plyometric training.
Conclusions OW is an effective training method to improve VJ height. The similar effects observed for OW and plyometric training on VJ height suggests that either of these methods would be beneficial when devising training programmes to improve VJ height.

INTRODUCTION

Vertical jump (VJ) ability is pivotal in numerous athletic skills and is linked to successful sports performance.[1–3] VJ height is strongly correlated with sprint running performance.[4–6] In soccer[7–9] and volleyball,[10 11] VJ performance has been linked to competition success in elite-standard teams. Furthermore, training interventions that have resulted in a 7–10% increase in VJ height were accompanied with improvement in agility performance by 4–11% and sprint running performance by approximately 3%.[12 13] Not surprisingly, the VJ test is regularly included as one of the assessments for talent identification in sports.[14–17]

Variations of VJ test protocols include the countermovement jump, the jump and reach also known as the 'Sargent jump test' and the squat jump. The countermovement jump and jump and reach involve bending of the knees immediately prior to jumping, while the squat jump is initiated from a position where the knees are bent (ie, squatting).[18 19] The countermovement jump and jump and reach are arguably the most popular because they mimic how jumping is usually performed in athletic pursuits.

VJ tests can be performed with or without an arm swing, with greater heights generally attained with an arm swing.[20 21] Performance of the VJ is largely dependent on factors such as maximal force capacity, rate of force development, muscle coordination and stretch-shortening cycle use.[22] Accordingly, these factors are often targeted in training programmes aimed at improving VJ height.

A popular training method used to improve VJ height is plyometric training,[23 24] which is commonly referred to as 'jump training'. Plyometric training involves performing activities that engage the stretch-shortening cycle (ie, active eccentric contraction followed by an immediate concentric contraction of the same muscle) to enhance the ability of muscles to generate power (eg, jumping).[25] Markovic[24] confirmed the effectiveness of plyometric training for improving VJ height. Plyometric training significantly improved VJ height from a countermovement jump by 7.5% and 8.7% with and without arm swing, respectively, compared to control groups. Other training methods commonly used to improve the VJ include traditional resistance training (eg, squats) and special strength exercises such as Olympic weightlifting (OW) (variations of the Olympic clean and jerk, and snatch lifts). While traditional resistance training can lead to improvements in VJ height,[26 27] OW is more effective.[28 29] Studies that have incorporated OW into their interventions have shown increases in VJ height by up to approximately 9%.[30 31] Consequently, it seems that training programmes incorporating either OW or plyometric training may lead to similar increases in VJ height.

While there have been meta-analyses conducted examining the effect of plyometric training on VJ height,[23 24] the precise effect of OW on VJ height remains unknown. Therefore, we (1) performed a meta-analysis to examine the effect of OW on VJ height, (2) compared OW to traditional resistance training and plyometric training on VJ height. And (3) performed a subgroup analysis to examine whether variations of VJ test protocols (ie, countermovement jump and jump and reach) influence these effects.

To cite: Hackett D, Davies T, Soomro N, *et al*. *Br J Sports Med* 2016;**50**:865–872.

METHODS

Literature search and study selection

Electronic database searches were performed using MEDLINE (via OvidSP), PubMed, SPORTDiscus (via EBSCO), Web of Science, CINAHL, Scopus and Google Scholar (restricted to the first 1000 citations) from earliest record to July 2015. The OW exercises were defined as any of the following: snatch, power snatch, power clean, hang clean, clean and jerk, split jerk, push jerk and high pull. Therefore, the following combination of search terms and Booleans were used: Olympic* OR snatch* OR power clean* OR hang clean* OR clean and jerk* OR split jerk OR push jerk OR high pull AND vertical jump* OR jump* OR countermovement jump*. After eliminating duplicates, the search results were screened by two reviewers against the eligibility criteria. Additionally, manual searches were conducted of relevant journals and reference lists obtained from articles. The present review included studies published in peer-reviewed journals (restricted to English) that have presented original research data on healthy humans. Inclusion criteria applied in this review were as follows: (1) randomised and non-randomised studies; (2) interventions that included at least one OW exercise; (3) studies with a comparison group that performed either no training/control, traditional resistance training or plyometric training; (4) training interventions lasting ≥6 weeks; and (5) studies that used VJ height as a dependent variable. Studies were excluded if: (1) the intervention involved children; or (2) participants had no resistance training experience.

