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Effects of Combined Strength Training Methods on Jump Performance: A Systematic Review and Meta-analysis of Controlled Studies

Efectos de los Métodos Combinados de Entrenamiento de Fuerza en el Rendimiento de Salto: Una Revisión Sistemática y Metaanálisis de Estudios Controlados

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Abstract. Actions of short-duration and maximal-effort, such as jumping, are decisive in sports. Using a combination of training (CT) method may be effective to provide variation in stimulus and to increase the overall training adaptation. However, studies analysing the effects of CT are generally limited by small sample sizes. This problem of underpowered studies may, thus, be resolved by pooling study results in a meta-analysis. The objective of this systematic review with meta-analysis was to examine the effects of plyometrics combined with additional training methods (e.g., strength, speed, change of direction (COD)) on vertical jump (VJ) performance, compared with controls groups (CG). The meta-analysis included peer-reviewed articles that incorporated CT in healthy participants and athletes, a CG, and a measure of jumping (CMJ, SJ, DJ and CMJA). The methodological quality of selected studies was assessed with the Cochrane risk of bias tool. Using the random-effects model, effect sizes (ES; Hedge's g) were calculated for jumping measures using means and SDs from pre- and post-tests for each dependent variable. Thirty-six studies were included, comprising 1,169 participants. CT improved VJ tests, CMJ (ES = 0.63; 95% CI = 0.49 to 0.77; $p < 0.001$), SJ (ES = 0.77; 95% CI = 0.45 to 1.10; $p < 0.001$), DJ (ES = 0.46; 95% CI = 0.14 to 0.77; $p = 0.005$) and CMJA height (ES = 1.01; 95% CI = 0.31 to 1.70; $p = 0.005$). CT is an effective way to improve VJ height in comparison to CG.
Keywords: Agility, Resistance Training, Speed, Acceleration, Plyometrics.

Resumen. Las acciones de corta duración y esfuerzo máximo, como los saltos, son decisivas en los deportes. El uso de un método de entrenamiento combinado (CT) puede ser efectivo para proporcionar variación en el estímulo y aumentar la adaptación general al entrenamiento. Sin embargo, los estudios que analizan los efectos del CT suelen estar limitados por tamaños de muestra pequeños. Este problema de estudios poco potentes puede resolverse mediante la agrupación de los resultados de los estudios en un metaanálisis. El objetivo de esta revisión sistemática con metaanálisis fue examinar los efectos de la pliometría combinada con métodos de entrenamiento adicionales (por ejemplo, fuerza, velocidad, cambio de dirección (COD)) en el rendimiento de salto vertical (VJ), en comparación con grupos de control (CG). El metaanálisis incluyó artículos revisados por pares que incorporaron CT en participantes saludables y atletas, un CG y una medida de salto (CMJ, SJ, DJ y CMJA). La calidad metodológica de los estudios seleccionados se evaluó con la herramienta de riesgo de sesgo de Cochrane. Utilizando el modelo de efectos aleatorios, se calcularon tamaños de efecto (ES; g de Hedge) para las medidas de salto utilizando medias y desviaciones estándar de las pruebas previas y posteriores para cada variable dependiente. Se incluyeron 36 estudios, con un total de 1,169 participantes. El CT mejoró las pruebas de VJ, CMJ (ES = 0.63; IC del 95% = 0.49 a 0.77; p < 0.001), SJ (ES = 0.77; IC del 95% = 0.45 a 1.10; p < 0.001), DJ (ES = 0.46; IC del 95% = 0.14 a 0.77; p = 0.005) y la altura de CMJA (ES = 1.01; IC del 95% = 0.31 a 1.70; p = 0.005). El CT es una forma efectiva de mejorar la altura del VJ en comparación con el CG.
Palabras clave: Agilidad, salto vertical, velocidad, aceleración, Pliometria, fuerza

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Introduction

Actions of short duration and maximal effort, such as jumping, play a crucial role in various team sports (e.g., soccer, volleyball) (Fathi et al., 2019; Sanchez-Sixto et al., 2021; Stølen et al., 2005). For instance, as much as 9.9% of soccer goals result from jumping actions (Faude et al., 2012). Notably, a significant correlation (B = −0.31, P = 0.012) has been identified between jump height in countermovement jump (CMJ) and squat jump (SJ) and final league standing in soccer, indicating team success (Arnason et al., 2004). Additionally, across various sports vertical jump (VJ), either as CMJ or SJ, was correlated with running sprint speed from 5m up to 40m (r = 0.53-0.80)(Cronin & Hansen, 2005; Marques et al., 2011; Shalfawi et al., 2011; Washif & Kok, 2021) .Moreover, jump height correlate with performance in volleyball (Ziv & Lidor, 2010), with scoring actions (i.e., spike, block, and serve) predominantly executed during vertical jumps (Sheppard et al., 2007, 2009). Further, in rugby league players, CMJ height correlate with tackling ability (r = 0.38, p<0.05) (Gabbett et al., 2011).

