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Review article

Effects of Physical Training Programs on Healthy Athletes' Vertical Jump Height: A Systematic Review With Meta-Analysis

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Abstract

Various physical training programs are widely used to enhance vertical jump height, but their relative effectiveness remains debated. This systematic review and meta-analysis evaluate effectiveness of four training methods -weight resistance, plyometric, complex, and routine training- on vertical jump height. A comprehensive search of six databases (PubMed, ERIC, Google Scholar, Web of Science, EBSCOhost, and Scopus) identified relevant studies coded based on training type, modality, and outcome measures. Methodological quality and statistical analysis were assessed using PEDro scale and R (version 4.1.3) with the 'meta' package. Eight studies revealed that plyometric training and weight resistance exercise increased vertical jump by 5.2 cm (95% CI: 2.6, 7.7 cm; I^2 = 4.7%) and 9.9 cm (95% CI: 6.7, 13.5 cm; I^2 = 0.0%), while improved squat jump by 1.5 cm (95% CI: 0.2, 2.6 cm; I^2 = 0.0%) and 3.1 cm (95% CI: 0.2, 2.6 cm; I^2 = 16.9%) compared to routine training. Fifteen studies indicated that plyometric training, weight resistance exercise, and complex training increased countermovement jump by 2.0 cm (95% CI: 1.4, 3.7 cm; I^2 = 0.0%), 2.2 cm (95% CI: 1.4, 3.7 cm; I^2 = 0.0%), and 5.0 cm (95% CI: 2.5, 7.6 cm; I^2 = 0.0%) compared to routine training. Complex training was more effective than weight resistance (2.6 cm; 95% CI: 0.2, 5.5 cm) and plyometric training (2.9 cm; 95% CI: 0.2, 5.8 cm), with no significant difference between weight resistance and plyometric training (0.2 cm; 95% CI: -1.0, 2.0 cm). Heterogeneity was low for most comparisons (I^2 = 0.0% to 16.9%), indicating consistent results across different interventions. This meta-analysis demonstrates that plyometric, weight resistance, and complex training significantly improve vertical, squat, and countermovement jump performance. Weight resistance is effective for vertical and stationary vertical jumps, while complex training is most effective for countermovement jumps.

Key words: Physical training programs, vertical jump, athletes, statistical analyses, training performance.

Introduction

Improving jump performance is crucial in numerous sports (Perez-Gomez and Calbet, 2013), particularly in team sports such as basketball, volleyball, and soccer(Arnason et al., 2004; Bobbert, 1990). Vertical jump capacity is strongly correlated with athletic success in a variety of sports because it reflects the explosive power needed for quick movements and jumps common in sports like basketball and volleyball. The vertical jump relies on the power of the lower extremity muscles, among other factors such as coordination and technique, and has been widely used as a standard measure of power performance (Driss et al., 1998). Furthermore, vertical jump performance helps estimate the composition of muscle fibers, as fast-twitch fibers, which are responsible for quick and powerful movements, play a key role in explosive actions like jumping (Bosco et al., 1983).

The vertical jump performance, a key measure of explosive power and athletic ability, is commonly used across many sports to evaluate and improve performance (Sheppard et al., 2008). Effective jump performance is vital for success in team sports such as basketball, soccer, and volleyball, where the strategic importance of jumping activities necessitates rapid and powerful jumps (Sattler et al., 2012). Specifically, vertical jump height has been previously proven to correlate with volleyball performance, as scoring actions like spiking, blocking, and serving are primarily executed during vertical jump (Sheppard et al., 2007; Sheppard et al., 2009; Ziv and Lidor, 2010). In basketball, higher jump heights favor shooting and rebounding conditions (Makaruk et al., 2020a), while in soccer, the explosive power manifested in the jump is critical for optimal performance and is considered in physical testing and talent selection (Castagna and Castellini, 2013).

Numerous strength training methods have been employed to enhance athletes' vertical jump performance, primarily categorized into plyometric training, weight resistance training, and complex training (Duthie et al., 2002; Ebben, 2002; Fry and Kraemer, 1997; Markovic, 2007). Plyometric training involves explosive movements utilizing the stretch-shortening cycle, a process in which muscles are rapidly stretched (eccentric phase) before immediately contracting (concentric phase) to increase muscle power and efficiency (Markovic, 2007). Exercises like box jumps, depth jumps, and jump drills in plyometric training help the neuromuscular system generate force quickly. They improve jump performance by increasing muscle responsiveness and coordination. For instance, box jumps build explosive power, helping athletes jump higher, while depth jumps strengthen muscles by combining stretching and rapid contraction. These drills also enhance joint stability, making athletes more agile and reducing injury risk, leading to better jump height and distance (Meylan and Malatesta, 2009). Current research indicates that plyometric training can significantly enhance jump performance due to its emphasis on high-speed, explosive movements (De Villarreal et al., 2010; Newton et al., 1999; Newton et al., 2006; Ziv and Lidor, 2010).

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Weight resistance training, on the other hand, focuses on increasing muscle strength and hypertrophy, thereby generating greater force, which directly translates to better jump performance by allowing athletes to produce more powerful takeoffs and achieve greater height and distance in their jumps (Fry and Kraemer, 1997). This training approach includes bilateral exercises such as squats, deadlifts, and leg presses, which enhance muscle strength and resistance, contributing to improved vertical jump performance. Squats and deadlifts, in particular, strengthen the quadriceps, hamstrings, and glutes, which are directly related to explosive power during jumps. Additionally, unilateral exercises like split squats and single-leg deadlifts improve balance and coordination, which are crucial for single-leg jumps and stability. Overall, combining both bilateral and unilateral exercises provides a more comprehensive improvement in vertical jump capacity (Suchomel et al., 2016; Docherty et al., 2004).

Complex training involves alternating a specific resistance exercise with a biomechanically similar plyometric exercise to enhance both strength and power. For example, an athlete might perform heavy squats followed by depth jumps, targeting the same muscle groups but in different ways. The resistance exercise builds maximal strength, while the plyometric movement enhances explosive power through the stretch-shortening cycle. This combination takes advantage of post-activation potentiation, where the resistance exercise primes the muscles and nervous system for more efficient force production during the plyometric movement (Steele, 2024). This method is particularly effective for improving athletic performance in movements requiring both strength and speed, such as vertical jumping.

Additionally, post-activation potentiation refers to the phenomenon where the performance of explosive movements, such as jumps, is enhanced after performing a heavy resistance exercise (Kasicki et al., 2024). The underlying mechanism involves a temporary increase in muscle force output due to heightened neural activation and improved muscle contractility following a high-intensity exercise (Li et al., 2024; Vigh-Larsen et al., 2021). Essentially, by performing a heavy resistance exercise (e.g., squats), the nervous system becomes more activated, allowing for greater power generation in subsequent plyometric or explosive exercises (e.g., jumps) (Ngo and Kazmi, 2024). This effect can be harnessed in complex training, which alternates between resistance exercises and plyometric movements to maximize power output (Cormier et al., 2024). This method aims to enhance muscle strength by alternating between strength and power exercises within the same training session. For example, performing a set of heavy squats followed by box jumps can improve neuromuscular system efficiency (Duthie et al., 2002; Ebben, 2002). It's well known that resistance training primarily focuses on building maximal strength, and plyometric training targets explosive power, complex training combines both elements, often leading to greater improvements in jump performance (Cormier et al., 2020; Makaruk et al., 2024; Thapa et al., 2021; Uthoff et al., 2021). Complex training, by leveraging the post-activation potentiation effect, can produce superior results compared to standalone methods, as it enhances both strength and power in a synergistic manner, which refers to the short-term increase in muscle contraction performance following brief maximal or near-maximal voluntary contractions (Thapa et al., 2024; Wang et al., 2023). For example, after performing a heavy squat, the muscles experience increased neural activation and enhanced muscle fiber recruitment, allowing for greater force output in subsequent explosive movements like jumps (Stone et al., 2022). This mechanism explains why complex training programs often result in superior performance improvements compared to traditional training methods, particularly in exercises like vertical jumping (Thapa et al., 2021). This dual focus allows athletes to transfer strength gains more effectively into explosive movements, such as jumping, compared to using just one approach (Jensen and Ebben, 2003; Mihalik et al., 2008; Pagaduan and Pojskic, 2020).

Although these training methods are widely used, their relative effectiveness is still debated. Some studies suggest that complex training is more effective by combining strength and power development, while others argue that traditional resistance or plyometric training may be more effective in certain cases, depending on the athlete's needs, experience level, and sport (Cao et al., 2024; Ramírez-delaCruz et al., 2022; Stone et al., 2022; Wang et al., 2023). Previous studies have employed various strength intervention methods to enhance athletes' jump performance, but a comprehensive analysis systematically comparing the effectiveness of these different training modalities on jump improvement is still lacking (Kotsifaki et al., 2022; Panoutsakopoulos et al., 2023; Şahin et al., 2022; Zhuravleva et al., 2023). Understanding the relative effectiveness of these methods is crucial for developing optimized training programs programmed to athletes' needs, as the available research presents varying conclusions on their efficacy. For example, while strength training has been shown to significantly improve vertical jump height in basketball players (Makaruk et al., 2020b; Uysal et al., 2023), other studies indicate that strength training is less effective than plyometric training in improving athletes' jump performance (Pardos-Mainer et al., 2021).

This systematic review and meta-analysis aim to examine and compare the effectiveness of various physical training programs, including resistance training, plyometric training, and complex training, on improving jump performance in terms of jump height, power output, and muscle strength. By analyzing previous research conclusions, this study seeks to provide evidence-based recommendations for athletes and coaches to improve jump performance, enhance explosive power, increase muscle strength, and optimize overall athletic performance.

Methods

Search strategy

This systematic review and meta-analysis have been conducted by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guideline (Page et al., 2021) and registered with the International Prospective Register of Systematic Reviews (INPLASY), registration number 202410012. A comprehensive electronic database search was conducted using PubMed, ERIC, Google Scholar, Web of Science, EBSCOhost, and Scopus while reviewing and excluding grey literature and relevant conference proceedings to include all pertinent articles and minimize publication bias. The key terms used in this study were combinations of {[“training” (Title/Abstract) OR “exercise*” (Title/Abstract) OR “intervention” (Title/Abstract) OR “physical training” (Title/Abstract) OR “exercise training” (Title/Abstract) OR “resistance training” (Title/Abstract) OR “strength training” (Title/Abstract) OR “aerobic exercise*” (Title/Abstract) OR “power training” (Title/Abstract) OR “fitness training” (Title/Abstract) OR “endurance training” (Title/Abstract) OR “conditioning training” (Title/Abstract) OR “physical therapy” (Title/Abstract)] AND [“vertical jump” (Title/Abstract) OR “vertical leap” (Title/Abstract) OR “squat jump” (Title/Abstract) OR “countermovement jump” (Title/Abstract) OR “drop jump” (Title/Abstract) OR “depth jump” (Title/Abstract). The database search was limited to peer-reviewed journal articles published in English up to April 2024. The search, identification, screening, and data extraction of the literature were independently conducted with any discrepancies resolved by authors (MS and XY).

