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Review article

Children's Sprint and Jump Performance after Plyometric-Jump Training: A Systematic Review

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Abstract

The effect of plyometric jump training on children's jump and sprint performance remains unclear. To explore the effects of PJT on jump and sprint performance in children and to further analyze the influence of participant characteristics and training variables. A literature search was conducted in the PubMed, Web of Science, and SPORTDiscus databases. The included studies (n = 17) involved 587 children, with study sample sizes ranging from 9 to 44 participants. Overall, PJT improved children's vertical jump performance involving squat jump and countermovement jump (ES = 0.78, 95% confidence interval [CI] = 0.41 - 1.16, I^2 = 63%, p < 0.01; n = 474), standing long jump performance (ES = 0.56, CI = 0.3-0.83, I^2 = 26%, p < 0.0001; n = 414), and sprint performance involving 5 m to 30 m distances (ES = -0.41, CI = -0.61 to -0.22, I^2 = 0%, p < 0.01; n = 424). Subgroup analysis showed non-tapering strategies (ES = 0.92, n = 88) resulted in significant difference than tapering strategies (ES = 0.37, n = 336 np = 0.01). Meta-regression showed a positive correlation between the total number of training sessions and standing long jump performance improvement (p = 0.03). Two studies have a high risk of bias (RoB), and 15 studies have a moderate RoB (some concerns). The GRADE assessment indicated a very low to low robustness of the evidence. In conclusion, PJT can improve children's jump and sprint performance. Increasing the number of training sessions may lead to better standing long jump results. However, the low to very-low robustness of the currently available evidence precludes recommendations regarding PJT for improving children's neuromuscular performance.

Key words: Plyometric exercise, stretch shortening cycle, physical fitness, physical functional performance.

Introduction

Plyometric jump training (PJT) is a form of plyometric training characterized by various types of jumping exercises (Ramirez-Campillo et al., 2020). Previous studies have confirmed that PJT can significantly improve strength (Ramirez-Campillo et al., 2023a; Sáez de Villarreal et al., 2010), jumping performance (Liu et al., 2024; Markovic, 2007; Ramirez-Campillo et al., 2023a), change of direction (COD) (Asadi et al., 2016; Miller et al., 2006; Ramirez-Campillo et al., 2023a), balance (Ramirez-Campillo et al., 2023a), sprinting performance (Liu et al., 2024) in adult. However, the specific mechanism of PJT is unclear, with potential mechanism including: the storage and utilization of elastic potential energy (Bosco et al., 1982), increased muscle pre-activation (Bobbert et al., 1996), stretch reflex (Komi and Gollhofer, 1997), desensitization of the Golgi tendon organ (Davies et al., 2015), and increased time for force development (Zatsiorsky et al., 2020).

The issue of insufficient physical activity among adolescents is a growing concern (Guthold et al., 2020). Resistance training has been demonstrated to effectively improve children's health by enhancing cardiovascular fitness, controlling body weight, strengthening bones, and reducing the risk of exercise-related injuries (Bergeron et al., 2015; Faigenbaum and Myer, 2010; Landry and Driscoll, 2012; Stricker et al., 2020). However, resistance training often requires specialized equipment and correct technical execution. For children, incorporating bodyweight exercises or integrating training with games may be more effective. Consequently, PJT has become widely used in children's training programs (Faigenbaum and Myer, 2010). Compared to traditional resistance training, PJT offers greater convenience, as it can be performed using only body weight and is not restricted by location.

It is relatively common to find recommendations regarding individuals to be able to squat 1.5 times their body weight before PJT (Wathen, 1993). However, most children cannot meet this requirement, and PJT have demonstrated to induce meaningful adaptations in pediatric population, without inducing injury of related detrimental secondary effects (Faigenbaum et al., 2009; Lloyd et al., 2011; Thomas et al., 2009), as most. Although some meta-analyses have investigated the effects of PJT on children, a part of studies fail to consider maturity levels (Ramirez-Campillo et al., 2020), while others conflate children with adolescents (Chen et al., 2023b), potentially leading to biased results, As children mature, they undergo physiological changes that differentiate them from adolescents and adults in aspects such as tendon stiffness (Kubo et al., 2014), muscle cross-sectional area (O'Brien et al., 2010), and motor unit recruitment (Grosset et al., 2008; Koh and Eyre, 1988), Moreover, studies have shown that sensitivity to training stimuli varies with maturity levels (Moran et al., 2017; Ramirez-Campillo et al., 2023a; Romero et al., 2021). Currently, there appears to be no dedicated meta-analysis on PJT specifically for children, and the impact of training-related variables (e.g., training

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frequency, volume, and rest intervals) and participant characteristics on PJT outcomes remains unclear. The aim of this study is to explore the effects of PJT on children's jumping and sprinting abilities and to identify factors influencing the effectiveness of PJT in this population.

Methods

This systematic review and meta-analysis was conducted following the PRISMA 2020 guidelines (Page et al., 2021), and has been registered in PROSPERO (registration number: CRD42024573354).

Search Strategy

We performed a comprehensive search across three databases: PubMed, Web of Science, and SPORTDiscuss, up to November 12, 2024. The search string used was as follows: (Plyometric or plyometrics or plyometric training or plyometric exercise or jump training or countermovement jump or CMJ or jump squat or drop jump or depth jump)) AND TS = (child or children or youth or youths or kid or kids or preadolescence or preadolescent or prepuberty or prepubertal). The detailed search process can be found in Appendix A.

Additionally, we manually searched the references of retrieved articles to prevent the omission of relevant studies. Two independent reviewers (W.H. and L.S.) screened the titles and abstracts, evaluating them against the inclusion criteria. A total of 16 articles were included in the final meta-analysis. Figure 1 provides a detailed overview of the search process.

Inclusion and exclusion criteria

Studies were evaluated based on the PICOS criteria, with the following inclusion standards: (1) Participants: The subjects were children, defined in accordance with previous related studies as males under 13 years and females under 11 years old (Lesinski et al., 2016; Lloyd et al., 2016a; Radnor et al., 2018).Based on previous studies (Lesinski et al., 2016; Ramirez-Campillo et al., 2023a), maturity was assessed using maturity offset or tanner score (PHV $<$ -1 or Tanner stage 1 - 2), without restrictions on height or weight. (2) Intervention: The experimental group underwent PJT intervention, with the possibility of engaging in specific training or other activities post-PJT. No restrictions on the type and direction of PJT. The main difference between the experimental and control groups was the implementation of PJT. (3) Control Group: The control group did not receive PJT intervention but could participate in specific training or other activities. This design aimed to isolate the effect of PJT. (4) Outcomes: The primary outcomes were jump and sprint performance, which are critical indicators of athletic ability in children.

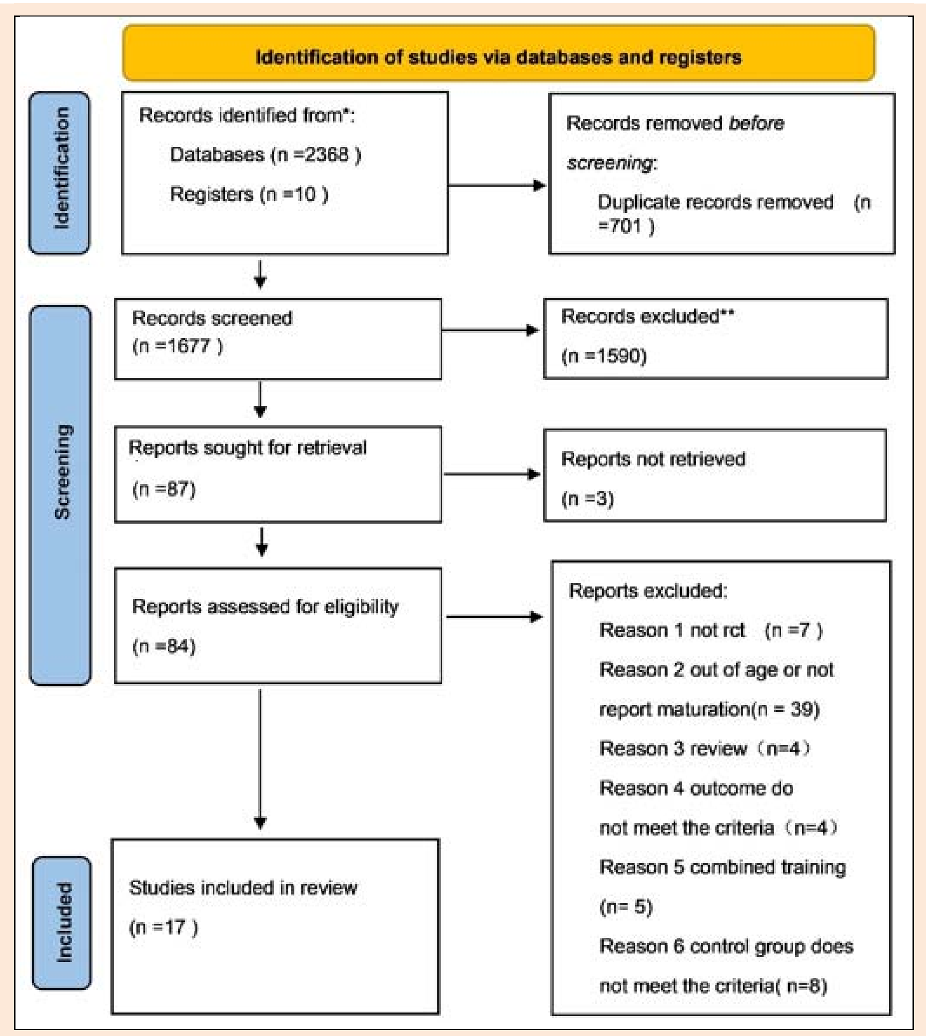

Figure 1. Flow diagram for the identification, screening and selection of studies.

Jump performance was assessed using various standardized tests, including countermovement jump (CMJ), squat jump (SJ), standing long jump (SLJ), and reactive strength index (RSI). Sprint performance was evaluated over distances ranging from 5 to 30 meters to capture short- and mid-distance acceleration and maximal speed capabilities (Kotzamanidis, 2006). Measurement protocols adhered to validated methods to ensure reliability and comparability across studies. (5) Study Design: Only randomized controlled trials (RCTs) published in peer-reviewed English journals were included.

Data extraction

All selected articles were imported into Endnote 21 (Clarivate Analytics, Philadelphia, PA) for management. The screening process was conducted independently by two researchers (W.H. and L.S.); any discrepancies were resolved by consulting a third researcher (Z.Q.). Data extracted included: (1) Jump and sprint performance metrics (≤10m, >10m). (2) Baseline characteristics of the participants, such as height and weight. (3) Training-related variables, including frequency, session duration, and total training period. Pre- and post-intervention data (mean ± standard deviation). For studies with multiple intervention phases (e.g., 4 weeks, 8 weeks), only data from the final phase were included. If a control group was used in multiple comparisons, the sample size was divided by the number of comparisons. When necessary, data were unavailable, we contacted the authors via email. Only one author responded and provided complete data. For articles with graphical data, we utilized WebPlotDigitizer software to extract relevant information.

Risk of bias assessment and certainty of evidence

The risk of bias for the included randomized controlled trials (RCTs) was evaluated using the Cochrane Risk of Bias Tool 2 (RoB2) (Sterne et al., 2019). This tool assesses five key domains: (I) bias arising from the randomization process; (ii) bias due to deviations from intended interventions; (iii) bias due to missing outcome data; (iv) bias in the measurement of the outcome; and (v) bias in the selection of the reported result. The risk of bias was qualitatively synthesized using RoB2. Two authors (W.H. and L.S.) independently assessed the risk of bias, and any discrepancies were resolved through discussion with a third author (Z.Q.). Sensitivity analyses were conducted to assess the robustness of the pooled estimates and to determine whether any specific study accounted for the observed heterogeneity. In this process, we employed a leave-one-out approach, systematically excluding each study from the meta-analysis one at a time, and observing the impact of excluding each study on the overall pooled estimate and heterogeneity. This method helped identify whether any specific study, due to factors such as sample size, study design, or other characteristics, had an excessive influence on the variability of the results. Additionally, we examined the changes after exclusion to further assess the stability of the pooled estimates, thereby ensuring the reliability of the conclusions.

Two authors (WH, LJY) rated the certainty of evidence by the Grading of Recommendations, Assessment, Development and Evaluation (GRADE), According to GRADE (Guyatt et al., 2011), the quality of evidence is categorized as "High, " "Moderate, " "Low, " or "Very Low." The criteria for downgrading the quality of evidence include the following factors:(1) Risk of Bias: I f 1/3 of the studies are assessed as having "some concern" or "high risk, " the evidence quality is downgraded by one level. If 1/2 of the studies are assessed as having "some concern" or "high risk, " the evidence quality is downgraded by two levels. (2) Inconsistency: When heterogeneity I^2 is >50%, the evidence quality is downgraded by one level, when it is I^2 >75%, the evidence quality is downgraded by two levels. (3) Indirectness: If the participants, interventions, comparisons, or outcomes in the studies do not directly align with the research question, the quality of evidence may be downgraded. (4)Imprecision: When the effect estimate is imprecise or the sample size is insufficient to draw robust conclusions, the quality of evidence will be downgraded.(5)Publication Bias: If there is evidence of publication bias, such as missing unpublished studies or funnel plot asymmetry, the quality of evidence will be downgraded.