Enhancing VJ performance involves the interaction of several factors, including the stretch-shortening cycle (SSC), rate of force development (RFD), maximal force capacity, and muscle coordination (Arabatzi et al., 2010; Fatouros et al., 2000). Various training methods have been studied to enhance VJ performance, including Plyometric Training (PL), resistance training (RT), muscle electrostimulation (EMS), and speed training (Maffiuletti et al., 2002; Newton & Kraemer, 1994; Sáez de Villarreal et al., 2015; Sáez de Villarreal et al., 2009).

RT involves training movements with external loads in a controlled manner and slow eccentric/concentric actions (Vissing et al., 2008). However, in the last decade, there has been a shift towards incorporating fast-paced movements within RT, aiming to move external loads as quickly as possible (Franco-Márquez et al., 2015; McBride et al., 2002; Rodríguez-Rosell, Torres-Torrelo, et al., 2017). The benefits of RT for athletes include increased ground reaction force generation capability, impulse (Aagaard et al., 2002), and RFD. These attributes make RT methods popular among coaches and researchers (Aagaard et al., 2002; Hoff et al., 2002; Hoff & Helgerud, 2004). The benefits obtained from RT interventions are attributed to increased strength, enhanced recruitment of motor units, and an increased firing rate of motor neurons (Häkkinen et al., 1984; Komi, 1986; Schmidtbleicher & Buhrle, 1987).

PL, on the other hand, involves jumping, hopping, and bounding exercises, both bilaterally and unilaterally, with brief foot-ground contact times (e.g., short SSC movements) around 100-250 ms (i.e., high or long jumps) and long SSC characterized by durations greater than 250 ms (i.e., CMJ) (Cormie et al., 2011b). The use of PL with male and female soccer players has demonstrated improvements in muscular power, maximal strength, sprinting, and acceleration capabilities (Ramirez-Campillo et al., 2020, 2021; Ramírez-Campillo et al., 2015).

Given the unique benefits of each method, combining multiple methodologies within a training session has emerged as an effective approach to optimize training effectiveness. It has been demonstrated that combining PL with RT within the same training session can lead to greater improvements in VJ performance (Arabatzi et al., 2010; Sanchez-Sixto et al., 2021). This combined approach has gained popularity due to its superior results in power improvement compared to using PL or RT in isolation (Adams et al., 1992; Fatouros et al., 2000; Zghal et al., 2019). Since VJ performance depends on multiple components, employing a single method may not be as effective as combining various training methods to introduce variation in stimuli and enhance overall training adaptation (Arabatzi et al., 2010).

Conducting a systematic review with meta-analysis is crucial for assessing the effectiveness of combined training methods on jump performance. It synthesizes findings from controlled studies, thereby elucidating the efficacy of these techniques. Moreover, it identifies patterns and biases in the literature, enhancing the understanding of available evidence. This process aids in addressing research gaps by tackling limitations such as inadequate sample sizes or lack of appropriate control groups.

Due to the inconsistencies reported in the literature, with positive (ES = 6.0; 2.7) (Kijowksi et al., 2015; Sáez de Villarreal et al., 2015) and negative results (ES = -1.08; -0.2) (Herrero et al., 2010; Porrati-Paladino & Cuesta-Barriuso, 2021), due to the limitation of the sample size of the intervention study (simple size = 5; 6) (Alvarez et al., 2012; Redondo et al., 2014) and the lack of meta-analysis, the necessity of conducting such a comprehensive review becomes evident. Moreover, because systematic reviews and meta-analyses conducted to date have focused primarily on analyzing the combination of specific training methodologies within the same session, such as plyometric (PL) and resistance training (RT), there is a gap in understanding the effects of combining PL with other training modalities like speed, mobility, balance, etc.

By integrating data from multiple studies, a meta-analysis offers a more comprehensive view of the effects of combined strength training methods, including PL combined with additional training methods such as strength, speed, COD, EMS, among others, on vertical jump (VJ) performance. Advancing this understanding informs sports professionals in enhancing their athletes' performance. Additionally, it significantly contributes to scientific literature and positively impacts sports practice by providing robust evidence on the benefits of these training methods. Furthermore, a meta-analysis can also provide valuable information for scientists and professionals to detect gaps and limitations related to PL combined with other training methods, providing suggestions for future avenues of research.

Therefore, the primary aim of this systematic review with meta-analysis was to examine the effects of PL combined with additional training methods on VJ performance, compared with active/passive control groups. This meta-analysis seeks to fill the gap in the literature and provide a comprehensive understanding of the efficacy of combined training methods in enhancing athletic performance.