Inclusion and exclusion criteria

This review included randomized controlled trials (RCTs) written in English and published in six databases (PubMed, ERIC, Google Scholar, Web of Science, EBSCOhost, and Scopus) up to March 2024. Studies that meet the criteria outlined in the participants, intervention, outcome, and sports or level will be considered for analysis. The following section describes the inclusion and exclusion criteria for the systematic review and meta-analysis. Articles meeting the following inclusion and exclusion criteria will be considered for inclusion: The exclusion criteria are as follows: (1) the included participants are healthy athletes of any age; (2) to be included in the meta-analysis, the study design must involve two or more groups; (3) the included articles must report on vertical jump performance in athletes, using vertical jump height as the outcome measure; (4) there were no restrictions on the type of sports or level of athletes.

The exclusion criteria are as follows: (1) studies that cannot be retrieved in full text; (2) studies that do not include strength training interventions; (3) studies that do not focus on athlete performance; (4) non-randomized controlled trials; and (5) studies that do not report numerical results.

Data extraction

Data extraction included information on athlete type, age, gender, height, weight, sample size, intervention description (type, intensity, duration, and frequency of the intervention), and study outcomes. Any data that was not extractable was noted, and appropriate methods were used to handle missing data to ensure the integrity of the analysis. This task was undertaken by one author (MS), with another author (XY) verifying the accuracy and completeness of the extracted data. Quality assessment was conducted by the author (MS), with discrepancies resolved through consensus with (XY). Unresolved issues were referred to the authors (MS and XY) for adjudication.

Quality assessment

The methodological quality of the included studies was assessed using the Physical Therapy Evidence Database (PEDro) scale (Albanese et al., 2020). The quality assessment was interpreted using the following 10-point scale: scores of 3 or below indicated poor quality, scores of 4-5 indicated moderate quality, and scores of 6-10 indicated high quality. The PEDro scale consists of 11 items designed to assess methodological quality. Each satisfied item contributes 1 point to the PEDro total score (ranging from 0-10 points). Since item 1 pertains to external validity, it was not included in the assessment of study quality.

Statistical analysis

All statistical analysis was performed in R (version 4.1.3, R Foundation for Statistical Computing, Vienna, Austria) using the meta for package (Viechtbauer, 2010). The outcomes used in this study to analyze jump performance included (1) countermovement jump, (2) squat jump, (3) drop jump, (4) stationary vertical jump, and (5) vertical jump. The types of strength training interventions included bodyweight training, complex training, core training, plyometric training, routine training, variable resistance training, and weight resistance exercise. We extracted mean values, standard deviations, and correlation coefficients of various outcome data for evaluation and analysis. When calculating the standard deviation of the difference before and after the intervention, given the means, standard deviations, and sample sizes (n) for pre- and post-intervention, we used the following formula (where Mean post represents the post-intervention mean, and mean pre-represents the pre-intervention mean): $Mean = Mean_{post} - Mean_{pre.}$ When estimating the standard deviation (SD), we used the following formula (where SD post represents the post-intervention standard deviation, and SD pre-represents the pre-intervention standard deviation). R is a constant, usually taken as 0.5:

$$SD = \sqrt{SDpost^{2} + SDpre^{2} - 2 * R * SD\,post * SDpre}$$

In this network meta-analysis, empirical evaluation was based on treatment rankings using Surface Under the Cumulative Ranking (SUCRA) scores (Daly et al., 2019). The cumulative probability plot and SUCRA scores are metrics used to evaluate the relative effectiveness of different treatments, reflecting the probability of a treatment being the best among all possible rankings. Previous studies have confirmed that treatment rankings based on SUCRA are robust for individual studies (Daly et al., 2019). The I^2 statistic was used to assess heterogeneity among studies and was classified as low, moderate, and high at 25%, 50%, and 75%, respectively (Higgins et al., 2003). If high heterogeneity was observed in the results, a random effects model was chosen to account for the correlation arising from using multiple lines of data within the same study (Higgins et al., 2003). In contrast, a fixed effects model was selected when homogeneity was good. All estimates were reported with their corresponding 95% CI. The α level was set at 0.05, indicating statistical significance.

Equity, diversity, and inclusion (EDI) statement

This study adhered to the principles of equity, diversity, and inclusion (EDI) (Wolbring and Lillywhite, 2021). The selection of athletes for the study was made without discrimination based on gender, race, or socioeconomic status. Additionally, efforts were made to ensure a diverse and representative sample. All procedures involved in the study were designed to be inclusive and accessible, ensuring that all included athletes had equal opportunities.

Results

Study selection

We identified a total of 15726 articles through database searches (PubMed, ERIC, Google Scholar, Web of Science, EBSCOhost, and Scopus) and an additional ten articles through reference lists, resulting in a total of 15736 studies considered for screening. After removing 8569 duplicates and excluding articles based on titles and abstracts, 7167 studies remained. These studies were independently screened by researchers (MS and XY) based on titles and abstracts, resulting in 134 studies meeting the criteria for full-text retrieval. Finally, 90 studies were excluded, leaving 44 studies included in this systematic review and meta-analysis (Table 1). Detailed information on the selection process is presented in Figure 1.

Methodological quality

The quality of the included studies was generally high, with an average PEDro score of 6.23 (range 5-9). Seven studies met the eligibility criteria based on factors such as study design, intervention relevance, and outcome measures (Ahmed, 2015; Asadi et al., 2016; Fonseca et al., 2022; Katushabe and Kramer, 2020; Kurt et al., 2023; Nunes et al., 2021; Sawyer et al., 2021; Thapa et al., 2023). Three studies met allocation concealment criteria (Ahmed, 2015; Egesoy et al., 2021; Fonseca et al., 2022), two studies implemented blinding to prevent bias (Ahmed, 2015; Thapa et al., 2023), and only one study used blinded assessors to ensure unbiased outcome evaluation (Khlifa et al., 2010). All included studies scored on random allocation, baseline comparability, follow-up, intention-to-treat analysis, and between-group comparison. Two studies were rated as medium quality (Taiar et al., 2019a; Taskin, 2016), with the others rated as high quality.

Study characteristics

In this study, the study characteristics are summarized based on the PICO principles as follows below.

Population

The total sample size across the 44 studies was 1342, with sample size ranging from 6 to 27 subjects per group. Among these, 36 included male participants (Abade et al., 2021; Ahmed, 2015; Ali et al., 2019; Aloui et al., 2019; Alves et al., 2010; Asadi et al., 2016; Barbalho et al., 2018; Chelly et al., 2009; Fonseca et al., 2022; Fowler et al., 1995; García-Pinillos et al., 2014; Hermassi et al., 2014; Hetzler et al., 1997; Iacono et al., 2017; Katushabe and Kramer, 2020; Khlifa et al., 2010; Klusemann et al., 2012; Kotzamanidis et al., 2005; Kurt et al., 2023; Latorre Román et al., 2018; Lu, 2015; Maciejczyk et al., 2021b; Nunes et al., 2021; Ramirez-Campillo et al., 2018; Saez de Villareal et al., 2023; Santos and Janeira, 2012; Sawyer et al., 2021; Seyhan, 2019; Taiar et al., 2019a; Thapa et al., 2023; Türkmen et al., 2022a; Váczi et al., 2013; Wang and Wang, 2023; Wong et al., 2010; Zhao et al., 2023), and 8 included female participants (Agostini et al., 2017; Egesoy et al., 2021; Guimarães et al., 2023; Huang et al., 2023; Martel et al., 2005a; Rubley et al., 2011; Simpson et al., 2020; Taskin, 2016). Nineteen studies focused on soccer (Abade et al., 2021; Ali et al., 2019; Alves et al., 2010; Barbalho et al., 2018; Chelly et al., 2009; Fonseca et al., 2022; García-Pinillos et al., 2014; Katushabe and Kramer, 2020; Kotzamanidis et al., 2005; Kurt et al., 2023; Maciejczyk et al., 2021b; Rubley et al., 2011; Sawyer et al., 2021; Taiar et al., 2019a; Taskin, 2016; Türkmen et al., 2022a; Váczi et al., 2013; Wong et al., 2010; Zhao et al., 2023), seven on basketball (Ahmed, 2015; Asadi et al., 2016; Hetzler et al., 1997; Khlifa et al., 2010; Klusemann et al., 2012; Latorre Román et al., 2018; Santos and Janeira, 2012), four included handball (Aloui et al., 2019; Hermassi et al., 2014; Iacono et al., 2017; Klusemann et al., 2012), four on volleyball (Guimarães et al., 2023; Lu, 2015; Martel et al., 2005a; Nunes et al., 2021), and one on each of gymnastics, cricket, tennis, parkour, field hockey, sprinting, and judo (Agostini et al., 2017; Ahmed, 2015; Egesoy et al., 2021; Seyhan, 2019; Thapa et al., 2023; Wang and Wang, 2023; Huang et al., 2023). Two studies did not specify the sport (Fowler et al., 1995; Simpson et al., 2020). The minimum age of participants was 8.72 ± 0.97 years (Latorre Román et al., 2018), and the maximum age was 24.95 ± 2.32 years (Wang and Wang, 2023). The minimum height was 133±7 cm (Latorre Román et al., 2018), and the maximum height was 192.58 ± 0.86 cm (Khlifa et al., 2010). The minimum weight was 30.56 ± 6.89 kg (Latorre Román et al., 2018), and the maximum weight was 102.8 ± 17.7 kg (Sawyer et al., 2021).

Intervention

The intervention periods ranged from 3 to 48 weeks. Three studies had a 3-week intervention (Fowler et al., 1995; Sawyer et al., 2021; Simpson et al., 2020), three lasted 4 weeks (Ahmed, 2015; Guimarães et al., 2023; Maciejczyk et al., 2021b), two spanned 5 weeks, and nine lasted 6 weeks (Ali et al., 2019; Alves et al., 2010; Fonseca et al., 2022; Huang et al., 2023; Katushabe and Kramer, 2020; Klusemann et al., 2012; Kurt et al., 2023; Thapa et al., 2023; Váczi et al., 2013). Twelve studies had 8-week interventions (Ahmed, 2015; Aloui et al., 2019; Asadi et al., 2016; Chelly et al., 2009; Egesoy et al., 2021; Hermassi et al., 2014; Lu, 2015; Ramirez-Campillo et al., 2018; Saez de Villareal et al., 2023; Seyhan, 2019; Taskin, 2016; Türkmen et al., 2022a), five lasted 12 weeks (García-Pinillos et al., 2014; Hetzler et al., 1997; Nunes et al., 2021; Taiar et al., 2019a; Wang and Wang, 2023), and one study each lasted 13, 14, 15, 20, and 48 weeks (Kotzamanidis et al., 2005; Rubley et al., 2011; Barbalho et al., 2018; Abade et al., 2021; Agostini et al., 2017).

Table 1. Population, study design PEDro scale.

