

Systematic Review

Effects of Plyometric Jump Training on Vertical Jump Performance in Female Gymnasts: A Systematic Review and Meta-Analysis

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Abstract

Plyometric jump training (PJT) is a training modality aimed at improving lower limbs' explosive strength, one of the key determinants of technical execution in gymnastics; however, its effects in female gymnasts remain insufficiently investigated in the meta-analyses. This meta-analysis aimed to evaluate the effects of supplementary PJT on different measures of vertical jump performance in female athletes participating in gymnastic disciplines compared with control groups undergoing routine gymnastics training. Five scientific databases and Google Scholar were searched according to PRISMA guidelines and the PICOS framework. The certainty of the evidence was evaluated using the GRADE approach. Eleven experimental studies (12 reports), selected from the 881 initially identified records, were included, with a total sample of 335 participants from rhythmic gymnastics ($n = 155$), gymnastics for all ($n = 73$), aerobic gymnastics ($n = 63$), and artistic gymnastics ($n = 44$). PJT produced moderate effects on improvements in CMJ (ES = 0.62, 95% CI = 0.20 to 1.04, $p = 0.01$, $I^2 = 41\%$), SLCMJ (ES = 0.68, 95% CI = -0.29 to 1.65, $p = 0.094$, $I^2 = 26$), CMJFA (ES = 1.07, 95% CI = -1.30 to 3.43, $p = 0.192$, $I^2 = 67.4\%$), DJ (ES = 0.68, 95% CI = -0.50 to 1.86, $p = 0.163$, $I^2 = 68.6\%$), and SJ (ES = 0.64, 95% CI = -0.21 to 1.49, $p = 0.103$, $I^2 = 54.1\%$) compared with the control groups. The certainty of evidence for the meta-analyzed outcomes ranged from very low to low. PJT duration (≤ 7 vs. > 7 weeks), total number of sessions (≤ 14 vs. > 14 sessions), and frequency (≤ 2 vs. > 2 sessions per week) did not significantly moderate the effects. PJT appears to be a practical and effective strategy for improving vertical jump performance in female gymnasts, although not all observed effects reached statistical significance. These findings support the inclusion of PJT as an effective complement to standard gymnastics practice while also highlighting the need for additional high-quality, discipline-specific research involving female gymnasts to refine optimal training parameters.



Academic Editors: Adrian Escudero-Tena, Diego Muñoz Marín and Sergio José Ibáñez Godoy

Received: 12 June 2026

Revised: 2 July 2026

Accepted: 3 July 2026

Published: 6 July 2026

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Keywords: athletic performance; lower limb; stretch–shortening cycle; training adaptations

1. Introduction

Plyometric jump training (PJT) is a specialized form of explosive strength training characterized by dynamic movements that utilize the stretch–shortening cycle (SSC) of skeletal muscle to enhance rapid force production and mechanical power output [1]. The SSC consists of a rapid eccentric muscle action immediately followed by a concentric contraction, enabling the storage and reutilization of elastic energy within the muscle–tendon complex, while

simultaneously enhancing neuromuscular activation via stretch-reflex mechanisms [2]. Typical plyometric jump exercises include countermovement jumps, drop jumps, bounding, hopping, and multiple jumps, which may be performed in bilateral or unilateral forms and are executed with maximal or near-maximal effort alongside minimal ground contact time to maximize reactive strength and power output [3]. Accordingly, these exercises are designed to enhance the capacity of the neuromuscular system to generate maximal force in the shortest possible time [4]. Given the high neuromuscular and mechanical demands of these movements, plyometric training promotes adaptations such as increased motor unit recruitment, improved intermuscular coordination, greater musculotendinous stiffness, and an enhanced rate of force development [3,5]. Numerous experimental studies and meta-analyses have shown that systematic plyometric training significantly improves performance outcomes, including vertical jump height, sprint acceleration, and change-of-direction ability in both athletic and physically active populations [6–8]. Consequently, plyometric exercises are widely integrated into conditioning programs across sport disciplines that require high levels of explosive power, speed, and agility [2].