Methods

Experimental Approach to the Problem

Data Sources and Searches. A systematic review with Meta-analysis was conducted following the guidelines of the Cochrane Collaboration (Cumpston et al., 2019). Findings were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009). The electronic search was conducted on the following electronic databases: PubMed, and Web of Knowledge. It considered articles published up until July 2021. The following keywords, combined in pairs (e.g., "Plyometric" AND "combined"), were introduced in the selected databases: "plyometric", "combined", "plyometrics", "stretch-shortening cycle", "strength", "sprint", "change of direction", "balance", "flexibility", "electrostimulation". Reference lists from relevant articles were examined to find other possible studies that fit the inclusion criteria.

Subjects

Inclusion and Exclusion Criteria. Studies published in English were considered for inclusion with no age or sex restrictions. The inclusion and exclusion criteria are detailed in Table 1

Table 1
Inclusion and exclusion criteria for studies at the selection stage of the systematic review.

Category	Inclusion criteria	Exclusion criteria
Population	Studies with no restriction of population were considered for inclusion with no age or sex restrictions.	Participants with health problems (e.g., injuries, recent surgery), the intervention was not performed in humans.
Intervention	Studies with experimental groups performing a combination of training methods (e.g., plyometric combined strength).	Studies that do not perform comparison between plyometric training, strength training, or a combination of these training methods; used the complex training methodology; The duration of the intervention was less than three weeks; The training program that had been carried out was not clearly shown; used supplements; the training effect was acute; combined plyometrics with aerobic training.
Comparator	Traditional control group (i.e., athletes participating in regular training schedules) or specific control group (perform a specific training)	Absence of control group.
Outcome	At least one measure related to physical fitness (e.g., vertical jump tasks) before and after the training intervention.	Lack of baseline and/or follow-up data; The results were not displayed clearly; the article was not in full text
Study design	Multi-arm trials.	Single-arm trials/observational studies.

Procedures

Study Selection and Data Extraction. Database searches were performed independently by 2 authors (C.L.M., and E.S.S.). After the removal of duplicates, abstracts were screened, and studies not related to the review's topic were excluded. The remaining articles that were not discarded were read. Then, independently, and blindly, two reviewers selected the studies for inclusion (C.L.M. and E.S.S.), according to the inclusion and exclusion criteria. If no agreement was achieved, a third party intervened (R.R.C.). The current review focused on the physical fitness of athletes as the main outcome. Since power characteristics are crucial during various athletic movements, measures of physical fitness were considered but not limited to vertical jump (i.e., height; distance; power). In cases where the required data were not clearly or completely reported, the authors of the study were contacted for clarification. If no response was obtained from the authors (after one attempts), or if the authors could not provide the requested data, the study outcome was excluded from further analysis. If data were only displayed in the form of figures but not tables, the study outcome was excluded from further analysis.

Data were extracted from the included studies using a form created in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Extracted data included the following information: the first author's name, year of publication, number of participants per group. We also extracted data regarding the participants' sex, age (years), body mass (kg), height (m), and previous RT/PL experience. If applicable, the type and level (e.g., professional, amateur) of sport practice were also extracted.

Risk of Bias Assessment. The methodological quality of selected studies that contained a control group was assessed with the Cochrane risk of bias tool (Higgins et al., 2011). Bias and study quality were assessed by (C.L.M., and E.S.S.) with any disagreements resolved by a third reviewer (R.R.C.). No studies were eliminated based on methodological quality regardless of the score obtained. The assessment for each of the 7 items includes the answer to a question. In response to this question, the term "Yes" was assigned when there is a low risk of bias, the term "No" was assigned when there is a high risk of bias and "Unclear" when there is not enough information. This evaluation scale has already been used by other reviews in this field using the same evaluation criteria (Cormier et al., 2020).

Statistical Analyses

Studies were meta-analytically aggregated if three or more relatively homogeneous studies were available for the same outcome measure. Effect sizes (ES; Hedge's g) were calculated for jumping measures using means and SDs from pre- and post-tests for each dependent variable. For studies that reported standard error, SDs were calculated by multiplying the standard error with the square root of the sample size (Lee et al., 2015). Data were standardized using post-intervention SD values. The random-effects model was used to account for differences between studies that might affect the intervention effects (Deeks et al., 2008; Kontopantelis et al., 2013). The ES values were presented with 95% confidence intervals (95% CIs). The ES magnitudes were interpreted using the following scale: <0.2, trivial; 0.2-0.6, small; >0.6-1.2, moderate; >1.2-2.0, large; >2.0_4.0, very large; >4.0, extremely large (Hopkins et al., 2009). In studies including more than one intervention group, the sample size of the active and specific-active control group was proportionately divided to facilitate comparisons across multiple groups (Deeks et al., 2008). The impact of study heterogeneity was assessed using the I^2 statistic, with values of <25%, 25-75%, and >75% representing low, moderate, and high levels, respectively (Higgins & Thompson, 2002). The risk of reporting bias was explored (with at least 10 studies) (Sterne et al., 2011) using the Egger's test (Egger et al., 1997), with $p<0.05$ implying bias. To adjust for risk of reporting bias, a sensitivity analysis was conducted using the trim and fill method (Duval & Tweedie, 2000), with L_0 as the default estimator for the number of missing studies (Shi & Lin, 2019). All analyses were carried out using the Comprehensive Meta-Analysis software (Version 2.0; Biostat, Englewood, NJ, USA). The level of statistical significance was set at $p<0.05$.