Author	Year	Eligibility criteria	Random allocation	Allocation concealment	Baseline comparability	Blind participants	Blind assessor	Blind therapist	Follow-up	Intention to treat analysis	Between group comparisons	Point measure variability	Total PEDro score
Abade et al.	2019	0	1	0	1	0	0	0	1	1	1	1	6
Agostini et al.	2017	0	1	0	1	0	0	0	1	1	1	1	6
Ahmed	2015	0	1	0	1	0	0	0	1	1	1	1	6
Al et al.,	2023	1	1	1	1	1	0	0	1	1	1	1	9
Ali et al.	2019	0	1	0	1	0	0	0	1	1	1	1	6
Aloui et al.	2019	0	1	0	1	0	0	0	1	1	1	1	6
Fonseca et al.	2022	1	1	1	1	0	0	0	1	1	1	1	8
Martel et al.	2005	0	1	0	1	0	0	0	1	1	1	1	6
Guimarães et al.	2023	0	1	0	1	0	0	0	1	1	1	1	6
Kotzamanidis et al.	2005	0	1	0	1	0	0	0	1	1	1	1	6
Taskin	2016	0	1	0	1	0	0	0	1	1	1	0	5
Rubley et al.	2011	0	1	0	1	0	0	0	1	1	1	1	6
Wong et al.	2010	0	1	0	1	0	0	0	1	1	1	1	6
Egesoy et al.	2021	1	1	1	1	0	0	0	1	1	1	1	8
Zhao et al.	2023	0	1	0	1	0	0	0	1	1	1	1	6
Taiar et al.	2019	0	1	0	1	0	0	0	1	1	1	0	5
Kurt et al.	2023	0	1	0	1	0	0	0	1	1	1	1	6
Seyhan	2019	0	1	0	1	0	0	0	1	1	1	1	6
Hetzler et al.	1997	0	1	0	1	0	0	0	1	1	1	1	6
Chelly et al.	2009	0	1	0	1	0	0	0	1	1	1	1	6
Garcia-Pinillos et al.	2014	0	1	0	1	0	0	0	1	1	1	1	6
Latorre Román et al.	2018	0	1	0	1	0	0	0	1	1	1	1	6
Khlifa et al.	2010	0	1	0	1	0	1	0	1	1	1	1	6
Hermassi et al.	2014	0	1	0	1	0	0	0	1	1	1	1	6
Katushabe and Kramer	2020	1	1	0	1	0	0	0	1	1	1	1	7
Thapa et al.	2023	1	1	0	1	1	0	0	1	1	1	1	8
Wang and Wang	2023	0	1	0	1	0	0	0	1	1	1	1	6
Nunes et al.	2021	1	1	0	1	0	0	0	1	1	1	1	7
Huang et al.	2023	0	1	0	1	0	0	0	1	1	1	1	6
Lu	2015	0	1	0	1	0	0	0	1	1	1	1	6
Santos and Janeira	2012	0	1	0	1	0	0	0	1	1	1	1	6
Asadi et al.	2017	1	1	0	1	0	0	0	1	1	1	1	7
Turkmen et al.	2022	0	1	0	1	0	0	0	1	1	1	1	6
Barbalho et al.	2018	0	1	0	1	0	0	0	1	1	1	1	6
Klusemann et al.	2012	0	1	0	1	0	0	0	1	1	1	1	6
Saez de Villareal et al.	2023	0	1	0	1	0	0	0	1	1	1	1	6
Alves et al.	2010	0	1	0	1	0	0	0	1	1	1	1	6
Váczi et al.	2013	0	1	0	1	0	0	0	1	1	1	1	6

Table 1. Continue…

Author	Year	Eligibility criteria	Random allocation	Allocation concealment	Baseline comparability	Blind participants	Blind assessor	Blind therapist	Follow-up	Intention to treat analysis	Between group comparisons	Point measure variability	Total PEDro score
Ramirez-Campillo et al.	2018	0	1	0	1	0	0	0	1	1	1	1	6
Iacono et al.	2017	0	1	0	1	0	0	0	1	1	1	1	6
Fowler et al.	1995	0	1	0	1	0	0	0	1	1	1	1	6
Simpson et al.	2020	0	1	0	1	0	0	0	1	1	1	1	6
Maciejczyk et al.	2021	0	1	0	1	0	0	0	1	1	1	1	6
Sawyer et al.	2021	0	1	0	1	0	0	0	1	1	1	1	6

Intervention frequency varied from once to seven times a week. Two studies had interventions once a week (Abade et al., 2021; Rubley et al., 2011), nineteen studies twice a week (Ahmed, 2015; Alves et al., 2010; Chelly et al., 2009; Egesoy et al., 2021; Fonseca et al., 2022; García-Pinillos et al., 2014; Hermassi et al., 2014; Huang et al., 2023; Iacono et al., 2017; Klusemann et al., 2012; Kurt et al., 2023; Latorre Román et al., 2018; Maciejczyk et al., 2021b; Nunes et al., 2021; Ramirez-Campillo et al., 2018; Seyhan, 2019; Váczi et al., 2013; Wong et al., 2010; Zhao et al., 2023), and sixteen studies three times a week (Agostini et al., 2017; Ahmed, 2015; Ali et al., 2019; Asadi et al., 2016; Barbalho et al., 2018; Hetzler et al., 1997; Katushabe and Kramer, 2020; Kotzamanidis et al., 2005; Lu, 2015; Saez de Villareal et al., 2023; Santos and Janeira, 2012; Sawyer et al., 2021; Taiar et al., 2019a; Taskin, 2016; Thapa et al., 2023; Türkmen et al., 2022a). Three studies had interventions four times a week (Fowler et al., 1995; Simpson et al., 2020; Wang and Wang, 2023), one study five times a week (Martel et al., 2005a), and two studies seven times a week (Aloui et al., 2019; Guimarães et al., 2023).

The duration of each strength intervention session ranged from 27 to 100 minutes. Sessions varied as follows: one study had 27 minutes (Egesoy et al., 2021), one study 30 minutes (Wang and Wang, 2023), one study 40 minutes (Lu, 2015), one study 40-80 minutes (Barbalho et al., 2018), one study 45 minutes (Simpson et al., 2020), two studies 60 minutes (Klusemann et al., 2012; Nunes et al., 2021), one study 60-90 minutes (Taiar et al., 2019a), five studies 90 minutes (Huang et al., 2023; Khlifa et al., 2010; Kurt et al., 2023; Santos and Janeira, 2012; Wong et al., 2010), and one study 100 minutes (Martel et al., 2005a). The duration was not specified in 27 studies (Abade et al., 2021; Agostini et al., 2017; Ahmed, 2015; Ali et al., 2019; Aloui et al., 2019; Alves et al., 2010; Asadi et al., 2016; Chelly et al., 2009; Fonseca et al., 2022; Fowler et al., 1995; García-Pinillos et al., 2014; Guimarães et al., 2023; Hermassi et al., 2014; Hetzler et al., 1997; Iacono et al., 2017; Katushabe and Kramer, 2020; Kotzamanidis et al., 2005; Maciejczyk et al., 2021b; Ramirez-Campillo et al., 2018; Rubley et al., 2011; Saez de Villareal et al., 2023; Seyhan, 2019; Taskin, 2016; Thapa et al., 2023; Türkmen et al., 2022a; Váczi et al., 2013).

Comparison

In this study, 35 studies used a two-group design (Agostini et al., 2017; Ahmed, 2015; Ali et al., 2019; Aloui et al., 2019; Asadi et al., 2016; Barbalho et al., 2018; Chelly et al., 2009; Fowler et al., 1995; García-Pinillos et al., 2014; Guimarães et al., 2023; Hermassi et al., 2014; Hetzler et al., 1997; Huang et al., 2023; Iacono et al., 2017; Katushabe and Kramer, 2020; Khlifa et al., 2010; Klusemann et al., 2012; Latorre Román et al., 2018; Lu, 2015; Maciejczyk et al., 2021b; Martel et al., 2005a; Nunes et al., 2021; Ramirez-Campillo et al., 2018; Rubley et al., 2011; Saez de Villareal et al., 2023; Santos and Janeira, 2012; Sawyer et al., 2021; Seyhan, 2019; Simpson et al., 2020; Taiar et al., 2019a; Taskin, 2016; Thapa et al., 2023; Váczi et al., 2013; Wang and Wang, 2023; Wong et al., 2010), and nine studies used a three-group design (Abade et al., 2021; Ahmed, 2015; Alves et al., 2010; Egesoy et al., 2021; Fonseca et al., 2022; Kotzamanidis et al., 2005; Kurt et al., 2023; Türkmen et al., 2022a; Zhao et al., 2023).

Outcome

This network meta-analysis included eight studies on vertical jump (Agostini et al., 2017; Asadi et al., 2016; Barbalho et al., 2018; Kurt et al., 2023; Rubley et al., 2011; Taiar et al., 2019b; Türkmen et al., 2022b; Váczi et al., 2013), eight studies on stationary vertical jump (Abade et al., 2021; Chelly et al., 2009; Hermassi et al., 2014; Khlifa et al., 2010; Latorre Román et al., 2018; Maciejczyk et al., 2021a; Martel et al., 2005b; Santos and Janeira, 2012), and fifteen studies on countermovement jump (Abade et al., 2021; Ali et al., 2019; Fonseca et al., 2022; García-Pinillos et al., 2014; Guimarães et al., 2023; Khlifa et al., 2010; Latorre Román et al., 2018; Maciejczyk et al., 2021a; Martel et al., 2005a; Nunes et al., 2021; Saez de Villareal et al., 2023; Santos and Janeira, 2012; Seyhan, 2019; Thapa et al., 2023; Zhao et al., 2023). Few studies focused on drop jump and stationary vertical jump (fewer than three). Specific outcome variables are detailed in Table 2.

Study outcomes

This study explores the effects of different training methods on athletes' vertical jump height performance, considering factors such as population, intervention, comparison, and environmental confounders based on the PICO principles of RCTs.

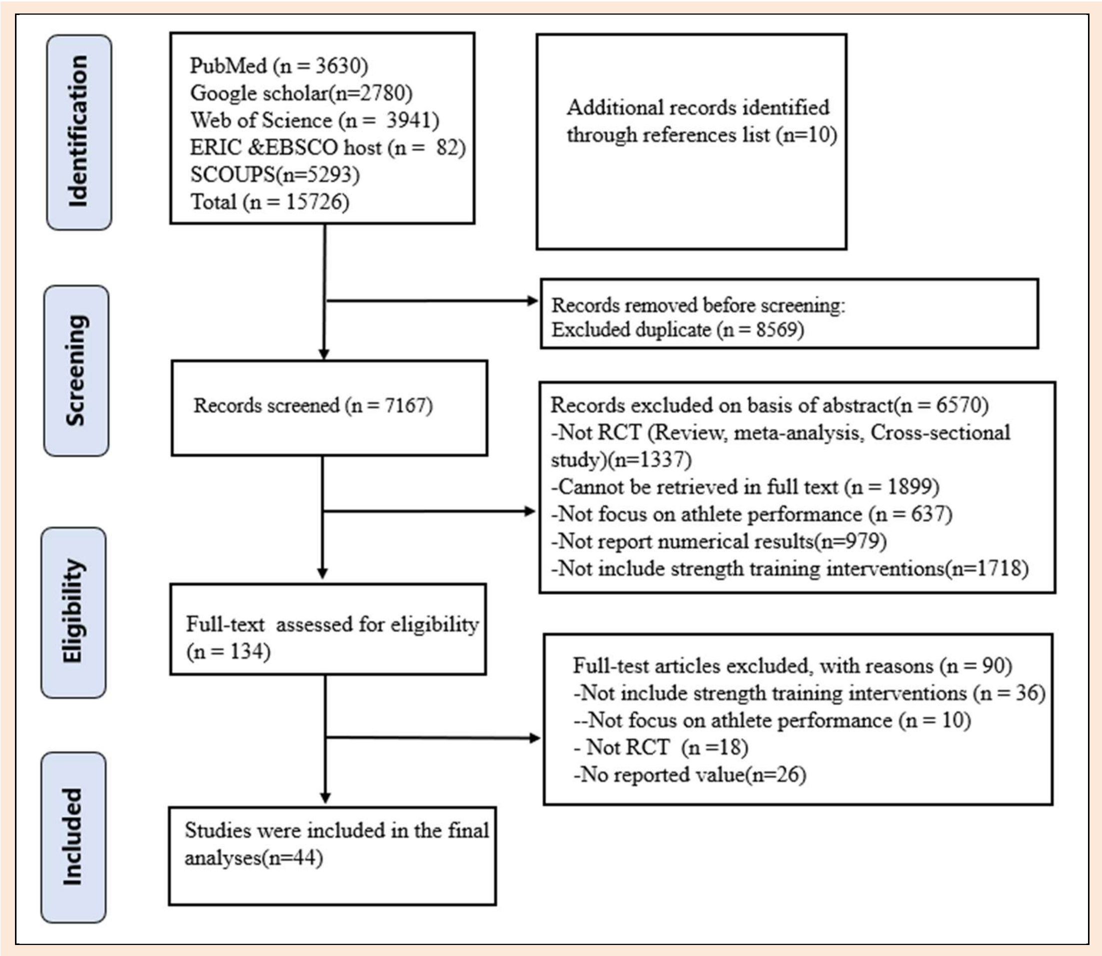

Figure 1. PRISMA flow diagram for study selection process.

