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Effects of plyometrics training on lower limb strength, power, agility, and body composition in athletically trained adults: systematic review and meta-analysis

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This meta-analysis assesses the impact of plyometric training on lower limb strength, power, agility, and body composition in athletically trained adults to inform its athletic applications. A systematic search of randomised controlled trials (RCTs) was conducted using PubMed, EMBASE, Cochrane, Web of Science, and Scopus databases on the effects of plyometrics training on physical fitness in athletically trained adults. Searches were conducted up to May 2025 using the PICOS framework. Methodological quality was assessed using the Cochrane risk of bias tool (ROB-2), and statistical analyses were performed using Review Manager (RevMan 5.4.1). Publication bias was assessed through funnel plot asymmetry and Egger's regression test. The certainty of evidence was assessed using the GRADE approach. 70 studies were incorporated in the analysis, involving 1703 conditioned adults, from the inception of the database up to May 2025. The results indicated that plyometric training significantly outperformed the control group in the following performance tests: 1RM squat (SMD = 0.53, 95% CI [0.23, 0.84], $p < 0.05$), sprint performance (10 m: SMD = − 0.50, 95% CI [− 0.86, − 0.14], $p < 0.05$; 20 m: SMD = − 0.53, 95% CI [− 0.90, − 0.17], $p < 0.05$; 30 m: SMD = − 0.57, 95% CI [− 0.93, − 0.20], $p < 0.05$), vertical jump tests (CMJ: SMD = 0.69, 95% CI [0.48, 0.89], $p < 0.05$; SJ: SMD = 0.47, 95% CI [0.22, 0.71], $p < 0.05$; CMJ-A: SMD = 0.83, 95% CI [0.50, 1.15], $p < 0.05$), reactive strength index (SMD = 0.80, 95% CI [0.49, 1.10], $p < 0.05$), standing long jump (SMD = 1.34, 95% CI [0.79, 1.90], $p < 0.05$), Illinois test: (SMD = − 0.64, 95% CI [− 1.18, − 0.10], $p < 0.05$), T-test: (SMD = − 0.41, 95% CI [− 0.76, − 0.07], $p < 0.05$) and reduced body fat percentage (SMD = − 0.71, 95% CI [− 1.09, − 0.32], $p < 0.05$). Plyometric training significantly improves lower-limb strength, jump height, sprint speed, agility, and body composition in athletically trained adults. These findings support its targeted application in explosive sports such as football, basketball, and sprinting to enhance key performance parameters.

Keywords Plyometrics training, Meta-analysis, Lower limb, Explosive power, Sprint performance, Athletes

In competitive sports, exceptional physical fitness and athletic performance are key determinants of success. Attributes such as explosive power[1,2], strength[3], speed[2], endurance and agility[4] are critical for an athlete's outstanding performance. Moreover, good physical fitness also provides protection for athletes and reduces the risk of injury[5–7]. Therefore, enhancing the effectiveness of training, while ensuring scientific rigor and safety, has become a continuous focus for scientists and coaches.

Plyometric training enhances the elasticity of muscles and tendons and improves neuromuscular efficiency by promoting rapid transitions between eccentric and concentric contractions, referred to as the "stretch–

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shortening cycle"[8]. Recent studies have shown that the SSC enables storage and rapid release of elastic energy during eccentric–concentric transitions, enhancing force output and mechanical efficiency[9]. Plyometric training can change the length of fascicles in the vastus lateralis and rectus femoris muscles, as well as increasing the pennation angle of the rectus femoris. It is also an effective way to increase tendon stiffness[10]. Due to its potential in enhancing strength, speed, and overall athletic performance, plyometric training has garnered widespread attention[11]. Over time, this training method has been iterated, with the training environment updated to include sand[12] and aquatic[13] areas, and has progressively been combined with other approaches, leading to the development of various combined and composite training programs[14,15], such as complex and contrast training[16,17]. Existing studies[18,19] indicate that compared with traditional resistance training or specialised training, plyometric training and its derived methods can significantly improve athletes' physical fitness and indirectly enhance their athletic skills[20]. These physical attributes are directly relevant to sports that require explosive power and rapid movements, such as football[3], rugby[21], and basketball[22]. Despite its widespread use and evident benefits across specific sports, the effects of plyometric training on a broader range of athletic populations remain underexplored.

Plyometric training not only improves athletes' physical fitness, including vertical jump[23], sprinting speed[3], change-of-direction ability[24] and so on but also significantly reduces the risk of sports injuries by inducing changes in neuromuscular control[25], making it beneficial for athletes of all ages and skill levels. While Ramirez-Campillo et al.[11] focused on basketball players, and others have primarily examined single-sport cohorts such as runners[26]or handball players[27], these studies were limited by narrow participant selection, lack of subgroup differentiation (e.g., training level or sport demands), or a focus on isolated outcomes such as jump height or sprint time. Broader athletic cohorts are less studied, a gap this meta-analysis addresses by including multiple sports. A systematic review and meta-analysis is warranted given the limitations of individual studies in generalising to broader athletic populations, and the capacity of systematic reviews to provide comprehensive, high-quality evidence based on rigorous methodology. Such an approach enhances the reliability of conclusions and supports evidence-based decision making in athletic training.

This study aims to conduct a comprehensive systematic review and meta-analysis to evaluate the effects of plyometric training and its derivatives on key physical fitness parameters in athletically trained adults, including lower limb strength, explosive power, sprint speed, agility, cardiovascular endurance, and body composition. Subgroup analyses are conducted by sport type, training frequency, intervention duration, and explosive demand to explore heterogeneity sources and effect moderators. Although runners and rugby players differ in physiological profiles, their shared neuromuscular development goals—such as power output and agility—justify pooled analysis with stratified interpretation. This approach offers a more comprehensive synthesis of plyometric training's effectiveness across athletic populations.

We hypothesise that plyometric training has significant positive effects on most fitness outcomes, particularly on explosive and speed-related performance, and that these effects may vary according to sport type and training duration. The findings aim to provide high-quality evidence for researchers, practitioners, and coaches to inform sport-specific training strategies.

Materials and methods

Search strategy and study selection

This systematic review and meta-analysis followed the 2020 PRISMA guidelines. The protocol was registered prospectively with PROSPERO on 11 November 2024 (registration number: CRD42024607692) prior to data extraction and synthesis. All subsequent stages of screening, data extraction, and synthesis were conducted according to PRISMA 2020 standards.

Two independent researchers (JY.S. and JB.S.) conducted the literature search process across five databases (PubMed, EMBASE, Cochrane, Web of Science, and Scopus), from their establish to May 2025. Discrepancies in retrieved records or search interpretations were discussed and resolved by a third researcher (S.S.), in line with best practice recommendations for systematic reviews.

Search terms were constructed based on the PICOS framework (see Table 1 for details) and combined using Boolean operators. The base search string was: ("plyometric" OR "jump training") AND ("strength" OR "power" OR "agility" OR "speed" OR "performance") AND ("athlete" OR "trained adult" OR "sportsman"). Minor adaptations of search syntax were required for different databases due to variations in indexing systems (e.g., MeSH terms in PubMed, EMTREE in EMBASE). These tailored search strategies are detailed in Table 2.

All retrieved records were imported into Zotero reference management software. Two independent reviewers (JY.S. and JB.S.) conducted the initial screening by removing duplicates, excluding non-RCTs and irrelevant

PICOS	Inclusion	Exclusion
Population	Healthy, athletically trained adults aged 18–40, training ≥ 3 times/week for ≥ 1 year	Non-adults; sedentary individuals; clinical populations
Intervention	Plyometric training (including plyometrics training groups paired with other exercises)	Intervention duration < 2 weeks; informal or undefined plyometric protocols
Comparison	Active or inactive control groups not participating in the plyometric training program	Controls receiving plyometric training
Outcomes	Performance and physical fitness tests (see data extraction section)	No physical performance or fitness outcomes; missing or incomplete data
Study Design	Randomised controlled trials (RCTs), English language	Non-RCTs (e.g., quasi-experimental, protocols); non-English articles

Table 1. PICOS framework with inclusion and exclusion criteria.