Published systematic reviews of experimental studies summarizing the effects of plyometric training indicate that only approximately 22% were conducted using data from female participants, and only about 7% focused on individual sports [9]. Systematic reviews have also shown the effectiveness of supplementary plyometric training in developing explosive strength of the lower-limb muscles in female athletes across various sport disciplines; however, the findings are still predominantly based on data from women participating in team sports. Younger athletes (<15 years) appear to be more responsive to plyometric training (moderate effect size) than older athletes (>15 years, small effect size), and the benefits of such training tend to increase with longer intervention durations (>8 weeks, moderate effect size) and higher training frequencies (>2 sessions per week, large effect size) [10]. However, in the meta-analysis by Stojanović et al. [11], the effect size for training interventions lasting less than 10 weeks was small and increased to a large effect size when training duration was ≥ 10 weeks. Moreover, the effects of plyometric training are sport-dependent [12] and may also vary depending on the type and number of exercises used, as well as training volume, intensity, sex, and competitive level of the participants [13].

Vertical jump performance is commonly assessed using standardized tests that differ in their neuromuscular and mechanical demands [3]. The countermovement jump (CMJ) involves the stretch–shortening cycle, while the single-leg CMJ (SLCMJ) evaluates unilateral jump performance and may highlight inter-limb differences in neuromuscular function and stability. The CMJ with free arm swing (CMJFA) includes upper-body contribution, whereas the squat jump (SJ) emphasizes concentric force production by minimizing the contribution of the stretch–shortening cycle. The drop jump (DJ) evaluates reactive strength and stretch–shortening cycle efficiency. Together, these tests provide complementary information on vertical jump performance under different neuromuscular and mechanical conditions and are widely used to evaluate lower-limb functional performance in athletes.

In gymnastic sports, a high level of lower-limb explosive strength is essential for rapid force production during take-off, contributing to greater lower-limb power, enhanced jump performance, and the successful execution of technically demanding elements. Proceeding sequentially through the distinct disciplines of gymnastics in which women participate, rhythmic gymnastics is a technically demanding discipline that combines elements of ballet, apparatus handling, and coordinated full-body movements performed to music. In this discipline, both execution quality and jump difficulty are key determinants of judges' scores. Consequently, the ability to rapidly generate force during take-off contributes to greater lower-limb power and enhanced jump performance. Accordingly, a greater jump or leap height provides gymnasts with increased time during the flight phase to adopt the body

positions required for specific elements [14,15]. Women's artistic gymnastics, by contrast, is a multifaceted discipline comprising vault, uneven bars, balance beam, and floor exercises, all of which require high levels of strength, coordination, and technical precision. Lower-limb explosive strength is a key determinant of performance, particularly in the execution of acrobatic jumps, where it contributes to greater take-off velocity, enabling greater flight height and more accurate body positioning during the aerial phase. Therefore, effective generation and transfer of explosive force through the lower extremities are essential for optimizing jump quality and overall routine execution [16,17]. Aerobic gymnastics is a high-intensity discipline characterized by the continuous performance of complex movement sequences that integrate coordination, strength, and endurance, all performed in synchrony with music. Lower-limb power plays a critical role in the execution of compulsory jumps, contributing to greater jump height and facilitating technical precision, thereby enhancing overall scoring potential. Additionally, the capacity to repeatedly generate explosive strength in the lower extremities underpins the dynamic quality of rebounds and transitions throughout the routine [18,19]. Gymnastics for All integrates elements from artistic, rhythmic, acrobatic, and aerobic gymnastics, and is performed collectively by groups of athletes on the gymnastics floor. Given the predominantly non-competitive nature of Gymnastics for All, skills are more commonly showcased in festival settings rather than formal competitive events [20]. Furthermore, an optimal level of explosive strength is a key determinant of post-landing stability following jump elements and dismounts, as it enables rapid force production and effective neuromuscular control required to attenuate impact forces, maintain balance, and reduce both injury risk [21,22] and the likelihood of execution errors [23].

The existing literature lacks comprehensive analyses of experimental studies examining the effects of supplementary PJT on the explosive strength of the lower-limb muscles in female gymnasts compared with routine training. Although one meta-analysis indicated that plyometric training contributes to improvements in gymnasts' jump performance [24], direct comparisons between PJT and routine training across different jump modalities in female gymnasts have not yet been undertaken. Therefore, the aim of this systematic review and meta-analysis was to evaluate the effects of supplementary PJT on various vertical jump performances in female athletes across gymnastic disciplines, compared with control groups of gymnasts undergoing routine training.

2. Materials and Methods

2.1. Study Design

The present systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which are established standards for the identification, selection, extraction, and analysis of studies (Supplementary Material). Additionally, guidelines specific to conducting systematic reviews in sport science were also followed [25,26].