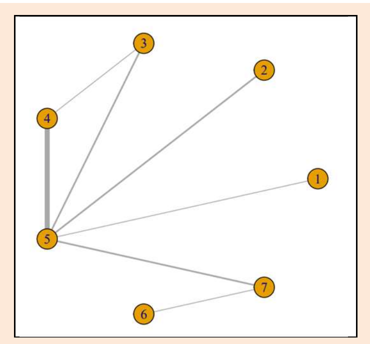

Figure 2. Network plot of training methods for vertical jump.

Vertical jump

Eight studies on vertical jump were included in the network meta-analysis, examining plyometric training, routine training, and weight resistance exercise (Agostini et al., 2017; Asadi et al., 2016; Barbalho et al., 2018; Kurt et al., 2023; Rubley et al., 2011; Taiar et al., 2019b; Türkmen et al., 2022b; Váczi et al., 2013) The network relationships among the training methods for the included subjects are shown in Figure 2. The network plot showed low heterogeneity (I^2 values of 4.7% and 0.0%), and the results were consistent (Figure 3). As shown in Table 3, both plyometric training and weight resistance exercise significantly improved vertical jump compared to routine training ($P < 0.05$). Plyometric training and weight resistance exercise increased vertical jump by 5.2 cm (95% CI: 2.6, 7.7 cm) and 9.9 cm (95% CI: 6.7, 13.5 cm) compared to routine training. The cumulative probability plot of vertical jump studies is shown in Figure 4. The SUCRA scores ranked weight resistance exercise highest (0.99212), followed by plyometric training (0.50709) and routine training (0.00078). Weight resistance exercise improved vertical jump by 4.8 cm more than plyometric training (95% CI: 0.7, 9.3 cm; $P < 0.05$).

Squat jump

Eight studies on squat jump were included in the network meta-analysis, involving plyometric training, routine training, and weight resistance exercise (Abade et al., 2021; Chelly et al., 2009; Hermassi et al., 2014; Khlifa et al., 2010; Latorre Román et al., 2018; Maciejczyk et al., 2021a; Martel et al., 2005b; Santos and Janeira, 2012). As shown in Figure 5, the network plot showed low heterogeneity ($I^2 = 0.0\%$ and 16.9%), and a fixed-effects model was used (Figure 6). As shown in Table 4, both plyometric training and weight resistance exercise significantly improved squat jump performance compared to routine training ($P < 0.05$). Plyometric training and weight resistance exercise increased squat jump by 1.5 cm (95% CI: 0.2, 2.6 cm) and 3.1 cm (95% CI: 0.2, 2.6 cm) compared to routine training. The SUCRA scores (Figure 7) ranked weight resistance exercise highest (0.95376), followed by plyometric training (0.53672) and routine training (0.00953). Weight resistance exercise improved stationary vertical jump by 1.7 cm (95% CI: -0.8, 4.2 cm) compared to plyometric training, but the difference was not statistically significant ($P > 0.05$).

Countermovement jump

Fifteen studies on countermovement jump were included in the network meta-analysis, encompassing four training methods: plyometric training, routine training, weight resistance exercise, and complex training (Abade et al., 2021; Ali et al., 2019; Fonseca et al., 2022; García-Pinillos et al., 2014; Guimarães et al., 2023; Khlifa et al., 2010; Latorre Román et al., 2018; Maciejczyk et al., 2021a; Martel et al., 2005a; Nunes et al., 2021; Saez de Villareal et al., 2023; Santos and Janeira, 2012; Seyhan, 2019; Thapa et al., 2023; Zhao et al., 2023). As shown in Figure 8, the network plot showed low heterogeneity ($I^2 = 0.0\%$) for all comparisons, and a fixed-effects model was used (Figure 9). As shown in Table 5, plyometric training, weight resistance exercise, and complex training all significantly improved countermovement jump performance compared to routine training ($P < 0.05$). Specifically, plyometric training increased countermovement jump by 2.0 cm (95% CI: 1.4, 3.7 cm), weight resistance exercise by 2.2 cm (95% CI: 1.4, 3.7 cm), and complex training by 5.0 cm (95% CI: 2.5, 7.6 cm) compared to routine training. As shown in Figure 10, the SUCRA scores ranked complex training highest (0.98365), followed by weight resistance exercise (0.55400), plyometric training (0.46195), and routine training (0.00040). Complex training improved countermovement jump by 2.6 cm (95% CI: 0.2, 5.5 cm) compared to weight resistance exercise ($P < 0.05$) and by 2.9 cm (95% CI: 0.2, 5.8 cm) compared to plyometric training ($P < 0.05$). Weight resistance exercise improved countermovement jump by 0.2 cm (95% CI: -1.0, 2.0 cm) compared to plyometric training, but the difference was not statistically significant ($P > 0.05$).

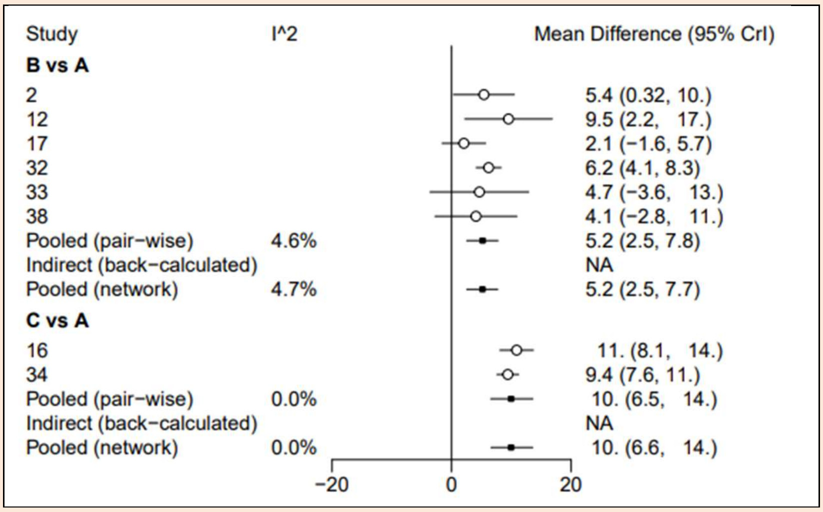

Figure 3. **Heterogeneity in training methods for vertical jump.**

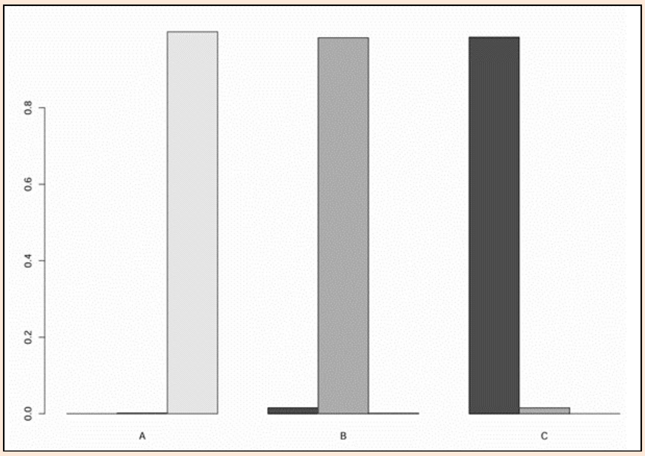

Figure 4. **Cumulative probability plot of network meta-analysis for vertical jump. A, Routine training; B, Plyometric training; C, Weight resistance exercise.**

Discussion

This systematic review and meta-analysis aimed to evaluate the relative effectiveness of various physical training programs on jump performance among athletes. Our study found that complex training, which combines plyometric and weight resistance exercise, led to the most significant improvements in jump performance compared to other training methods. Plyometric training alone also demonstrated strong benefits, particularly in enhancing explosive power, while routine training and weight resistance exercise showed more moderate improvements. These findings suggest that incorporating both strength and power-focused exercises can optimize jump performance in athletic populations.

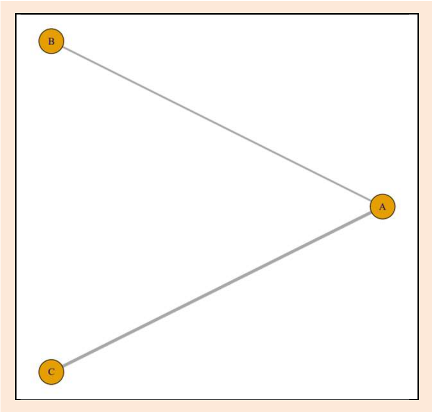

Figure 5. **Network plot of training methods for squat jump. A, routine training; B, Plyometric training; C, weight resistance exercise.**

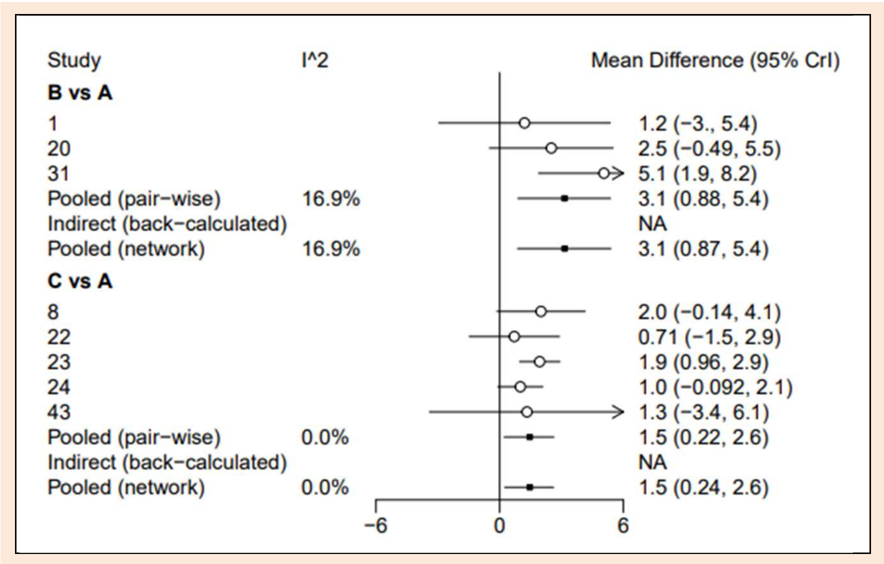

Figure 6. **Heterogeneity in training methods for squat jump.**

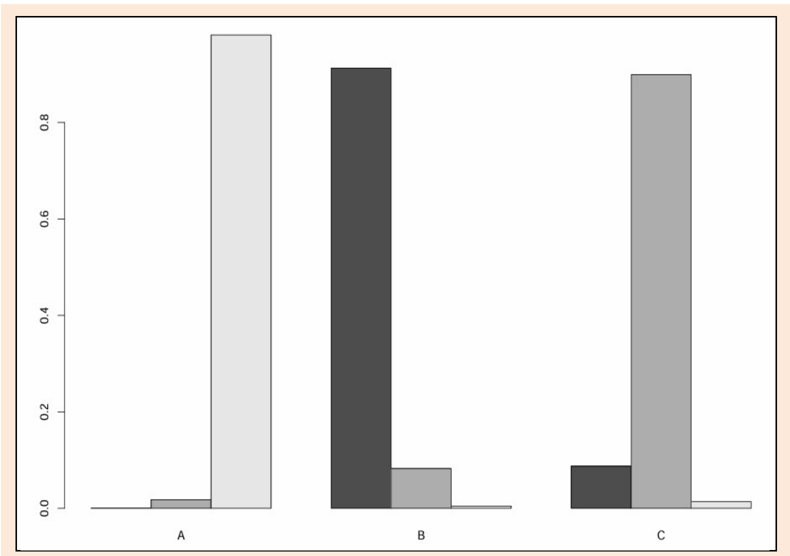

Figure 7. **Cumulative probability plot of network meta-Analysis for squat jump. A, Routine training; B, Weight resistance exercise; C, Plyometric training.**