Search	**PUBMED = 1830**
#1	Plyometric exercise[MeSH Terms]
#2	(((((((((((((((((((((((((Plyometric exercise) OR (Exercise, Plyometric)) OR (Exercises, Plyometric)) OR (c)) OR (Plyometric Training)) OR (Plyometric Trainings)) OR (Training, Plyometric)) OR (Trainings, Plyometric)) OR (Plyometric Drill)) OR (Drill, Plyometric)) OR (Drills, Plyometric)) OR (Plyometric Drills)) OR (Stretch–Shortening Exercise)) OR (Exercises, Stretch–Shortening)) OR (Exercise, Stretch–Shortening)) OR (Stretch Shortening Exercise)) OR (Stretch–Shortening Exercises)) OR (Stretch–Shortening Drill)) OR (Drills, Stretch–Shortening)) OR (Drill, Stretch–Shortening)) OR (Stretch Shortening Drill)) OR (Stretch–Shortening Drills)) OR (Stretch–Shortening Cycle Exercise)) OR (Cycle Exercises, Stretch–Shortening)) OR (Cycle Exercise, Stretch–Shortening)) OR (Exercises, Stretch–Shortening Cycle)) OR (Exercise, Stretch–Shortening Cycle)) OR (Stretch Shortening Cycle Exercise)) OR (Stretch–Shortening Cycle Exercises)
#3	(#1) OR (#2)
#4	Athletes[MeSH Terms]
#5	((((((((((((Athletes) OR (Athlete)) OR (Professional Athletes)) OR (Athlete, Professional)) OR (Athletes, Professional)) OR (Professional Athlete)) OR (Elite Athletes)) OR (Athlete, Elite)) OR (Athletes, Elite)) OR (Elite Athlete)) OR (College Athletes)) OR (Athlete, College)) OR (Athletes, College)) OR (College Athlete)
#6	(#4) OR (#5)
#7	(#3) AND (#6)
Search	**Cochrane = 623**
#1	(Plyometric exercise) OR (Exercises, Stretch–Shortening Cycle) OR (Cycle Exercises, Stretch–Shortening) OR (Exercise, Stretch–Shortening Cycle) OR (Stretch Shortening Cycle Exercise) (Word variations have been searched)
#2	(Cycle Exercise, Stretch–Shortening) OR (Stretch–Shortening Cycle Exercise) OR (Stretch–Shortening Cycle Exercises) OR (Exercises, Stretch–Shortening) OR (Drill, Stretch–Shortening) (Word variations have been searched)
#3	(Exercise, Stretch–Shortening) OR (Stretch–Shortening Drills) OR (Stretch Shortening Drill) OR (Stretch–Shortening Exercise) OR (Stretch–Shortening Drill) (Word variations have been searched)
#4	(Stretch–Shortening Exercises) OR (Stretch Shortening Exercise) OR (Drills, Stretch–Shortening) OR (Plyometric Exercises) OR (Exercise, Plyometric) (Word variations have been searched)
#5	(Plyometric Training) OR (Drills, Plyometric) OR (Plyometric Trainings) OR (Plyometric Drill) OR (Exercises, Plyometric) (Word variations have been searched)
#6	(Training, Plyometric) OR (Plyometric Drills) OR (Drill, Plyometric) OR (Trainings, Plyometric) (Word variations have been searched)
#7	#1 OR #2 OR #3 OR #4 OR #5 OR #6
#8	(Athletes) OR (Elite Athletes) OR (Elite Athlete) OR (Athlete, Elite) AND (Athletes, Elite)
#9	(Athletes, College) OR (Athlete, College) OR (College Athletes) OR (College Athlete) AND (Athlete)
#10	(Professional Athlete) OR (Athletes, Professional) OR (Professional Athletes) OR (Athlete, Professional)
#11	#8 OR #9 OR #10
#12	#7 AND #11
Search	**WOS = 1356**
#1	((((((((((((((((((((((((((TS = (Plyometric exercise)) OR TS = (Exercise, Plyometric)) OR TS = (Exercises, Plyometric)) OR TS = (Plyometric Exercises)) OR TS = (Plyometric Training)) OR TS = (Plyometric Trainings)) OR TS = (Training, Plyometric)) OR TS = (Trainings, Plyometric)) OR TS = (Plyometric Drill)) OR TS = (Drill, Plyometric)) OR TS = (Drills, Plyometric)) OR TS = (Plyometric Drills)) OR TS = (Stretch–Shortening Exercise)) OR TS = (Exercises, Stretch–Shortening)) OR TS = (Exercise, Stretch–Shortening)) OR TS = (Stretch Shortening Exercise)) OR TS = (Stretch–Shortening Exercises)) OR TS = (Stretch–Shortening Drill)) OR TS = (Drills, Stretch–Shortening)) OR TS = (Drill, Stretch–Shortening)) OR TS = (Stretch Shortening Drill)) OR TS = (Stretch–Shortening Drills)) OR TS = (Stretch–Shortening Cycle Exercise)) OR TS = (Cycle Exercises, Stretch–Shortening)) OR TS = (Cycle Exercise, Stretch–Shortening)) OR TS = (Exercises, Stretch–Shortening Cycle)) OR TS = (Exercise, Stretch–Shortening Cycle)) OR TS = (Stretch Shortening Cycle Exercise)) OR TS = (Stretch–Shortening Cycle Exercises) and Preprint Citation Index (Exclude – Database)
#2	((((((((((((TS = (Athletes)) OR TS = (Athlete)) OR TS = (Professional Athletes)) OR TS = (Athlete, Professional)) OR TS = (Athletes, Professional)) OR TS = (Professional Athlete)) OR TS = (Elite Athletes)) OR TS = (Athlete, Elite)) OR TS = (Athletes, Elite)) OR TS = (Elite Athlete)) OR TS = (College Athletes)) OR TS = (Athlete, College)) OR TS = (Athletes, College)) OR TS = (College Athlete) and Preprint Citation Index (Exclude – Database)
#3	#1 AND #2 and Preprint Citation Index (Exclude – Database)
Search	**Embase = 934**
#1	'plyometric exercise'/exp OR 'plyometric exercise' OR (plyometric AND ('exercise'/exp OR exercise)) OR 'exercise, plyometric':ti,ab,kw OR 'exercises, plyometric':ti,ab,kw OR 'plyometric trainings':ti,ab,kw OR 'training, plyometric':ti,ab,kw OR 'trainings, plyometric':ti,ab,kw OR 'plyometric drill':ti,ab,kw OR 'drill, plyometric':ti,ab,kw OR 'drills, plyometric':ti,ab,kw OR 'plyometric drills':ti,ab,kw OR 'stretch–shortening exercise':ti,ab,kw OR 'exercises, stretch–shortening':ti,ab,kw OR 'exercise, stretch–shortening':ti,ab,kw OR 'stretch shortening exercise':ti,ab,kw OR 'stretch–shortening exercises':ti,ab,kw OR 'stretch–shortening drill':ti,ab,kw OR 'drills, stretch–shortening':ti,ab,kw OR 'drill, stretch–shortening':ti,ab,kw OR 'stretch shortening drill':ti,ab,kw OR 'stretch–shortening drills':ti,ab,kw OR 'stretch–shortening cycle exercise':ti,ab,kw OR 'cycle exercises, stretch–shortening':ti,ab,kw OR 'cycle exercise, stretch–shortening':ti,ab,kw OR 'exercises, stretch–shortening cycle':ti,ab,kw OR 'exercise, stretch–shortening cycle':ti,ab,kw OR 'stretch shortening cycle exercise':ti,ab,kw OR 'stretch–shortening cycle exercises':ti,ab,kw
#2	'athletes'/exp OR athletes OR athlete:ti,ab,kw OR 'professional athletes':ti,ab,kw OR 'athlete, professional':ti,ab,kw OR 'athletes, professional':ti,ab,kw OR 'professional athlete':ti,ab,kw OR 'elite athletes':ti,ab,kw OR 'athlete, elite':ti,ab,kw OR 'athletes, elite':ti,ab,kw OR 'elite athlete':ti,ab,kw OR 'college athletes':ti,ab,kw OR 'athlete, college':ti,ab,kw OR 'athletes, college':ti,ab,kw OR 'college athlete':ti,ab,kw
#3	#1 AND #2
Search	**Scopus = 1851**
#1	TITLE-ABS-KEY ("Plyometric exercise* ") OR TITLE-ABS-KEY ("Plyometric Training* ") OR TITLE-ABS-KEY ("Plyometric Drill* ") OR TITLE-ABS-KEY ("Stretch–Shortening Exercise* ") OR TITLE-ABS-KEY ("Stretch–Shortening Drill* ") OR TITLE-ABS-KEY ("Stretch–Shortening Cycle Exercise* ")
#2	(ALL ("Athlete* ") OR ALL ("Professional Athlete* ") OR ALL ("Elite Athlete* ") OR ALL ("College Athlete* "))
#3	#1 AND #2

Table 2. Search stragety.

titles. They then screened abstracts and full texts according to the eligibility criteria. Disagreements were resolved through discussion with a third reviewer (S.S.). The study selection process is illustrated in the PRISMA flow diagram (Fig. 1).

Inclusion and exclusion criteria

Studies were considered eligible if they met the following criteria:

(1) Participants were healthy, athletically trained adults aged 18 to 40 years, with a minimum training frequency of three sessions per week for at least one year. Tier 2: Trained/Developmental and above of the Participant Classification Framework[28]; (2) The intervention group received plyometric training, either as a standalone protocol or in combination with other exercise modalities (e.g., resistance or sprint training); (3) The control group consisted of participants not exposed to plyometric training; (4) The study was designed as a randomised controlled trial (RCT); (5) The publication was available in English.

Studies were excluded if they:

(1) were non-RCTs (e.g., quasi-experimental studies, case reports, protocols, conference abstracts); (2) included participants who were under 18 years of age, untrained, or from clinical or rehabilitation populations; (3) had an intervention period shorter than two weeks; (4) applied plyometric training to the control group; or (5) were published in a language other than English.

A summary of the inclusion and exclusion criteria, organised by the PICOS framework, is presented in Table 1.

Only English-language studies were included due to practical constraints in translation and data verification. Although language restrictions may introduce bias, previous evidence[11] suggests minimal impact on effect size estimates in exercise-related meta-analyses.

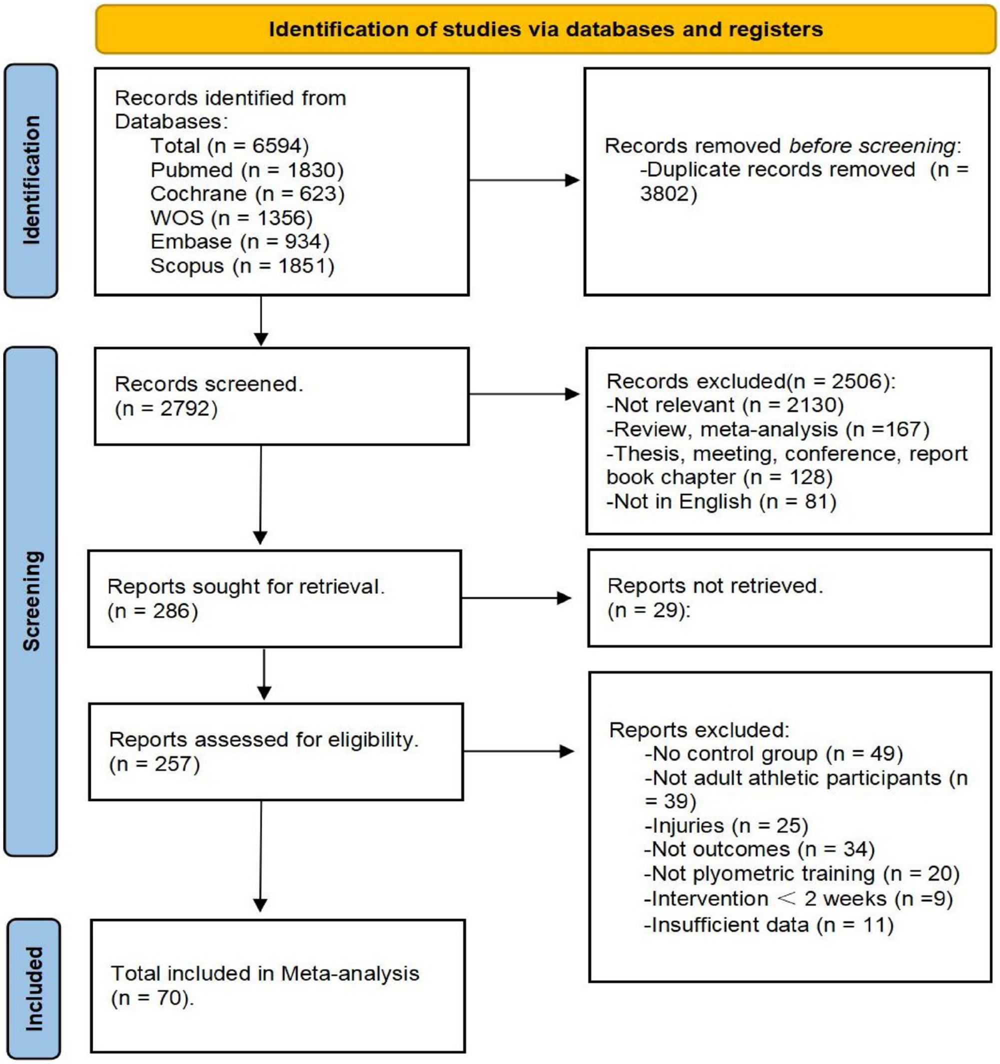

Fig. 1. Systematic reviews and meta-analyses flow diagram.

Data extraction

A standardised and predefined data extraction framework comprising fifteen items was applied to record the key information from the analysed studies, specifically including the details listed: (1) Authors, (2) Year of publication, (3) Country or region, (4) Average age, (5) Sample size, (6) Sport, (7) Training level, (8) Training frequency, (9) Training duration, (10) Repetitions, (11) Sets, (12) Inter-set rest time, (13) Minimum recovery time between sessions, (14) Total ground contact time, (15) Content.

The primary outcome measures were physical fitness and performance indicators, including:

Lower-body strength: one-repetition maximum (1RM) squat, isokinetic strength of quadriceps or hamstrings; Lower-body power: countermovement jump (CMJ), squat jump (SJ), CMJ with arm swing (CMJ-A), standing long jump, peak power, and reactive strength index (RSI); Speed: sprint performance over 5 m, 10 m, 15 m, 20 m, and 30 m distances; Agility: T-test and Illinois agility test; Aerobic capacity: maximal oxygen uptake (VO_2max); Body composition: body fat percentage.