2.2. Search Strategy

Up to 15 January 2026, a comprehensive search was conducted across five scientific databases: MEDLINE, SPORTDiscus with Full Text, Academic Search Ultimate (via EBSCOhost), PubMed, and Web of Science. The search strategy combined terms related to gymnastic disciplines, such as "rhythmic gymnastics," "artistic gymnastics," "aerobic gymnastics," "Gymnastics for All," "acrobatic gymnastics," "female athletes," "female gymnasts," and "aesthetic sports," with intervention-related terms including "plyometric training," "plyometric exercise," "plyometric drill," "ballistic training," "explosive," "force-velocity," "stretch-shortening cycle," "stretch-shortening exercise," and "jump training," using Boolean operators "AND" and "OR."

Additionally, the search was supplemented by manual screening of the reference lists of eligible studies [27] as well as searches in Google Scholar.

2.3. Eligibility Criteria (Inclusion/Exclusion)

To define the eligibility criteria, the Population, Intervention, Comparison, Outcomes, Study Design framework was followed [28].

Inclusion criteria: The present review included original, full-text research articles written in English and published in peer-reviewed scientific journals. Eligible studies involved cohorts of healthy female gymnasts (rhythmic, artistic, aerobic, and Gymnastics for All), with no restrictions regarding age or competitive level. Studies were required to examine the effects of a plyometric jump training program implemented in addition to routine gymnastics training in the experimental group for a minimum duration of four weeks, using randomized or non-randomized controlled trial designs. Control groups were required to perform only routine gymnastics training.

Furthermore, studies had to report at least one pre- and post-intervention outcome measure of vertical jump performance, assessed using the following movement patterns: countermovement jump (CMJ), single-leg countermovement jump (SLCMJ), countermovement jump with free arms (CMJFA), drop jump (DJ), or squat jump (SJ).

Included studies were required to incorporate PJT programs defined as involving movements in which the muscles operate through the SSC, such as jumps, hops, landings, and multiple-jump drills performed bilaterally or unilaterally. These programs required an intense eccentric phase followed by a rapid transition to the concentric phase of muscle action and were aimed at improving the ability of muscles to generate maximal force in the shortest possible time. Programs combining PJT with functional core training or strength training, as well as programs including upper-limb plyometrics, were also included.

Exclusion criteria: Studies were excluded if they had male participants or mixed-sex samples without separate female data, lacked a control group, or involved athletes with health problems (e.g., injury or recent surgery). Studies were also excluded if they did not clearly describe the vertical jump height test used or did not report sufficient numerical data for analysis. Additionally, unpublished articles, conference abstracts, proceedings, dissertations, PhD theses, case studies, and review papers were excluded.

2.4. Data Extraction

Information extracted from the included full-text articles encompassed sample size and participant characteristics (gymnastic discipline, age, body height and mass, training experience, competitive level, and gymnastic training load where available), as well as details of the PJT interventions (duration, frequency, session duration, number of sessions, types of exercises, training period, and intensity). The process of data extraction was carried out by the first reviewer (K.S.-P.) using a standardized form developed in Microsoft Excel, and then the second reviewer (T.P.-I.) independently verified all the extracted data.

2.5. Risk of Bias and Certainty of Evidence

Risk of bias was assessed using design-specific tools. Randomized controlled trials (RCTs) were evaluated using the Cochrane Risk of Bias tool, version 2 (RoB 2), which examines bias arising from the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting [29]. Non-randomized intervention studies (NRSS) were assessed using the ROBINS-I tool, which evaluates bias relative to a hypothetical well-performed randomized trial across seven domains, including confounding, participant selection, classification of interventions, deviations from intended interventions, missing data, outcome measurement, and selection of reported results [30].

The certainty of evidence for each outcome was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach [31]. Evidence from RCTs was initially rated as high certainty, whereas evidence from NRSs was initially rated as low certainty. Certainty was downgraded based on risk of bias, inconsistency, indirectness, imprecision, and publication bias and upgraded when large effect sizes or dose–response relationships were observed [32,33]. Overall certainty of evidence was classified as high, moderate, low, or very low. All assessments were performed independently by two reviewers (K.S.-P. and T.P.-I.), with any disagreements resolved through discussion and consensus.

2.6. Statistics

The meta-analysis was conducted using SZTOS software [34] with the R package meta [35]. A random-effects model was used because the included studies were drawn from published articles and differed in participant age, sport discipline, intervention duration and frequency, and type of plyometric exercises. Meta-analysis was conducted when at least three studies reported the same outcome variable [36,37], with statistical significance set at $p < 0.05$. When fewer than five studies were available, a random-effects model with the Hartung–Knapp adjustment was applied [38].