Quality analysis

Methodological quality of studies meeting the inclusion criteria were assessed using the Downs and Black checklist.[32] The tool consists of 27 items rated as No=0, Unable to determine=0 and Yes=1. The checklist was slightly modified so that the final item (number 27) relating to statistical power was consistent with the scoring used for the other items (ie, from the original score of 0 to 5 to No=0, Unable to determine=0 and Yes=1). Additionally, an extra item was added to the checklist, which was exercise supervision; therefore the modified tool consisted of 28 items (see online supplement A). Summed scores ranged from 0 to 28 points with higher scores reflecting higher quality research. Scores above 20 were considered good; 11–20, moderate; and below 11 were considered poor methodological quality. Studies were rated independently by two reviewers and checked for internal (intra-rater) consistency across items before scores were amalgamated into a spreadsheet for discussion. Disagreements between ratings were resolved by discussion or sought from a third reviewer if no consensus was reached by discussion.

Data extraction

Data was extracted by two independent reviewers using standardised forms that included information about the participant characteristics, sample size, study design, intervention details and outcome measures. Mean±(SD) VJ height (ie, outcome measure) for OW, control, traditional resistance training and plyometric training, pretraining and post-training was extracted. Disagreements regarding data extraction were discussed by the two reviewers until consensus was achieved. When a consensus could not be reached, a third reviewer adjudicated. Two articles that met the inclusion criteria were from the same study with one article reporting the effects from OW versus traditional resistance training[33] and the other article reporting the effects of OW versus plyometric training.[34] Additionally, the same data was reported for OW versus control in these articles, therefore the article published earlier was used to extract the required data.[34] These two articles (one study) as well as another study reported results from a combination of vertical jump tests including the countermovement jump, squat jump[31 33 34] and depth jump.[33] It was decided that only the countermovement jump data would be extracted from these studies because no other study that met the inclusion criteria reported data from the squat or depth jump. Another, two articles that met the inclusion criteria failed to provide complete mean pretraining and post-training VJ height data.[35 36] In these cases, attempts were made to contact the authors (ie, emails) to obtain missing data. All authors contacted provided the information that was requested.

Statistical analysis

All analyses were conducted using Comprehensive Meta-analysis, V.2 (Biostat Inc, Englewood, New Jersey, USA). Cohen's d effect sizes (ES) were calculated by dividing total change (ie, change in VJ height following OW minus change in VJ height following comparison intervention) by the pooled SD of the change scores of OW and comparison interventions.[37] Cohen's d was used to calculate effect sizes because it is commonly used in sport sciences[38] and also enables comparisons of an experiment's ES results to known benchmarks. According to Cohen,[39] an ES of 0.2 is considered a small effect, 0.5 as a moderate effect and 0.8 as a large effect. Mean relative change (%) (post-training minus pretraining VJ height, divided pretraining VJ height, multiplied by 100) and absolute change (cm) for VJ height was calculated for the OW and comparison groups (control, traditional resistance training and plyometric training). Mean difference in relative and absolute changes between groups was also performed (ie, OW minus comparison group changes in VJ height). Between-study variability was examined using the I^2 measure of inconsistency. This statistic, expressed as a percentage between 0 and 100, provides a measure of how much of the variability between studies is due to heterogeneity rather than chance.[40] Heterogeneity thresholds were set as I^2=25% (low), I^2=50% (moderate) and I^2=75% (high).[40] A random-effects model of meta-analysis was applied to the pooled data even though heterogeneity was equal to zero (see Results section). The fixed-effects model was also calculated and reported to test the robustness of the analyses.

A funnel plot and rank correlations between effect estimates and their SE using Kendall's τ statistic[41] were used to examine publication bias. For the rank correlations, publication bias was suggested when a significant result ($p<0.05$) was found. Subsequently, there was one study that included jump squats in the OW intervention,[35] which is shown to improve VJ height.[26 42–44] However, this study was not excluded from the analysis because no publication bias was found when it was included and the ES calculated was not decreased when this study was excluded. The primary analyses compared the effect of OW versus (1) control; (2) traditional resistance training; and (3) plyometric training on VJ height. A subgroup analysis using only OW (one-group pre–post-training) was performed for studies that assessed VJ height via the countermovement jump versus jump and reach test. A *Z*-test was used to compare the mean effect for OW on countermovement jump versus jump and reach performance, as described by Borenstein *et al*.[45] The level of significance was set at $p<0.05$.