For each outcome, we preferentially extracted the post-intervention mean and standard deviation (mean ± SD) for both intervention and control groups. If only pre–post values or other summary statistics (e.g., SE, CI, t-values) were reported, standard formulas recommended in the Cochrane Handbook were used for conversion.

When results were only available in graphical form, numerical values were extracted using WebPlotDigitizer (version 4.6). Where standard deviations were missing, they were estimated from confidence intervals or standard errors in accordance with the Cochrane Handbook.

Two independent reviewers (JY.S. and JB.S.) independently and blindly extracted all data from each included study. To assess inter-rater reliability, a random subset of 13 studies (approximately 20% of the total) was selected for comparison. An intraclass correlation coefficient (ICC) was calculated using a two-way mixed-effects model with absolute agreement. The ICC value was 0.92, indicating excellent agreement between the two reviewers. Discrepancies were resolved through discussion with a third reviewer (S.S.).

Risk of bias of individual studies

Each randomised controlled trial included in this study was appraised using the version 2 of the Cochrane risk-of-bias tool for randomised trials (ROB-2). The following five domains were assessed: (1) bias arising from the randomisation process, (2) bias due to deviations from intended interventions, (3) bias due to missing outcome data, (4) bias in measurement of the outcome, and (5) bias in selection of the reported result.

Each domain was judged as "low risk," "some concerns," or "high risk" based on signalling questions and domain-level algorithms outlined in the ROB-2 framework. An overall risk of bias judgment for each study was derived as follows: Low risk if all domains were rated as "low risk"; Some concerns if at least one domain was rated as "some concerns" and none as "high risk"; High risk if at least one domain was rated as "high risk" or multiple domains were rated as "some concerns" that substantially lower confidence in the result. Two researchers (JY.S. and JB.S.) independently evaluated the quality of all studies, while a third researcher (S.S.) was responsible for resolving any differences in opinion. In cases of missing or ambiguous data, attempts were made to contact the original authors via email. If no response was received or data remained insufficient, the study was excluded from analysis.

Data analysis

This meta-analysis used Review Manager software (version 5.4.1, Copenhagen: Nordic Cochrane Centre, Cochrane Collaboration, 2020) to evaluate the effects of the interventions. In studies with exercise as the intervention, considering the different testing methods for continuous outcome variables reported in the reviewed articles, the standardised mean difference (SMD) was selected as the most appropriate effect size measure, with a 95% confidence interval (CI) applied for the analysis. A random-effects model was applied to account for between-study variability. Given the expected methodological heterogeneity in participant characteristics, training protocols, and measurement tools across included studies, a random-effects model was chosen to account for both within-study and between-study variance.

I^2 was used to quantify heterogeneity, with thresholds defined as low (< 25%), moderate (25–75%), and high (> 75%). For outcomes with high heterogeneity in subgroup analyses, we investigated the effects of intervention type (PLYO, weighted PLYO, derivation of PLYO, even and non-hard surface PLYO), frequency (≤ 2 repetitions, > 2 repetitions), total training duration (≤ 6 weeks, > 6 weeks), level of explosive demand (high, low), and total contact volume (< 900, 900–1400, > 1400)[29] on outcome measures. Results with $p < 0.05$ were statistically significant.

Publication bias was assessed using funnel plot asymmetry and Egger's regression test ($p < 0.10$). Where bias was detected, adjusted estimates were obtained using the trim-and-fill method. Visual inspection of funnel plot asymmetry was used as a qualitative indicator, where noticeable asymmetry or clustering of smaller studies on one side of the mean suggests potential publication bias. To assess the robustness of the meta-analysis results, sensitivity analyses were performed using Stata/SE 17.0 (StataCorp LLC, College Station, TX, USA). A leave-one-out approach was applied to evaluate the influence of each individual study on the pooled effect size. Additionally, studies with extreme effect sizes or high risk of bias were excluded in separate models to examine the consistency of the findings.

We used GRADE for quality of evidence evaluation. This evaluation method consists of five scoring dimensions: risk of bias, inconsistency, indirectness, imprecision and publication bias. Based on the evaluation of these dimensions, the quality of evidence was categorised into four basic (very low, low, moderate and high).

Results

Study identification and selection

The search strategy initially retrieved a total of 6,594 articles from electronic databases. After duplicate removal, 2,792 articles remained and were subsequently screened by titles and abstracts, resulting in the exclusion of 2,506 articles. From the remaining 286 articles, full-text versions of 29 articles were unavailable. For these studies, the corresponding authors were contacted via email to request access. If no response was received after two follow-ups or if the full text remained inaccessible, the study was excluded from further review. After full-text review, 187 articles were omitted due to: non-randomised controlled trials, non-English articles, non-adult athletes, non-healthy populations, incomplete data, intervention duration less than 2 weeks, and interventions not meeting the inclusion criteria of this study. Ultimately, 70 articles were included in this review (Fig. 1).

Quality assessment of the included studies

Risk of bias was evaluated using the Cochrane Risk of Bias 2 (ROB 2) tool across five domains. Low risk was most frequently observed in missing outcome data (56 studies, 80%) and measurement of outcomes (59 studies, 84%), reflecting consistent reporting and widespread use of standardised, objective performance metrics (e.g., 1RM, countermovement jump, sprint tests).

By contrast, randomisation procedures presented 13 studies (18%) classified as high risk due to insufficient allocation concealment and poorly reported sequence generation.

Deviations from intended interventions also posed methodological limitations; 11 studies (6%) were rated high risk, primarily due to the inherent difficulty of implementing blinding and maintaining adherence in field-based exercise trials.

For selective reporting, a substantial majority of studies (98%) were rated as “some concerns”, typically due to the absence of prospective registration and discrepancies between prespecified and reported outcomes.

Overall, 73% of the included studies were judged to have “some concerns”, and 19 studies were rated “high risk” in at least one domain. These findings highlight persistent challenges in the methodological rigour of physical training interventions. Future research should prioritise prospective trial registration, transparent outcome reporting, and stronger design safeguards to enhance the internal validity and reproducibility of findings in applied research (Fig. 2 and S1).

Study characteristics

The aggregated sample size of the 70 included studies comprised 1,703 individuals, with group sizes varying between 4 and 51. The included participants were athletes of varying skill levels or active individuals engaged in regular training. The training intervention periods ranged between 3 and 16 weeks: 3 weeks (1 study[30]), 4 weeks (3 studies[23,31,32]), 6 weeks (28 studies[12,33–59]), 7 weeks (2 studies[60,61]), 8 weeks (24 studies[13,18,62–83]), 9 weeks (2 studies[84,85]), 10 weeks (6 studies[22,86–90]), 12 weeks (3 studies[19,91,92]), and 16 weeks (1 study[93]). Eighteen studies[12,13,22,36,48,51–55,60,61,71,77,78,82,90,94] involved plyometrics training methods compared to a control group. Overall, most studies (52/70, 74%) employed interventions lasting 6 to 8 weeks, with a training frequency of 1 to 4 sessions per week. The participant population was predominantly male (80%), and jump volumes varied considerably, ranging from 254 to 9,576 per program. The main types of plyometrics training include vertical jumps, deep jumps, lateral jumps, horizontal jumps, weighted jumps, and complex or contrast training (S 2).

Study outcomes

The results of the meta-analysis for the indicators are summarised in Table 3.

Strength and explosive power

The plyometric training group achieved significantly better results than the control group in the 1RM squat test (SMD = 0.53, 95% CI [0.23, 0.84], $p = 0.0006$), indicating that plyometric training significantly improves lower body maximal strength. This suggests that plyometric training has a moderate to large effect on improving 1RM squat performance. Heterogeneity analysis revealed moderate heterogeneity in the results of the included studies ($I^2 = 5\%$), indicating that the effect of plyometric training on 1RM squat performance is relatively consistent across studies ($Chi^2 = 7.36$, df = 7, $p = 0.39$) (Fig. 3).

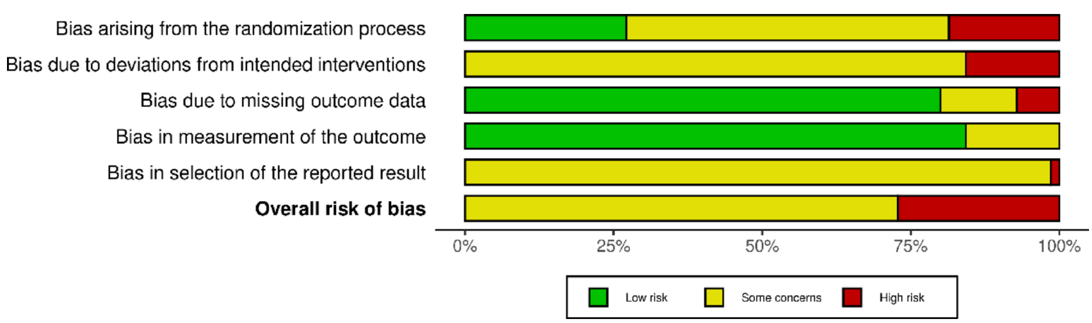

Fig. 2. Risk of bias assessment.

Outcome	N	Mean difference (95% of CI)	p	I^2 (p)
Strength indicators				
1RM	188	0.53 (0.23, 0.84)	0.0006	5% (0.39)
ISO-H	125	0.53 (−0.03, 1.08)	0.06	54% (0.07)
ISO-Q	113	0.29 (−0.46, 1.05)	0.44	72% (0.007)
Speed indicators				
5 m	191	−0.29 (−0.58, 0.00)	0.05	0% (0.49)
10 m	406	−0.50 (−0.86, −0.14)	0.06	66% (< 0.0001)
15 m	103	−0.46 (−1.16, 0.24)	0.20	65% (0.02)
20 m	342	−0.53 (−0.90, −0.17)	0.004	62% (0.0009)
30 m	355	−0.57 (−0.93, −0.20)	0.003	63% (0.0007)
Lower limb explosive power				
CMJ	1006	0.69 (0.48, 0.89)	< 0.00001	57% (< 0.00001)
SJ	628	0.47 (0.22, 0.71)	0.0002	52% (0.001)
CMJ-A	279	0.83 (0.50, 1.15)	< 0.00001	37% (0.10)
CMJ-POWER	189	0.24 (−0.07, 0.55)	0.14	12% (0.34)
SJ-POWER	131	0.13 (−0.30, 0.55)	0.57	32% (0.19)
RSI	184	0.80 (0.49, 1.10)	< 0.00001	0% (0.51)
SLJ	372	1.34 (0.79, 1.90)	< 0.00001	81% (< 0.00001)
Maximal oxygen uptake				
VO_{2max}	152	0.14 (−0.30, 0.58)	0.53	42% (0.10)
Agility indicators				
T-test	336	−0.41 (−0.76, −0.07)	0.02	58% (0.003)
Illinois-test	165	−0.64 (−1.18, −0.10)	0.02	62% (0.02)

Table 3. Summary of meta-analyses of interval group versus control group. 1RM, Maximum squat strength test; ISO-H/Q, Isometric strength tests in hamstring or quadriceps; CMJ, Counter movement jump; SJ, Squat jump; CMJ-A, Counter movement jump with arm; RSI, Reactive strength index; SLJ, Standing long jump.