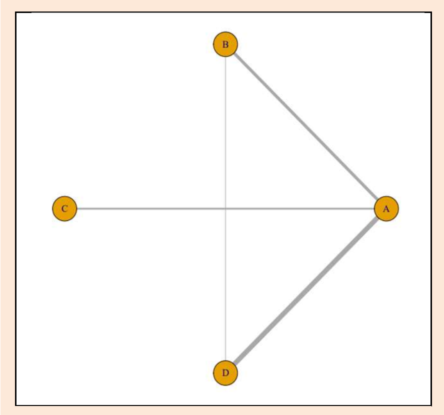

Figure 8. Network plot of training methods for countermovement jump. A, Routine training; B, Weight resistance exercise; C, Complex training; D, Plyometric training.

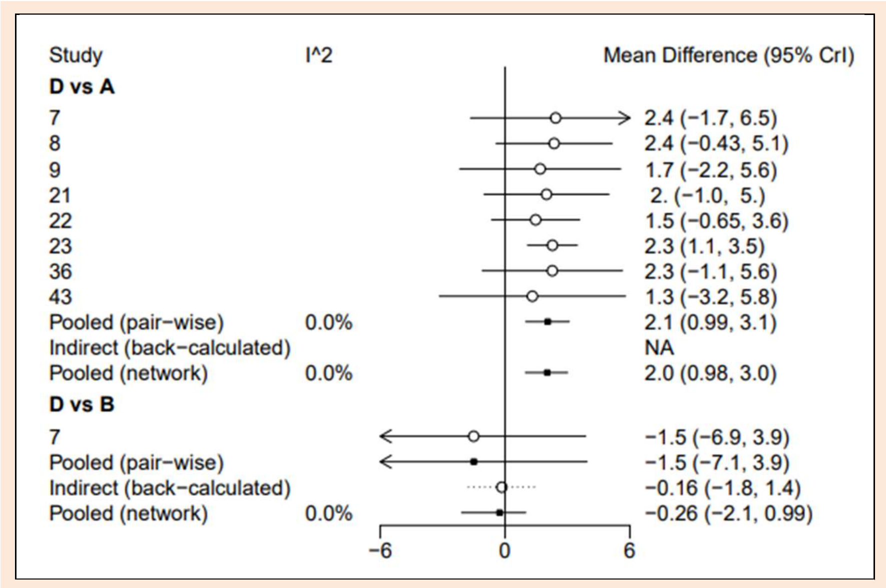

Figure 9. Heterogeneity in Training Methods for countermovement jump.

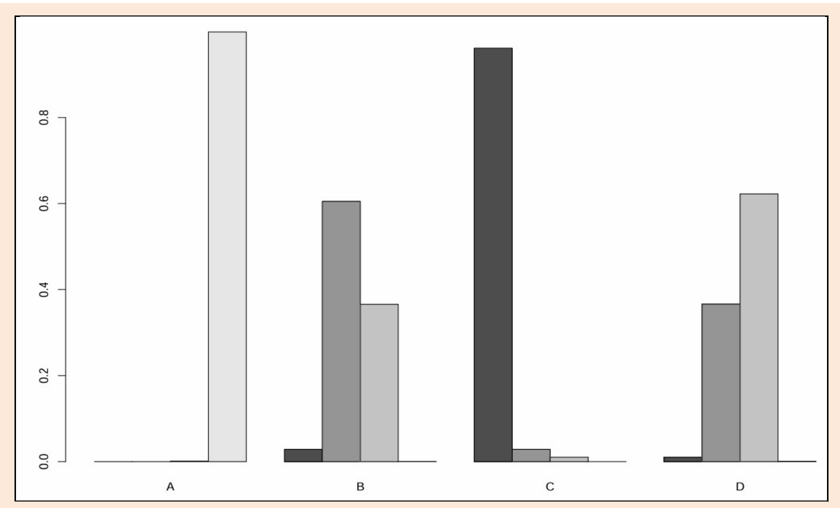

Figure 10. Cumulative probability plot of network meta-analysis for countermovement jump. A, Routine training; B, Weight resistance exercise; C, Complex training; D, Plyometric training.

Table 2. Studies characteristics.

Population						Training program					Outcome				
Author, year	**Athletes**	**Age (years)**	**Gen.**	**Height (cm)**	**Weight (kg)**	**Type**	**Sample size (n)**	**Duration (Weeks)**	**Freq. (Days/ Week)**	**Session (Min)**	**Counter-movement Jump (%)**	**Squat Jump (%)**	**Drop Jump (%)**	**Svertical Jump (%)**	**Vertical Jump (%)**
Abade et al., 2019	Soccer	C:16.6 ± 0.56 T:16.6 ± 0.56	M	C:176.3 ± 5.8 T:176.3 ± 5.8	C:66.6 ± 6.2 T:66.6 ± 6.2	C: routine training E:weight resistance ex	16(8/8)	20	1		C:5.6↑ T:8.5↑				C:0 T:0
		C:16.6 ± 0.56 T:16.6 ± 0.56	M	C:176.3 ± 5.8 T:176.3 ± 5.8	C:66.6 ± 6.2 T:66.6 ± 6.2	C: routine training E:weight resistance ex	16(8/8)	20	1		C:5.6↑ T:5.6↑				C:0 T:0
Agostini et al., 2017	Gymnas-tics	C:15.2 ± 1.5 T:15.4 ± 1.2	F	C:165.0 ± 7.0 T:169.0 ± 2.0	-	C:routine training E:plyometric training	30(15/15)	12	3						C:9.7↑* T:8.4↑*
		C:15.2 ± 1.5 T:15.4 ± 1.2	F	C:165.0 ± 7.0 T:169.0 ± 2.0	-	C:routine training E:plyometric training	30(15/15)	24	3						C:18.1↑* T:16↑*
		C:15.2 ± 1.5 T:15.4 ± 1.2	F	C:165.0 ± 7.0 T:169.0 ± 2.0	-	C:routine training E:plyometric training	30(15/15)	36	3						C:23.5↑* T:28.7↑*
		C:15.2 ± 1.5 T:15.4 ± 1.2	F	C:165.0 ± 7.0 T:169.0 ± 2.0	-	C:routine training E:plyometric training	30(15/15)	48	3						C:28.4↑* T:42.3↑*
Ahmed, 2015	Basketball	C:18.0 ± 0.5 T:18.0 ± 0.7	M	C:179.6 ± 1.6 T:179.9 ± 1.7	C:67.4 ± 1.0 T:67.6 ± 1.3	C:routine training E:complex training	24(12/12)	8	3						C:8.6↑* T:24.1↑*
Ali et al., 2023	Cricket	C:19.7 ± 1.3 T:19.5 ± 1.6	M	C:176.7 ± 6.1 T:174.9 ± 8.4	C:64.4 ± 10.2 T:62.9 ± 11.0	C:routine training E:plyometric training	28(14/14)	4	2					C:-0.6↓ T:11.8↑	
		C:19.7 ± 1.3 T:19 ± 1.4	M	C:176.7 ± 6.1 T:170.2 ± 7.3	C:64.4 ± 10.2 T:55.8 ± 6.8	C:routine training E:complex training	28(14/14)	4	2					C:-0.6↓ T:11.5↑	
Ali et al., K., 2019	Soccer	C:21.5 ± 1.8 T:22.0 ± 2.4	M	C:171.2 ± 4.8 T:173.4 ± 5.3	C:65.0 ± 5.2 T:69.3 ± 5.2	C:routine training E:complex training	24(12/12)	6	3		C:0.9↑ T:8↑				
Aloui et al., 2019	Handball	C:18.8 ± 0.8 T:18.3 ± 0.8	M	C:185.0 ± 7.0 T:184.0 ± 5.0	C:78.7 ± 13.8 T:83.4 ± 17.0	C:routine training E:Vroutine training	30(15/15)	8	7			C:3.4↑ T:13.2↑			
Fonseca et al., 2022	Soccer	C:17.3 ± 0.5 T:17.3 ± 0.7	M	C:174.6 ± 7.9 T:175.9 ± 5.8	C:68.3 ± 8.0 T:65.4 ± 6.3	C:routine training E:plyometric training	17(9/8)	6	2		C:0.7↑ T:7.6↑				
		C:17.3 ± 0.5 T:17.4 ± 0.5	M	C:174.6 ± 7.9 T:174.2 ± 5.1	C:68.3 ± 8.0 T:67.2 ± 8.0	C:routine training E:weight resistance ex	16(8/8)	6	2		C:0.7↑ T:12.1↑*				
Martel et al., 2005	Volleyball	C:15.5 ± 1.5 T:15.4 ± 1.3	F	C:169.1 ± 5.9 T:170.8 ± 4.8	C:61.3 ± 7.6 T:60.8 ± 8.4	C:routine training E:plyometric training	54(27/27)	5	5	100	C:0.8↑ T:9.4↑*				
Guimarães et al., 2023	Volleyball	C:19.5 ± 3.7 T:19.5 ± 3.7	F	C:182.0 ± 2.1 T:180.0 ± 3.0	C:66.9 ± 6.4 T:67.7 ± 4.3	C:routine training E:plyometric training	17(9/8)	4	7		C:3.8↑ T:9.5↑				
Kotzamanidis et al., 2005	Soccer	C:17.8 ± 0.3 T:17.1 ± 1.1	M	C:176.0 ± 1.3 T:175.0 ± 2.5	C:75.0 ± 1.8 T:72.5 ± 2.2	C:routine training E:weight resistance ex	23(11/12)	13	3				C:3.3↑ T:2.6↑		
		C:17.8 ± 0.3 T:17.0 ± 1.1	M	C:176.0 ± 1.3 T:178.0 ± 3.5	C:75.0 ± 1.8 T:73.5 ± 1.2	C:routine training E:complex training	24(12/12)	13	3				C:3.3↑ T:5.5↑*		

C, Control group; E, Experimental group; Freq., Frequency; M, Male; F, Female; BT, Bodyweight Training; complex training, Complex Training; CT, Core Training; plyometric training, Plyometric Training; routine training, Routine Training; Vroutine training, Variable Resistance Training; Weight resistance exercise, Weight Resistance Exercise; countermovement jump, Countermovement jump; squat jump, Squat jump; drop jump, drop jump; Svertical jump, Stationary vertical jump; Vertical jump, Vertical Jump;↑*, indicates significant increase; ↑indicates increase.