Effect sizes (ESs) were calculated using Cohen's d [39], corrected for small sample bias using Hedges' g [40]. The reported coefficients were expressed as standardized mean differences (SMDs) with 95% confidence intervals (95% CIs), based on change scores calculated according to Cochrane Handbook recommendations [41]. The SMD effect sizes were interpreted using sport-specific criteria as follows: <0.2 trivial; 0.2 – 0.6 small; >0.6 – 1.2 moderate; >1.2 – 2.0 large; >2.0 – 4.0 very large; and >4.0 extremely large [39]. Heterogeneity was assessed using the I^2 statistic, with values of $<25\%$, 25 – 75% , and $>75\%$ indicating low, moderate, and high heterogeneity, respectively [42]. The interpretation of results followed sports and exercise medicine guidelines [38].

2.7. Additional Analysis

To assess the potential influence of moderating variables on the effects of PJT, subgroup analyses were performed using a random-effects model. Subgroup analyses were performed only when a sufficient number of studies were available. As CMJ outcomes were reported in the largest number of studies, subgroup comparisons were conducted for CMJ to explore potential moderating effects of PJT adaptations. The median was used to divide participants according to overall plyometric program duration (≤ 7 vs. >7 weeks), total number of training sessions (≤ 14 vs. >14), and weekly training frequency. Because the calculated median frequency was 2.25 sessions per week and values below this threshold mainly represented interventions of 2 sessions per week, the split of ≤ 2 vs. >2 sessions per week was used for clearer and more practical interpretation. This approach allowed examination of whether different exposure levels to the intervention were associated with distinct training outcomes. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Literature Search Procedure

The results of the systematic literature search are presented in the PRISMA flow diagram (Figure 1). Initially, 877 records were identified in databases including SPORTDiscus with Full Text, Academic Search Ultimate, MEDLINE (via EBSCOhost), Web of Science, and PubMed. An additional four records were identified through Google Scholar, resulting in a total of 881 records. After removal of duplicates, 284 records remained for title and abstract screening. A total of 260 records were excluded during this screening phase, leaving 28 full-text articles assessed for eligibility (24 articles from Databases and 4 articles from Google Scholar). Subse-

quently, 17 full-text articles that did not meet the inclusion criteria were excluded. Ultimately, 11 studies (12 reports) were included in the systematic review and meta-analysis.