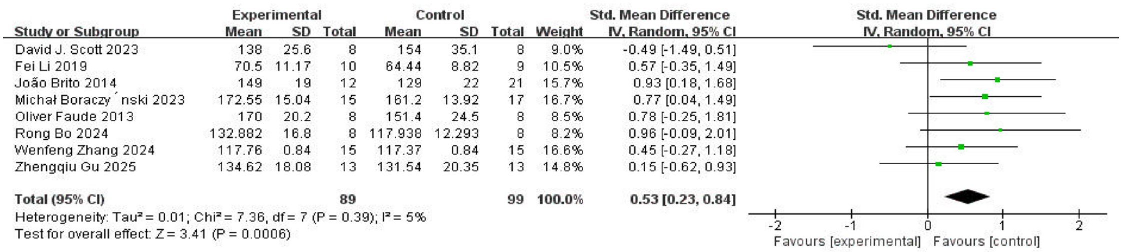

Fig. 3. 1RM squat forest plots.

Comparison between plyometrics training and control groups in the isometric strength tests (including quadriceps and hamstring torque) demonstrated a slight extent, but no significant difference was presented. In the quadriceps torque test (SMD = 0.29, 95% CI [−0.46, 1.05], $p = 0.44$) and the hamstring torque test (SMD = 0.53, 95% CI [−0.03, 1.08], $p = 0.06$). Overall, plyometric training had a limited effect on improving isometric strength, with slight differences in the gains for quadriceps and hamstrings. Quadriceps isometric torque ($I^2 = 72\%$, $p = 0.007$) and hamstring isometric torque ($I^2 = 54\%$, $p = 0.07$) both showed moderate to high levels of heterogeneity (Figs. 4, 5).

Plyometric training showed significant improvements of varying degrees in the CMJ, SJ, and CMJ-A tests. In the CMJ test (SMD = 0.69, 95% CI [0.48, 0.89], $p < 0.00001$), SJ test (SMD = 0.47, 95% CI [0.22, 0.71], $p = 0.0002$), and CMJ-A test (SMD = 0.83, 95% CI [0.50, 1.15], $p < 0.00001$), the plyometric training group significantly outperformed the control group. In terms of heterogeneity, the CMJ test showed moderate heterogeneity ($I^2 = 57\%$, $p < 0.00001$), and the SJ test also showed moderate heterogeneity ($I^2 = 52\%$, $p = 0.001$), indicating that the impact of plyometric training on vertical jump height may vary across studies due to different conditions. In contrast, the heterogeneity of the enhanced CMJ-A test was lower ($I^2 = 37\%$, $p = 0.10$), with more stable results and less impact from study conditions (Figs. 6, 7, 8).

Plyometric training had a limited effect on increasing peak jump power output, with no significant differences compared to the control group. For CMJ peak power (SMD = 0.24, 95% CI [−0.07, 0.55], $p = 0.14$) and SJ peak power (SMD = 0.13, 95% CI [−0.30, 0.55], $p = 0.57$), the differences did not reach statistical significance. In terms

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bo Cao 2023	189.5	27	10	147.1	23	10	18.3%	1.62 [0.58, 2.66]
Gary B. Wilkerson 2004	181.64	29.1	11	169.38	27.3	8	19.8%	0.41 [-0.51, 1.34]
João Brito 2014	216	27	12	207	27	21	22.5%	0.33 [-0.39, 1.04]
Rohit K. Thapa 2023	164.4	51.3	8	157.5	30.6	6	18.1%	0.15 [-0.91, 1.21]
Yosser Cherni 2021	103	17	15	118	17	12	21.4%	-0.86 [-1.65, -0.06]
Total (95% CI)			**56**			**57**	**100.0%**	**0.29 [-0.46, 1.05]**

Heterogeneity: Tau² = 0.52; Chi² = 14.20, df = 4 (P = 0.007); I² = 72%
Test for overall effect: Z = 0.77 (P = 0.44)

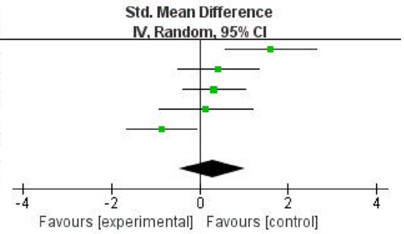

Fig. 4. ISO-Q forest plot.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Gary B. Wilkerson 2004	98.12	20.91	11	100.81	21.85	8	18.6%	-0.12 [-1.03, 0.79]
João Brito 2014	130	13	12	114	15	21	22.0%	1.09 [0.33, 1.85]
Michał Boraczy ́nski 2023	138.6	6.61	15	132.91	4.85	17	22.5%	0.97 [0.23, 1.71]
Rohit K. Thapa 2023	100	23.2	8	83.2	10.7	6	14.9%	0.83 [-0.29, 1.95]
Yosser Cherni 2021	71.3	12.5	15	73	9.4	12	22.0%	-0.15 [-0.91, 0.61]
Total (95% CI)			**61**			**64**	**100.0%**	**0.53 [-0.03, 1.08]**

Heterogeneity: Tau² = 0.21; Chi² = 8.68, df = 4 (P = 0.07); I² = 54%
Test for overall effect: Z = 1.86 (P = 0.06)

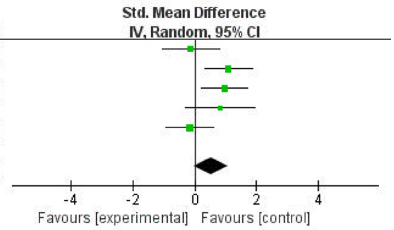

Fig. 5. ISO-H forest plot.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
abbas aSadi 2017	50.5	2.2	8	47.2	2.1	8	1.9%	1.45 [0.31, 2.59]
Alberto Sánchez-Sixto 2021	35	4	11	34	3	12	2.6%	0.27 [-0.55, 1.10]
AMANDA M. TURNER 2003	38	7	10	42	10	8	2.3%	-0.45 [-1.40, 0.49]
Bahri Gjinovci 2017	48.5	5.2	21	34.1	7.1	20	2.7%	2.28 [1.48, 3.08]
BENT R. RONNESTAD 2008	36.7	1.9	8	35.7	1.4	7	2.1%	0.56 [-0.48, 1.60]
Carlos G. Freitas-Junior 2020	47	3	4	44	5	5	1.5%	0.63 [-0.74, 2.00]
Daniel Sporri 2018	35.9	5.5	11	36.4	6.3	9	2.5%	-0.08 [-0.96, 0.80]
Danny Lum 2022	31.4	6.7	9	30.8	6.1	8	2.3%	0.09 [-0.86, 1.04]
Eduardo Saez de Villareal 2023	43.22	2.7	12	38.15	4.8	12	2.4%	1.26 [0.37, 2.15]
Eduardo Sáez de Villarreal 2024	41.15	4.8	12	39.05	4.2	12	2.6%	0.45 [-0.36, 1.26]
Fabián Rosas 2017	26.4	3	8	29.4	6.3	9	2.2%	-0.57 [-1.54, 0.41]
Fei Li 2019	34.51	3.85	10	34.26	4.22	9	2.4%	0.06 [-0.84, 0.96]
Felipe García-Pinillos 2019	31.59	6.01	51	29.3	7.07	45	3.8%	0.35 [-0.06, 0.75]
FOTINI ARABATZI 2010	36.1	6.4	9	35.2	5.8	9	2.4%	0.14 [-0.79, 1.07]
Javier Sánchez-Sánchez 2022	43.59	4.58	10	36.48	3.74	13	2.2%	1.66 [0.68, 2.64]
JAVIER YANCI 2016	41.8	4.79	12	37.04	4.39	12	2.5%	1.00 [0.14, 1.86]
Kamran Ali 2019	46.98	4.84	12	43.97	6.92	12	2.6%	0.49 [-0.33, 1.30]
LAURENCE A. HOUGHTON 2013	41.9	6.1	7	35.6	4.6	8	1.9%	1.11 [-0.01, 2.22]
Maarten Lievens 2019	40.07	4.86	11	42.19	4.64	11	2.5%	-0.43 [-1.28, 0.42]
Michał Boraczy ́nski 2023	0.4132	0.01	15	0.3985	0.0094	17	2.7%	1.48 [0.68, 2.27]
Min-Hsien Wang 2020	69.27	3.87	10	66.79	3.76	10	2.4%	0.62 [-0.28, 1.53]
Mohamed Chedly Jlid 2020	32.19	4.69	14	30.64	3.34	13	2.8%	0.37 [-0.40, 1.13]
MOHAMED SOUHAIEL CHELLY 2010	41	3	12	39	2	11	2.5%	0.75 [-0.10, 1.60]
Morten Strate 2022	3.58	3.86	17	-0.06	2.81	14	2.8%	1.03 [0.27, 1.79]
NICOLAS BERRYMAN 2010	35.3	3.6	11	35.2	4.2	5	2.1%	0.03 [-1.03, 1.08]
Oliver Faude 2013	41.4	3.5	8	39.8	2.4	8	2.2%	0.50 [-0.50, 1.50]
Rafail Georgios Pechlivanos 2024	33	6	10	32	6	10	2.5%	0.16 [-0.72, 1.04]
RIADH KHLIFA 2010	49.03	1.14	9	46.02	1.53	9	1.8%	2.12 [0.91, 3.34]
Ricardo Berton 2022	39.9	5.2	15	38.7	5.1	15	2.9%	0.23 [-0.49, 0.95]
Robert W. Spurrs 2003	43	8	8	32	6	9	1.9%	1.49 [0.38, 2.60]
Rodrigo Ramírez-Campillo-1 2015	29.4	5.8	19	26.6	4.3	19	3.1%	0.54 [-0.11, 1.19]
Rodrigo Ramirez-Campillo 2018	31.5	7.5	8	29.9	5.1	7	2.1%	0.23 [-0.79, 1.25]
Rodrigo Ramírez-Campillo-2 2015	37.6	4	21	32.8	3.8	21	3.1%	1.21 [0.54, 1.87]
S. SEDANO 2011	39.1	2.2	11	36.8	2	11	2.4%	1.05 [0.15, 1.96]
Seifeddine Brini 2022	43.76	5.63	13	38.15	2.79	13	2.5%	1.22 [0.37, 2.07]
Seifeddine Brini 2023	42.5	5.71	14	38.14	2.68	14	2.7%	0.95 [0.16, 1.74]
SILVIA SEDANO CAMPO 2009	29.3	1	10	25.9	0.9	10	1.4%	3.42 [1.95, 4.90]
Wilson,G. J. 1993	39.5	9	13	38	8.2	14	2.8%	0.17 [-0.59, 0.93]
Yosser Cherni 2021	37.2	5.1	15	32.9	4	12	2.7%	0.90 [0.10, 1.70]
YUHUI GE 2024	63.83	4.01	10	60.55	2.46	10	2.3%	0.94 [0.01, 1.88]
Zhengqiu Gu 2025	50.06	8.12	13	48.37	6.617	13	2.8%	0.22 [-0.55, 0.99]
Total (95% CI)			**512**			**494**	**100.0%**	**0.69 [0.48, 0.89]**

Heterogeneity: Tau² = 0.25; Chi² = 93.70, df = 40 (P < 0.00001); I² = 57%
Test for overall effect: Z = 6.50 (P < 0.00001)

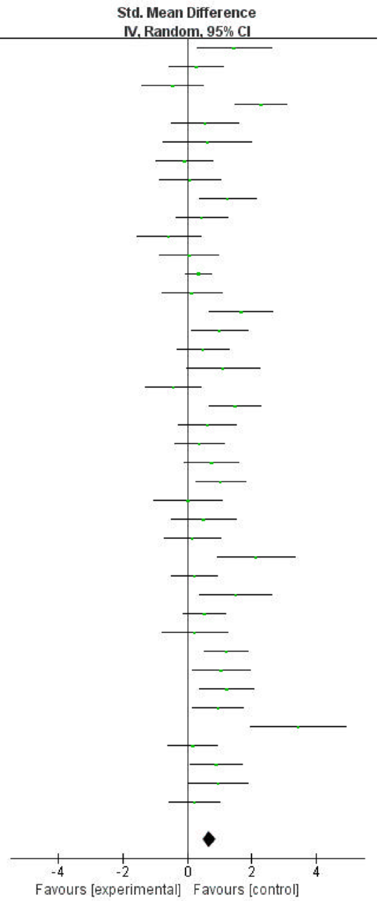

Fig. 6. CMJ forest plot.