Table 2. Continue…

Population						Training program					Outcome				
Author, year	**Athletes**	**Age (years)**	**Gen.**	**Height (cm)**	**Weight (kg)**	**Type**	**Sample size (n)**	**Duration (Weeks)**	**Freq. (Days/ Week)**	**Session (Min)**	**Counter-movement Jump (%)**	**Squat Jump (%)**	**Drop Jump (%)**	**Svertical Jump (%)**	**Vertical Jump (%)**
Taskin, 2016	Soccer	C:18.6 ± 0.8 T:19.1 ± 1.2	F	C:159.1 ± 3.9 T:160.6 ± 4.2	C:52.2 ± 3.6 T:56.5 ± 3.33	C:routine training E:CT	40(20/20)	8	3						C:-0.1↓ T:13.4↑
Rubley et al., 2011	Soccer	C:13.4 ± 0.5 T:13.4 ± 0.5	F	C:162.5 ± 5.7 T:162.5 ± 5.7	C:50.8 ± 5.1 T:50.8 ± 5.1	C:routine training E:plyometric training	14(7/7)	7	1						C:-7.6↓ T:8.3↑*
		C:13.4 ± 0.5 T:13.4 ± 0.5	F	C:162.5 ± 5.7 T:162.5 ± 5.7	C:50.8 ± 5.1 T:50.8 ± 5.1	C:routine training E:plyometric training	14(7/7)	14	1						C:-5.4↓ T:18.7↑
Wong et al., 2010	Soccer	C:21.0 ± 1.0 T:24.6 ± 1.5	M	C:173.0 ± 1.0 T:176.0 ± 2.0	C:63.7 ± 1.6 T:71.4 ± 1.9	C:routine training E:complex training	39(20/19)	8	2	90					C:0.3↑ T:3.9↑*
Egesoy et al., 2021	Tennis	C:11.8 ± 1.5 T:11.8 ± 1.5	F	C:147.9 ± 11.8 T:147.9 ± 11.8	C:44.5 ± 8.4 T:44.5 ± 8.4	C:routine training E:CT	24(12/12)	8	2	27	C:1.9↑ T:9↑				
		C:11.8 ± 1.5 T:11.8 ± 1.5	F	C:147.9 ± 11.8 T:147.9 ± 11.8	C:44.5 ± 8.4 T:44.5 ± 8.4	C:routine training E:CT	24(12/12)	8	2	27	C:1.9↑ T:13.3↑				
Zhao et al.., 2023	Soccer	C:15.3 ± 0.5 T:15.2 ± 0.5	M	C:179.4 ± 5.2 T:180.0 ± 4.5	C:75.2 ± 5.7 T:74.2 ± 6.5	C:routine training E:weight resistance ex	12(7/5)	5	2	75	C:2.6↑ T:1.3↑				
		C:15.3 ± 0.5 T:15.3 ± 0.3	M	C:179.4 ± 5.2 T:178.9 ± 8.2	C:75.2 ± 5.7 T:74.3 ± 7.7	C:routine training E:weight resistance ex	12(7/5)	5	2	75	C:2.6↑ T:2.4↑				
Taiar et al., 2019	Soccer	C:23.0 ± 3.8 T:23.5 ± 2.4	M	C:177.4 ± 4.3 T:178.4 ± 3.5	C:72.9 ± 3.4 T:73.5 ± 2.3	C:routine training E:weight resistance ex	20(10/10)	12	3	60-90					C:10.9↑* T:35.1↑*
Kurt et al., 2023	Soccer	C:12.1 ± 0.9 T:12.1 ± 0.9	M	C:155.0 ± 10.0 T:155.0 ± 10.0	C:44.6 ± 8.0 T:44.6 ± 8.0	C: routine training E:plyometric training	23(12/11)	6	2	90					C:-7.9↓ T:-0.7↓
		C:12.1 ± 0.9 T:12.1 ± 0.9	M	C:155.0 ± 10.0 T:155.0 ± 10.0	C:44.6 ± 8.0 T:44.6 ± 8.0	C:routine training E:plyometric training	23(12/11)	6	2	90					C:-7.9↓ T:0
Seyhan, 2019	Parkour	C:19.0 ± 0.9 T:19.5 ± 1.1	M	C:173.7 ± 4.6 T:175.8 ± 8.9	C:67.7 ± 7.2 T:66.5 ± 5.3	C:routine training E:weight resistance ex	12(6/6)	8	2		C:0.5↑ T:5↑*				
Hetzler et al., 1997	Baseball	C:13.6 ± 0.9 T:13.6 ± 0.9	M	C:162.0 ± 7.0 T:166.9 ± 6.1	C:52.2 ± 10.3 T:58.2 ± 7.8	C:routine training E:weight resistance ex	20(10/10)	12	3						C:0 T:3.2↑
Chelly et al., 2009	Soccer	C:17.0 ± 0.5 T:17.0 ± 0.3	M	C:174.0 ± 8.0 T:173.0 ± 3.0	C:60.0 ± 7.0 T:59.0 ± 6.0	C:routine training E:weight resistance ex	22(11/11)	8	2			C:1.9↑ T:9.8↑*			
Garcia-Pinillos, et al., 2014	Soccer	C:16.4 ± 1.5 T:15.5 ± 1.3	M	C:169.1 ± 0.1 T:172.1 ± 0.1	C:61.5 ± 9.5 T:68.3 ± 11.2	C:routine training E:plyometric training	30(17/13)	12	2		C:2.2↑ T:7.1↑*				
Latorre Román et al., 2018	Basketball	C:8.7 ± 1.0 T:8.7 ± 1.0	M	C:133.0 ± 7.0 T:133.0 ± 7.0	C:30.6 ± 6.9 T:30.6 ± 6.9	C:routine training E:plyometric training	58(30/28)	10	2	10-29	C:6↑* T:14.1↑*				
Khlifa et al., 2010	Basketball	C:24.2 ± 0.2 T:23.6 ± 0.3	M	C:192.6 ± 0.9 T:191.7 ± 0.5	C:82.61 ± 0.8 T:81.72 ± 0.5	C:routine training E:plyometric training	18(9/9)	10	6	90	C:1.8↑* T:7↑*				
Hermassi et al., 2014	Handball	C:20.1 ± 0.2 T:20.1 ± 0.3	M	C:190.0 ± 2.0 T:189.0 ± 3.0	C:88.6 ± 1.1 T:85.8 ± 3.1	C:routine training E:plyometric training	24(14/10)	8	2			C:5.1↑* T:7.1↑*			

C, Control group; E, Experimental group; Freq., Frequency; M, Male; F, Female; BT, Bodyweight Training; complex training, Complex Training; CT, Core Training; plyometric training, Plyometric Training; routine training, Routine Training; Vroutine training, Variable Resistance Training; Weight resistance exercise, Weight Resistance Exercise; countermovement jump, Countermovement jump; squat jump, Squat jump; drop jump, drop jump; Svertical jump, Stationary vertical jump; Vertical jump, Vertical Jump;↑*, indicates significant increase; ↑indicates increase.

Table 2. Continue…

Population						Training program					Outcome				
Author, year	Athletes	Age (years)	Gen.	Height (cm)	Weight (kg)	Type	Sample size (n)	Duration (Weeks)	Freq. (Days/ Week)	Session (Min)	Counter-movement Jump (%)	Squat Jump (%)	Drop Jump (%)	Svertical Jump (%)	Vertical Jump (%)
Katushabe and Kramer, 2020	Soccer	C:20.5 ± 1.9 T:20.5 ± 1.9	M	C:181.0 ± 7.0 T:174.0 ± 8.0	C:70.41 ± 5.25 T:70.56 ± 3.22	C:routine training E:Vroutine training	17(9/8)	6	3					C:6.7↑ T:9.5↑	
Thapa et al., 2023	Field hockey	C:21.7 ± 1.6 T:20.6 ± 1.5	M	C:168.5 ± 4.7 T:171.3 ± 8.8	C:65 ± 2.6 T:61.8 ± 7.9	C:routine training E:complex training	14(8/6)	6	3		C:-2.4↓ T:13.2↑				
Wang and Wang, 2023	Sprinter	C:23.3 ± 2.7 T:25.0 ± 2.3	M	C:187.0 ± 7.1 T:184.3 ± 7.6	C:71.26 ± 5.79 T:69.05 ± 7.79	C:routine training E:BT	30(15/15)	12	4	30					C:3.4↑ T:18.5↑
Nunes et al., 2021	Volleyball	C:13.1 ± 0.4 T:12.8 ± 0.7	M	C:161.1 ± 6.4 T:160.1 ± 10.7	C:55.3 ± 12.1 T:51.8 ± 13.6	C: routine training E:complex training	32(16/16)	12	2	60	C:-6.1↓ T:11.4↑				
Huang et al., 2023	Judo	C:14.3 ± 1.16 T:14.9 ± 0.6	F	C:165.2 ± 6.6 T:164.4 ± 7.6	C:56.12 ± 7.6 T:64.6 ± 10.7	C: routine training E:weight resistance ex	19(9/10)	6	2	90	C:14↑ T:4.2↑				
Lu, 2015	Volleyball	C:17.5 ± 2.2 T:17.5 ± 2.2	M	C:178.3 ± 6.6 T:178.3 ± 6.6	C:67.6 ± 5.9 T:67.6 ± 5.9	C:routine training E:plyometric training	20(10/10)	8	3	40					C:0 T:1.5↑
Santos and Janeira, 2012	Basketball	C:14.2 ± 0.4 T:14.5 ± 0.6	M	C:173.2 ± 7.6 T:172.7 ± 8.1	C:61.1 ± 11.4 T:61.6 ± 8.0	C:routine training E:weight resistance ex	25(15/10)	10	3	90	C:-7.7↓* T:10.2↑*				
Asadi et al., 2017	Basketball	C:18.5 ± 0.8 T:18.5 ± 0.8	M	C:186.1 ± 5.6 T:186.1 ± 5.6	C:78.4 ± 7.6 T:78.4 ± 7.6	C:routine training E:plyometric training	16(8/8)	8	3						C:0.2↑ T:14.3↑*
Turkmen et al., 2022	Soccer	C:17.7 ± 0.5 T:17.3 ± 0.5	M	C:179.7 ± 9.8 T:175.0 ± 7.8	C:70.7 ± 12.1 T:76.4 ± 12.4	C:routine training E:CT	16(8/8)	8	3						C:2.5↑* T:7.2↑*
Nunes et al., 2021	Volleyball	C:17.7 ± 0.5 T:17.2 ± 0.4	M	C:179.7 ± 9.8 T:175.8 ± 5.1	C:70.7 ± 12.1 T:61.4 ± 4.3	C:routine training E:plyometric training	16(8/8)	8	3						C:2.5↑* T:13.5↑*
Barbalho et al., 2018	Soccer	C:19.1 ± 0.9 T:18.8 ± 0.8	M	C:176.3 ± 8.6 T:178.4 ± 6.2	C:72.0 ± 5.9 T:73.1 ± 6.6	C:routine training E:weight resistance ex	22(11/11)	15	3	40-80					C:-7.4↓* T:9.5↑*
Klusemann et al., 2012	Basketball	C:14.5 ± 1 T:14.5 ± 1	M	C:179.0 ± 10.0 T:179.0 ± 10.0	C:67.0 ± 12.0 T:67.0 ± 12.0	C:routine training E:BT	26(13/13)	6	2	60					C:0 T:4.9↑*
Saez de Villareal et al., 2023	Handball	C:20.6 ± 1.6 T:19.8 ± 2.2	M	C:180.2 ± 2.8 T:178.3 ± 4.3	C:81.2 ± 5.2 T:79.1 ± 8.3	C:routine training E:plyometric training	24(12/12)	8	3		C:1.6↑ T:7.1↑				
Alves et al., 2010	Soccer	C:17.4 ± 0.6 T:17.4 ± 0.6	M	C:175.3 ± 6.3 T:175.3 ± 6.3	C:70.3 ± 8.3 T:70.3 ± 8.3	C:routine training E:BT	15(9/6)	6	1		C:-2.6↓ T:0.2↑	C:-0.7↓ T:9.6↑*			
		C:17.4 ± 0.6 T:17.4 ± 0.6	M	C:175.3 ± 6.3 T:175.3 ± 6.3	C:70.3 ± 8.3 T:70.3 ± 8.3	C:routine training E:BT	14(8/6)	6	2		C:-2.6↓ T:2.4↑	C:-0.7↓ T:12.6↑*			
Vaczi et al., 2013	Soccer	C:22.7 ± 1.4 T:21.9 ± 1.7	M	C:180.6 ± 3.7 T:180.1 ± 4	C:78.6 ± 3.1 T:75.9 ± 2.7	C:routine training E:plyometric training	24(12/12)	6	2						C:-0.2↓ T:8.9↑*
Ramirez-Campillo et al., 2018	Soccer	C:17.6 ± 0.5 T:17.3 ± 1.1	M	C:174.9 ± 5.3 T:177.1 ± 5.9	C:68.3 ± 3.6 T:64.9 ± 5.5	C:plyometric training E:plyometric training	18(9/9)	8	2		C:8.1↑* T:5.3↑	C:5.7↑* T:5.7↑			
Iacono et al., 2017	Handball	C:23.4 ± 4.6 T:23.4 ± 4.6	M	C:192.5 ± 3.7 T:192.5 ± 3.7	C:87.8 ± 7.4 T:87.8 ± 7.4	C:BT E:BT	18(9/9)	10	2		C:8.7↑* T:4.2↑*				