Summary measures, synthesis of results, and publication bias

Data analysis was performed using R software (version 4.4.1, Australia) Meta-analysis was conducted when at least three studies were available. Effect sizes (ES) were calculated using Hedge's g based on pre- and post-intervention mean differences and standard deviations. Changes from pre- to post-intervention were calculated as M post-M pre, and the pooled standard deviation were as (Borenstein et al., 2021):

$$\text{Spooled} = \sqrt{\text{SD1}^2 + \text{SD2}^2 - 2 * \text{R} * \text{SD1} * \text{SD2}}:$$

A random-effects model was used to interpret differences between the PJT and control groups. ES values were interpreted as trivial (<0.2), small (0.2 to 0.5, medium (0.5 to 0.8), and large (>0.8) (Cohen, 1992). Heterogeneity across studies was assessed using the I^2 statistic, with I^2 values of 0 - 25% indicating negligible heterogeneity, 25 - 75% indicating moderate heterogeneity, and 75 - 100% indicating substantial heterogeneity (Higgins et al., 2003). Statistical significance for all analyses was set at $p \leq 0.05$. Publication bias was assessed qualitatively using funnel plots when more than 10 studies were included, and quantitatively using Egger's test. If significant bias was detected, the trim-and-fill method was applied to adjust for it. The p-values <0.05 were considered statistically significant.

Subgroup analysis and meta-regression

Subgroup analyses were performed based on sprint distance (10m≥, >10m) and vertical jump (VJ) type (SJ, CMJ). Additionally, potential moderators, including gender, training experience, progressive overload, taper strategy, and training modality, were evaluated through subgroup analysis. Meta-regression was conducted for continuous variables such as program duration (training weeks and total training sessions), training frequency (sessions per week), and training volume (mean and total round contacts). Meta-regression was only performed when the number of ESs exceeded ten.

Results

Literature search

A total of 2155 studies were identified through database searches, with an additional study identified through reference lists. After removing duplicates, 1, 532 studies remained. Titles and abstracts were screened, resulting in 72 studies for full-text evaluation. Ultimately, 17 studies met the inclusion criteria, involving 611 children, of whom 343 were in the PJT groups across 19 intervention arms, with sample sizes ranging from 9 to 44 participants (see Table 1).

The PJT interventions lasted 4-12 weeks, with a training frequency of 1-2 sessions per week and session durations of 15 - 60 minutes. The average number of ground contacts per session ranged from 39 to 185, with total ground contacts ranging from 360 to 2960. Recovery periods between sessions were ≥48-168 hours. Due to the lack of standardized intensity classifications for PJT in children, training intensity was not quantified. Only one study reported intra-session rest periods of 7 seconds (see Table 2).

Risk assessment and certainty of evidence

The quality of the studies included in this meta-analysis was evaluated using the RoB2 tool. Most studies were deemed to have sufficient quality for inclusion in the meta-analysis. Two studies (Drouzas et al., 2020; Michailidis, 2015) (11.7%) were judged to have a high risk of bias, while the remaining studies (Asadi et al., 2018; Bogdanis et al., 2019; Chaouachi et al., 2014; Katsikari et al., 2020; Lloyd et al., 2012; Lloyd et al., 2016b; Marta et al., 2022; Michailidis et al., 2013; Moran et al., 2017; Negra et al., 2020a; 2020b; Sammoud et al., 2019; 2021; 2022; 2024; Tottori and Fujita, 2019) exhibited some concerns, primarily related to allocation concealment and blinding processes (see Figure 2). Results of the GRADE analyses are provided in Table 3. We chose seven outcomes for the analysis (Table 4). According to the GRADE assessment, the certainty of evidence was considered very low to low.

Meta-Analysis Results

Vertical jump

Thirteen studies evaluated CMJ, involving 14 experimental groups and 13 control groups, with a total of 407 participants. PJT had a moderate effect on VJ performance (ES = 0.78, 95% CI = 0.31 - 1.16, I^2 = 63%, $p < 0.01$, Supplementary Figure 1). CMJ demonstrated a large ES (0.81), which was higher than that of SJ (0.57)(Supplementary Figure 2). However, the difference did not reach statistical significance (P = 0.35; see Table 3, Supplementary Figure 2). Egger's test indicated publication bias (p = 0.0042)(Funnel plot in Supplementary Figure 3), after applying the trim-and-fill method in the meta-analysis, the ES decreased to 0.44 (see Supplementary Figure 6). When each study was removed one at a time, the ES ranged from 0.67 (CI: 0.32 - 1.02) to 0.86 (CI: 0.49 - 1.23) (Supplementary Figure 4 and funnel plot in Supplementary Figure 5).

Horizontal jump

Twelve studies with 13 experimental and 12 control groups, totaling 414 participants, were included in the meta-analysis for SLJ. PJT had a moderate effect on SLJ performance (ES = 0.56, CI = 0.3-0.83, I^2 = 26%, $p < 0.0001$) (Table 3, Supplementary Figure 12). Egger's test indicated publication bias (p = 0.03)(Funnel plot in Supplementary Figure 13), after applying the trim-and-fill method in the meta-analysis, the ES decreased to 0.31. When each study was removed one at a time, the ES ranged from 0.47 (CI: 0.24 - 0.71) to 0.63 (CI: 0.36 - 0.90) (see Supplementary Figure 14). However, after removing two study (Chaouachi et al., 2014; Marta et al., 2022), the heterogeneity decreased significantly, dropping to 10% and 1%, respectively (see Supplementary Figure 15).

Table 1. Training characteristics.

Study	Fre	TD	Typ	Pro	Tap	TCT	MCT	RWS	RS	Dura	RBS	Exp
Llyod et.al 2012a	2/W	25-40	Mix	Yes	No	740	93	N/R	90S	4W	48h	No Ath
Llyod et.al 2012b	2/W	25-40	Mix	Yes	No	740	93	N/R	90S	4W	48h	No Ath
Michailidis et.al 2013	2/W	20-25	Mix	Yes	No	N/R	N/R	N/R	90-180S	12W	72h	Ath
Llyod et.al 2016	2/W	≤60	Mix	Yes	No	479	39	N/R	60-120S	6W	48h	No Ath
Bogdanis et.al 2019	2/W	N/R	Mix	No	No	2960	185	N/R	30S	8W	48h	Ath
Tottori 2019	1/W	60	Double	Yes	Yes	795	99	N/R	N/R	8W	168h	No Ath
Asadi et.al 2018	2/W	30-40	Double	No	No	720	60	7s	120S	6W	N/R	Ath
Sammoud et.al 2019	2/W	25-30	Double	Yes	No	680	55	N/R	90S	6W	72h	Ath
Drouzas et.al 2020a	2/W	15	Double	Yes	Yes	720	45	N/R	N/R	8W	N/A	Ath
Drouzas et.al 2020b	2/W	15	Single	Yes	Yes	360/per leg	23/per leg	N/R	N/R	8W	N/R	Ath
Negra et.al 2020b	2/W	35-40	Mix	Yes	N/R	N/A	N/A	N/R	90s	12W	72h	Ath
Sammoud et.al 2021	2/W	25-30	Mix	Yes	No	720	45	N/R	90s	8W	72h	Ath
Marta et.al 2022	2/W	30	Mix	Yes	No	N/A	N/A	N/A	N/R	8W	48h	No Ath
Sammoud et.al 2024	2/W	N/A	Mix	Yes	No	1286	80	N/A	90s	8W	72h	Ath
Chaouachi et.al 2014	2/W	N/A	Double	Yes	Yes	N/A	N/A	N/A	180s	8W	48h	No Ath
Michailidis, 2015	2/W	N/A	Mix	Yes	No	1120	56	N/A	N/A	8W	N/A	Ath
Negra et.al 2020a	2/W	25-35	Double	Yes	No	1284	80	N/A	90s	8W	72h	Ath
Sammoud et.al 2022	2/W	35-40	Double	Yes	No	N/A	N/A	N/A	90s	12W	72h	Ath
Katsikari et.al 2020	2/W	≤60	Mix	Yes	No	1060	53	N/R	N/R	10W	48h	No Ath

Abbreviation: Exp = Experience; RBS = Recover between session; Dura = Duration; RS = Rest between set; RWS = Rest within set; MCT = Man contact time; TCT = Total contact time; Tap = Taper; Pro = Progressive; Typ = Type; SD = Session duration; Fre = Frequency; N/R = Not report; N/A = Not applicable: Double = Double leg plyometric jump training; Single = Single leg plyometric jump training; Mix = Combined double and single leg Plyometric jump training.

Table 2. Subject characteristics.

Study	Gen	N	Expe	Con	Outcome	Mat	Age	Height	Weight
Michailidis et.al 2013	Male	PJT = 24 Con = 21	PJT	PE	10m, 20m, 30m SJ, CMJ, SLJ	Tan 1	10.9 10.8	147.00 145.00	42.50 41.70
Michailidis, 2015	Male	PJT = 11 Con = 10	PJT+Soc	Soc	10m, 30m, SLJ	Tan1	11.3 11.4	146.00 147.00	42.30 43.20
Llyod et.al 2016	Male	PJT = 10 Con = 10	PJT	PE	10m, 20m, SJ RSI	-1.5 -1.5	12.7 12.8	159.60 157.00	56.00 54.90
Asadi et.al 2018	Male	PJT = 10 Con = 10	PJT+Soc	Soc	CMJ, 20m	-1.8 -1.9	11.5 11.7	138.30 137.40	31.00 33.10
Bogdanis et.al 2019	Female	PJT = 33 Con = 17	PJT+Gym	Gym	CMJ, RSI, SJ 10m, 20m	All = -4.9	8.1 7.9	129.30 129.80	28.70 27.50
Sammoud et.al 2019	Male	PJT = 14 Con = 12	PJT+Swim	Swim	CMJ, SLJ	-3.09 -2.8	10.5 10.7	143.00 146.00	36.20 38.20
Tottori and Fujita 2019	Male	PJT = 9 Con = 11	PJT	Acti	SLJ, CMJ, SJ 10m	-3.5 -3.1	10.9 10.3	142.30 138.60	35.20 38.10
Drouzas et.al 2020	Male	UPJT = 23 BPJT = 23 Con = 22	PJT + Soc	Soc	5m, 10m, 20m CMJ, SJ	-2.9 -3.2 -2.9	9.9 10 10.2	142.20 139.20 141.60	39.30 36.10 38.60
Negra et.al 2020a	Male	PJT = 13 Con = 11	PJT+Soc	Soc	20M	-1.3 -1.8	12.7 12.7	158.6 1520	43.70 39.90
Negra et.al 2020b	Male	PJT = 11 Con = 11	PJT+Soc	Soc	20m SLJ, CMJ, SJ	-1.52 -1.51 Tan1-Tan2	12.8 12.7	156.4 153.2	46.60 43.20
Sammoud et.al 2021	Female	PJT = 12 Con = 10	PJT+Swi	Swim	CMJ SLJ	-1.5 -1.34	10.1 10.5	146.90 143.60	36.39 38.41
Marta et.al 2022	Male/Female	PJT = 41 Con = 39	PJT+PE	PE	CMJ SLJ 20m	Tan1-Tan2	10.8 10.72	145.37 140.00	40.19 37.58
Sammoud et.al 2019	Male	PJT = 11 Con = 11	PJT+Soc	Soc	5m,10m, 20m 30m	-1.5 -1.7	12.7 12.8	156.40 153.20	45.90 42.60
Sammoud et.al 2024	Male	PJT = 13 Con = 14	PJT+Soc	Soc	CMJ, SLJ	-1.6 -2.5	12.7 11.6	155.80 148.10	47.90 39.40
Llyod et.al 2012a	Male	PJT = 20 Con = 21	PJT	pe	RSI	-3.76 -3.86	9.6 9.4	133.20 135.48	32.75 32.64
Llyod et.al 2012b	Male	PJT = 22 Con = 22	PJT	pe	RSI	-1.8 -1.86	12.2 12.3	151.89 151.67	44.78 47.38
Chaouchachi, et.al 2014	Male	PJT = 17 Con = 13	PJT	Acti	CMJ,SLJ, 5m	Tan1-Tan2	11.0 11.0	149.80 150.40	40.10 41.10
Sammoud et.al 2022	Male	PJT = 11 Con = 11	PJT+Soc	Soc	10m,20m, 30m	-1.7 -1.7	12.8 12.7	156.40 153.20	45.90 42.60
Katsikari et.al 2020	Female	PJT = 12 Con = 12	PJT	pe	CMJ,SJ,RSI	Tan1-Tan2	ALL = 10.1	146.00 144.00	38.40 38.80

Abbreviation: Gen=Gender; Expe=Experiment group; Con=Control group; PJT=Plyometric training; Mat=maturation; PE=PE Class; Soc=Soccer; Swim=Swimming; Gym=Gymnastics; Acti=Daily activity or Sports activity; Tan=Tanner score; CMJ=Countermovement jump; SLJ=Stand long jump; RSI=Reactive strength index; 5m, 10m, 20m, 30m=Sprint distance, ALL=all subject. Note; UPJT refers to unilateral plyometric training; BPJT refers to bilateral plyometric training; unless specifically noted, maturity is indicated as maturity offset; height is measured in cm; weight is measured in kg.