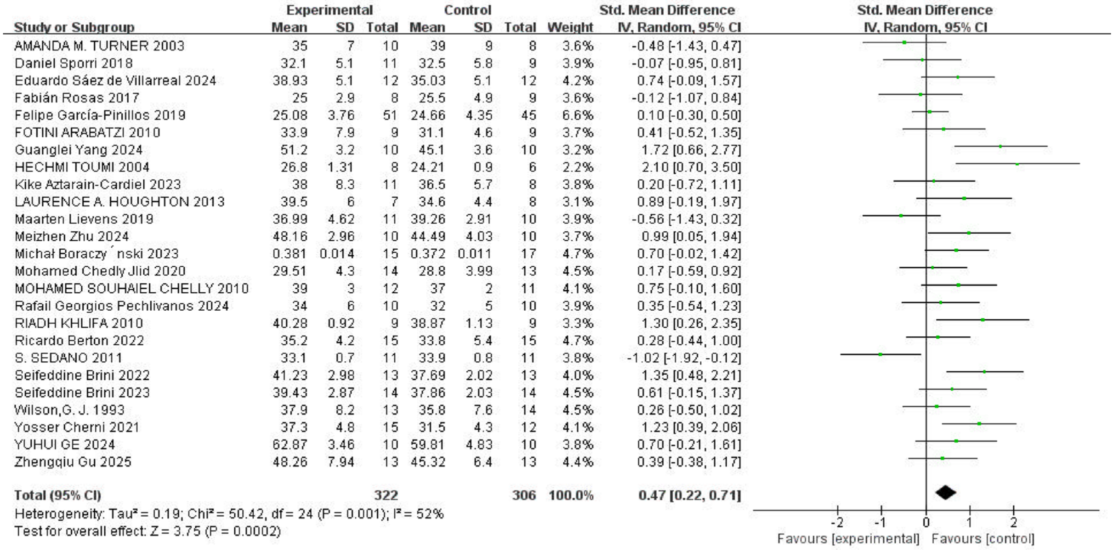

Fig. 7. SJ forest plot.

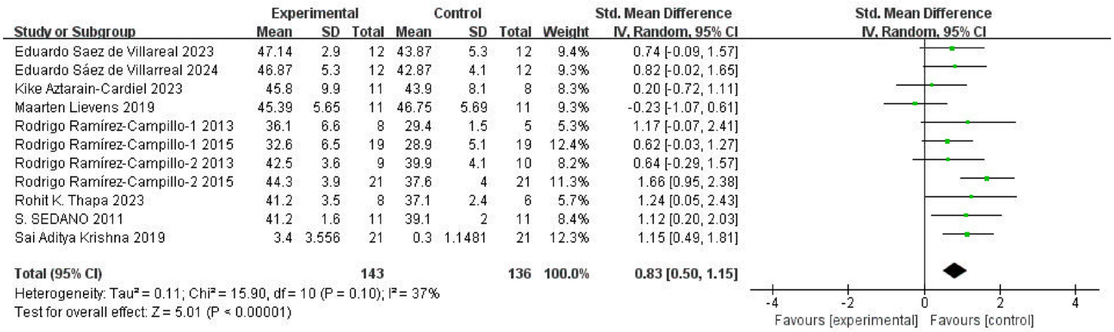

Fig. 8. CMJ-A forest plot.

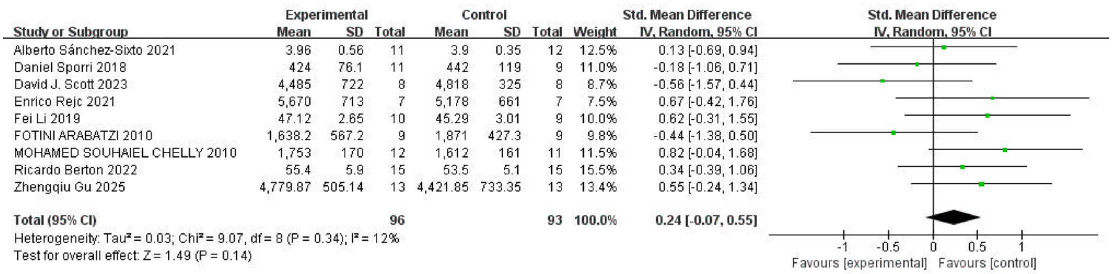

Fig. 9. CMJ-power forest plot.

of heterogeneity, the CMJ peak power results were more consistent ($I^2 = 12\%$, $p = 0.34$), while SJ peak power showed mild heterogeneity ($I^2 = 32\%$, $p = 0.19$) (Figs. 9, 10).

Plyometric training has a moderate to large positive effect on improving the reactive strength index (RSI) (SMD = 0.80, 95% CI [0.49, 1.10], $p < 0.00001$), with a significant difference compared with the control group. In terms of heterogeneity, plyometric training showed high consistency in improving RSI ($I^2 = 0\%$, $p = 0.51$) (Fig. 11).

Plyometric training is effective in improving horizontal power, with a significant difference in standing long jump performance compared to the control group (SMD = 1.34, 95% CI [0.79, 1.90], $p < 0.00001$). In terms of heterogeneity, the effect of plyometric training on horizontal power showed high heterogeneity ($I^2 = 81\%$, $p < 0.00001$) (Fig. 12).

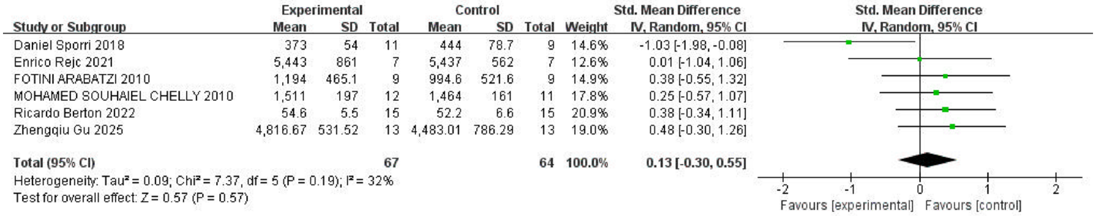

Fig. 10. SJ-power forest plot.

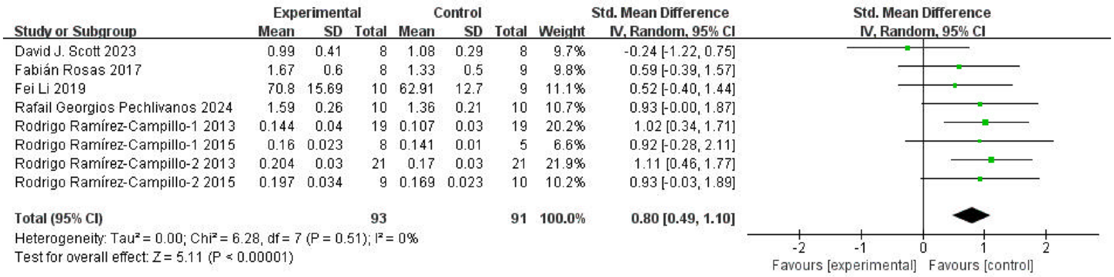

Fig. 11. RSI-40 forest plot.

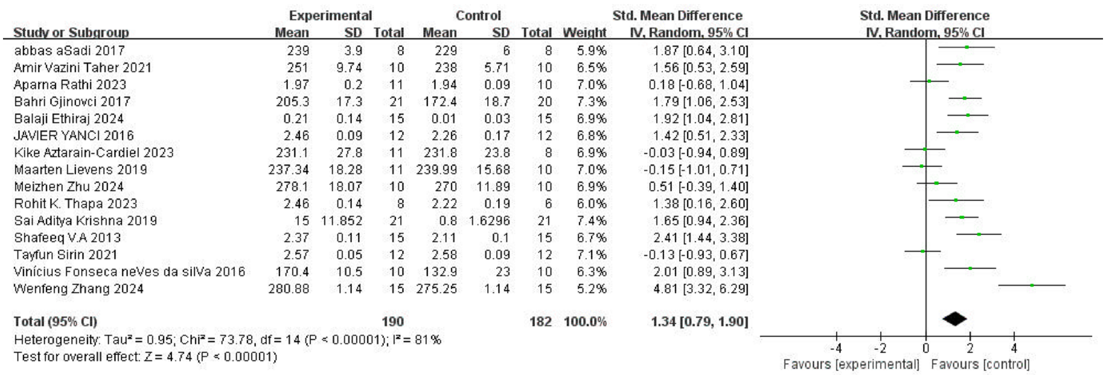

Fig. 12. Standing long jump forest plot.

Speed and agility

The plyometric training group showed varying degrees of improvement in sprint performance across different distances. Overall, the standardised mean differences (SMD) for each test were close to moderate effects, but there were differences in statistical significance and heterogeneity. Only the 10 m sprint test (SMD = − 0.50, 95% CI [− 0.86, − 0.14], $p = 0.006$) showed a significant moderate improvement. The 5 m sprint test (SMD = − 0.29, 95% CI [− 0.58, 0.00], $p = 0.05$) and the 15 m sprint test (SMD = − 0.46, 95% CI [− 1.16, 0.24], $p = 0.20$) did not demonstrated significant variation between the plyometric training and control groups, indicating a relatively weaker effect of plyometric training on the 5 m and 15 m sprints. In terms of heterogeneity, the effect of plyometric training on the 5 m sprint was more consistent ($I^2 = 0\%$, $p = 0.49$), while differences were observed in the 10-m sprint ($I^2 = 64\%$, $p = 0.0002$) and the 15 m ($I^2 = 65\%$, $p = 0.02$) (Figs. 13, 14, 15).