Results

The initial search yielded 1,271 articles from databases and 11 from other sources. After duplicates removal, 333 remained and were screened by titles and abstracts. The remaining articles were screened based on the inclusion and exclusion criteria. After the study selection process, 36 studies were included (Figure 1).

General characteristics of studies

The basic characteristics of the participants and the programming parameters of the combined interventions from the included studies are displayed in (Table 2).

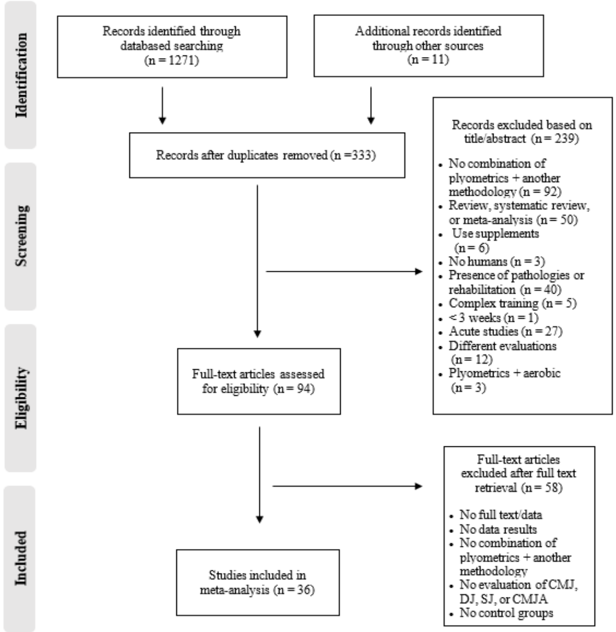

Figure 1. Flow diagram for the different stages of the systematic review process.

Table 2
Characterization of participants groups and training interventions

	Nº subjects	Age (year)	Weight (kg)	Height (cm)	Gender	Years' exp	Strengh exp	Fit	Group level	Sport	Treatment	Duration	Nº sessions	Test Test
Aloui 2021	17	16	64.5	173	M	6	YES	Elite	Na	Soc	PL+SP + COD	8	16	SJ+AVA
Álvarez 2012	5	24.2	68.09	171.9	M	7.9	NR	NR	Reg	Golf	PL+RT	6	12	SJ CMJ
Arabatzi 2010	10	20.3	85.2	185	M	NR	YES	Good	NR	NR	PL+RT	8	24	SJ CMJ
Arabatzi 2010	10	20.3	85.2	185	M	NR	YES	Good	NR	NR	PL+RT	8	24	SJ CMJ
Arede 2019	9	14	56.2	165	M	5	YES	Good	Reg	Bask	PL + RT +SP+COD + BAL	8	32	SJ+CMJ
Bouteraa 2018	16	16	56.6	168	W	NR	NR	NR	Reg	Bask	PL +BA	8	16	SJ+CMJ +DJ
Chaouachi 2014	14	13	45.9	158	M	0	NO	Re	No ath	No sport	PL+ BA	8	24	CMJ
Fathi 2019	20	14.7	68.7	177	M	NR	NR	Elite	Na	Vol	PL+RT	16	32	SJ CMJ
Fatouros 2000	10	20	79.9	178	M	NR	NO	NR	NR	NR	PL+RT	12	36	AVA
Faude 2013	8	23.1	78.9	183	M	10	NR	Re	Reg	Soc	PL+RT + SP	7	14	CMJ + DJ
Floría 2019	17	23.1	60.4	168	W	5	NR	NR	NR	Bask	PL+RT	6	12	CMJ
Franco-Márquez 2015	20	14.7	60.3	171	M	5	NO	Good	Reg	Soc	PL+RT +SP+COD	6	12	CMJ
Hammami 2018	14	14	69.3	178	M	4	YES	Elite	Na	Hand	PL+SP + COD	6	12	SJ+CMJ +AVA
Herrero 2010	11	21	80.2	179	M	0	NR	NR	No ath	No sport	PL+RT + EL	4	16	SJ+CMJ +AVA
Herrero 2010	8	21	79	172	M	0	NR	NR	No ath	No sport	PL+RT	4	16	SJ+CMJ +AVA
Hunter 2002 A	14	24	82.9	NR	M	NR	YES	NR	NR	Mix	PL+RT + FL	10	20	CMJ+DJ +DJ+DJ