RESULTS

Description of studies

The database searches yielded 3642 potential articles and three additional articles were identified from reference lists. After removal of duplicates (n=820), 2825 remained with a further 2802 removed after screening using title and abstract. The full text of the remaining 23 articles were reviewed for more detailed evaluation and resulted in the exclusion of 16 articles. Based on the eligibility criteria, seven articles (six studies) were included in the final analysis (figure 1). The six studies described a total of 232 participants, of which 113 were athletes involved in various sports (eg, football, soccer, basketball, etc),[36] 47 were footballers,[28 35] 15 were soccer players and 57 were university/college physical education students.[31 33 34] The footballers (n=47) and approximately 60% of university/college physical education students (n=35) had greater than 1 year resistance training experience, while all the other participants (n=150) had less than 1 year resistance training experience (table 1). One study did not report the distribution of sex or age in the intervention groups.[36] Based on the studies where this information was reported, there were 109 male and 10 female participants respectively, and their combined weighted mean age was 19.5 ±2.2 years (range 15.9–22 years).

Of the six studies (seven articles) included, three studies compared OW versus control;[28 31 34] four studies compared OW versus traditional resistance training;[28 33 35 36] and two studies (three articles) compared OW versus plyometric training.[30 31 34] For the OW group, two or more OW exercises were used in four studies (five articles)[28 31 33–35] and one OW exercise in the other two studies,[30 36] per training session (table 1). Exercise specifics for OW included 2–6 sets of 3–12 repetitions at either 70–93% 1RM (one repetition maximum), to momentary muscular failure (ie, repetition maximum or RM), or at loads individually determined. Training was performed 2–4 times per week with interventions lasting for a period of 6–15 weeks. There was one study where OW exercises were included only after 5 weeks of a 15-week intervention.[35] The control group either participated in a sports programme or did not exercise, and the traditional resistance training group performed the same resistance training prescription as the OW (except for the exercises) with an emphasis on explosive concentric movements.[28 33 35 36] The plyometric training group performed a variety of jumping type activities.

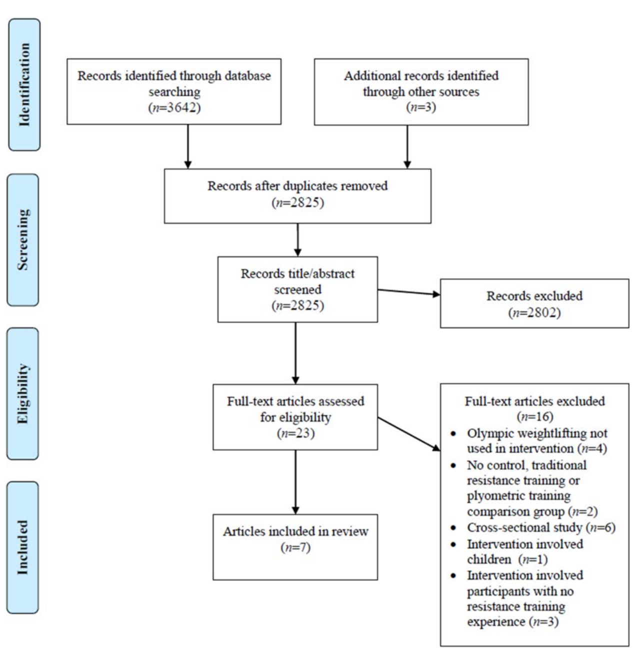

Figure 1 PRISMA flow diagram of literature screening process.

VJ height was assessed via the countermovement jump test in three studies (four articles)[31 33–35] and jump and reach test in three studies.[34 42 52] For the studies that used the countermovement jump test, a force platform,[33 34] position transducer[35] or contact mat[31] was used, and participants had to place their hands on hips (ie, eliminating arm swing) during the test. The studies that used the jump and reach test required participants to swing their arms when jumping. A standardised warm-up prior to the VJ was performed in three studies (four articles),[30 33 34 36] non-specific (eg, self-selected) warm-up in one study[28] and a warm-up was not reported in the remaining two studies.[31 35] Habituation of the VJ test was performed in three studies (four articles),[30 33 34 36] and no habituation was reported for three studies.[28 31 35] The best of three VJ for pre/post-testing was reportedly used for three studies (four articles),[31 33 34 36] the best of numerous attempts was reported for two studies[28 35] and the average of the best three out of 7–10 VJ attempts for the remaining study.[30]

Primary outcomes

Table 2 reports the % change in VJ performance following OW versus control, traditional resistance training and plyometric training and summarises the pooled estimates of effects.

OW versus control

There was an 8.7% (95% CI 3.5 cm to 5.9 cm) mean increase in VJ height following OW compared to a 1% increase (95% CI −0.6 cm to 1.2 cm) in VJ height for control (table 2). This represented a mean difference between groups of 7.7% (95% CI 3.4 cm to 5.4 cm). Expressing the pooled data as an ES indicated a moderate effect favouring OW (ES=0.62, 95% CI 0.04 to 1.22) and was statistically significant (p=0.03; figure 2). The pooled estimate was the same when a fixed-effect model was used. Heterogeneity of the effect of OW versus control on VJ height was equal to zero ($I^2 = 0\%$). Both the funnel plot and Kendall's τ statistic (r=0.33; p=0.61) showed no publication bias for OW versus control on VJ height.