Plyometric training showed significant improvements in both the 20 m and 30 m sprint tests, outperforming the control group at both distances. The 20 m sprint test (SMD = − 0.53, 95% CI [− 0.90, − 0.17], $p = 0.004$) and the 30 m sprint test (SMD = − 0.57, 95% CI [− 0.93, − 0.20], $p = 0.003$) both showed significant effects. In terms of heterogeneity, the 20 m sprint test showed moderate heterogeneity ($I^2 = 62\%$, $p = 0.0009$), and the 30 m sprint test also exhibited noticeable heterogeneity ($I^2 = 63\%$, $p = 0.0007$), suggesting that the effect of plyometric training on maximal speed may vary under different conditions (Figs. 16, 17).

The impact of plyometric training on the agility T-test revealed significant difference compared to the control group (SMD = − 0.41, 95% CI [− 0.76, − 0.07], $p = 0.02$). In terms of heterogeneity, plyometric training showed moderate heterogeneity in its effect on horizontal power ($I^2 = 58\%$, $p = 0.003$) (Fig. 18).

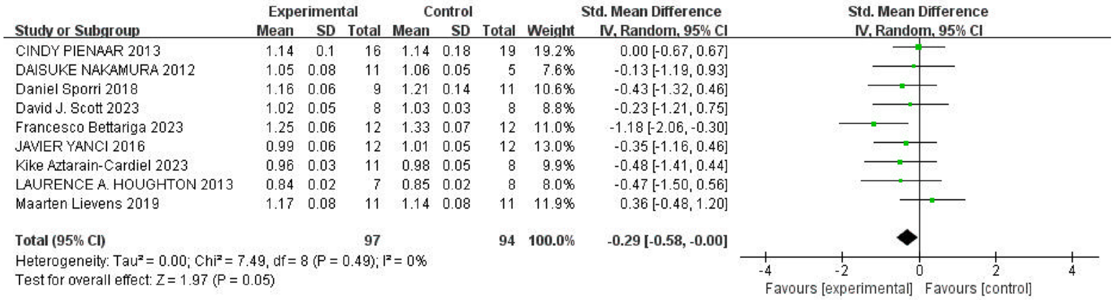

Fig. 13. 5 m forest plot.

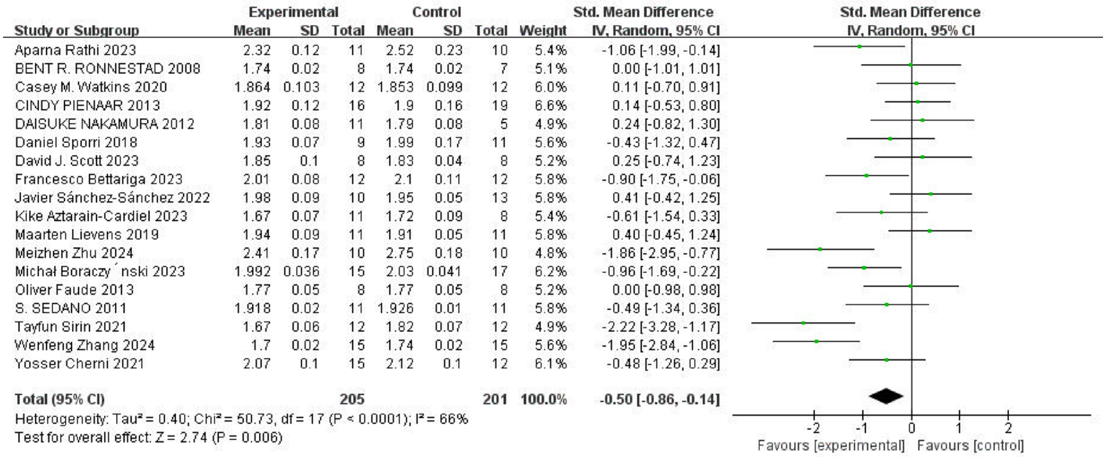

Fig. 14. 10 m forest plot.

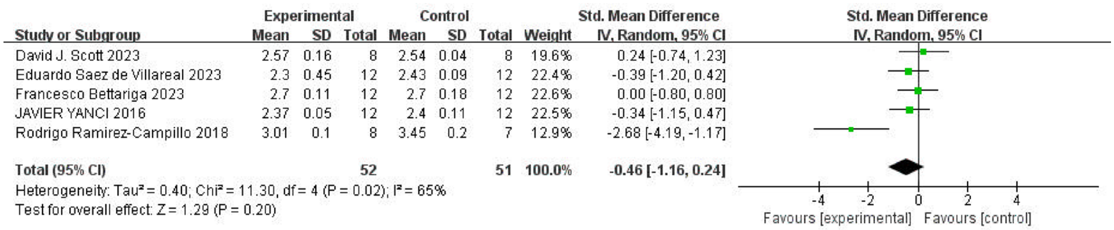

Fig. 15. 15 m forest plot.

Plyometric training showed a moderate positive effect in the Illinois test, with a significant difference compared to the control group (SMD = −0.64, 95% CI [−1.18, −0.10], p = 0.02). In terms of heterogeneity, plyometric training showed moderate heterogeneity in its effect on horizontal power (I^2 = 62%, p = 0.02) (Fig. 19).

Maximal oxygen uptake and body composition

Maximal oxygen uptake did not differ significantly between participants in the plyometric training group and those in the control group (SMD = 0.14, 95% CI [−0.30, 0.58], p = 0.53). In terms of heterogeneity, plyometric training showed more consistency in its effect on maximal oxygen uptake (I^2 = 42%, p = 0.10) (Fig. 20).

Plyometric training showed a moderate positive effect in reducing body fat percentage, with a significant difference compared to the control group (SMD = −0.71, 95% CI [−1.09, −0.32], p = 0.0003). In terms of heterogeneity, plyometric training showed consistency in its effect on body fat percentage (I^2 = 0%, p = 0.58) (Fig. 21).

Subgroup analysis

We explored subgroup analyses of five aspects of intervention types, contact volume, training duration, training frequency, and sports explosive demand.

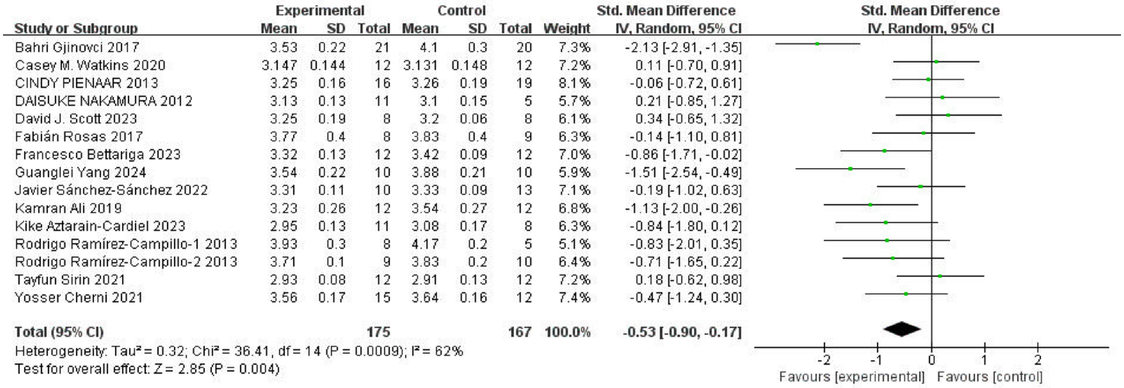

Fig. 16. 20 m forest plot.

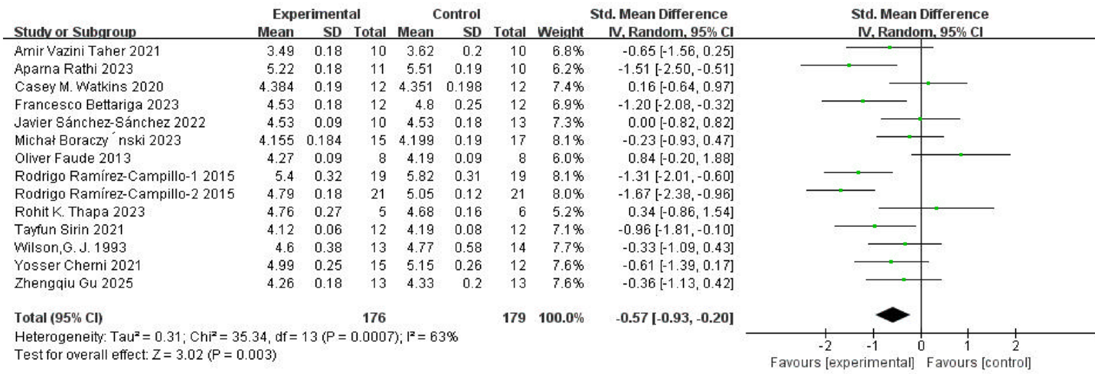

Fig. 17. 30 m forest plot.

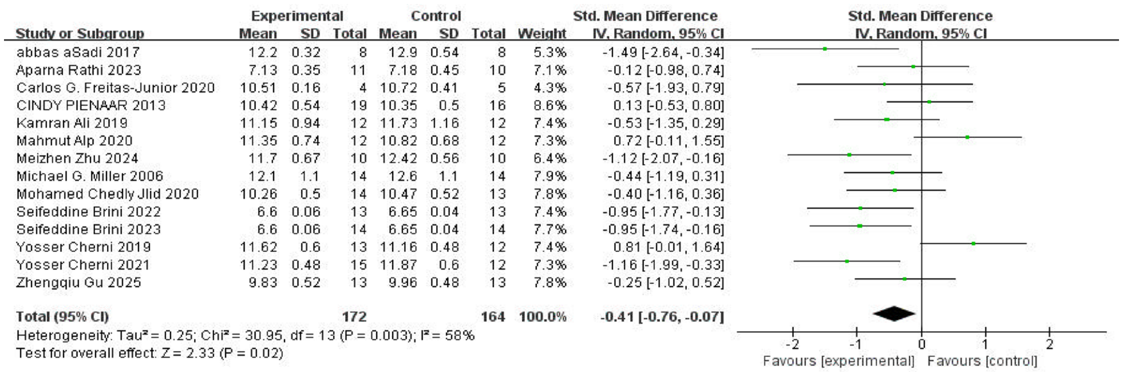

Fig. 18. T-test forest plot.

For CMJ, the contact volume ($p=0.0002$) and sport explosive power demands ($p=0.04$) significantly influenced the intervention effect. Improvement was most significant for > 1400 contacts (SMD = 1.27, 95% CI [0.86, 1.69], $I^2=62\%$) during the intervention, followed by < 900 contacts (SMD = 0.65, 95% CI [0.39, 0.90], $I^2=0\%$). Programmes with high explosive demands (SMD = 0.83, 95% CI [0.57, 1.09], $I^2=60\%$) demonstrated significant improvements. Frequency ($p=0.01$) was the main factor influencing the effectiveness of SLJ interventions, with > 2 times per week (SMD = 2.33, 95% CI [1.36, 3.29], $I^2=75\%$) being significantly better than ≤ 2 times per week (SMD = 0.82, 95% CI [0.21, 1.43], $I^2=77\%$).