Table 3. GRADE grading of recommendations assessment, development and evaluation of the Meta-analysis.

Outcomes	Study design	RoB	Incon	Indirect	Impre	PubBs	Other	N of patients		SMD (95%CI)	Certainty of evidence	Importance
								Exp	Control			
VJ	RTC	Very serious	Serious	Not serious	Not serious	Serious	-	268	206	.77(.41, 1.16)	Very Low	Critical
Sprint-PER	RTC	Very serious	Not serious	Not serious	Not serious	Not serious	-	250	197	-.41(-.61, -.22)	low	Critical
RSI	RTC	Very serious	Not serious	Not serious	serious	Not serious	-	97	82	.13(-.52, .78)	Very Low	Important
SLJ	RTC	Very serious	Not serious	Not serious	Not serious	serious	-	224	190	.58(.30, .83)	Very Low	Critical

RoB: Risk of bias; Incon: Inconsistency; Indirect: Indirectness; Impre: Imprecision; PubB: Publication bias; Exp: Experimental; VJ= Vertical Jump; SPRINT-P= Sprint Performance; RSI=Reactive strength index; SLJ=Stand long jump; CI: Confidence interval, SMD: Standardized mean difference; According to Cohen'd regulations on effect sizes(Brydges, 2019), SMD=0.2 was set as the minimum clinically important difference (MICD), SMD≥0.8 as a large effect size; a: Risk of bias for included studies, more than 1/3 for some concerns or high risk of bias; b: Risk of bias for included studies, more than 1/2 for some concerns or High risk of bias; c: Heterogeneity assessment I2 ≥ 50%; d: Heterogeneity assessment I2 ≥75%; e: Heterogeneity between subjects, measures and interventions; f: MCID included in the 95% CI portion of the effect size; g: 95% CI of the effect size fully incorporates the MCID.

Table 4. **Meta-analysis result.**

Moderator	N	SMD (95%CL)	p	I²	RW	difference
VJ	474	0.78 (0.41 to 1.16)	<0.01	63%	6.1% - 10.1%	
CMJ	395	0.81 (0.34 to 1.29)	< 0.01	71%	58.5%	P = 0.35
SJ	289	0.57 (0.23 to 0.92)	< 0.01	24%	41.5%	
SLJ	414	0.56 (0.30 to 0.83)	<0.001	26%	5.7% - 14.8%	
RSI	179	0.13 (-0.52 to 0.78)	0.61	52%	15.2% - 23.3%	
Speed-P	424	-0.41 (-0.61 to -0.22)	< 0.01	0	4.4% - 19.6%	
10m<	375	-0.39 (-0.6 to -0.18)	< 0.01	31%	56.1%	P = 0.31
≤10m	298	-0.56 (-0.79 to -0.32)	< 0.05	0%	43.9%	

VJ= Vertical Jump; CMJ=Countermovement Jump; SJ=Stand Jump; SLJ=Stand Long Jump; RSI=Reactive Strength Index; SPEED-P= Speed Performance.

Figure 2. **Risk of bias-2 (RoB-2) assessments.**

Reactive strength index

Four studies evaluated RSI, including five experimental groups and four control groups, with a total of 175 participants. PJT did not have a significant effect on RSI (ES = 0.13, CI = -0.52 - 0.78, I² = 52%, p = 0.61) (Table 5, see Supplementary Figure 11)). When each study was removed one at a time, the ES ranged from 0.67 (CI: 0.32 - 1.02) to 0.86 (CI: 0.49 - 1.23). However, after removing two studies, the heterogeneity decreased significantly, dropping to 15.2% and 26.9%, respectively (see Supplementary Figure 16). Bubble plot of the total session in SLJ was given in Figure 3.

Sprint performance

Thirteen studies, including 14 experimental groups and 13 control groups with 414 participants, assessed sprint performance. PJT had a moderate effect on sprint performance (ES = -0.41, CI = -0.61 to -0.22, I² = 0%, p <

0.01, Supplementary Figure 7). When analyzed by distance, both ≤10m and >10m sprints had moderate and small effect sizes (ES = -0.56 and -0.39, respectively), with no significant difference between the two (P = 0.3) (see Table 3, Supplementary Figure 8). Egger's test did not indicate publication bias (p = 0.995) (Funnel plot in Supplementary Figure 9). When each study was removed one at a time, the ES ranged from -0.37 (CI: -0.57 - -0.17) to -0.47 (CI: -0.63 - -0.31) (see Supplementary Figure 10).

Table 5. Subgroup analyses for vertical jump.

All	All	n	SMD	I²	RW	p
Training type	Double leg	152	1.18 (-0.52; 2.87)	13%	24.7%	P = 0.43
	Single leg	34	0.35 (-0.37; 1.08)	N/A	7.6%	
	Mix	338	0.72 (0.31 - 1.13)	67%	67.7%	
Load type	Progressive	404	0.73 (0.41; 1.04)	52%	87.2%	P = 0.55
	Not progressive	70	1.51 (-14.98 – 18)	92%	12.8%	
Deload	Taper	88	0.37 (0.30; 0.43)	0	21.5%	P = 0.01
	Not taper	386	0.91 (0.44; 1.38)	70%	78.5%	
Exp	Athlete	330	0.92 (0.42; 1.42)	62%	70.8%	P = 0.12
	Not athlete	144	0.43 (-0.29; 1.16)	42%	29.2%	
Gender	Male	298	0.90 (0.42; 1.38)	56%	78.5%	P = 0.01
	Female	96	0.74 (-0.51; 1.98)	42%	21.5%	
	Both	80	0.00 (-0.43; 0.43)	N/A	10.1%	

SMD=standard mean difference; RW= relative weight; Exp=experience.

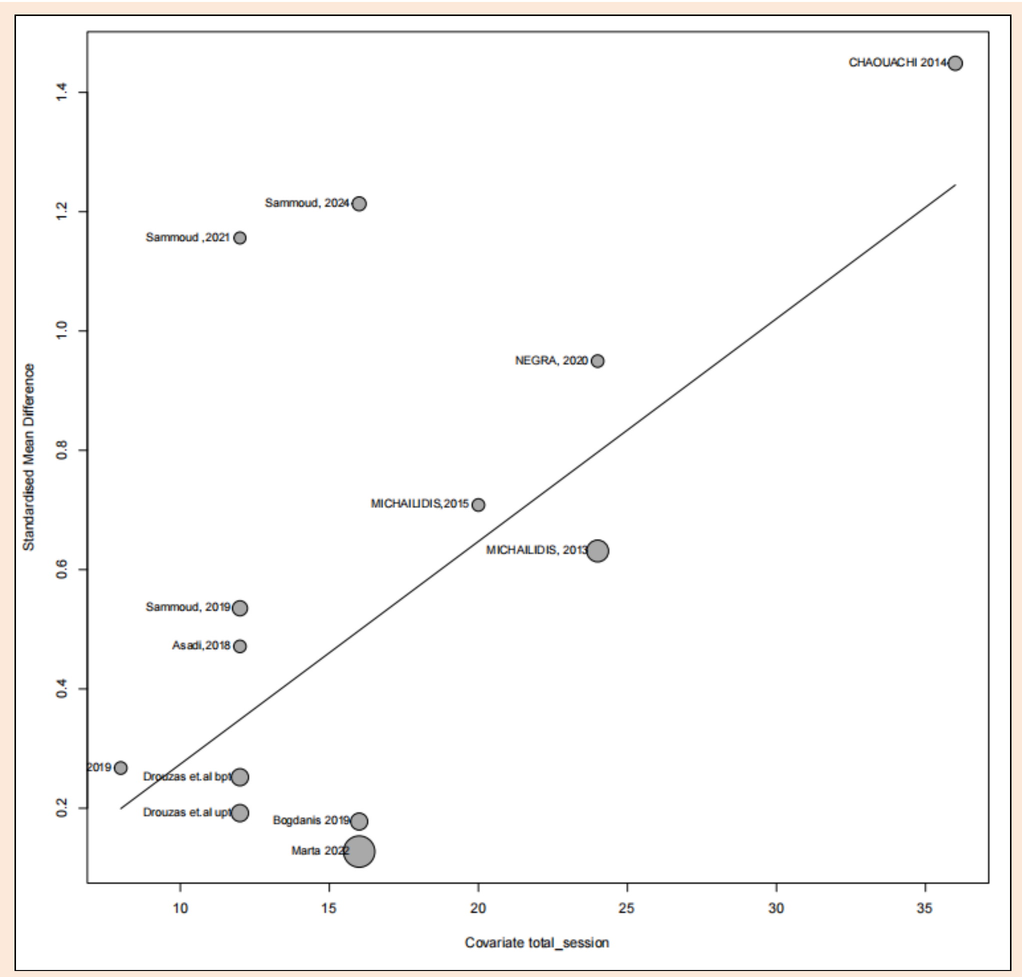

Figure 3. Bubble plot of the total session in SLJ. The bubble chart shows a positive correlation (β = 0.04, p = 0.03) between the effectiveness of SLJ training and the number of training sessions.

Subgroup analysis and meta-regression

The subgroup analysis revealed that the effects of not using a tapering strategy were superior to those of using a tapering strategy (No taper: ES = 0.91, Taper: ES = 0.37, P = 0.01). Furthermore, males showed better improvement than females and mixed groups (see Table 5 and Table 6). Meta-regression indicated a positive correlation between the total number of training sessions and the effectiveness of PJT on standing long jump (SLJ) performance (P = 0.03) (see Figure 3), while other variables did not significantly predict PJT effectiveness (P > 0.05).

Table 6. Subgroup analysis of sprint.

All	All	n	SMD	I²	RW	p
Training type	Double leg	152	-0.33 (-0.66; 0)	13%	34%	P = 0.81
	Single leg	34	-0.51 (-1.24; 0.22)	N/A	6.9%	
	Mix	261	-0.45 (-0.7; -0.42)	0	59.1%	
Load type	Progressive	377	-0.38 (-0.59; -0.17)	0	85.2%	P = 0.51
	Not progressive	70	-0.59 (-0.44; 3.23)	24%	14.8%	
Deload	Taper	118	-0.37 (-0.66; -0.09)	0	25.6%	P = 0.71
	Not taper	328	-0.43 (-0.71; -0.15)	14%	74.4%	
Exp	Athlete	294	-0.49 (-0.77; -0.21)	1%	63.9%	P = 0.15
	Not athlete	153	-0.27 (-0.55; -0.01)	0%	36.1%	
Gender	Male	314	-0.38 (-0.61; -0.15)	0%	70.4%	P = 0.39
	Female	50	-0.82 (-1.42; -0.21)	N/A	10%	
	Both	83	-0.33 (-0.76; -0.1)	N/A	19.6%	

SMD=standard mean difference; RW= relative weight; Exp=experience.

Discussion

This systematic review and meta-analysis aimed to investigate the effects of PJT on children's jump and sprint performance, comparing the results with control groups. The findings indicated that PJT can moderately improve children's jump and sprint performance. In subgroup analyses of VJ, the ES for CMJ was larger than for SJ (0.81 vs. 0.57), though the difference was not statistically significant (P = 0.35). Similarly, when analyzing sprint distances, both ≤10m and >10m showed moderate effect sizes (ES = -0.56 and -0.39, respectively), with no significant difference between them (P = 0.3). Subgroup analyses also showed that gender (males > females > mixed groups) and taper strategy (no taper > taper), influenced the effectiveness of vertical jump training. Meta-regression indicated that the total number of training sessions was positively correlated with SLJ performance improvements (P = 0.03). Except for sprint, which showed low heterogeneity ($I^2 = 0$), VJ, SLJ, and RSI exhibited moderate heterogeneity (I^2 = 26% - 63%). Egger's test was used to assess publication bias, and when $p < 0.05$, the trim-and-fill method was applied to sensitivity analysis. The results revealed publication bias in both VJ and SLJ, with the ES decreasing to 0.44 and 0.31, respectively, after applying the trim-and-fill method. Furthermore, a leave-one-out analysis was performed, revealing that excluding individual studies did not affect the overall ES. However, heterogeneity was significantly reduced after excluding specific studies (Chaouachi et al., 2014; Katsikari et al., 2020; Lloyd et al., 2012; Marta et al., 2022), suggesting that these studies contributed substantially to the overall heterogeneity. This reduction in heterogeneity may be attributed to differences in factors such as study design, sample characteristics, or intervention protocols. These findings underscore the importance of adopting more consistent methodologies in future research to minimize heterogeneity and enhance the comparability of results.