OW versus traditional resistance training

A mean 7.5% (95% CI 2.8 cm to 4.7 cm) improvement in VJ height was found following OW compared to a 2.4% (95% CI 0.5 cm to 1.8 cm) increase in VJ height following traditional resistance training (table 2). This represented a mean difference between groups of 5.1% (95% CI 2.2 cm to 3 cm). Expressing the pooled data as an ES indicated a moderate effect favouring OW (ES=0.64, 95% CI 0.34 to 0.95). A statistically significant effect was found favouring OW (p=0.00004; figure 3). The pooled ES value was the same when a fixed-effect model was used. Heterogeneity of the effect of OW versus traditional resistance training on VJ height was equal to zero ($I^2 = 0\%$). No publication bias for OW versus traditional resistance training on VJ height was found based on the results from the funnel plot and Kendall's τ statistic (r=0; p=1.0).

OW versus plyometric training

There was a 10.2% (95% CI 3.3 cm to 5.3 cm) increase in VJ height following OW compared to a 9% (95% CI 2.7 cm to 4.4 cm) increase in VJ height following plyometric training (table 2). This represented a mean difference between groups of 1.2% (95% CI 0.1 cm to 1.5 cm). Expressing the pooled data as an ES indicated a small effect (ES=0.11, 95% CI −0.08 to 0.45) (figure 4), and no statistically significant effect was found (p=0.39). The pooled ES value was the same when a fixed-effect model was used. Heterogeneity of the effect of OW

Table 1 Characteristics of studies

Study	Group	n	S	Age (years)	Exercises	Freq (days/week)	Intensity	Duration (week)
Arabatzi *et al*[34]	OW*	9	M	20.3	SN, HP, PC, C&J, HSQ	3/7	4–6×6RM	8
	PT	9	M	20.3	Jumps, skips, hops, bounds, HSQ	3/7	4–6×6 rep	8
	CON	8	M	20.3	Normal daily activity	–	–	–
Arabatzi and Kellis[33]	OW*	9	M	20.3	PC, SN, C&J, HP, HSQ	3/7	4×4–6 rep @ 75–90% 1RM	8
	TRT	9	M	20.3	LP, LC, LE, BP, HSQ	3/7	4×4–6 rep @ 75–90% 1RM	8
Channell and Barfield[28]	OW	11	M	15.9	PC, PJ+AUX	3/7	PC (3–5×5–10 rep @ 30–100% 1RM), PJ (3–5×5–10 RM)	8
	TRT	10	M	15.9	SQ, DL+AUX	3/7	SQ (3–5×5–10 rep @ 30–100% 1RM), DL (3–5×5–10RM)	8
	CON	6	M	15.9	Sports participation	–	–	8
Hoffman *et al*[35]	OW	10	M	19.3	SN, CL, PJ, SQ, SQJ+VL/AUX	4/7	2–5×3–10RM (OW after week 5)	15
	TRT	10	M	18.9	SQ, DL, BP, SP, LatP, SR, UR+VL/ AUX	4/7	3–5×4–10RM	15
Moore *et al*[30]	OW	8	M/F	20.2	HC, DL+TRT	3/7	3×6RM	11
	PT	7	M/F	20.2	Jumps, skips, hops, bounds+TRT	3/7	PT: 1–3×10–15 rep, 1–3×15–30 sec, 1–3×16 m; TRT: 3×6RM	11
Scherfenberg and Burns[36]	OW	55	M/F	–	HC+AUX	2/7	HC: 6×3–6 rep @ 70–93% 1RM	6
	TRT	58	M/F	–	SQ+AUX	2/7	SQ: 6×3–6 rep @ 70–93% 1RM	6
Tricoli *et al*[31]	OW	7	M	22.0	HP, PC, C&J, HSQ	3/7	3–4×4–6RM	8
	PT	8	M	22.0	Jumps, skips, hops, bounds, HSQ	3/7	4–10×4 rep	8
	CON	7	M	22.0	Normal daily activity	–	–	–

*=same group of participants.
Auxiliary lifts are a single joint exercise targeting a small muscle group (eg, leg extension, bicep curls) compared to a multijoint compound exercise which targets larger muscle groups (eg, squats, lat pulldown).
AUX, auxiliary lifts; BP, bench press; C&J, clean and jerk; CL, clean; CON, control; d, days; DL, dead lift; Freq, frequency; HC, hang clean; HP, high pull; HSQ, half squat; LatP, lat pulldown; LC, leg curl; LE, leg extension; LP, leg press; M/F, both males and females; M, males; OW, Olympic weightlifting; PC, power clean; PJ, push jerk; PT, plyometric training; RM, repetition maximum; S, sex; SN, snatch; SP, shoulder press; SQ, squat; SQJ, squat jump; TRT, traditional resistance training; UR, upright row; VL/AUX, variations of previously mentioned lifts and auxiliary lifts; wk, weeks.

versus plyometric training on VJ height was equal to zero. The funnel plot and Kendall's τ statistic (r=0.33; p=0.60) showed no publication bias for OW versus plyometric training on VJ height.