Hunter 2002 B	11	24	82.9	NR	M	NR	YES	NR	NR	Mix	PL + RT	10	20	CMJ+DJ +DJ+DJ
Kijowksi 2015	9	21.2	79.5	182	M	NR	YES	NR	NR	No sport	PL+RT	4	8	SJ CMJ
Lyttlee 1996	11	24	72.5	178	M	NR	NO	NR	RE	Mix	PL+RT	8	16	SJ CMJ
Makhlouf 2018	20	11	36.6	147	M	3	NR	Elite	Na	Soc	PL+COD	8	16	CMJ
Makhlouf 2018	21	11	36.9	145	M	3	NR	Elite	Na	Soc	PL+ BA	8	16	CMJ
Martínez-López 2012	27	18	61.6	168	B	5	NR	NR	NR	Track	PL+ EL	8	16	SJ+CMJ +DJ
Martínez-López 2012	23	18	59.1	166	B	5	NR	NR	NR	Track	PL+ EL	8	16	SJ+CMJ +DJ
Martínez-López 2012	24	18	56.2	163	B	5	NR	NR	NR	Track	PL+ EL	8	16	SJ+CMJ +DJ
Otero-Esquina 2017	12	17	69.4	176.7	NR	NR	NR	Elite	Inter	Soc	PL+RT + SP	7	7	CMJ
Otero-Esquina 2017	12	17	69.4	176.7	NR	NR	NR	Elite	Inter	Soc	PL+RT + SP	7	14	CMJ
Pérez-Gómez 2008	16	23.4	71.2	174.9	NR	NR	NR	NR	NR	NR	PL+RT	6	18	SJ+CMJ
Pienaar 2013	19	18.94	89.96	183.38	M	11	NR	Re	Na	Rug	PL+RT	4	12	AVA
Porrati-Paladino 2021	9	21	61.8	163	W	7	NR	Re	Reg	Soc	PL+RT	6	18	CMJ
Prieto 2021	15	14.2	56.9	169	M	5	NR	Elite	Reg	Soc	PL+SP	8	16	CMJ
Prieto 2021	15	17.2	65.3	171	M	5	NR	Elite	Reg	Soc	PL+SP	8	16	CMJ
Qi 2019	31	10.6	37.5	142.9	NR	NR	NR	Re	NR	NR	PL+RT + SP	4	8	AVA
Racil 2020	9	15.7	59.5	170	M	4	NR	Good	Reg	Track	PL+FL	12	36	SJ+ CMJ
Ramos Veliz 2014	16	20.43	81.43	180.33	M	8	NR	Good	Na	Wat	PL+RT	18	36	CMJ
Redondo 2014	6	24.8	70.46	173.3	M	9.7	NR	NR	Na	Fen	PL+RT	6	12	SJ CMJ
Rodríguez-Rosell 2016	15	12.7	47.6	158	NR	3	NO	Good	NR	Soc	PL+RT + SP	6	12	CMJ
Rodríguez-Rosell 2017	10	24.5	74.5	176	NR	8	NO	Re	Reg	Soc	PL+RT +SP+COD	6	12	CMJ
Rodríguez-Rosell 2017	15	12.6	46.3	158	NR	2	NO	NR	Reg	Soc	PL+RT +SP+COD	6	12	CMJ
Rodríguez-Rosell 2017	14	14.6	59.6	170	NR	4	NO	Elite	Reg	Soc	PL+RT +SP+COD	6	12	CMJ
Rodríguez-Rosell 2017	14	16.4	69.1	172	NR	6	NO	NR	Reg	Soc	PL+RT + SP+COD	6	12	CMJ
Ronnestad 2008	8	24	73.5	180	M	NR	YES	Elite	Na	Soc	PL+RT	7	14	SJ CMJ
Sáez de Villarreal 2015	13	15	57	168	NR	6	NR	Good	Na	Soc	PL+SP	9	18	CMJ +AVA
Sánchez-Sixto 2021	13	23	60.14	168	W	5	NR	NR	NR	Bask	PL+RT	6	12	CMJ

Tricoli 2005	8	22	73.4	179.4	M	NR	YES	Re	Amat	NR	PL+RT	8	24	SJ CMJ
Usman 2019	30	19.6	66	176	M	NR	NR	NR	NR	Vol	PL+FL	8	16	AVA
Zghal 2019	14	14.5	60.2	172	NR	5	NO	Good	Reg	Soc	PL+RT + SP	7	14	SJ+CMJ +DJ

NR: No report; Exp: Experience; M: Male, F:Female, B: Both; Fit: Fitness, Re: Regular; Int: International, Na: Nacional, Reg: Regional, Amat: Amateur, No athletes: No ath; Soccer: Soc, Basketball: Bask, volleyball: Vol, Water polo: War, Rugby: Rug, Fencing: Fen, Track and Field: Tra, Mixed sports: Mix, Handball: hand; PL:Pliometrics, RT: Resistance training, Speed: SP, Change of direction: COD, Electroestimulation: EL, Balance: BA, Flexibility: FL; Avalakov: AVA

Study quality

The methodological quality of eligible studies is shown in Table 3.All studies should be considered at high risk of bias. Likewise, the overall assessment should be high risk of bias. Most studies (36/40, 90%) were at low risk of bias arising from randomization, and all studies had low risk of attrition bias, reporting bias, and other bias. High risk of performance and detection bias was found for every study, and high risk of selection bias was detected for most studies, there was only one exception.