Our study indicates that PJT has a moderate effect on VJ performance (ES = 0.78), which aligns with previous studies(Chen et al., 2023b; Kons et al., 2023; Lehnert et al., 2009; Mroczek et al., 2019; Ramirez-Campillo et al., 2023a; Ramírez-de la Cruz et al., 2022; Saez de Villarreal et al., 2009).VJ performance is one of the variables most positively influenced by PJT (Kons et al., 2023), effectively reflecting lower limb neuromuscular function. The studies included in our meta-analysis were conducted on prepubescent children, and the physiological improvements observed can be attributed to enhancements in neuromuscular function, such as increased motor unit recruitment, better intra- and inter-muscular coordination, and improved storage and utilization of elastic potential energy (Markovic and Mikulic, 2010). A study at the muscle fiber level demonstrated that after 8 weeks of PJT, muscle fiber force, diameter, and calcium sensitivity were significantly enhanced. These findings suggest that PJT not only facilitates neural adaptations but also induces favorable physiological changes at the muscle fiber level, thereby contributing to improved athletic performance (Malisoux et al., 2006). Egger's test revealed the presence of publication bias, and after applying the trim-and-fill method, the ES decreased to 0.44, indicating the need for further research to confirm these findings.

When analyzing the subgroup based on jump types, we found that the ES for PJT on CMJ was greater than on SJ (0.81 vs. 0.57), although this difference was not statistically significant. Previous studies have suggested that PJT has a more significant effect on CMJ compared to SJ (Stojanović et al., 2017), This can be explained by the specificity of training -both PJT and CMJ involve the stretch-shortening cycle (SSC), making them more biomechanically similar. In contrast, SJ without eccentric phase, which might limit training gains. Additionally, SJ is not a natural movement, and some studies have observed unintended reversal actions during SJ, which require considerable practice to overcome (Van Hooren and Zolotarjova, 2017).We suspect that many studies included in our analysis may not have adequately eliminated SSC effects, potentially interfering with SJ mechanics after PJT, One study (Cormie et al., 2009) reported that an increase in countermovement depth after training led to higher jump heights, possibly resulting in a subconscious increase in countermovement depth during SJ testing., Given the correlation between reversal depth and jump height (Pérez-Castilla et al., 2021), this might have compromised the validity of the test. Unfortunately, the included studies did not report kinematic indicators during testing, which could have provided more insight into the mechanisms of PJT adaptation. Future research should focus on investigating changes in kinematics and dynamics.

Compared to the control groups, the PJT group showed a significant, moderate improvement in SLJ performance (ES = 0.56), consistent with previous research (Chaabene and Negra, 2017; Chen et al., 2023b).Most of the studies we included did not specifically target horizontal force vectors in PJT exercises, suggesting that vertical vector PJT exercises can also improve horizontal jump performance in children (Gonzalo-Skok et al., 2019). A correlation between vertical and horizontal force-velocity profiles was found in low-level athletes but not in high-level athletes (Jiménez-Reyes et al., 2018). Combining horizontal and vertical PJT exercises may improve outcomes (Ramírez-Campillo et al., 2015a). To enhance SLJ performance, incorporating more horizontal or combined exercises may be beneficial.

The RSI is an indicator used to assess an athlete's ability to generate force quickly, typically calculated as jump height divided by ground contact time, which effectively reflects lower limb neuromuscular function (Flanagan and Comyns, 2008).Our meta-analysis found that PJT did not improve RSI in children (P = 0.61), whereas earlier research showed that PJT could effectively improve RSI (Ramirez-Campillo et al., 2023b). However, this study did not sufficiently consider the characteristics specific to the pediatric population, which could explain the differences in results. Lloyd et al., (2012) found that significant RSI improvements were observed only in the 12-year-old PJT group, while no significant differences were noted in the 9- and 15-year-old groups. Although both the 9- and 12-year-old groups were prepubescent, this discrepancy suggests that RSI might have a developmental sensitive period, although this has not been definitively established. Considering that 9-year-old children have more compliant Achilles tendons (Kubo et al., 2001), weaker motor unit recruitment abilities (Belanger and McComas, 1989), poorer intermuscular coordination (Frost et al., 1997; Lazaridis et al., 2010), and larger Golgi tendon organs (Ovalle, 1987), these differences in potential influencing factors could account for the varying adaptation capacities. Both maturity level and the specificity of the sport could impact the adaptability to training (Dallas et al., 2020; Davies et al., 2021; Laffaye et al., 2016). Similarly, a study did not show improvements in RSI (César and Davide, 2009). Given the limited research focusing on this population, future studies should prioritize investigating RSI in children.

Consistent with previous research (Sáez de Villarreal et al., 2012), our meta-analysis found that PJT has a moderate effect on sprint performance (ES = -0.41). When we conducted a subgroup analysis based on sprint distance, both the ≤10m group and the >10m group showed moderate and small effect sizes (ES = -0.56 and -0.39, respectively), with no significant difference between the two (P = 0.3). The effect sizes found in our study are smaller than those reported in earlier research (Ramirez-Campillo et al., 2022), which could be attributed to differences in the age of participants. The ≤10m sprint distance is considered a measure of initial acceleration, (Delecluse et al., 1995; Kotzamanidis, 2006; Michailidis et al., 2013), which effectively reflects an individual's ability to accelerate, while distances greater than 10m reflect the transition from acceleration to maximum velocity. Contrary to the findings of the present study, some research has indicated that PJT may not lead to improvements in 10m sprint performance (Karagianni et al., 2020; Kotzamanidis, 2006; Michailidis et al., 2019; Söhnlein et al., 2014; Thomas et al., 2009), . These inconsistencies might result from differences in the PJT interventions used. Shorter sprints (≤10 m) rely heavily on horizontal force production, while sprints over 10m increasingly depend on vertical force (Morin et al., 2012; Ramírez-Campillo et al., 2015a; Ramirez-Campillo et al., 2022). It is crucial to maintain a proper balance between horizontal and vertical force for sustaining maximum speed (Morin et al., 2012). Few studies have examined the force vector direction in PJT, which may contribute to the conflicting findings. There is a high correlation between horizontal and vertical force-velocity profiles for low level population (Jiménez-Reyes et al., 2018), meaning that vertical PJT may improve acceleration. However, as the sprint distance increases, the proportion of horizontal force may decrease, potentially reducing sprint performance. Therefore, horizontal PJT may be particularly important for sprint performance (Jiménez-Reyes et al., 2018; Morin et al., 2012; Morin, 2013; Ramírez-Campillo et al., 2015a; Sáez de Villarreal et al., 2012). As is well known, speed is the product of stride length and stride frequency. However, compared to adults, improvements in children's speed capacity may be more driven by stride length , it is contrast with adults (Rimmer and Sleivert, 2000). In younger children, sprinting ability tends to rely more on step frequency (Meyers et al., 2015; Tottori and Fujita, 2019), and as they grow, stride length significantly contributes to speed increases, although step frequency might slightly decrease as ground contact time increases. PJT can help maintain step frequency while increasing stride length, potentially enhancing sprint performance in children (Tottori and Fujita, 2019).

Subgroup analysis showed the difference in results between genders; however, this should be interpreted with caution, as there was only one study each for females and mixed groups. Prior studies have examined no significant difference in PJT adaptation between males and females (Ramírez-Campillo et al., 2016; Skurvydas and Brazaitis, 2010). Since gender differences have not yet emerged in boys and girls at the prepubescent stage, these differences might be smaller, and more research is needed to explore gender differences in this population.

Regarding tapering strategies, we found that the results were worse when tapering was used compared to not tapering, which contrasts with previous research (Ramirez-Campillo et al., 2021). This result should be cautiously interpreted, as only three studies used tapering strategies, and differences in sample sizes might have influenced the ES. Tapering has been shown to effectively improve performance in elite athletes by allowing recovery and performance enhancement after several weeks of high-intensity or high-volume training, which might place athletes in a state of non-functional overreaching (Aubry et al., 2014). The training intensity and volume in the included studies might not have been sufficient to cause non-functional overreaching in children, so tapering might have reduced the training adaptations. However, given concerns about overuse in children and their sensitivity to detraining, we recommend tapering strategies in long-term training. Discussing the application of tapering strategies is beyond the scope of this paper, but previous studies suggest that maintaining or reducing intensity, lowering small to moderate loads, and keeping training frequency consistent for 1-2 weeks might be effective (Bosquet et al., 2007; Ramirez-Campillo et al., 2021; Travis et al., 2020). Our study did not find that progressive overload influenced training outcomes, which might be due to differences in PJT protocols across studies. Progressive overload is a crucial principle in resistance training (Zatsiorsky et al., 2020), as maintaining the same load is insufficient to provide new stimuli due to individual adaptations. This strategy aims to continually stimulate new adaptations, using this strategy might be more effective (Ramírez-Campillo et al., 2015b). PJT can place considerable force, and during drop jump (DJ), children might experience landing forces of 4 times body weight (Pedley et al., 2022). Sudden increases in training load could lead to injury, so children should gradually increase PJT intensity and volume, and should have a solid foundation of muscle strength before starting PJT, as recommended in the studies by Lloyd (Lloyd et al., 2011) and Turner (Turner and Jeffreys, 2010).

Among training variables, we found that the total number of training sessions was correlated with SLJ performance, consistent with previous research (Ramirez-Campillo et al., 2022; Ramirez-Campillo et al., 2023b; Saez de Villarreal et al., 2009; Sáez de Villarreal et al., 2012), Unfortunately, the small number of studies included in our analysis prevented us from further analyzing training volume (i.e., ground contacts). Chen et al., (2023a) found that low-volume ground contacts were more effective for CMJ, while high-volume ground contacts were more effective for SJ. Asadi et al., (2017) suggested that PJT training twice a week, with 1, 400 jumps over 7 weeks, at a moderate intensity might be an appropriate dose for COD. For sprint performance, high-intensity training (more than 80 jumps per session) for 10 weeks (more than 18 sessions) might maximize the likelihood of significant performance improvement (Saez de Villarreal et al., 2009). Another study suggested that training for more than 10 weeks with more than 20 sessions and using a high-intensity protocol (more than 50 jumps per session) seemed to offer the greatest likelihood of substantial performance gains. There may be a training threshold, beyond which additional training does not lead to further gains (Aztarain-Cardiel et al., 2024; Bouguezzi et al., 2020; Chaabene and Negra, 2017; Ramírez-Campillo et al., 2014). Training effects result from the combination of various variables, leading to differences between studies. Therefore, it is essential to consider factors such as the trainee's experience, strength level, gender, age, training intensity, and training volume in combination when designing PJT programs (Ramirez-Campillo et al., 2020).

Children and adolescents are two distinct groups, though previous studies have often treated them as a homogeneous population (Chen et al., 2023a; Chen et al., 2023b). Children typically exhibit underdeveloped neuromuscular function and weaker SSC capacity (Pedley et al., 2022). Post-pubertal individuals demonstrate superior performance in CMJ, SLJ, and sprinting compared to prepubescent children. The deficits in SSC capacity in children may be attributed to smaller muscle cross-sectional areas, lower tendon stiffness, heightened sensitivity of Golgi tendon organs, and poorer recruitment of type II muscle fibers (Radnor et al., 2018). These differences in performance before and after puberty highlight the critical role of maturation. During puberty, increases in circulating testosterone, desensitization of the Golgi tendon organs, and improvements in pre-activation capacity enhance SSC function, leading to better athletic performance (Tumkur Anil Kumar et al., 2021). Future studies should carefully distinguish between these two populations, as maturity may lead to biased outcomes (Asadi et al., 2017; Lloyd et al., 2016b). There appears to be some controversy regarding adaptations across different maturity levels (Asadi et al., 2017; Lloyd et al., 2012; Lloyd et al., 2016b). The discrepancies in the literature may results from differences in training protocols. Two studies employed training designs with low intensity and high volume respectively (Asadi et al., 2018; Lloyd et al., 2016b), as well as high intensity and low volume, respectively. This appears to suggest that more physically mature children may be more sensitive to high-intensity training, warranting further investigation into this topic. DJ involve very high impact forces, and children with lower strength may not be able to effectively utilize such high eccentric loads, resulting in sharp impact peaks and longer ground contact times, which increase the discrepancy between landing and take-off peak forces (Pedley et al., 2022). Therefore, DJ may be unsuitable for individuals with underdeveloped SSC capacity. More mature individuals, with better neuromuscular function, require higher training intensity compared to less mature individuals maybe more sensitive to DJ. Coaches should carefully consider the balance between training intensity and volume when designing programs.

None of the included studies reported landing strategies during PJT, and different landing strategies might lead to different adaptations (Laurent et al., 2020).We refer to jumps with longer contact times as CMJ-style jumps, while those with shorter contact times are termed bound-style jumps (Marshall and Moran, 2013). Walsh et al. (2004) suggest that improvements in post-test VJ performance, without considering jumping technique, do not necessarily indicate a true enhancement in the subject's jumping ability. It appears that subjects unknowingly altered their contact times, and this change resulted in different jump outcomes. CMJ-style landing strategies might better improve jump height, while bound-style landing strategies might better improve lower limb stiffness. (Laurent et al., 2020; Marshall and Moran, 2013), it is essential to consider the principle of sport specificity when planning training. Children, due to their weaker muscle strength and more compliant tendons, tend to use CMJ-style landing strategies (Lazaridis et al., 2010). Given the limited research in this area, future studies should focus more on landing strategies in children.