C, Control group; E, Experimental group; Freq., Frequency; M, Male; F, Female; BT, Bodyweight Training; complex training, Complex Training; CT, Core Training; plyometric training, Plyometric Training; routine training, Routine Training; Vroutine training, Variable Resistance Training; Weight resistance exercise, Weight Resistance Exercise; countermovement jump, Countermovement jump; squat jump, Squat jump; drop jump, drop jump; Svertical jump, Stationary vertical jump; Vertical jump, Vertical Jump;↑*, indicates significant increase; ↑indicates increase.

Table 2. Continue…

Population						Training program					Outcome				
Author, year	**Athletes**	**Age (years)**	**Gen.**	**Height (cm)**	**Weight (kg)**	**Type**	**Sample size (n)**	**Duration (Weeks)**	**Freq. (Days/ Week)**	**Session (Min)**	**Counter-movement Jump (%)**	**Squat Jump (%)**	**Drop Jump (%)**	**Svertical Jump (%)**	**Vertical Jump (%)**
Fowler, et al., 1995	-	C:22.3 ± 2.4 T:22.7 ± 1.2	M	C:180.0 ± 7.0 T:181.0 ± 5.0	C:77.3 ± 7.2 T:77.5 ± 8.7	C:weight resistance ex E:weight resistance ex	18(9/9)	3	4		C:4.8↑* T:7.2↑*				
Simpson et al., 2020	-	C:22 ± 3 T:21 ± 2	F	C:160.0 ± 4.0 T:170.0 ± 3.0	C:63.0 ± 7.8 T:67.0 ± 4.0	C:routine training E:weight resistance ex	19(9/10)	3	4	45	C:0 T:8.1↑				
Maciejczyk et al., 2021	Soccer	C:18.2 ± 1.8 T:21 ± 3	M	C:161.7 ± 4.3 T:164.5 ± 6.91	C:55 ± 5.39 T:61.3 ± 13.86	C:routine training E:plyometric training	15(7/8)	4	2		C:1.8↑ T:6.5↑*	C:3.9↑ T:9.1↑*			
Sawyer et al., 2021	Soccer	C:18-25 ± - T:18-25 ± -	M	C:182.3 ± 5.1 T:180.7 ± 8	C:102.8 ± 17.7 T:100.3 ± 27.1	C:weight resistance ex E:Vroutine training	40(20/20)	3	3	90					C:-3.1↓ T:0.7↑

C, Control group; E, Experimental group; Freq., Frequency; M, Male; F, Female; BT, Bodyweight Training; complex training, Complex Training; CT, Core Training; plyometric training, Plyometric Training; routine training, Routine Training; Vroutine training, Variable Resistance Training; Weight resistance exercise, Weight Resistance Exercise; countermovement jump, Countermovement jump; squat jump, Squat jump; drop jump, drop jump; Svertical jump, Stationary vertical jump; Vertical jump, Vertical Jump;↑*, indicates significant increase; ↑indicates increase.

Table 3. Meta-analysis results of vertical jump studies.

	Routine training	Plyometric training
Plyometric training	5.2 (2.6, 7.7)	-
Weight resistance exercise	9.9 (6.7, 13.5)	4.8 (0.7, 9.3)

Table 4. Meta-analysis results of squat jump studies.

	Routine training	Plyometric training
Plyometric training	1.5 (0.2, 2.6)	-
Weight resistance exercise	3.1 (0.2, 2.6)	1.7 (-0.8, 4.2)

Table 5. Meta-analysis results of countermovement jump studies.

	Routine training	Plyometric training	Weight resistance exercise
Plyometric training	2.0 (1.4, 3.7)	-	-
Weight resistance exercise	2.2(1.4, 3.7)	0.2 (-1.0, 2.0)	-
Complex training	5.0 (2.5, 7.6)	2.9 (0.2, 5.8)	2.6 (0.2, 5.5)

Vertical jump

The network meta-analysis for vertical jump, incorporating eight studies, revealed significant improvements in vertical jump performance with both plyometric training and weight resistance exercise compared to routine training (Agostini et al., 2017; Asadi et al., 2016; Barbalho et al., 2018; Kurt et al., 2023; Rubley et al., 2011; Taiar et al., 2019b; Türkmen et al., 2022b; Váczi et al., 2013). Specifically, plyometric training increased vertical jump by 5.2 cm, while weight resistance exercise led to a 9.9 cm improvement. These results underscore the effectiveness of both plyometric and weight resistance exercise in enhancing explosive power, a critical component of athletic performance (Chen et al., 2024; Makaruk et al., 2024). The SUCRA score is relevant because it provides a quantitative measure of the relative effectiveness of each training method. A higher SUCRA score indicates a greater likelihood that a training method is the most effective (Kim et al., 2022). In this case, the weight resistance exercise having the highest SUCRA score (0.99212) suggests it is the most effective method for improving vertical jump performance, followed by plyometric training (0.50709), while routine training was the least effective (0.00078). The comparison between weight resistance exercise and plyometric training showed a significant improvement of 4.8 cm in favor of weight resistance exercise, suggesting its superior efficacy.

This study indicates that the effectiveness of training methods for improving vertical jump height performance follows the order of weight resistance exercise > plyometric training > routine training. These findings suggest that incorporating weight resistance exercises as the foundation of a training program could lead to the most significant improvements in jump performance. Plyometric training, which emphasizes explosive power, should also be included as a supplementary method to further enhance neuromuscular efficiency. Ultimately, combining weight resistance and plyometric exercises may yield the best results in optimizing vertical jump performance, especially in athletic populations aiming for peak performance. The observed improvements can be attributed to specific physiological mechanisms activated by these training methods (Nagappan et al., 2020).

Weight resistance exercise primarily stimulates muscle hypertrophy and neural adaptations, such as increased motor unit recruitment and firing rates, which enhance muscle force production and power output (Škarabot et al., 2021). In contrast, plyometric training activates the stretch-shortening cycle, which improves muscle stiffness, elastic energy storage, and release, resulting in more efficient force generation during explosive movements like jumping (Chen et al., 2023). These distinct adaptations lead to significant improvements in vertical jump height. Weight resistance exercise, which includes heavy-resistance training, free weight exercises (e.g., squats, deadlifts), and machine-based exercises (e.g., leg press), primarily focuses on inducing muscle hypertrophy and promoting neural adaptations (Nagatani et al., 2022; Thiele et al., 2020). These neural adaptations include increased motor unit recruitment, improved firing rates, and enhanced synchronization of muscle fibers, which contribute to greater muscle strength and power (Walker, 2021). These adaptations increase muscle force production and overall power output, leading to significant improvements in athletes' vertical jump height (Berton et al., 2018; Fatouros et al., 2000; Shaner et al., 2014; Stojanović et al., 2017).

Squat jump

For squat jump, the network meta-analysis included eight studies and demonstrated that both plyometric training and weight resistance exercise significantly improved squat jump performance compared to routine training. Plyometric training increased squat jump by 1.5 cm, while weight resistance exercise led to a 3.1 cm improvement. The cumulative probability plot indicated that weight resistance exercise had the highest SUCRA score (0.95376), followed by plyometric training (0.53672) and routine training (0.00953). Although the comparison between weight resistance exercise and plyometric training suggested a 1.7 cm improvement in favor of weight resistance exercise, the difference was not statistically significant.

Several factors could account for this lack of above significance. First, the sample size of the studies may have been too small to detect a meaningful difference between the two training methods, reducing statistical power. Second, the variability in training protocols -such as differences in intensity, duration, and frequency of the interventions- could have contributed to inconsistent outcomes. Additionally, individual differences in athlete characteristics, such as baseline strength levels, training experience, or neuromuscular efficiency, might have influenced how each participant responded to the different training modalities (Trowell et al., 2020). Lastly, while weight resistance and plyometric training activate distinct physiological mechanisms—weight resistance training primarily induces muscle hypertrophy and neural adaptations (e.g., increased motor unit recruitment and firing rates) (Siddique et al., 2020; Škarabot et al., 2021), plyometric training enhances the stretch-shortening cycle and improves muscle elasticity and reactive strength (Ramirez-Campillo et al., 2021b).This convergence in functional outcomes may obscure the statistical advantages of one training modality over the other, as the end results in jump performance improvements are achieved through complementary, rather than mutually exclusive, physiological adaptations (de Oliveira Castro et al., 2022; Ramirez-Campillo et al., 2021a).

This study indicates that the effectiveness of training methods for improving stationary vertical jump height performance follows the order of weight resistance exercise > plyometric training > routine training. The superior performance of weight resistance exercise in stationary vertical jump can be attributed to the increased muscle cross-sectional area and enhanced neural drive, leading to greater force production during the concentric phase of the jump (Aagaard and Andersen, 1998; Schoenfeld, 2010). The increase in muscle cross-sectional area, achieved through hypertrophy, allows for greater force production due to the increased number of muscle fibers available to generate power (Kruse et al., 2021). This translates directly to improved vertical jump performance, as more force can be applied against the ground during the takeoff phase.