Improvement in 20 m sprint was significantly effective for both > 1400 contacts (SMD = − 1.63, 95% CI [− 2.24, − 1.01], $I^2=31\%$) and < 900 contacts (SMD = − 0.37, 95% CI [− 0.73, − 0.02], $I^2=10\%$) and superior to the 900–1400 contacts (SMD = 0.08, 95% CI [− 0.41, 0.58], $I^2=0\%$).Training duration ($p<0.00001$) was the main factor influencing the effectiveness of the 30 m intervention (≤ 6 weeks SMD = − 0.22, 95% CI [− 0.28, − 0.16],

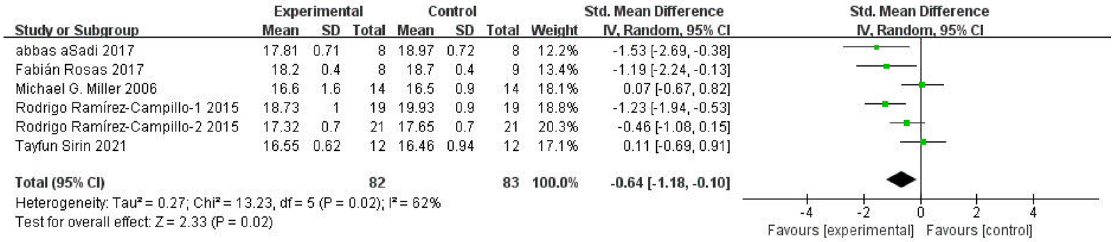

Fig. 19. Illinois test forest plot.

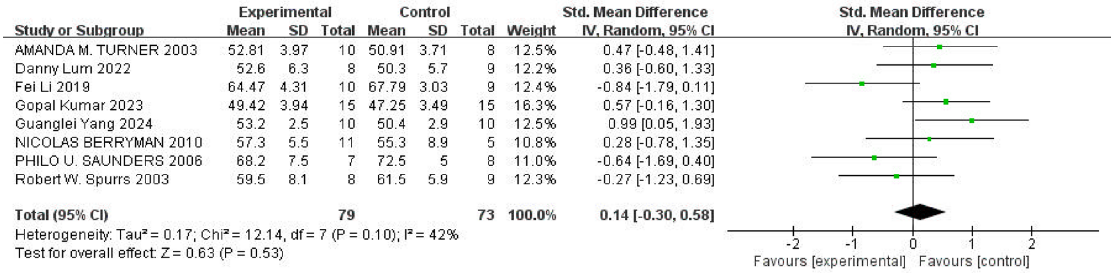

Fig. 20. VO2max forest plot.

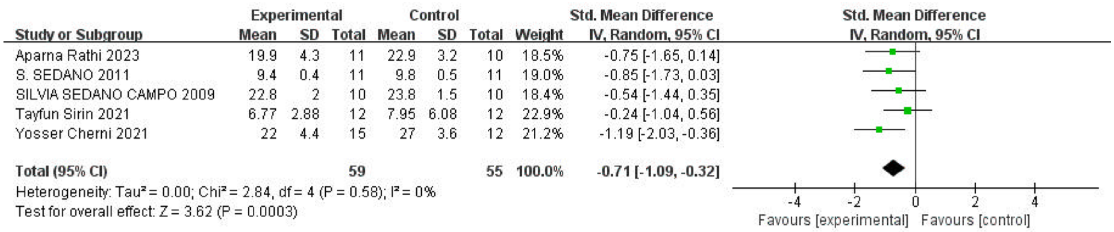

Fig. 21. Body fat forest plot.

$I^2 = 76\%$; > 6 weeks SMD = − 0.04, 95% CI [− 0.08, 0.00], $I^2 = 41\%$).Detailed results of subgroup analyses and forest plots are available in the supplementary 3 and 4.

Publication bias analysis

In the 19 different funnel plots of the included studies, a generally symmetrical distribution was observed, with no obvious signs of bias. Additionally, Egger's regression test (S3) for each funnel plot did not show significance (all $p > 0.05$). These consistent results indicate a low risk of publication bias across different analytical levels, affirming the representativeness and robustness of this meta-analysis. Furthermore, sensitivity analyses were conducted to evaluate the reliability of the results. These analyses revealed no instances of extreme values exerting a substantial influence on the outcomes (Fig. 22).

Assessment of evidence quality

The certainty of evidence was assessed according to the GRADE method, and S5 presents the results of the certainty of evidence for each outcome. Reasons for one or more levels of reduced certainty include (1) risk of bias (moderate), (2) inconsistency (i.e., significant heterogeneity was found), (3) imprecision (i.e., small number of participants and/or CIs spanning small effect sizes), and (4) publication bias (i.e., asymmetry of the funnel plots was found). The level of certainty of the evidence for 2 outcomes was moderate, 11 outcomes were low, and 6 outcomes were very low.

Discussion

This systematic review and meta-analysis combined the effects of plyometric training and its derived methods (e.g., sand training, weighted vest training, complex training) on various physical fitness parameters in adult athletes. These parameters included body composition, cardiovascular endurance, lower limb strength, lower limb explosive power, agility, and speed. The 70 included studies involved 1,703 athletes, providing a sufficient sample size. The analysis results demonstrate that, compared to traditional strength training and regular

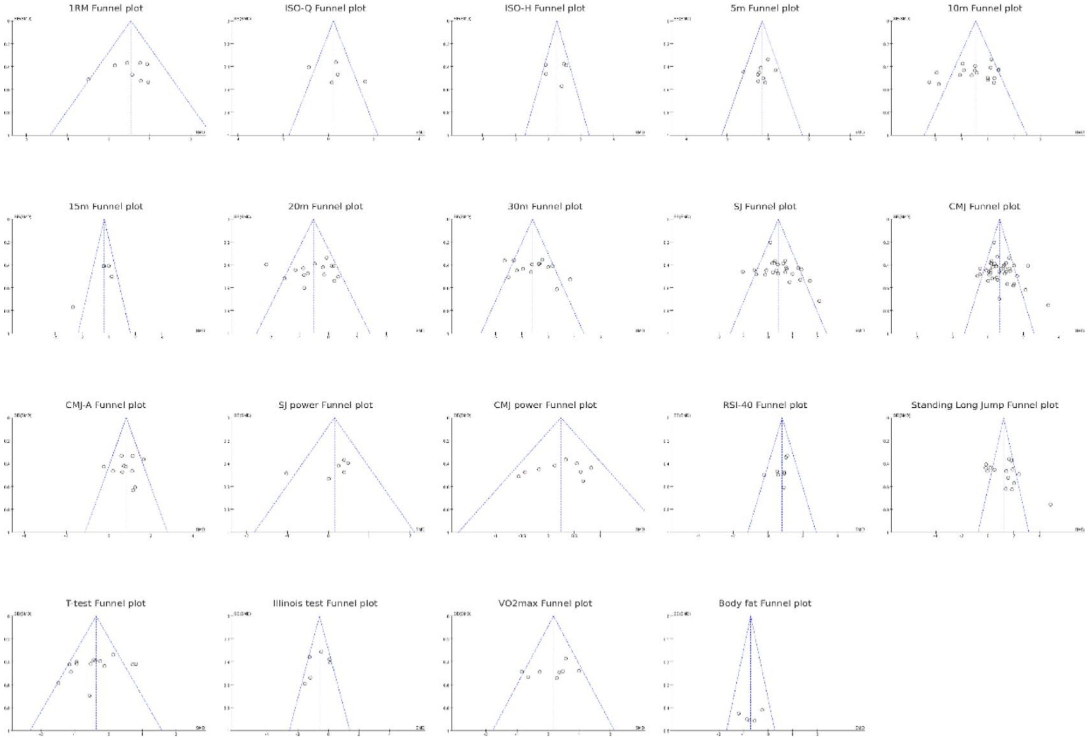

Fig. 22. Publication bias analysis.

training, plyometric training had significant positive effects on several parameters, including lower body squat maximal strength, sprint performance (10 m, 20 m, and 30 m), vertical jump (CMJ, SJ, CMJ-A), reactive strength index (RSI), and standing long jump. Additionally, body fat percentage and agility tests (such as the Illinois test) showed moderate improvements.

Lower limb strength and power

Lower limb maximal strength

The results of the review indicate that plyometric training significantly improved lower body maximal strength, supporting previous research[95]. Recent meta-analyses have shown that plyometric training significantly improves lower limb strength in athletes from team sports[11,27]. Building on this, our study expands the evidence base by including a broader range of athletic populations, thereby supporting the generalizability of this training approach across diverse sport disciplines. The mechanism behind this improvement is primarily attributed to the unique effect of the stretch–shortening cycle (SSC), which provides more effective stimulation for lower limb strength development and optimises power output[95]. The combination of rapid eccentric contraction followed by explosive concentric contraction not only stores and releases elastic energy but also strengthens the maximal strength output of major muscle groups (such as the quadriceps and gluteus maximus), especially in dynamic compound movements like squats[96].

Standing long jump

In addition to enhancing maximal strength, plyometric training showed significant benefits for horizontal power output, as reflected in standing long jump performance. The standing long jump is an important indicator of lower body strength and explosiveness, and improvements in performance are closely related to enhanced muscle strength and tendon elasticity[25]. The use of high-intensity dynamic compound movements in plyometric training significantly activates type II fast-twitch muscle fibres, enhancing neural recruitment efficiency and neuromuscular coordination[97], which involve increased motor unit recruitment, firing frequency, and improved synchronisation[25], thereby providing stronger support for power output in movements like squats and standing long jump[25,98]. Plyometric training significantly improved performance in the standing long jump by strengthening the SSC mechanism and tendon elasticity reserve[99]. Subgroup analysis suggests that a frequency exceeding two sessions per week may be optimal for enhancing standing long jump performance, particularly in power-oriented training cycles.

Vertical jump performance

Plyometric training had a particularly significant effect on improving vertical jump performance (e.g., CMJ, SJ, and CMJ-A), and these findings are consistent with previous reviews[11,100]. At the same time, our findings, in line with recent evidence, suggest that improvements in countermovement jump performance are most pronounced when the total number of ground contacts exceeds 1400. Moreover, athletes engaged in high-explosiveness sports such as basketball and football appear to benefit more than those in endurance-oriented disciplines like long-distance running. Plyometric training, through its high-intensity and rapid movement characteristics, enhances the neural system's ability to synchronise motor unit activation, thereby improving muscle contraction speed, coordination, and overall vertical jump performance[97,101]. Additionally, based on the theory of skill transfer[91], most plyometric training programs involve exercises that counteract the athlete's own body weight. This generates neural adaptation to vertical movements against gravity, and the adaptation and familiarity with movement and force patterns may also contribute to improved vertical jump performance[102]. The lack of significant improvement in CMJ and SJ power output may be related to the training regimen. Plyometric training typically focuses on short-duration, high-intensity training emphasising overall coordination and power output, while single-session high-power output requires higher intensity loads and prolonged force accumulation, areas where traditional heavy-load strength training has a clear advantage[11,63].

Reactive strength index

Notably, in addition to improving explosiveness, plyometric training has also been shown to significantly enhance the reactive strength index (RSI), further highlighting its role in optimising the performance of rapid explosive movements. Ankle joint stability and stiffness are particularly important in high-speed movements[99]. Plyometric training enhances the efficiency of converting ground reaction forces into upward explosive power by improving lower limb joint and tendon stiffness and optimising muscle–tendon unit behavior[103], while also significantly improving Reactive Strength Index (RSI) performance. This is of significant importance for jumping, sprinting, and complex dynamic movements[21,53].