Based on the training characteristics of the included studies, we recommend PJT twice per week for a duration of more than 12 weeks, with 55 ground contacts per session and a total of 720 ground contacts. There should be a rest interval of 48 - 72 hours between sessions. Depending on the child's training experience and an assessment of their SSC capacity, exercises of low-to-moderate or low-to-high intensity should be employed, incorporating both horizontal and vertical exercises. This approach has been shown to effectively improve VJ and SLJ performance. For sprint performance, we recommend training twice per week for 12 weeks, with 58 ground contacts per session and a rest interval of 48 - 72 hours between sessions. The intensity should be adjusted according to the individual's ability, and a combination of horizontal and vertical exercises is suggested to effectively enhance sprinting performance.

Limitations

Some potential limitations are discussed. First, the number of included studies is limited (n = 17), with only 5 groups used for the RSI analysis, which greatly restricts the accuracy of the research. Most of the excluded studies were omitted due to the lack of maturity reporting. Future research on children and adolescents should focus on maturity, as it may potentially influence training adaptations. Second, we did not quantify training intensity, which might introduce bias into our findings. Although there are recommendations for PJT intensity in adults, we believe these are not suitable for children, as children are not merely smaller versions of adults, and adult standards are not necessarily applicable to them. Third, we used the Tanner scale and maturity offset as criteria for study inclusion, but these two methods are not identical. Although we applied stricter inclusion criteria to ensure that the included studies were conducted on an immature population, we must acknowledge that this approach introduces some bias. Studies on children should report maturity levels, preferably using bone age assessment as the gold standard, to draw more scientifically sound conclusions. Fourth, many of the studies included in our analysis did not provide detailed reports on intervention specifics, such as ground contacts, rest intervals during non-cyclic actions, and landing strategies, preventing us from conducting more.

Additionally, the use of different measurement devices may also contribute to the heterogeneity among studies. We recommend using force plates in jump-related experiments to obtain more comprehensive kinematic and kinetic data. In sprint tests, it is advisable to use high-reliability equipment, such as photocell timing gates and radar guns.

Only two studies focused on girls, so we cannot be certain whether the current conclusions can be applied to them. Gender differences are an important factor, even though the differences between boys and girls before puberty seem minimal. Future research should include more studies specifically targeting girls. We also found that most of the studies were conducted on child athletes with relatively small sample sizes. Athletes and normal children are certainly not comparable, which raises doubts about whether the findings of this study are applicable to the general child population. Future research should more carefully distinguish between different groups and sports disciplines.

The GRADE level of the study is "very low" to "low, " indicating that more research is needed in the future to explore this topic further and to enhance the quality of evidence, ultimately leading to more conclusive findings.

Conclusion

Plyometric jump training can effectively improve children's performance in various types of jumps (CMJ, SJ, SLJ) and sprints (≤10m and >10m). Subgroup analyses revealed that training experience, gender, and the use of taper strategies can influence the effectiveness of the training. Meta-regression results indicated a positive correlation between the total number of training sessions and training outcomes.

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Key points

- Plyometric training can improve children's jumping ability and sprinting ability.
- The number of training sessions has a certain correlation with the effectiveness of enhanced training in improving standing long jump performance.
- We recommend that coaches select appropriate intensities based on the actual conditions of the children, carefully consider high-intensity exercises, and adopt a gradual approach, implementing suitable methods at the appropriate times.

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Supplementary Materials

SPORTDisscus: S1 TI (“plyometric" or "plyometrics" or "plyometric training" or "plyometric exercise" or "jump training" or "countermovement jump" or "cmj" or "jump squat" or "drop jump" or "depth jump”) OR AB (“plyometric" or "plyometrics" or "plyometric training" or "plyometric exercise" or "jump training" or "countermovement jump" or "cmj" or "jump squat" or "drop jump" or "depth jump”)

S2 TI (“child" or "children" or "youth" or "youths" or "kid" or "kids" or "preadolescence" or "preadolescent" or "prepuberty" or "prepubertal”) OR AB (“child" or "children" or "youth" or "youths" or "kid" or "kids" or "preadolescence" or "preadolescent" or "prepuberty" or "prepubertal”)

S1 AND S2

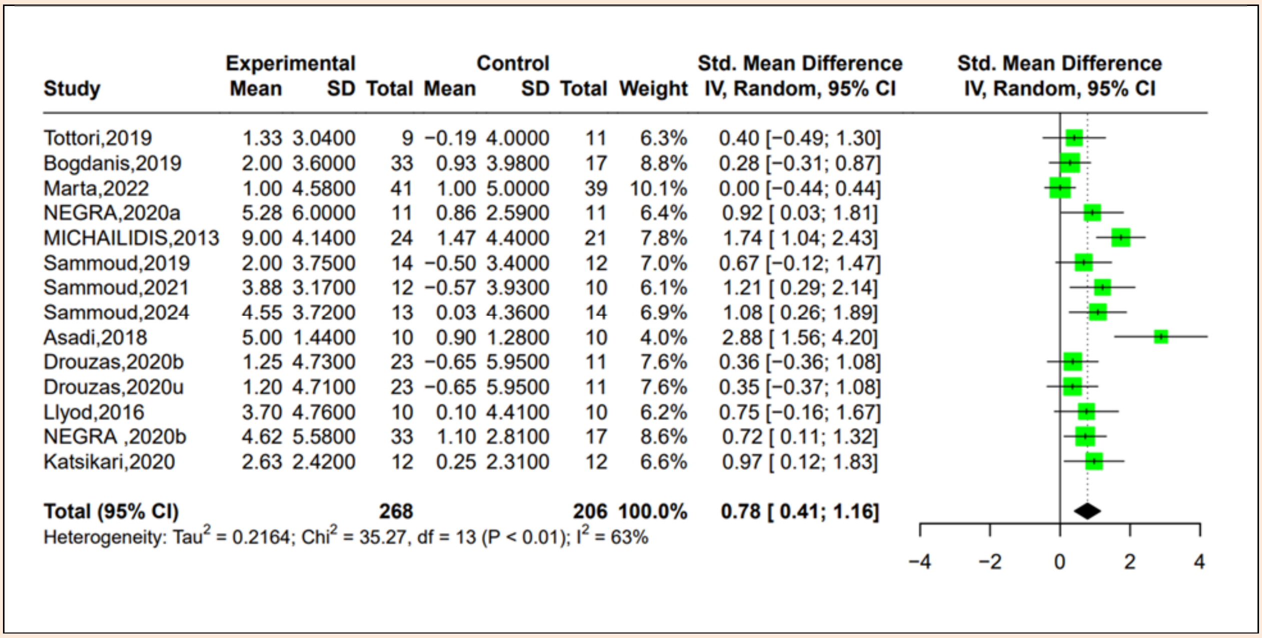
Web of Science: (TS= ("child" or "children" or "youth" or "youths" or "kid" or "kids" or "preadolescence" or "preadolescent" or "prepuberty" or "prepubertal")) AND TS= (“plyometric" or "plyometrics" or "plyometric training" or "plyometric exercise" or "jump training" or "countermovement jump" or "cmj" or "jump squat" or "drop jump" or "depth jump")

PubMed: #1"plyometric"[Title/Abstract] OR "plyometrics"[Title/Abstract] OR "plyometric training"[Title/Abstract] OR "plyometric exercise"[Title/Abstract] OR "jump training"[Title/Abstract] OR "countermovement jump"[Title/Abstract] OR "cmj"[Title/Abstract] OR "jump squat"[Title/Abstract] OR "drop jump"[Title/Abstract] OR "depth jump"[Title/Abstract]

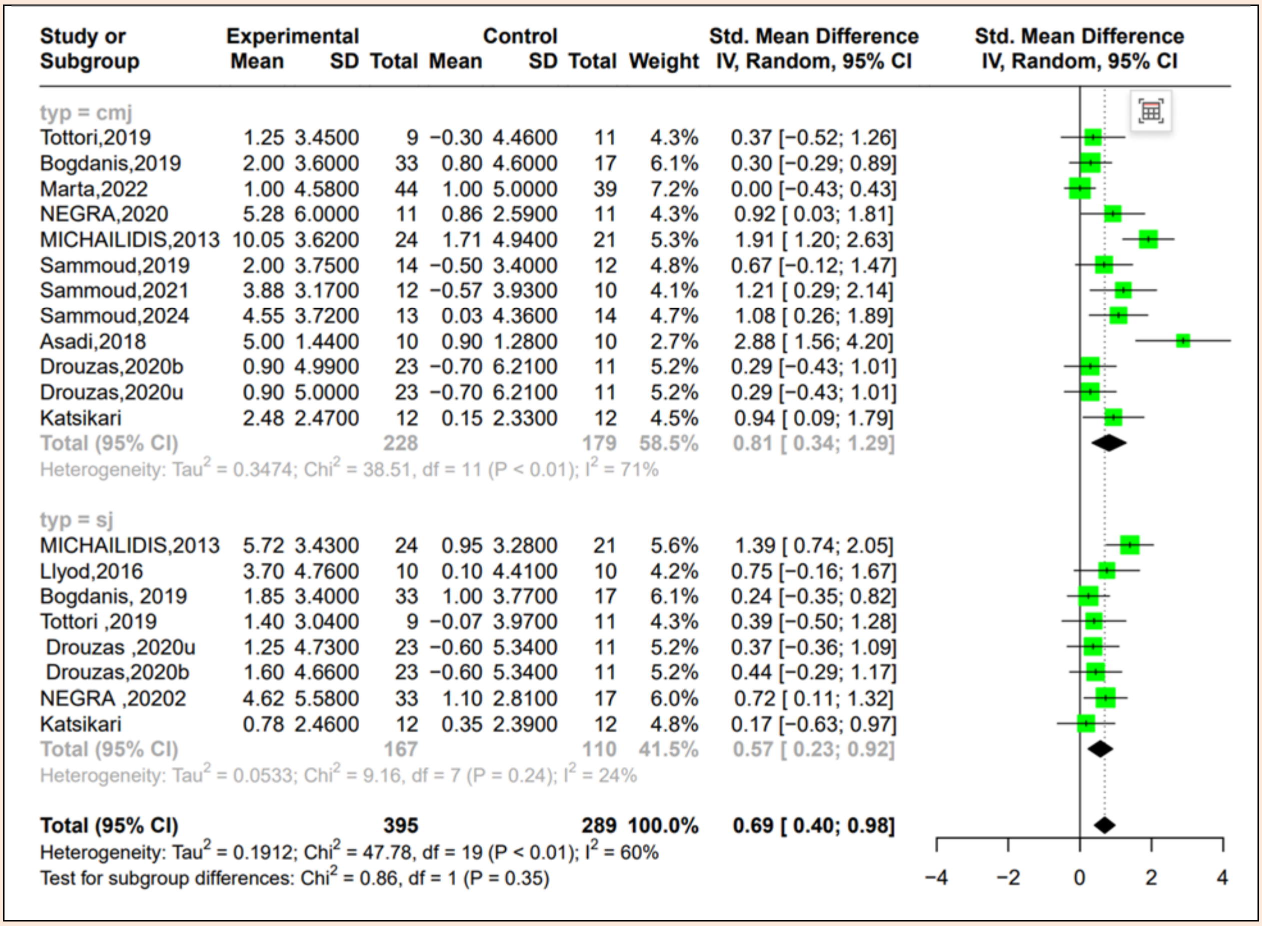
#2"child"[Title/Abstract] OR "children"[Title/Abstract] OR "youth"[Title/Abstract] OR "youths"[Title/Abstract] OR "kid"[Title/Abstract] OR "kids"[Title/Abstract] OR "preadolescence"[Title/Abstract] OR "preadolescent"[Title/Abstract] OR "prepuberty"[Title/Abstract] OR "prepubertal"[Title/Abstract]

#1AND#2

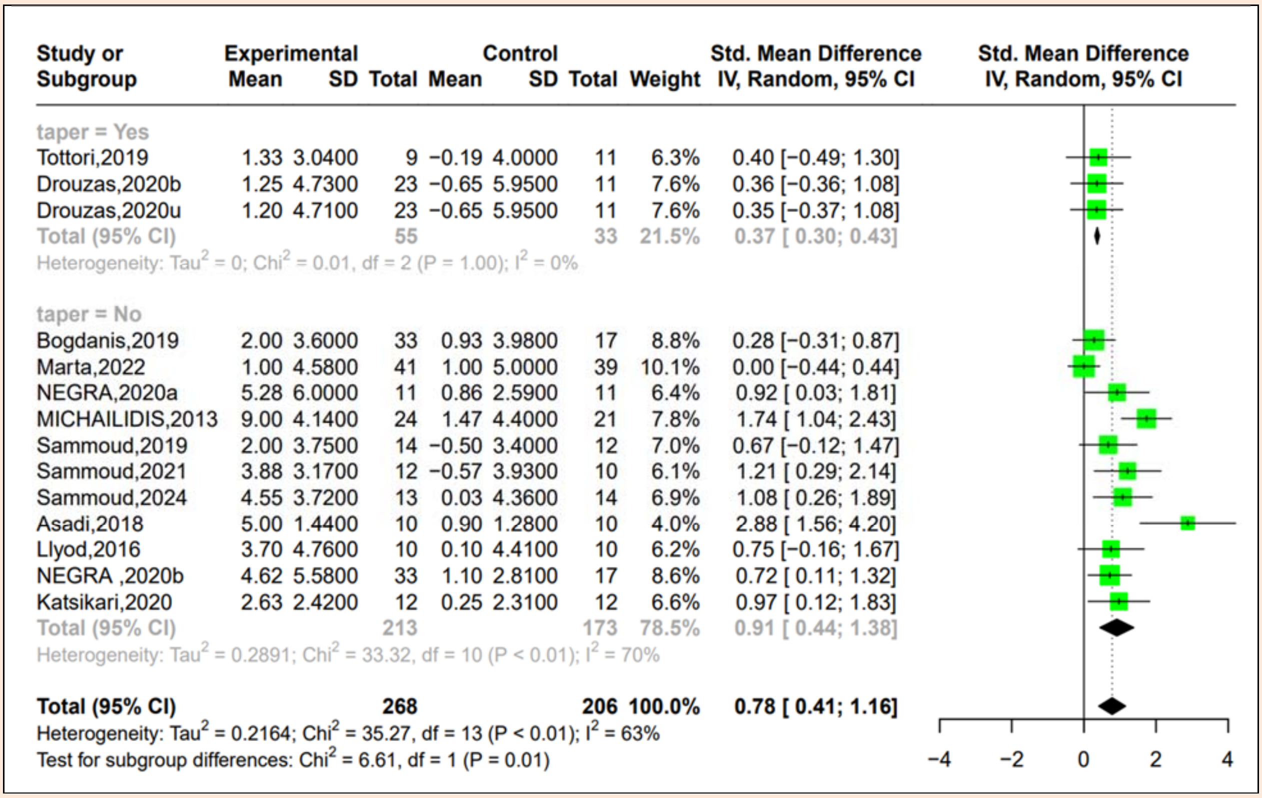
Appendix A. The detailed search process.