Effect of OW on countermovement jump versus jump and reach performance

A mean 8.9% (95% CI 2.6 cm to 4.5 cm) improvement in countermovement jump height compared to a 5.9% (95% CI 2.8 cm to 3.5 cm) increase in jump and reach height was found following OW. This effect was moderate based on a pooled ES value of 0.71 for the countermovement jump (95% CI 0.28 to 1.15) and small for the jump and reach (ES=0.27, 95% CI 0.04 to 0.51). Both the effects of OW on countermovement jump and jump and reach performance were statistically significant (p=0.001 and p=0.00001 respectively), while no significant difference in effect was found between countermovement jump and jump and reach (p=0.27).

Quality analysis

The mean quality rating score was 18.3±2.1 out of a possible 28 (table 3). All studies scored 0 for blinding of participants/investigators, recruiting participants over same period of time, randomised intervention assignment concealment and adequate adjustment for confounders. The item with the lowest score was for actual probability values (mean score 0.1±0.2). Other low scores were found for characteristics of participants lost to follow-up, participants representative of the entire population which they were recruited, and adjusting for different lengths of follow-ups (mean score 0.3±0.5). Best scores were found for the majority of the reporting items (eg, study aims, outcomes, participant characteristics, confounders, etc) with all studies scoring 1. Best scores were also found for treatment being representative of participants, not data dredging, appropriate statistical tests, accuracy of outcome measures, recruitment of participants from the same population and sufficient power to detect effect (all studies scored 1). Study compliance was high approximately 90% for all studies except one where it could not be determined whether compliance was reliable.[28] Four studies randomised participants into intervention groups[31 33 34 36] and all studies had supervised exercise interventions.

DISCUSSION

Our overall results suggest OW significantly improves VJ height by 7.7% (95% CI 3.4 cm to 5.4 cm) compared to control (ES=0.62; ie, moderate effect), and by 5.1% (95% CI 2.2 cm to 3 cm) compared to traditional resistance training (ES=0.64; ie, moderate effect). In contrast, there was little difference between OW and plyometric training for change in VJ height. Additionally, similar increases in VJ height following OW were found for the countermovement jump and jump and reach. Heterogeneity of effects for all meta-analyses was equal to zero, suggesting that all the studies examined the same effect. There were no substantial change in mean effects or CIs when using random and fixed-effects models, providing evidence that the results from all meta-analyses were robust. However, despite no publication bias found for VJ height, methodological quality for the included studies was only moderate. Some caution is

Table 2 Summary of the effects of Olympic weightlifting on vertical jump height compared to resistance training and plyometric training