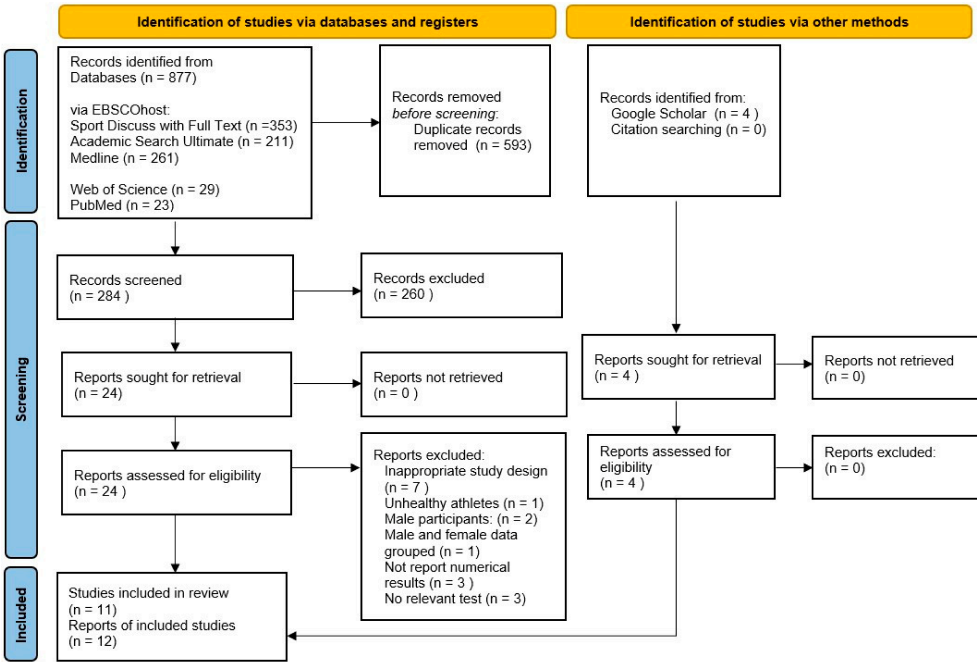


Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

3.2. Methodological Quality and Risk of Bias Assessment

The methodological quality of the included studies was evaluated using the RoB 2 tool for seven RCTs, while the ROBINS-I tool was applied to four NRSs. Across the RCTs (Figure 2), the overall risk of bias was rated as “some concerns” in all trials. All RCTs showed “some concerns” regarding bias in the randomization process, deviations from the intended interventions, and selection of the reported results [43–49]. Six of the seven RCTs were rated as having a low risk of bias for missing outcome data and outcome measurement. Only one study [43] showed “some concerns” across all domains. Figure 3 summarizes the domain-specific and overall ROBINS-I risk-of-bias judgments for the four included NRSs. Across the NRSs, two studies were judged to have a serious risk of bias due to confounding [50,51], resulting in an overall serious risk of bias rating. The remaining two studies [52,53] demonstrated a predominantly moderate risk of bias across most domains and were therefore judged as having an overall moderate risk of bias.

		Risk of bias domains					Overall
		D1	D2	D3	D4	D5	
Study	Agostini et al. (2017)	⊖	⊖	⊖	⊖	⊖	⊖
	Bogdanis et al. (2019)	⊖	⊖	⊕	⊕	⊖	⊖
	Cabrejas et al. (2023)	⊖	⊖	⊕	⊕	⊖	⊖
	Hall et al. (2016)	⊖	⊖	⊕	⊕	⊖	⊖
	Karagianni et al. (2020)	⊖	⊖	⊕	⊕	⊖	⊖
	Ma et al. (2024)	⊖	⊖	⊕	⊕	⊖	⊖
	Ng et al. (2023)	⊖	⊖	⊕	⊕	⊖	⊖
Domains:		D1: Bias arising from the randomization process. D2: Bias due to deviations from intended intervention. D3: Bias due to missing outcome data. D4: Bias in measurement of the outcome. D5: Bias in selection of the reported result.					Judgement
							⊖ Some concerns ⊕ Low

Figure 2. Domain-specific and overall risk-of-bias assessment of the included randomized controlled trials using the RoB 2 tool [43–49].

The certainty of evidence for each outcome was assessed using the GRADE approach (Table 1). RCTs were initially rated as high-certainty evidence, whereas NRSs were initially rated as low-certainty evidence. The results from RCTs and NRSs were pooled; therefore, the certainty assessment considered the overall body of evidence. Because RCTs provided the majority of data for CMJ, the certainty of evidence was initially rated as high. For SLCMJ, CMJFA, and SJ, NRSs provided the majority of data, while for DJ, the evidence was derived more evenly from both RCTs and NRSs. Accordingly, these outcomes were initially rated as low certainty and were subsequently downgraded based on predefined GRADE domains.

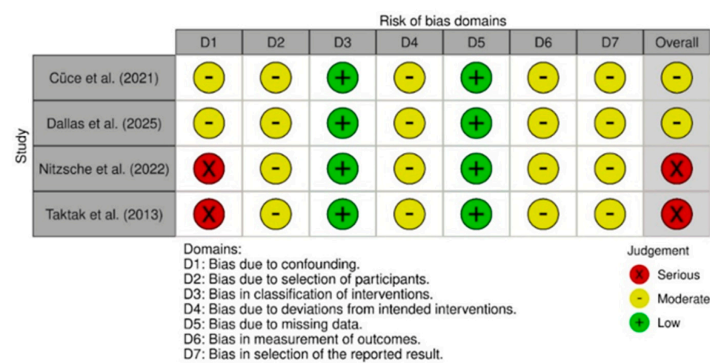


Figure 3. Domain-specific and overall risk-of-bias assessment of the included non-randomized intervention studies using the ROBINS-I tool [50–53].

Table 1. Certainty of evidence for meta-analyzed outcomes.