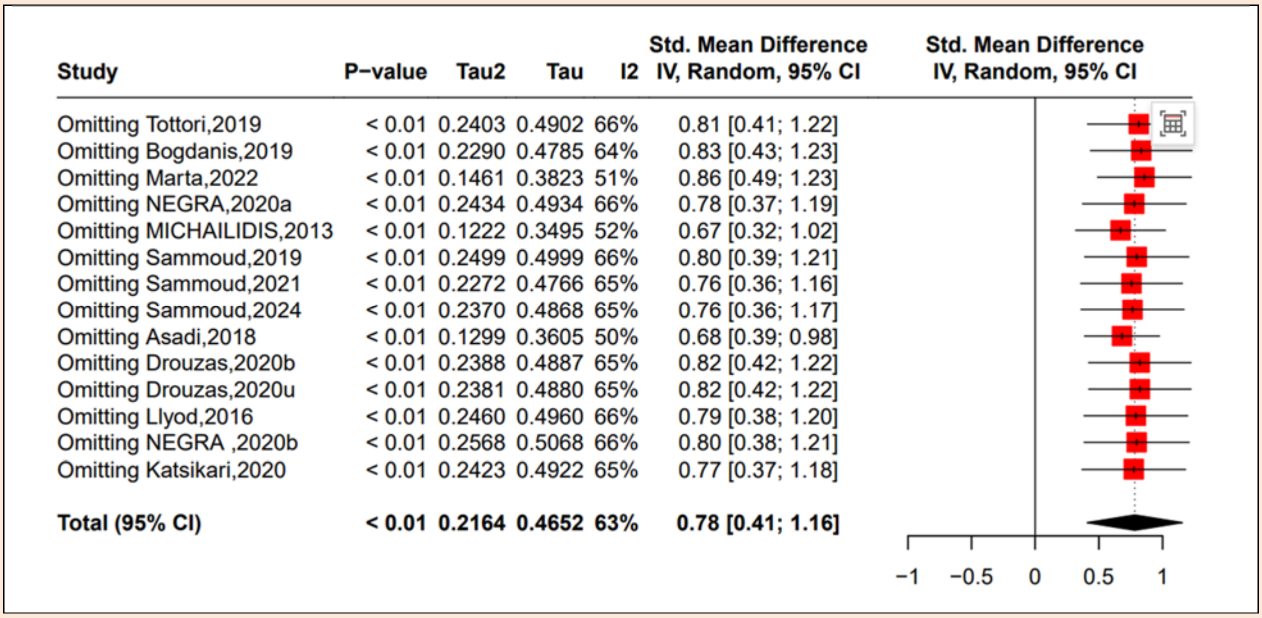
Supplementary Figure 1. Forest plot of vertical jump.



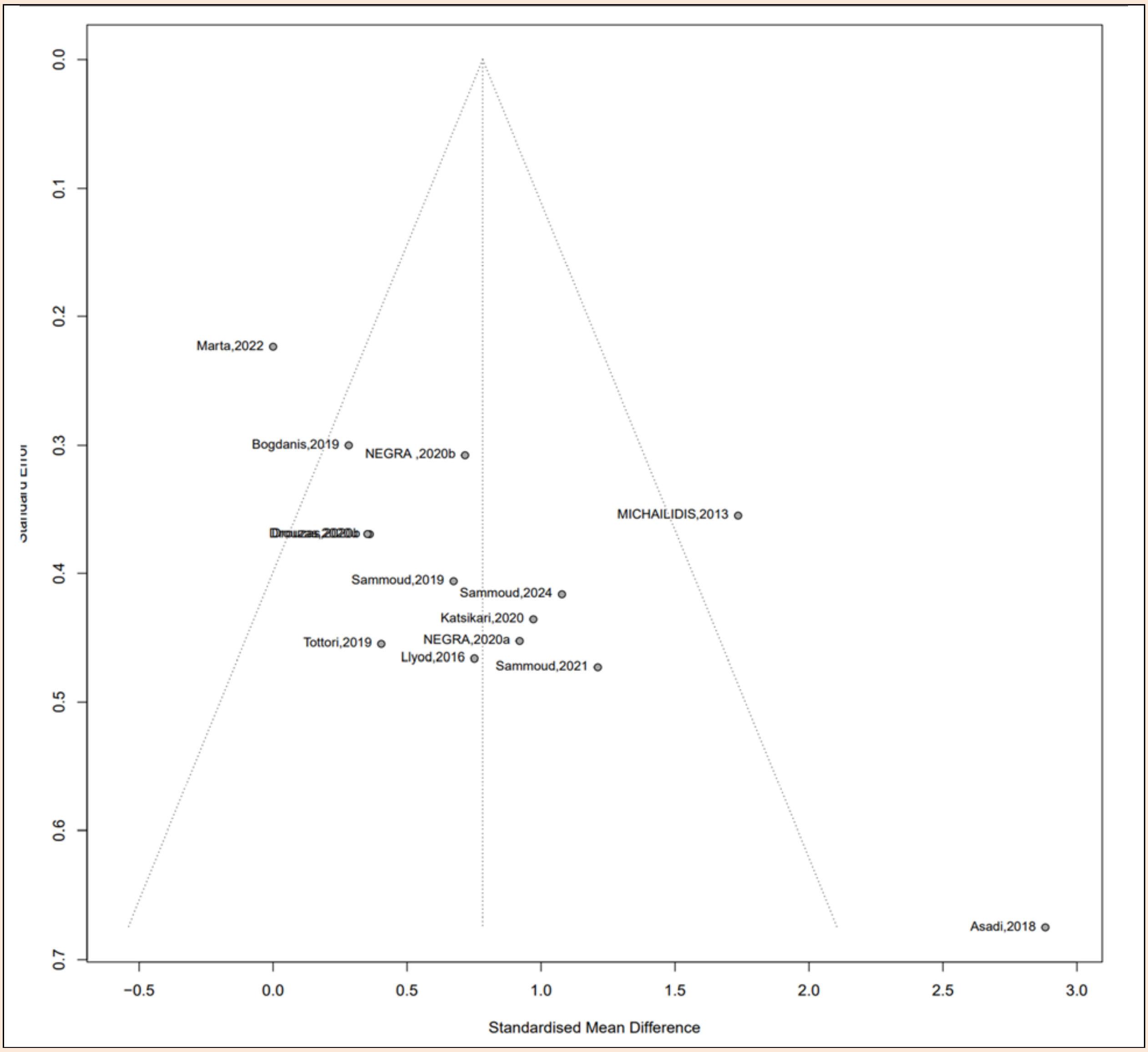
Supplementary Figure 2. **Subgroup analysis of vertical jump (CMJ vs SJ), CMJ have higher ES.**



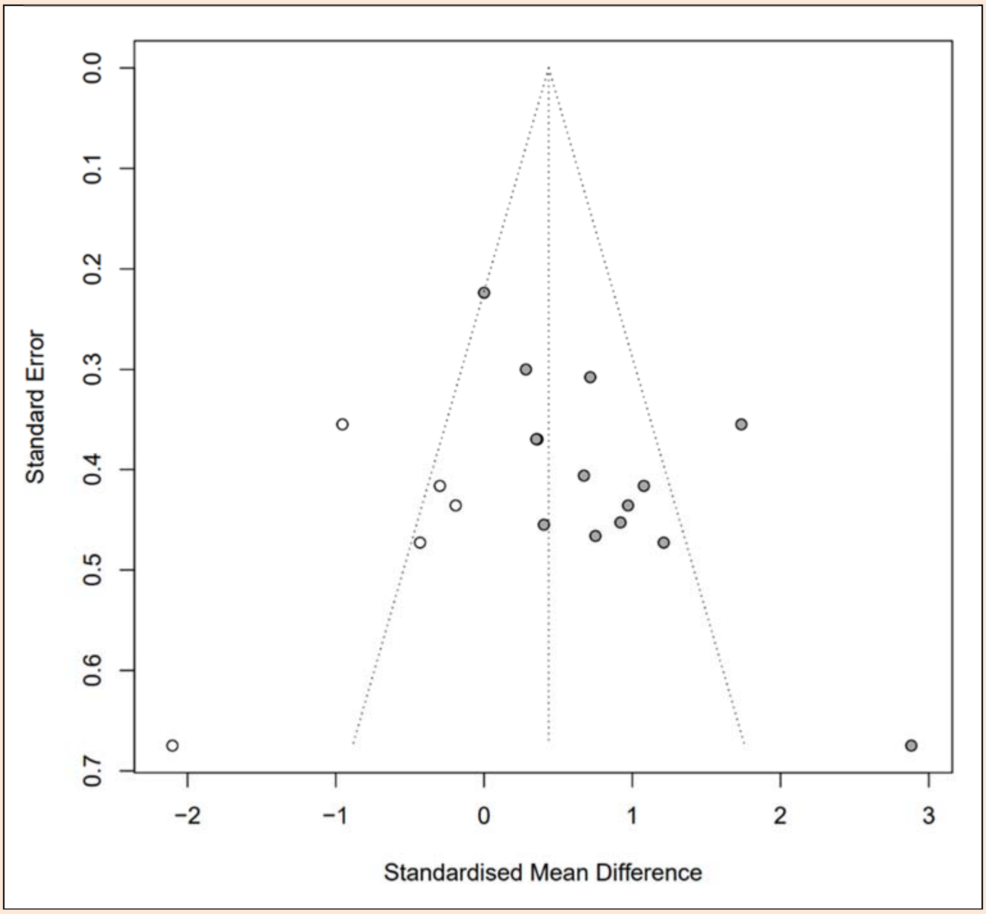
Supplementary Figure 3. **Subgroup analysis of vertical jump Taper vs no Taper. This suggests that not using a taper can achieve better results.**



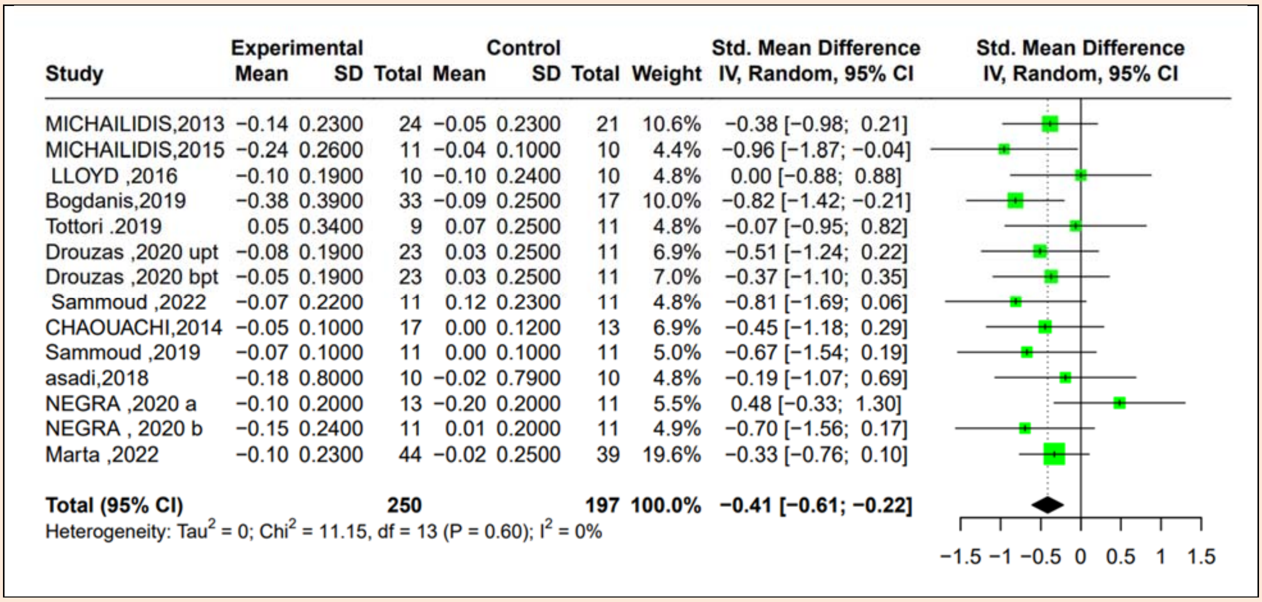
Supplementary Figure 4. **Sensitivity analysis of vertical jump.**