	OW VJ Height				Comparison Group VJ Height							
	n	Pretraining (cm)	Post-training (cm)	Per cent change	n	Pretraining (cm)	Post-training (cm)	Per cent change	Per cent change (diff b/w groups)	Effect size (SE)	95% CI of Effect Size	p Value
Control												
Arabatzi *et al*[34]	9	34.6±7.5	39.8±6.8	15.0	8	33.3±5.2	35.2±5.8	5.7	9.3	0.52 (0.49)	−0.45 to 1.49	0.13
Tricoli *et al*[31]	7	42.2±2.1	45.0±2.6	6.6	7	42.2±4.9	42.6±5.2	0.1	6.5	0.58 (0.55)	−0.49 to 1.65	0.28
Channell and Barfield[28]	11	57.5±7.2	60.1±3.9	4.5	6	59.1±9.1	57.4±7.7	−2.9	7.4	0.79 (0.53)	−0.24 to 1.82	0.29
Mean effect				8.7				1.0	7.7	0.62 (0.30)	0.04 to 1.22	0.03
Traditional resistance training												
Arabatzi and Kellis[33]	9	34.6±7.5	39.8±6.8	15.0	9	31.3±2	33.4±3.0	6.7	8.3	0.58 (0.48)	−0.36 to 1.53	0.23
Hoffman *et al*[35]	10	44.2±2.1	46.8±6.1	5.9	10	40.8±8.9	40.5±6.8	−0.7	6.6	0.45 (0.45)	−0.44 to 1.34	0.32
Channell and Barfield[28]	11	57.5±7.2	60.1±3.9	4.5	10	47.2±9.5	48.3±8.9	2.3	2.2	0.22 (0.44)	−0.64 to 1.08	0.61
Scherfenberg and Burns[36]	55	57.9±11.8	60.6±3.0	4.7	58	57.4±12.3	58.1±2.2	1.2	3.5	0.77 (0.20)	0.39 to 1.16	<0.01
Mean effect				7.5				2.4	5.1	0.64 (0.16)	0.34 to 0.95	<0.01
Plyometric training												
Arabatzi *et al*[34]	9	34.6±7.5	39.8±6.8	15.0	9	31.5±6.3	36.1±6.4	14.6	0.4	0.09 (0.47)	0.22 to −0.84	0.19
Tricoli *et al*[31]	7	42.2±2.1	45.0±2.6	6.6	8	40.2±3.9	42.5±3.0	5.7	0.9	0.18 (0.52)	0.27 to −0.84	0.34
Moore *et al*[30]	8	47.3±16.4	51.5±21.2	8.9	7	41.4±10.0	44.2±11.1	6.7	2.2	0.08 (0.52)	0.26 to −0.93	0.16
Mean effect				10.2				9.0	1.2	0.11 (0.29)	−0.08 to −0.45	0.39

Pretraining and post-training values are presented as mean±SD.
% change=post-training minus pretraining VJ height, divided pretraining VJ height, multiplied by 100.
% change (diff b/w groups)=% change VJ height (OW) minus % change VJ height (comparison group).
Effect size (ES) and 95% CIs values from random effects model.
Statistical significance is accepted as $p \leq 0.05$.
b/w, between; diff, difference; OW, Olympic weightlifting; VJ, vertical jump.

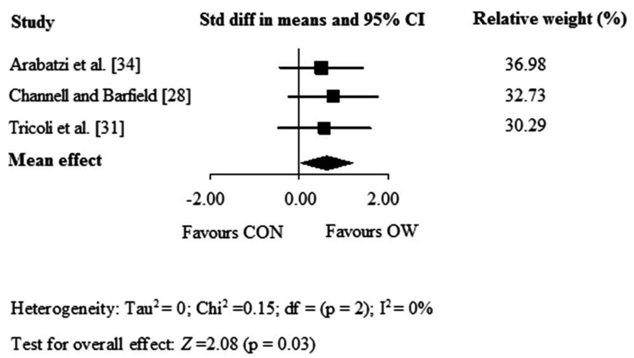

Figure 2 Effect of Olympic weightlifting versus control on vertical jump height. OW, Olympic weightlifting; CON, control.

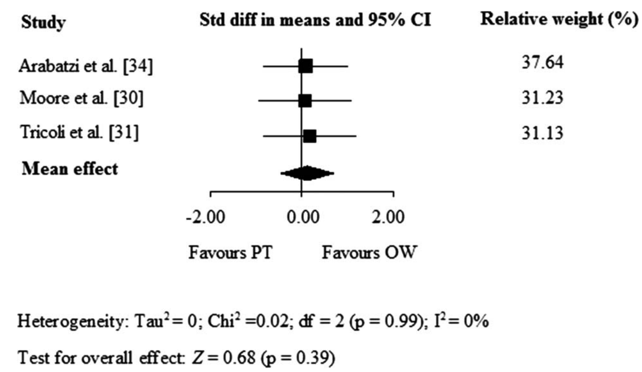

Figure 4 Effect of Olympic weightlifting versus plyometric training on vertical jump height. OW, Olympic weightlifting; PT, plyometric training.

required regarding the precise effects of OW compared to control, traditional resistance training and plyometric training on VJ height.

Mechanisms—how does OW improve VJ performance?

Findings from this review confirm that a significant 7.7% (95% CI 3.4 cm to 5.4 cm) improvement in VJ height can be achieved following OW. A common explanation for the transfer between OW and the VJ is the increased force demands (ie, load used on the barbell) placed on the neuromuscular system while performing a similar movement pattern.[31 46 47] During both OW and the VJ, acceleration is a common characteristic that occurs throughout the entire movements. However, while the aim of OW is to vertically displace the barbell, the intent of the VJ is to vertically displace the body. Recently, MacKenzie *et al*[48] highlighted the different kinematic patterns of the power clean and VJ via muscle activation pattern data. Differences were observed for the relative timing of peak activation, maximum level of activation and activation/deactivation of leg muscle groups. Additionally, peak force and rate of force development were found to be significantly greater for the power clean compared to VJ.[48] Other studies have reported similar kinetic values (peak force and rate of force development) between OW and VJ,[46 49 50] Therefore, the underlying mechanisms for improvements in VJ height following OW may be related to changes in peak force and rate of force development.