Isokinetic strength tests

In this study, plyometric training did not show significant improvements in isokinetic strength of the quadriceps and hamstrings at an angular velocity of 60°/s. This result may be explained by the principle of training specificity: plyometric training primarily enhances explosive power and neuromuscular activation rather than maximizing torque output under constant angular velocity conditions[104]. In contrast, traditional resistance training—with its sustained tension loads—may be more effective in targeting isokinetic strength gains[79].

Consistent with our findings, recent studies have reported that while plyometric interventions can enhance athletes' performance, but no significant improvements in isokinetic strength[18,23,69]. However, some research results support the contribution of plyometric training to isokinetic strength testing[35,80].

Therefore, variations in participant characteristics, intervention duration, measurement equipment, and testing procedures may account for the inconsistencies in observed outcomes. Future evaluations should carefully consider these methodological factors to more accurately elucidate the true effects of plyometric training.

Sprint and agility performance

Sprint performance

This study demonstrated that plyometric training exhibited greater adaptive advantages compared to normal training in improving short-distance sprint performance (10 m, 20 m, and 30 m). One possible explanation is the contribution of the stretch–shortening cycle (SSC), which may enhance force output by storing elastic energy during the eccentric phase and rapidly releasing it during the subsequent concentric phase, thereby potentially improving neuromuscular efficiency and power production[105]. In addition, these performance gains could also be attributed to neural adaptations, such as increased motor unit activation, enhanced intermuscular coordination, and improved reflexive responses[25]. This has been extensively demonstrated in this mechanism dominant activities such as jumping and sprinting[106].

However, plyometric training did not show significant effects on 5 m and 15 m sprints. This may be partly due to variations in the intervention protocols, training surface, or athlete populations across studies. Additionally, the small number of studies reporting 5 m and 15 m outcomes limits the stability and generalisability of the pooled estimates. Evidence suggests that shorter sprint distances (≤ 10 m) rely more heavily on horizontal force production[107], whereas longer sprint distances place greater emphasis on vertical force[108]. As for the 15 m sprint, it potentially reflects a transitional phase where neither maximal acceleration nor steady-state sprint mechanics dominate, thus making performance improvements more sensitive to individual variability, training specificity, and baseline fitness. It is also possible that previous meta-analyses reporting positive effects included different sets of studies, target populations (e.g., elite vs. sub-elite athletes), or broader definitions of plyometric training. These factors may collectively reduce the likelihood of detecting a consistent training effect at this intermediate distance. Another review study found similar results[109]. Due to limited available data, the influence of moderating factors on sprint-related adaptations remains unclear. While current evidence supports the efficacy of plyometric training in enhancing sprint performance, further high-quality studies are needed to strengthen these conclusions.

Agility performance

In addition to linear sprint performance, plyometric training also demonstrated benefits in agility-based assessments. The Illinois agility test and the T agility test were used to determine the ability to accelerate, decelerate, turn in different directions, and run at different angles. Improvements in agility test scores further demonstrate the neural adaptation effects of plyometric training. Improvements in neural drive efficiency and both intramuscular and intermuscular coordination enable athletes to perform better in complex multidirectional movements, particularly showing significant advantages in rapid transitions between deceleration and acceleration[77,110]. Plyometric training emphasizes power production, which may induce neural adaptations that lead to accelerated motor unit recruitment and enhanced intermuscular coordination, thereby enhancing the speed and magnitude of power output[95]. Simultaneously, such programs may strengthen eccentric control in the lower limbs, thereby reducing braking time during deceleration. Together, these adaptations are considered critical for enhancing change-of-direction ability in athletic performance[111,112].

Furthermore, while numerous studies have demonstrated that plyometric training significantly improves change-of-direction (COD) ability across participants of varying ages and sports[11,27,113], the inclusion of adult athletes in this study may have influenced the results. This is likely due to the athletes' higher baseline agility levels and the fact that the control group also underwent alternative training.

In summary, plyometric training shows promise in enhancing multidirectional agility, though variations in test sensitivity and participant characteristics may affect outcome consistency. Future studies should clarify the relationship between agility metrics and training adaptations and adopt more rigorous designs to improve the reliability and interpretability of findings.

Maximal oxygen uptake and body composition

Plyometric training excels in optimising body composition. Studies have shown a significant reduction in body fat percentage after training[114], which is particularly important for sports such as high jump and endurance running[115], where both body composition and strength are crucial, but this result is contrary to the previous review study[116], probably because of the previous review was orientated towards an untrained healthy population, which differs from this review. Body fat percentage shows a negative correlation with athletes' vertical jump and sprint performance[117,118]. Plyometric training effectively reduces body fat percentage, further supporting its ability to enhance strength and athletic performance in a short period. Additionally, it offers a practical training solution for athletes aiming to manage their body fat levels.

Plyometric training primarily activates fast-twitch muscle fibres through rapid, short-duration, high-intensity stimuli, improving explosiveness and power output, but it provides relatively insufficient long-term adaptive stimulus for type I slow-twitch fibers and cardiovascular endurance[119,120]. As a result, VO_{2max} did not significantly improve, indicating that cardiovascular function and endurance were not sufficiently developed. Current research suggests that no strength training method has an effect on VO_{2max} in middle-distance runners[121,26], This result aligns with findings in a recent review[26], which noted that plyometric and other neuromuscular training modalities rarely elicit meaningful changes in VO_2max due to insufficient aerobic stimulus and low cardiovascular load. These findings suggest that plyometric training is not an effective method for improving aerobic endurance in trained populations, particularly when compared to sustained aerobic conditioning protocols. This review provides in-depth corroboration that plyometrics training also has a negligible effect on VO_{2max}[107].

Moderator effects and sources of heterogeneity

This meta-analysis confirmed the overall effectiveness of augmentative training, but there was high heterogeneity in some of the pooled results. To further explain these differences, subgroup analyses were performed in terms of intervention type, contact volume, intervention duration, frequency, and sport explosive demands. The results revealed moderators that may influence the variance in training effects.

The results showed that the volume of contact was a significant moderator of CMJ and 20 m sprint performance. Specifically, the greatest enhancement was produced by the intervention with more than 1400 touches, followed by the 900-touch group. In contrast, the moderate group (900–1400 touches) did not show significant changes. This finding suggests the existence of a 'dose threshold' for augmentative training, whereby a sufficient degree of repetitive stimulation is required to effectively induce neuromuscular adaptations that result in significant performance gains[25]. Furthermore, the training effect of CMJ was found to be contingent upon the specific explosive power requirement, with enhanced training outcomes observed in sports requiring higher levels of explosive power (e.g., basketball, volleyball). This phenomenon may be attributed to the individual's inherent muscle mobilisation capacity and the congruence between movement type and sport demands, thereby amplifying the 'specific transfer effect' of the training-sport task[122]. In the standing long jump, the training frequency was a significant moderator. Higher effect sizes were obtained in the intervention group that trained >2 times per week compared to the ≤ 2 times per week group, suggesting that repetitions at higher frequencies may contribute to improvements in lower limb explosiveness, possibly through adaptation by enhancing motor unit recruitment and coordination mechanisms. In the 30-m sprint, subgroup analyses of training cycles demonstrated that a duration of ≤ 6 weeks of intervention was superior to a duration of >6 weeks. This is likely to result in faster performance gains through early neurally-driven adaptations (e.g., improved motor unit synchronisation and faster reaction times). However, longer-term interventions may have reached an adaptive plateau in the absence of incremental increases in intensity.

The volume of contacts, the frequency and duration of training, and the congruence between the training content and the nature of the specialised sport may collectively constitute significant mechanistic sources of variance in the efficacy of augmentative training interventions.

General summary and practical implications

In summary, plyometric training, with the stretch–shortening cycle (SSC) as its core mechanism, shows significant effects in improving lower body strength, explosiveness, sprint speed, multidirectional movement abilities, and reducing body fat percentage, making it an important method in athlete training. Its unique advantages make it an important complement to traditional strength training, particularly suited for the training goals of short-duration, high-intensity exercises. Coaches and trainers can use it as an effective tool to enhance athletic performance, promoting it across various sports. However, future research should further expand the scope of plyometric training and pay more attention to the training arrangements for different special needs to achieve more comprehensive physical development and meet the diverse needs of athletes in different specialties. In order to reduce methodological heterogeneity and improve the comparability of results between different trials, there is a need for standardised training programmes, unified outcome measures and clear participant profiles.

Strengths and limitations

Firstly, this meta-analysis utilised a large sample, comprising data from 70 studies and 1703 participants. Additionally, we incorporated hybrid interventions with plyometric training as the basis, allowing for comparisons with traditional interventions based on the original plyometric methods, thus offering updated and comprehensive evidence-based recommendations. Secondly, it provides a comprehensive and systematic basis for evaluating the impacts of plyometric training on various physical fitness parameters, such as strength, explosiveness, speed, agility, and body fat percentage.

At the same time, our review, like those on which it is based, has some limitations:

Variation in training duration. The interventions ranged from 2 to 16 weeks across studies, which may have contributed to inconsistent adaptations and widened the heterogeneity of training outcomes. Future studies should apply minimum duration thresholds (e.g., > 6 weeks) to enhance result comparability.

Participant variability. Differences in training background, age, sex ratio, and fitness level (e.g., some studies included amateur athletes, others national-level) may have influenced responsiveness to plyometric training. Subgroup analysis or stratification based on these variables is recommended in future reviews.

Inconsistencies in training protocols. Included studies differed in frequency (1–4 sessions/week), intensity, rest intervals, and jump volume (ranging from 254 to 9576 total jumps). Future research should report training load using standardised descriptors (e.g., session-RPE, weekly volume) for better cross-study comparability.

Heterogeneity in testing methods. Diverse outcome assessment tools were used (e.g., optical systems vs. force plates for CMJ; electronic vs. manual timing for sprint/agility tests), which may affect the precision and objectivity of the results. The adoption of validated and uniform measurement tools is encouraged.

Limited reporting on sport-specific effects. Some studies failed to clearly identify the sport discipline of participants, preventing analysis of sport-specific responses. Future reviews should consider separating performance effects by sport type (e.g., court-based vs. field-based athletes) when feasible.

Conclusions

In summary, plyometric training has a positive impact on improving lower limb maximal strength (e.g., 1RM squat), vertical jump height (e.g., CMJ, SJ), reactive strength index (RSI), standing long jump, sprint speed (10 m, 20 m, 30 m), agility (Illinois test and T test), and body fat percentage in conditioned individuals. These effects are likely mediated by neuromuscular adaptations and enhanced utilisation of the stretch–shortening cycle. This result highlights the practical value of plyometric training in improving physical fitness, particularly in sports that emphasise explosive power and speed, such as soccer and basketball.

However, there were no significant gains observed in the 5 m and 15 m sprints, maximal oxygen uptake (VO_2max), isokinetic strength tests at 60°/s, and lower body jump power performance.

To enhance comparability across studies, future trials should reduce methodological heterogeneity by standardising training protocols, defining outcome measures clearly, and reporting intervention parameters in detail. Investigating moderating factors such as sport type, training background, and intervention duration may also improve understanding of differential responses.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

JY.S. and JB.S. wrote the main manuscript text; JY.S. and Q.Z. prepared all figures; S.S. supervised the project and edited the manuscript. All authors reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

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