Supplementary Figure 5. **Funnel plot of vertical jump.**



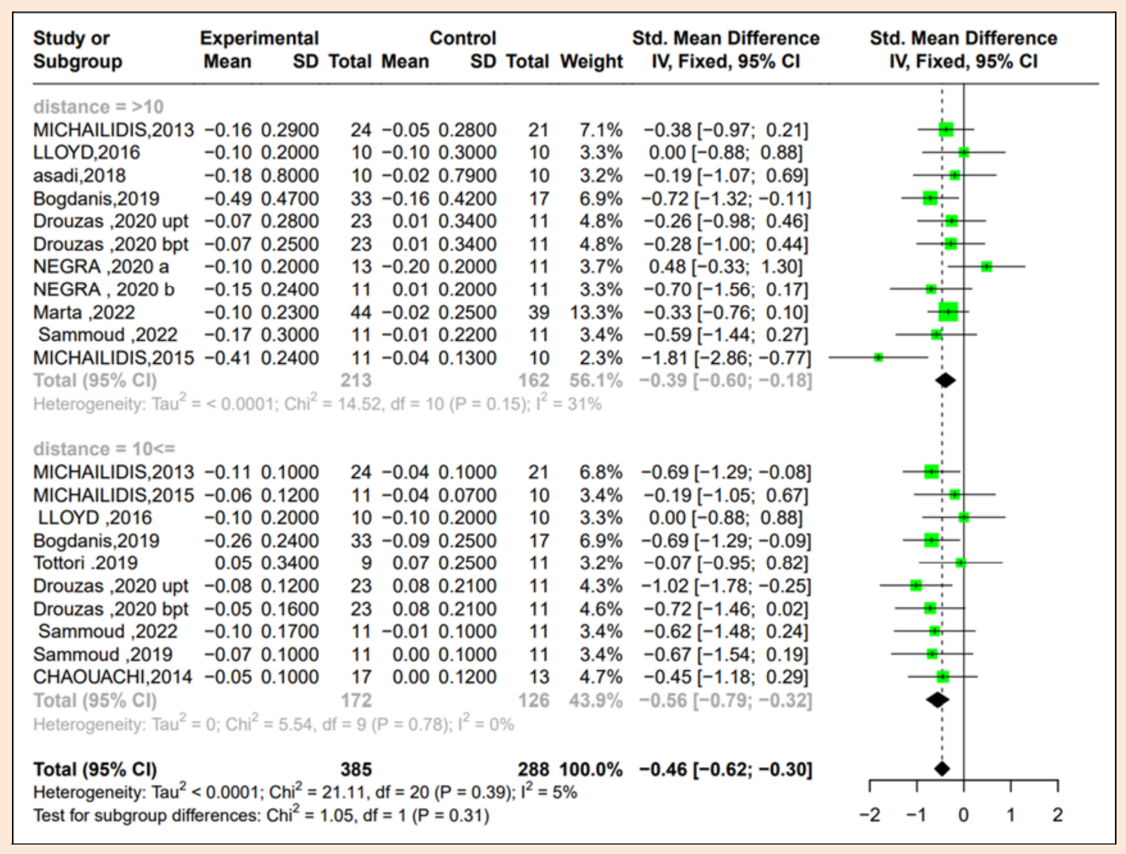
Supplementary Figure 6. Plot of trim and fill method in vertical jump. Adding virtual data points to make the funnel plot more symmetrical, the effect size (ES) decreased to 0.44 after using the Trim and Fill method.



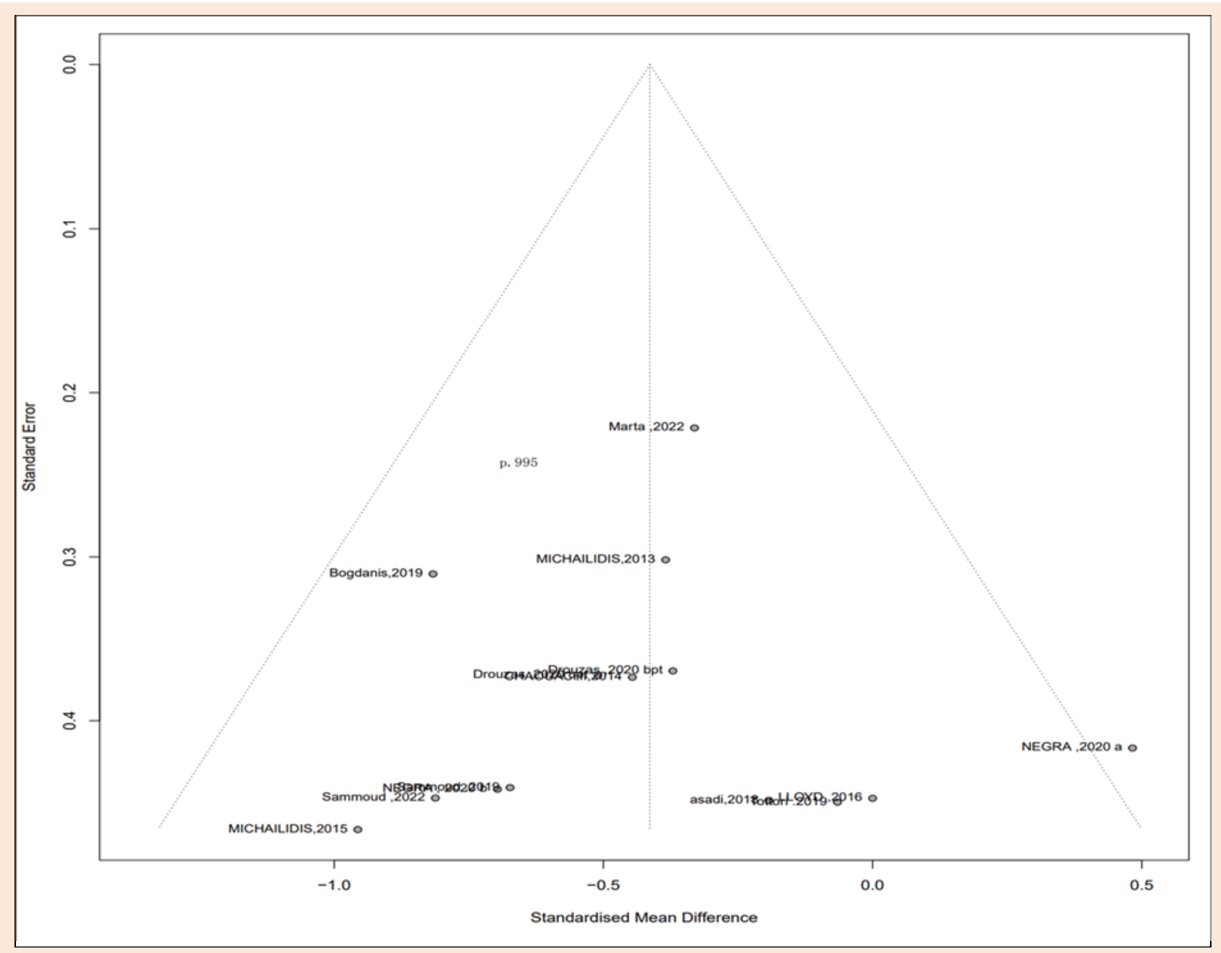
Study	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
MICHAILIDIS,2013	−0.14	0.2300	24	−0.05	0.2300	21	10.6%	−0.38 [−0.98; 0.21]
MICHAILIDIS,2015	−0.24	0.2600	11	−0.04	0.1000	10	4.4%	−0.96 [−1.87; −0.04]
LLOYD ,2016	−0.10	0.1900	10	−0.10	0.2400	10	4.8%	0.00 [−0.88; 0.88]
Bogdanis,2019	−0.38	0.3900	33	−0.09	0.2500	17	10.0%	−0.82 [−1.42; −0.21]
Tottori .2019	0.05	0.3400	9	0.07	0.2500	11	4.8%	−0.07 [−0.95; 0.82]
Drouzas ,2020 upt	−0.08	0.1900	23	0.03	0.2500	11	6.9%	−0.51 [−1.24; 0.22]
Drouzas ,2020 bpt	−0.05	0.1900	23	0.03	0.2500	11	7.0%	−0.37 [−1.10; 0.35]
Sammoud ,2022	−0.07	0.2200	11	0.12	0.2300	11	4.8%	−0.81 [−1.69; 0.06]
CHAOUACHI,2014	−0.05	0.1000	17	0.00	0.1200	13	6.9%	−0.45 [−1.18; 0.29]
Sammoud ,2019	−0.07	0.1000	11	0.00	0.1000	11	5.0%	−0.67 [−1.54; 0.19]
asadi,2018	−0.18	0.8000	10	−0.02	0.7900	10	4.8%	−0.19 [−1.07; 0.69]
NEGRA ,2020 a	−0.10	0.2000	13	−0.20	0.2000	11	5.5%	0.48 [−0.33; 1.30]
NEGRA , 2020 b	−0.15	0.2400	11	0.01	0.2000	11	4.9%	−0.70 [−1.56; 0.17]
Marta ,2022	−0.10	0.2300	44	−0.02	0.2500	39	19.6%	−0.33 [−0.76; 0.10]
Total (95% CI)			**250**			**197**	**100.0%**	**−0.41 [−0.61; −0.22]**

Heterogeneity: $Tau^2 = 0$; $Chi^2 = 11.15$, df = 13 (P = 0.60); $I^2 = 0\%$

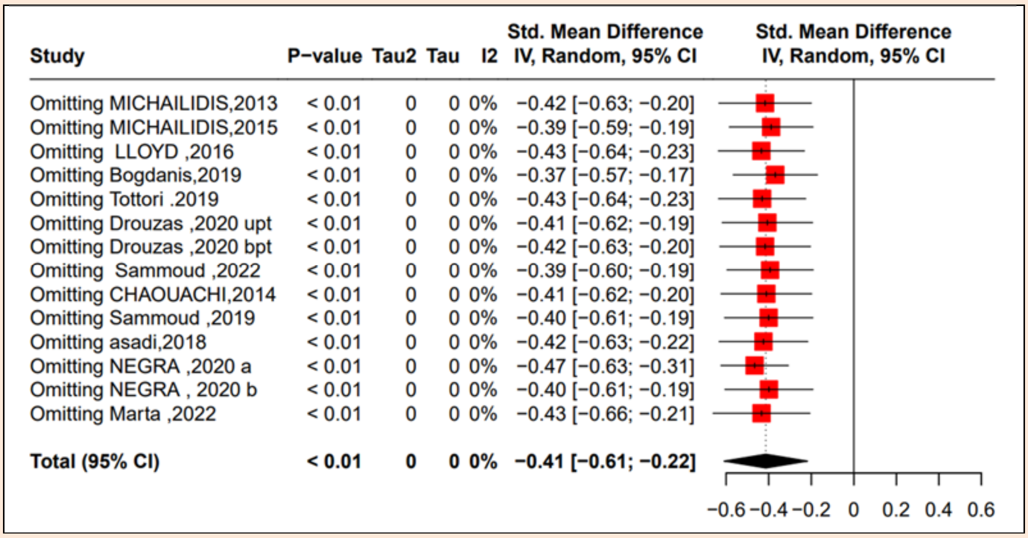
Supplementary Figure 7. **Forest plot of sprint.**



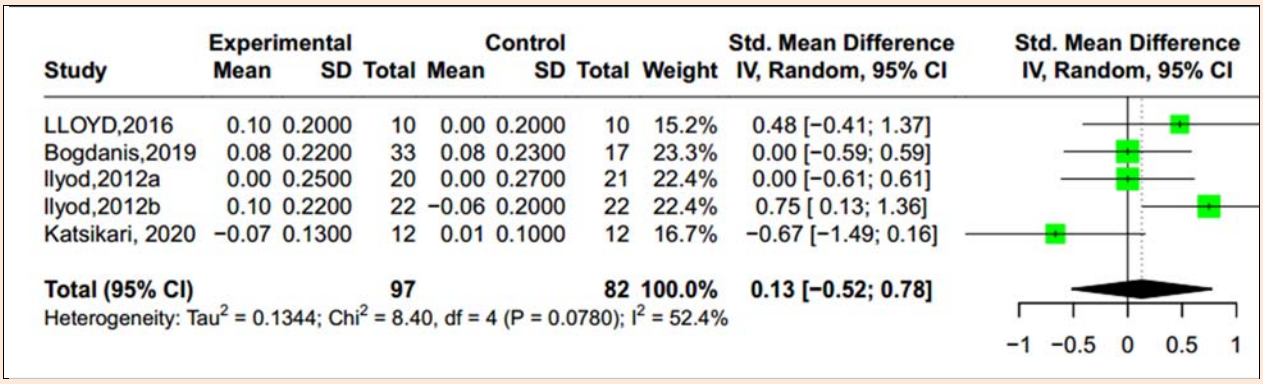
Supplementary Figure 8. **Subgroup analysis of Sprint (10m≤ vs 10m<), 10m ≤ have higher ES.**