Despite the majority of the traditional resistance training programmes utilising protocols aimed to increase maximal force and rate of force development,[28 33 35 36] greater improvements in VJ height were found for OW. Improvement in maximal

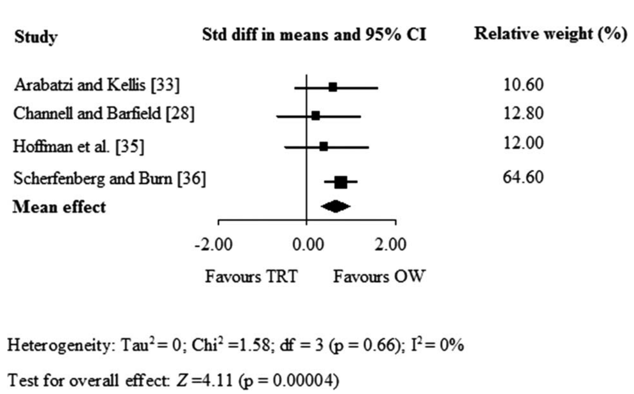

Figure 3 Effect of Olympic weightlifting versus traditional resistance training on vertical jump height. OW, Olympic weightlifting; TRT, traditional resistance training.

force can be achieved with exercises such as squats; however they show very low correlation with VJ performance.[51] This suggests that increases in maximal force of prime movers following traditional resistance training may not effectively transfer to velocities that simulate the speed of VJ performance.[52] Additionally, performing OW requires greater skill compared to traditional resistance training exercises and may result in different neural adaptations.[11 26] As such, adaptations related to learning, coordination and the ability to recruit motor units of prime movers following OW may explain the greater improvements in VJ height compared to traditional resistance training.

Another explanation for the greater improvement in VJ height following OW compared to traditional resistance training could be attributed to the different power output stimuli on the neuromuscular system. Much greater power outputs are typically exhibited for OW exercises compared to traditional resistance training exercises, even when there is an increased emphasis on generating high power outputs during traditional resistance training.[53] The main factor that explains the difference between power outputs from OW and traditional resistance training exercises are the changes in velocity of movement.[47 53 54] During an OW exercise, the barbell is allowed to accelerate through the entire range of movement and the barbell's upward movement is controlled by gravity. In contrast, traditional resistance training exercises require the deceleration of barbell velocity actively towards the end of the lift. This characteristic of traditional resistance training exercises makes OW more appealing for improving an athlete's maximum power (ie, rate of work which is largely dependent by the highest force generated).[47 55]

What about plyometric training? How does it compare to OW?

In this systematic review with meta-analysis, OW and plyometric training had similar effects on VJ height. Moreover, further evidence for similar effects of OW and plyometric training on VJ height is noted when comparing the 7.7% improvement from OW with the 7.5–8.7% improvement previously reported from plyometric training.[24]

Interestingly, plyometric training may affect VJ height in a different manner than the mechanisms described above for OW. It has been suggested that plyometric training enhances the ability to utilise the stretch-shortening cycle and increase motor-unit recruitment during a concentric contraction.[44 56] However, muscle activity patterns do not change following plyometric training despite increases in VJ height.[57 58] Improved VJ performance following plyometric training may be due to changes to the mechanical properties of the muscle-tendon complex.

Table 3 Results of methodological quality

Author	Items	Reporting*										External Validity†			Internal validity															Score
															Bias‡							Confounding§								
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Total/28
Arabatzi *et al*[34]		1	1	1	1	1	1	1	0	0	0	1	0#	1	0	0	1	0#	1	1	1	1	0#	1	0	0#	0#	1	1	17
Arabatzi and Kellis[33]		1	1	1	1	1	1	1	0	0	0	1	0#	1	0	0	1	0#	1	1	1	1	0#	1	0	0#	0#	1	1	17
Channell and Barfield[28]		1	1	1	1	1	1	1	0	0	0	1	0#	1	0	0	1	0#	1	0#	1	1	0#	0	0	0#	0#	1	1	15
Hoffman *et al*[35]		1	1	1	1	1	1	1	1	1	0	1	0#	1	0	0	1	1	1	1	1	1	0#	0	0	0	1	1	1	20
Moore *et al*[30]		1	1	1	1	1	1	1	0	0	1	1	0#	1	0	0	1	1	1	1	1	1	0#	0	0	0#	0#	1	1	18
Scherfenberg and Burns[36]		1	1	1	1	1	1	1	1	0	0	1	1	1	0	0	1	0#	1	1	1	1	0#	1	0	0	1	1	1	20
Tricoli *et al*[31]		1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	1	0#	1	1	1	1	0	1	0	0	1	1	1	21
Mean		1	1	1	1	1	1	1	0.4	0.3	0.1	1	0.3	1	0	0	1	0.3	1	0.9	1	1	0	0.6	0	0	0.4	1	1	18.3