Table 3.
Methodological quality. Risk of bias table: review of authors' judgments about each risk of bias item across all included studies (studies with control group)

	Random sequence generation (Selection bias)	Allocation concealment (Selection bias)	Blinding of participants and personnel (Performance bias)	Blinding of outcome assessment (Detection bias)	Incomplete outcome data (Attrition bias)	Selective reporting (Reporting bias)	Other bias
Aloui 2021	+	-	-	-	+	+	+
Álvarez 2012	+	-	-	-	+	+	+
Arabatzi 2010	+	-	-	-	+	+	+
Arede 2019	-	-	-	-	+	+	+
Bouteraa 2018	+	-	-	-	+	+	+
Chaouachi 2014	+	-	-	-	+	+	+
Fathi 2019	+	-	-	-	+	+	+
Fatouros 2000	-	-	-	-	+	+	+
Faude 2013	+	-	-	-	+	+	+
Floría 2019	+	-	-	-	+	+	+
Franco 2015	-	-	-	-	+	+	+
Hammami 2018	+	-	-	-	+	+	+
Herrero 2010	+	-	-	-	+	+	+
Hunter 2002	+	-	-	-	+	+	+
Kijowksi 2015	+	-	-	-	+	+	+
Lyttlee 1996	+	-	-	-	+	+	+
Makhlouf 2018	+	-	-	-	+	+	+
Martinez 2012	+	-	-	-	+	+	+
Otero 2017	-	-	-	-	+	+	+
Pérez 2008	+	-	-	-	+	+	+
Pienaar 2013	+	-	-	-	+	+	+
Porrati 2021	+	+	-	-	+	+	+
Prieto 2021	+	-	-	-	+	+	+
Qi 2019	+	-	-	-	+	+	+
Racil 2020	+	-	-	-	+	+	+
Ramos 2014	+	-	-	-	+	+	+
Redondo 2014	+	-	-	-	+	+	+
Rodríguez 2016	+	-	-	-	+	+	+
Rodríguez 2017	+	-	-	-	+	+	+
Rodríguez 2017	+	-	-	-	+	+	+
Ronnestad 2008	+	-	-	-	+	+	+
Sáez de Villarreal 2015	+	-	-	-	+	+	+
Sanchez-sixto2021	+	-	-	-	+	+	+
Tricoli 2005	+	-	-	-	+	+	+
Usman 2019	+	-	-	-	+	+	+
Zghal 2019	+	-	-	-	+	+	+

Meta-Analyses

CMJ. Thirty-one studies provided data for countermovement jump performance, involving 41 experimental and 34 control groups (pooled n = 970). Results showed a moderate effect of trained participants on CMJ performance (ES = 0.63; 95% CI = 0.49 to 0.77; $p < 0.001$; I2 = 39.8%; Egger's test p = 0.110; Figure 2) when compared to CG. When results were analysed as per athletes' involvement in specific-active or traditional-active CG, no significant moderator effect was noted for type of control (p=0.869 between groups; specific-active: 6 data points, ES = 0.73, I2 = 48.6%; traditional-active: 35 data points, ES = 0.69; I2 = 40.1%). When CMJ results were analysed as per athletes involvement in a combination of 2 training methods (28 data points; ES = 0.71; p<0.001; I2 = 52.8%) compared to ≥3 training methods (13 data points; ES = 0.67; p<0.001; I2 = 0.0%), no significant moderator effect was noted (p = 0.797 between groups).

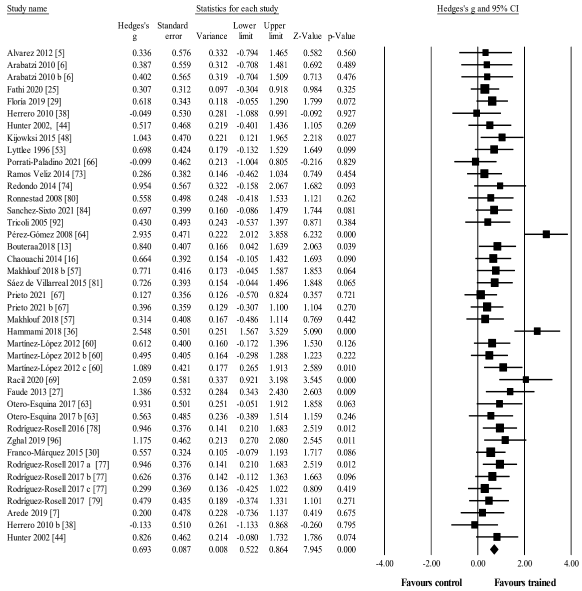

Figure 2. CMJ. Forest plot of changes in countermovement jump, in athletes participating in combined training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The black rhomboid reflects the overall result.