Enhanced neural drive, which includes increased motor unit recruitment and firing frequency, improves the efficiency of muscle contractions, allowing for faster and more powerful movements (Del Vecchio et al., 2024). Together, these adaptations enable athletes to generate more explosive power during jumping, leading to greater vertical jump heights and overall performance improvements (Marshall et al., 2021). Although resistance exercise does not improve aerobic performance, the increase in muscle size and strength significantly enhances athletes' squat jump performance (Walberg, 1989).

Traditional resistance training is generally not designed to significantly improve aerobic capacity, as it focuses on short bursts of high-intensity effort rather than sustained endurance activities. However, some studies suggest that resistance training, particularly when performed with lighter loads and higher repetitions, can contribute to improvements in muscular endurance and overall cardiovascular health (Devries and Giangregorio, 2023; Jansen et al., 2024; Ma et al., 2024). Additionally, combining resistance training with aerobic exercises in a concurrent training program can enhance both strength and aerobic capacity (García-Pallarés and Izquierdo, 2011). Therefore, while resistance training alone may not significantly improve aerobic performance, it can play a supporting role. The positive impact of plyometric training on stationary vertical jump height has been well-documented (Markovic, 2007). However, it is important to note that the effectiveness of plyometric training can vary based on the specific protocols used and the athletes' prior training history (Docherty et al., 2004).

Countermovement jump

The network meta-analysis for countermovement jump, which included fifteen studies, revealed that all three alternative training methods (plyometric training, weight resistance exercise, and complex training) significantly improved countermovement jump performance compared to routine training (Abade et al., 2021; Ali et al., 2019; Fonseca et al., 2022; García-Pinillos et al., 2014; Guimarães et al., 2023; Khlifa et al., 2010; Latorre Román et al., 2018; Maciejczyk et al., 2021a; Martel et al., 2005a; Nunes et al., 2021; Saez de Villareal et al., 2023; Santos and Janeira, 2012; Seyhan, 2019; Thapa et al., 2023; Zhao et al., 2023). Plyometric training increased countermovement jump by 2.0 cm, weight resistance exercise by 2.2 cm, and complex training by 5.0 cm. The SUCRA scores indicated that complex training was the most effective method (0.98365), followed by weight resistance exercise (0.55400), plyometric training (0.46195), and routine training (0.00040).

Complex training's superior effectiveness may be attributed to its comprehensive approach, integrating various elements of strength and conditioning. This approach capitalizes on the principle of post-activation potentiation, where performing heavy resistance exercises primes the neuromuscular system, enhancing subsequent explosive movements such as jumps (Yu et al., 2024). Research has shown that this combination leads to greater improvements in power output, muscle strength, and neuromuscular efficiency compared to performing either resistance or plyometric training alone (Morris et al., 2022). By simultaneously targeting both maximal force generation from resistance training and explosive power from plyometric exercises, complex training provides a more comprehensive stimulus -encompassing multiple facets of strength, power, and neuromuscular coordination- that leads to superior improvements in athletic performance, particularly in activities like vertical jump (Pellegrino et al., 1991).

Based on this study, the training effects on improving countermovement jump height are ranked as follows: complex training > weight resistance exercise > plyometric training > routine training. The complex training approach pairs a targeted resistance exercise with a biomechanically similar plyometric exercise, alternating them in sequence (Poulos et al., 2018). The purpose of the complex training program is to benefit from the short-term increase in muscle contraction performance after brief maximal or near-maximal voluntary contractions (Comyns et al., 2007). The theoretical basis for complex training's superiority lies in its combination of heavy resistance exercises followed by plyometric exercises, which exploit the potentiation effect. This is supported by research showing that the post-activation potentiation effect -enhanced muscle contractile performance following heavy resistance exercises- can significantly improve power output during subsequent plyometric movements(Turner et al., 2015). Studies such as those by Cormie demonstrated that athletes who engaged in complex training experienced greater improvements in explosive strength, particularly in vertical jump performance, compared to those who followed traditional resistance or plyometric training alone (Cormie et al., 2011a). This potentiation effect results in greater muscle activation and enhanced power output in subsequent movements (Ebben, 2002).

The significant improvements observed with complex training emphasize the importance of combining different training modalities to target multiple physiological adaptations (Ribeiro et al., 2021). By incorporating both heavy resistance exercises for strength development and plyometric exercises for explosive power, complex training creates a more diverse stimulus for the neuromuscular system (Ebben and Watts, 1998). This training variability enhances both maximal force production and the ability to generate power quickly, which is crucial for activities like jumping (Cormie et al., 2011b). Research by Cormie supports this, showing that athletes who engage in complex training programs experience greater performance gains in vertical jump height compared to those using traditional resistance or plyometric training alone (Cormier et al., 2020). This highlights the need for training programs to be varied and specific to the desired performance outcomes.

Weight resistance training ranks second, primarily focusing on muscle hypertrophy and neural adaptations, which increase muscle force production and overall power output, essential for enhancing countermovement jump performance (Berton et al., 2018; Fatouros et al., 2000; Shaner et al., 2014). Resistance training increases muscle cross-sectional area, which directly enhances force production capabilities (Moquin et al., 2021). This increase in muscle mass, combined with improved neural adaptations -such as enhanced motor unit recruitment, firing frequency, and inter-muscular coordination- leads to greater overall power output (Stone et al., 2021). These adaptations are crucial for enhancing countermovement jump performance, as the ability to generate maximal force rapidly is key to achieving higher jumps (Cross et al., 2021). For example, studies have shown that athletes participating in resistance training programs over 8 to 12 weeks experience significant gains in strength and power, which directly translate to improved vertical jump performance (T Katushabe and Kramer, 2020). Additionally, resistance training has been shown to improve lower body strength endurance, allowing athletes to sustain explosive movements for longer durations, further contributing to enhanced athletic performance (Taul-Madsen et al., 2021).

Plyometric training demonstrated a significant positive impact on jump performance, which aligns with previous research findings. The improvements observed can be attributed to the enhancement of the stretch-shortening cycle, which allows for more efficient use of stored elastic energy during explosive movements (Su et al., 2024). However, our results also suggest that plyometric training alone may not be as effective as combining it with resistance training, particularly for athletes seeking to maximize both strength and power. Plyometric training primarily enhances explosive power but may not sufficiently increase maximal muscle strength, which resistance training effectively promotes (Morris et al., 2022). Therefore, combining plyometric training with resistance training allows athletes to develop both strength and power more comprehensively (Ramirez-Campillo et al., 2021b). This is consistent with studies such as those by Markovic, which emphasize the need for varied training modalities to optimize athletic performance (Markovic et al., 2020). The practical implication for coaches and athletes is to integrate plyometric exercises into a broader training regimen that includes resistance training, as this combination can yield greater improvements in vertical jump height and overall explosive performance than plyometric training alone (Markovic, 2007). However, the effectiveness of plyometric training may vary depending on the specific protocols used and the athletes' prior training history (Goodwin and Jeffreys, 2021). Different plyometric protocols -such as the type of exercises (e.g., box jumps, depth jumps, bounding), volume (sets and repetitions), intensity (height of jumps or depth of landings), and rest intervals- can lead to varying outcomes in performance improvements (Watkins et al., 2021). For example, a protocol that emphasizes high-intensity depth jumps may elicit different adaptations than one focused on lower-intensity bounding exercises (Goodwin and Jeffreys, 2021).

Additionally, athletes with more advanced training backgrounds may respond differently to plyometric training compared to novice athletes (Watkins et al., 2021). Those with higher baseline strength and neuromuscular efficiency may experience greater benefits from plyometric exercises, as they can better utilize the stretch-shortening cycle and elastic energy storage (Goodwin and Jeffreys, 2021). In contrast, athletes with limited strength or plyometric experience may require a longer adaptation period to see significant gains, and they may benefit more from incorporating resistance training to build foundational strength first (Zatsiorsky et al., 2020). As a result, the variability in outcomes can be attributed to the interaction between the training protocols and the athletes' individual characteristics, including their strength levels, experience, and specific needs (Docherty et al., 2004).

In comparison, routine training has the least effect on improving countermovement jump performance. Routine training typically involves general conditioning exercises such as jogging, bodyweight movements, and light resistance work, which maintain overall fitness but do not specifically enhance explosive power or vertical jump capabilities (Chaabene et al., 2021). These programs often lack the high-intensity, targeted exercises necessary for muscle hypertrophy, neural adaptations, and the enhancement of the stretch-shortening cycle, all crucial for increasing jump height (Barrio et al., 2023). Without incorporating heavy resistance or plyometric exercises, athletes may experience limited improvements in vertical jump performance (Makaruk et al., 2020b). Therefore, while routine training is beneficial for general conditioning, it should be supplemented with specialized strength and power training to optimize athletic performance in activities requiring jumping ability (Barrio et al., 2023).

Implications and Future Directions

The findings of this study demonstrated that complex training, which integrates plyometric and weight resistance exercises, is the most effective approach for improving vertical jump performance. Coaches and practitioners should consider incorporating complex training into structured programs, particularly during preparatory or performance-enhancing phases of training. Plyometric training alone remains a highly effective method for improving explosive power. Athletes who may not have access to weightlifting facilities or those in sports requiring rapid force production, such as basketball, volleyball, and soccer, can still achieve significant improvements in jump performance through plyometric sessions. However, when possible, combining plyometrics with resistance training may result in greater improvements. While traditional resistance training contributes to jump performance improvements, its effects appear more moderate compared to complex or plyometric training. This indicates that strength development alone may not be sufficient for maximizing jump performance. Coaches should ensure that strength-focused programs also include elements of speed and power training to achieve well-rounded athletic development. These results emphasize the importance of periodizing training programs to integrate both strength and power components. Coaches and practitioners should program training in a way that combine heavy resistance training with plyometrics to optimize neuromuscular adaptations. Additionally, individual athlete characteristics, sport demands, and training history should be considered when selecting the most appropriate training method.

Limitations

The studies in our analysis varied significantly in design, participant characteristics, and measurement methods, making direct comparisons difficult and potentially affecting our conclusions. Additionally, many studies had short intervention periods and a limited number of investigations for each training method, which weakens the evidence regarding the effectiveness of longer training durations. Furthermore, our review may be subject to publication bias, as studies with negative or non-significant results are less likely to be published, and most included studies lacked long-term follow-up, limiting our ability to assess the sustainability of training effects.

Conclusion

This systematic review and meta-analysis demonstrate that plyometric training, weight resistance exercises, and complex training are effective in enhancing various aspects of jump performance in athletes. Weight resistance exercises consistently improve vertical and squat jump performance by increasing muscle strength. Meanwhile, complex training, which combines resistance and plyometric exercises, emerges as the most effective method for improving countermovement jump performance by simultaneously enhancing strength and explosive power. These findings highlight the importance of incorporating both resistance and plyometric training into athletes' programs to maximize their jumping abilities. By integrating these training methods, coaches can optimize athletic performance and better prepare athletes for sports that require superior jump capabilities.

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Key points

- Plyometric, weight resistance, and complex training programs significantly enhance vertical jump, squat jump, and countermovement jump performances in athletes, providing valuable evidence for optimizing training regimens.
- Weight resistance training is particularly effective in improving vertical jump and squat jump, whereas complex training is superior for enhancing countermovement jump performances. There is no significant difference between weight resistance and plyometric training for vertical jump improvements.
- The low heterogeneity (I^2 ranging from 0.0% to 16.9%) across studies suggests a high level of consistency and reliability in the findings, supporting robust conclusions about the effectiveness of different physical training programs on jump performance in athletes.

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