*Reporting category includes items such as, study aims, reported outcomes, participant characteristics, confounders, adverse events and loss to follow-up.
† External validity includes questions regarding the study population.
‡ Internal validity—bias includes items such as blinding, follow-up and compliance.
§ Internal validity—confounding includes items such as study selection, randomisation and study power.
1, criteria met; 0, criteria not met; #, unable to determine, scored 0.

Thus, higher stiffness level of the lower limb muscles during the VJ facilitating greater amounts of stored elastic energy, hence increase VJ height.[57–59] Consequently, it seems that improvement in VJ height following plyometric training may be related to changes in the mechanical properties of muscle-tendon complex, while muscle activation strategies likely explain the improvement following OW.

Which type of VJ test protocol should I use?

The variations of VJ test protocols did not influence the effect of OW on VJ height despite the countermovement jump performed without an arm swing while the jump and reach used an arm swing. Greater jump heights will generally be achieved with the VJ when performed with an arm swing compared to without an arm swing.[18 21] The greater height attained with the VJ with an arm swing is thought to be due to extra force for the propulsion of the body produced by the arms.[18 21] Hawkins *et al*[29] assessed VJ height with and without an arm swing, and found approximately 25% greater VJ height attained with an arm swing at baseline.[29] This difference remained approximately the same following an OW intervention. Besides arm swing, the jump and reach also involves aspects of both flexibility and coordination. However, the similar improvements in the countermovement jump and jump and reach (8.9% and 5.9%, respectively) tends to suggest that following OW, there will be small to negligible differences in VJ performance despite different testing protocols.

Practical implications for coaches, strength and conditioning professionals and sports medicine

Findings from this review suggest that more emphasis should be placed on OW when devising training programmes for athletes when targeting VJ performance. However, training programmes should be balanced with a combination of OW and traditional resistance training exercise because these two methods of training may complement each other to increase VJ height.[36] The similar improvements in VJ following OW and plyometric training allows strength and coaching coaches the flexibility to use either of these training methods to maximise VJ performance. However, designing a training programme alternating between these training methods (ie, periodisation) may be the best approach to reduce the risk of VJ performance plateauing or decreasing throughout a training cycle.

Our study has limitations. First, the OW interventions differed between studies in terms of the type of OW exercise used, number of OW exercises performed and when the OW exercises were implemented in the programme. Although, no publication bias and an almost identical pooled estimate with the random and fixed-effects models provide confidence that the training conditions were similar. Therefore, the only difference between studies was their power to detect changes in VJ height. Another potential limitation was the moderate methodological quality of studies included in this review. Across the six studies (seven articles), only the criteria of 15 items were fully met. However, there were five items where it could not be determined whether they were met. Hence, it is possible that the methodological quality of the included studies was underestimated. Additionally, half of the studies assessed VJ height using 'the' jump and reach, which is shown to be less reliable than the countermovement jump.[19] Though the similar increases in VJ height following OW for the countermovement jump and jump and reach provides confidence that VJ test protocols did not confound the results. Finally, a potential weakness of this review was the small number of ES available. Therefore, this may impact the ability to generalise the precise effects of OW for improving VJ height.

SUMMARY

This systematic review with meta-analyses demonstrates that OW significantly improves VJ height by 7.7% and by 5.1% compared with traditional resistance training. This improvement may be meaningful for athletes involved in speed, agility and power-related sports. The similar effect of OW and plyometric training on VJ height increases the options available for athletes and coaches when devising a training programme targeting VJ performance.

What are the new findings?

- In this first systematic review with meta-analysis of studies, we found a 7.7% (95% CI 3.4 to 5.4 cm) improvement in vertical jump height with Olympic weightlifting compared with control.
- In our comparison of Olympic weightlifting to traditional resistance training we found a 5.1% (95% CI 2.2 cm to 3 cm) greater improvement in vertical jump height.
- In our comparison of Olympic weightlifting to plyometric training we found a negligible improvement of 1.2% (95% CI 0.1 cm to 1.5 cm) in vertical jump height.

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Contributors DH and TD were responsible for systematic search, data extraction and weighted means, quality ratings. All authors were involved in the study design, drafting and editing of manuscript.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

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