SJ. Sixteen studies provided data for squat jump, involving 20 experimental and 16 CG (pooled n = 430). Results showed a moderate effect of trained participants on SJ (ES = 0.77; 95% CI = 0.45 to 1.10; p < 0.001; I2 = 60.0%; Egger's test p = 0.797; Figure 3 when compared to controls. When results were analysed as per athletes' involvement in specific-active or traditional-active CG, no significant moderator effect was noted for type of control (p=0.601 between groups; specific-active: 5 data points, ES = 0.91, I2 = 50.8%; traditional-active: 15 data points, ES = 0.72; I2 = 64.2%).

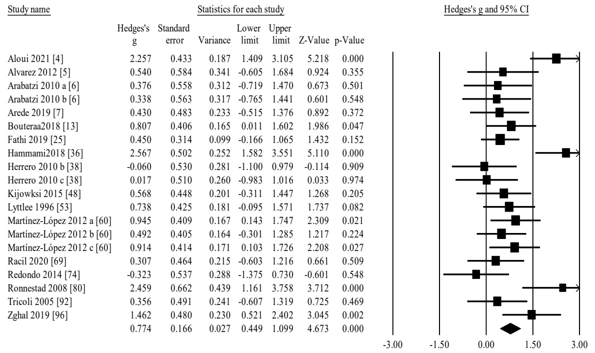

Figure 3. SJ. Forest plot of changes in squat jump, in athletes participating in combined training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The black rhomboid reflects the overall result.

CMJA. Eight studies provided data for countermovement jump with arms performance, involving 9 experimental and 8 control groups (pooled n = 282). Results showed a moderate effect of trained participants on CMJA performance (ES = 1.01; 95% CI = 0.31 to 1.70; p = 0.005; I2 = 85.8%; Figure 4) when compared to controls. Results were not analysed as per athletes' involvement in specific-active or traditional-active CG, as all CG involved traditional-active participants.

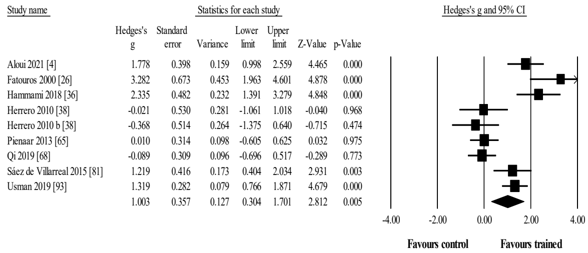

Figure 4. CMJA. Forest plot of changes in countermovement jump witharms (i.e., Abalakov), in athletes participating in combined training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The black rhomboid reflects the overall result.

DJ. Five studies provided data for drop jump performance, involving 12 experimental and 7 control groups (pooled n = 237). Results showed a small effect of trained participants on DJ performance (ES = 0.46; 95% CI = 0.14 to 0.77; p = 0.005; I2 = 26.3%; Figure 5) when compared to controls. When results were analysed as per athletes' involvement in specific-active or traditional-active CG, a significant moderator effect was noted for type of control (p = 0.021 between groups; specific-active: 3 data points, ES = -0.01, I2 = 0.0%; traditional-active: 9 data points, ES = 0.61; I2 = 0.0%).

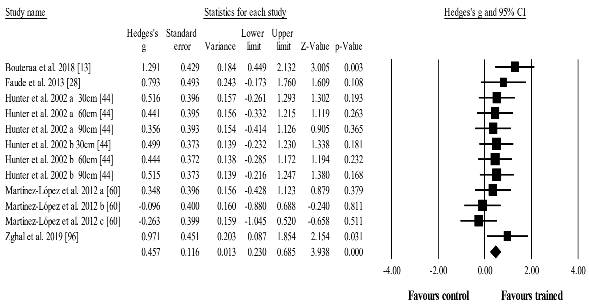

Figure 5. DJ. Forest plot of changes in drop jump, in athletes participating in combined training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The black rhomboid reflects the overall result.

Discussion

The aim of this meta-analysis was to assess the impact of CT in comparison to control conditions on jumping performance. Our findings indicate that CT can effectively enhance performance in CMJ (Effect Size, ES=0.63), SJ (ES=0.77), CMJA (ES=1.01), and DJ (ES=0.46) when compared to control conditions (active and passive). Additionally, when analysing CMJ results based on athletes' involvement in plyometric training combined with one versus two or more training methods, no significant moderator effects were observed. This suggests that sport scientists and strength and conditioning professionals can choose either combination method to achieve positive adaptations in neuromuscular performance variables in both sport and healthy populations.