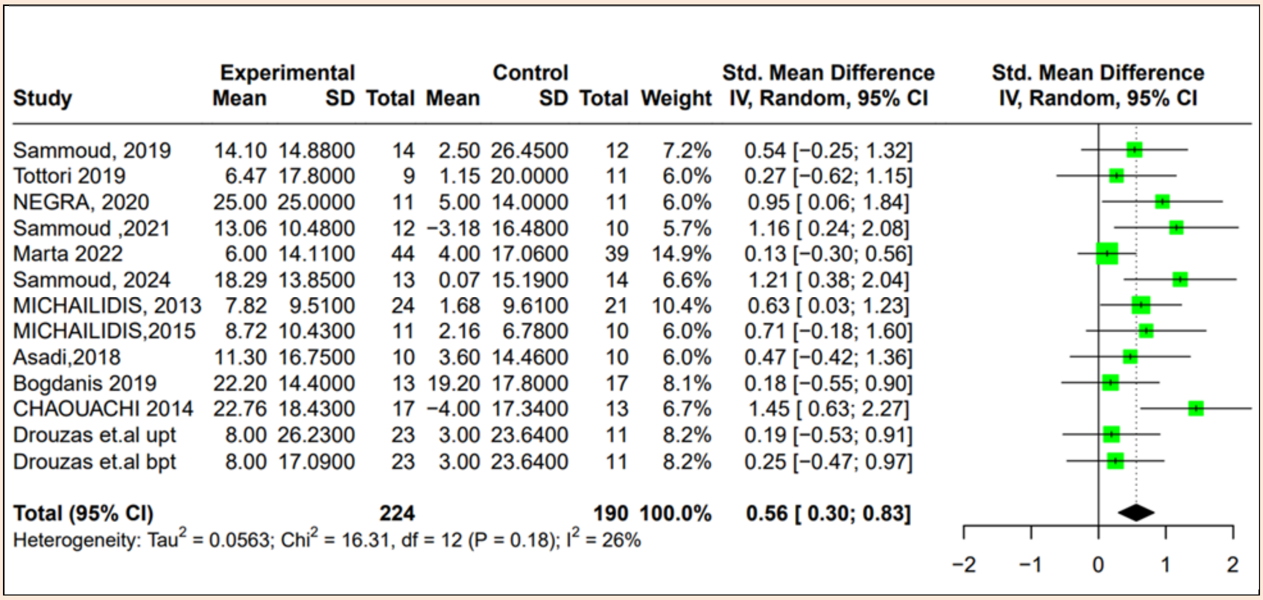
Supplementary Figure 9. **Funnel plot of sprint.**



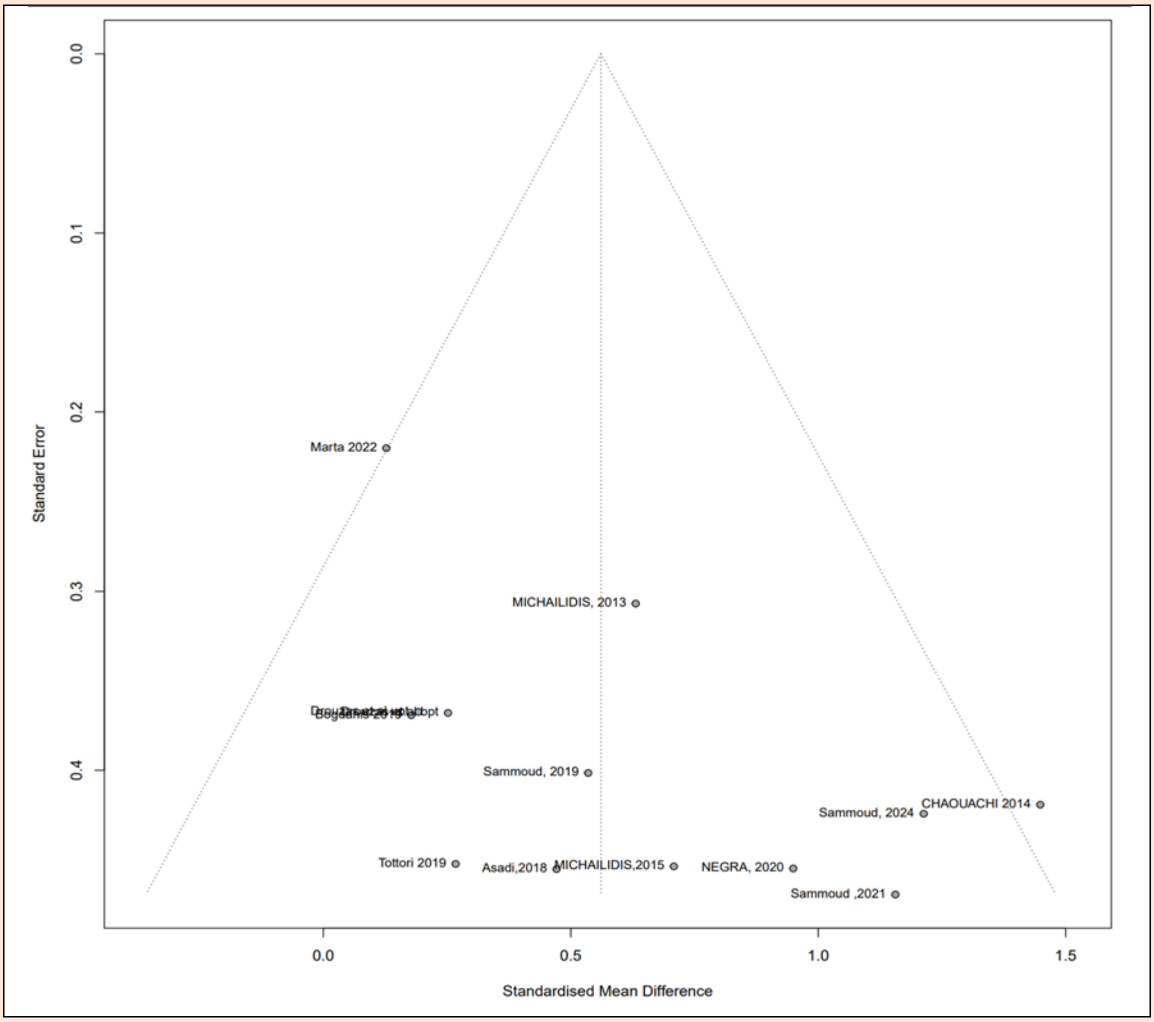
Supplementary Figure 10. **Sensitivity analysis of sprint.**



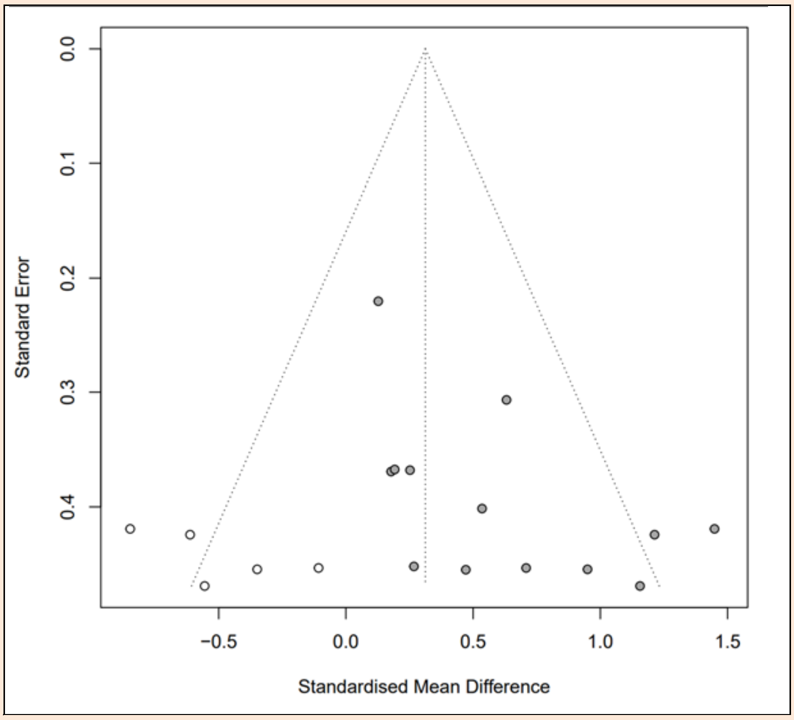
Supplementary Figure 11. **Forest plot of RSI.**



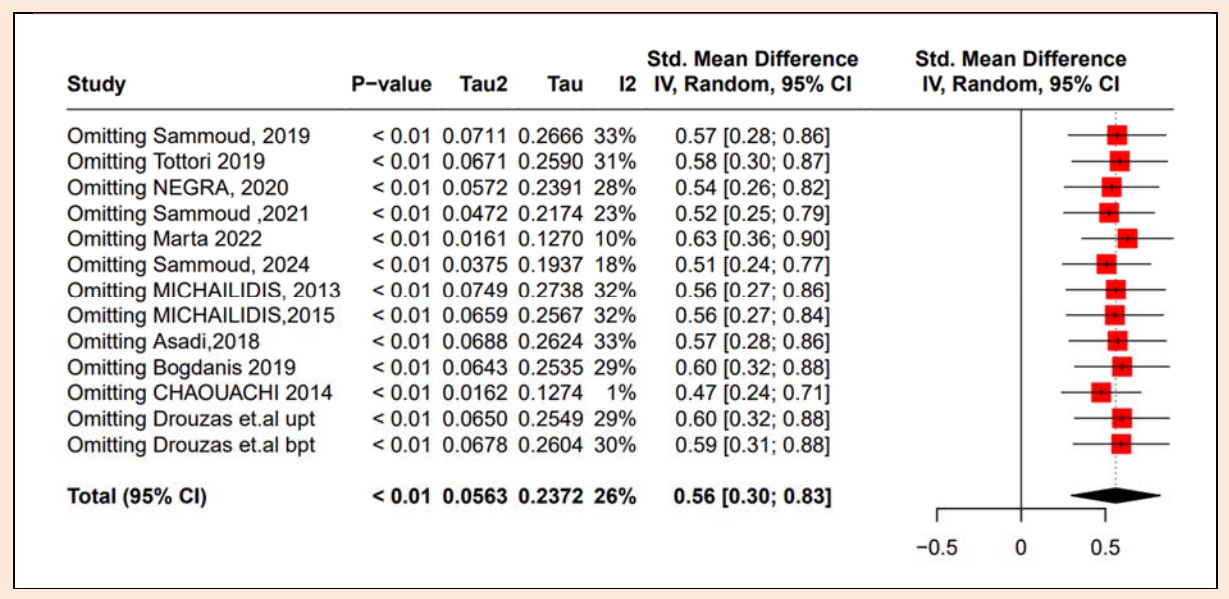
Supplementary Figure 12. **Forest plot of SLJ.**



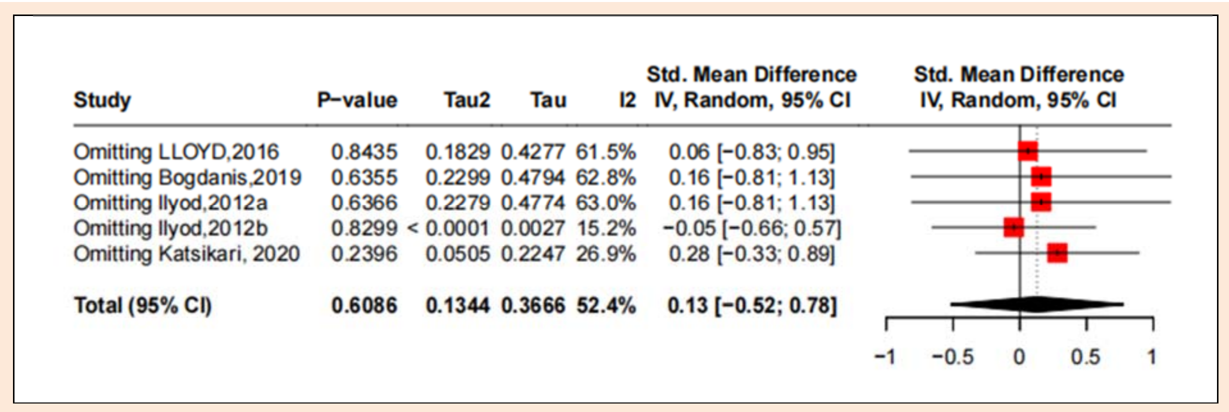
Supplementary Figure 13. **Funnel plot of SLJ.**



Supplementary Figure 14. **Plot of trim and fill method in SLJ. Adding virtual data points to make the funnel plot more symmetrical, the effect size (ES) decreased to 0.31 after using the Trim and Fill method.**



Supplementary Figure 15. Sensitivity analysis of SLJ.



Supplementary Figure 16. Sensitivity analysis of RSI.