The results of this meta-analysis provides confirmation to previous narrative reviews (Bauer et al., 2019; Cormier et al., 2020; Thapa et al., 2021) on the effects of PL training combined with RT for the improvement of VJ ability. These improvements in VJ due to PL combined are highly relevant because it has been shown that a 10% increase in VJ is then transferred to an increase in sport-specific jumping (Bobbert, 1990; Markovic, 2007; Sáez de Villarreal et al., 2009). The level of the athletes has to be taken into account, in many studies included in the meta-analysis the athletes were of a low level (Chaouachi et al., 2014; Faude et al., 2012; Pienaar & Coetzee, 2013; Porrati-Paladino & Cuesta-Barriuso, 2021; Qi et al., 2019). It could be assumed that the relatively novel and higher-loaded strength training stimulus might have produced a strong adaptive response, although explicit testing of this hypothesis is needed.

The results of this meta-analysis align with previous narrative reviews (Bauer et al., 2019; Cormier et al., 2020; Thapa et al., 2021) on the positive effects of PL combined with RT for improving VJ ability. These improvements are particularly significant, as a 10% increase in VJ has been shown to translate into enhanced sport-specific jumping (Bobbert, 1990; Markovic, 2007; Sáez de Villarreal et al., 2009). It's important to consider the athletes' level, as many studies included in the meta-analysis involved low-level athletes (Chaouachi et al., 2014; Faude et al., 2012; Pienaar & Coetzee, 2013; Porrati-Paladino & Cuesta-Barriuso, 2021; Qi et al., 2019). The relatively novel and higher-loaded strength training stimulus in these studies may have elicited a strong adaptive response, though further explicit testing of this hypothesis is warranted.

The improvements observed in VJ performance after CT may result from both mechanical and physiological adaptations like those obtained with PL or RT programs. However, these improvements may be enhanced when these methods are combined in the same training session (Carter & Greenwood, 2014; Robbins, 2005; Sale, 2002). Hormonal adaptations, such as an increase in testosterone, and cellular adaptations favouring strength-power generation contribute to these improvements (Ali et al., 2019; Beaven et al., 2011). Notably, CT may help preserve the number of type IIx fibers, crucial for high-speed contractions during maximal-intensity and short-duration actions like VJ (Stasinaki et al., 2015; Grgic et al., 2021; Macaluso et al., 2012, 2014). Greater recruitment of fast-twitch muscle fibers during CT, possibly due to the combination of high loads at low speed with low loads at high speed, has also been observed (Gołaś et al., 2016). Additionally, CT may enhance coordination and synchronization of muscle groups, improving motor skills and transfer of energy during concentric and eccentric phases of muscle movement (J. Cronin et al., 2001; Robbins, 2005). These adaptations contribute to improvements in speed, jumping, and agility (Cavaco et al., 2014; García-Pinillos et al., 2014)

From another perspective, CT may optimize the athlete's strength-velocity curve by combining low loads (PL) with high loads (RT) (Cormie et al., 2011a). This ensures that the athlete has trained across the full spectrum of the force-velocity continuum. Considering the significance of the force-velocity spectrum parameters (Jiménez-Reyes et al., 2022), the performance improvements observed after CT may be attributed to optimizing the force-velocity spectrum (Jiménez-Reyes et al., 2016, 2019).

However, some limitations need acknowledgment. Firstly, there was high heterogeneity among the studies due to differences in populations and training characteristics. Secondly, the absence of CT studies involving female participants (only five studies) suggests caution in extrapolating current findings to female athletes. Future research should address this gap. Additionally, the disproportionate inclusion of plyometric combined strength studies compared to PL combined with other methods underscores a gap in the literature. The use of various instruments and testing procedures for VJ measurements, both direct and indirect, may have influenced the outcome of results (Thapa et al., 2021). Despite these limitations, combined plyometric training emerges as a favourable approach for enhancing vertical jump compared to control conditions (active and passive), with significant improvements observed across all VJ tests despite high heterogeneity among studies.

In conclusion, this systematic review and meta-analysis aimed to investigate the specific impact of combined training on jump performanceon different jump tests (CMJ, CMJA, SJ and DJ) in athletes from various sports and in healthy individuals. The results indicate that both athletes and healthy participants can experience beneficial improvements in jump height outcomes through combined training. These improvements are typically of moderate magnitude, especially with training interventions lasting more than three weeks. Despite some variability in the results, there is a reasonable level of confidence in predicting positive training effects for athletes and healthy individuals in the future. Overall, the findings suggest that the included training programs effectively targeted and challenged the mechanical and neuromuscular demands of jumping.

Practical Application

From an applied perspective, combined methods may be used to achieve positive adaptations on neuromuscular performance. Combined strength training is effective to improve VJ height on healthy participants and athletes. This may be of interest for coaches and athletes seeking a more time-efficient way to incorporate lower-load and higher-load exercises in their training program. Among the various combinations evaluated, the integration of plyometric and strength training emerges as the most appealing, particularly in disciplines where enhancing vertical jump performance is target. This preference is grounded in the remarkable development of mechanical and physiological adaptations it promotes, which are crucial for enhancing athletic performance holistically. However, the role potential moderator variables such as frequency, duration, or total number of sessions, and the specific dose-response relationships following combined training, particularly in the long term, are unclear at present.

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