Outcomes	Number of Participants and Studies	Certainty Assessment					Overall Certainty (GRADE)
		Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	
CMJ	243 6 RCTs, 2 NRSs	Serious ^a	Not serious	Not serious	Serious ^c	None detected ^d	⊕⊕⊕⊕ Low
SLCMJ	117 3 RCTs	Serious ^a	Not serious	Serious ^b	Serious ^c	None detected ^d	⊕⊕⊕⊕ Very low
CMJFA	64 1 RCT, 2 NRSs	Serious ^a	Not serious	Not serious	Serious ^c	None detected ^d	⊕⊕⊕⊕ Very low
DJ	108 2 RCTs, 2 NRSs	Serious ^a	Not serious	Not serious	Serious ^c	None detected ^d	⊕⊕⊕⊕ Very low
SJ	132 1 RCT, 3 NRSs	Serious ^a	Not serious	Not serious	Serious ^c	None detected ^d	⊕⊕⊕⊕ Very low

^a Risk of bias was downgraded by one level due to unclear allocation concealment and lack of preregistration in several RCTs or because the outcome was not clearly specified; NRSs were downgraded by one level due to moderate confounding (e.g., maturation) and selection bias. ^b Indirectness was downgraded by one level because two trials [45,47] used combined interventions (core + plyometric; strength-power + plyometric), limiting attribution of effects solely to PJT. ^c Imprecision was downgraded by one level due to small sample sizes ($n = 10$ – 30 per group) and wide confidence intervals. ^d Publication bias was not suspected because there was no evidence of selective reporting; included studies varied in journals, publication years, and countries, with generally transparent reporting of outcomes.

3.3. Study Characteristics

All included studies involved 335 female gymnasts, representing rhythmic gymnastics ($n = 155$), Gymnastics for All ($n = 73$), aerobic gymnastics ($n = 63$), and artistic gymnastics ($n = 44$). Among these participants, 179 underwent supplementary PJT, while the remaining 156 served as active control participants, with mean age ranges of 8.1–18.2 years and 7.9–18.4 years, respectively. The training duration ranged from 4 to 48 weeks, training frequency from 2 to 3 sessions per week, and total number of sessions from 12 to approximately 100. The characteristics of the participants and details of the training programs included in the studies are presented in Table 2.

Table 2. Characteristics of the included studies.

Study	Population				Plyometric Training Programs									
	Athletes/ Sport Level/ Training Load	Age (Years)	Height (cm)	Weight (kg)	Sample Size (n) EG/CG	Duration (Weeks)	Freq. (Days/Week)	Session (Min)/ Sessions (n)	Total Jumps (n)	Type	Comb.	Training Period	Int.	Test
Agostini et al. (2017) [43]	RG/Reg./ 4.0 ± 0.20 h/daily	EG: 14.4 ± 1.2 CG: 15.2 ± 1.5	EG: 169.0 ± 2.0 CG: 165.0 ± 7.0	EG: NR CG: NR	30 (15/15)	48	2–3	15–20/ ~100	NR	Mix	No	All season	NR	CMJFA
Bogdanis et al. (2019) [44]	GFA/C.G./ 3 × 90 min/week	EG: 8.1 ± 0.7 CG: 7.9 ± 0.8	EG: 129.3 ± 6.1 CG: 129 ± 7.6	EG: 28.7 ± 5.8 CG: 27.5 ± 6.0	50 (33/17)	8	2	~27/16	2960	Mix	No	Pre-season	P	CMJ, SLCMJ, DJ 20 cm, SJ
Cabrejas et al. (2023) [45]	RG/Reg./NR	EG: 10.52 ± 1.9 CG: 10.43 ± 1.8	EG: 144.0 ± 1.0 CG: 144.0 ± 1.1	EG: 37.8 ± 9.8 CG: 38.2 ± 8.0	44 (23/21)	8	3	30/24	~4280	Mix	Yes (FC)	Comp.	H	CMJ, SLCMJ
Cüce et al. (2021) [52]	Aero/Reg./NR	EG: 12.93 CG: 12.89	EG: 146.0 CG: 144.0	EG: 34.0 CG: 31.0	14 (7/7)	6	2	~18/12	NR	Mix	No	NR	H	CMJFA, SJ
Dallas et al. (2025) [53]	RG/Nat./NR				24 (12/12)	6	2	45/12	1092	Mix	No	NR	NR	SJ
		Total Sample:	Total Sample:	Total Sample:										
		EG: 10.63 ± 1.3	EG: 144.0 ± 1.0	EG: 35.82 ± 6.8										
		CG: 10.63 ± 1.2	CG: 145.0 ± 1.1	CG: 39.75 ± 10.3										
	AG/Nat./NR				24 (12/12)	6	2	45/12	1092	Mix	No	NR	NR	
Hall et al. (2016) [46]	AG/Reg./ ~10 h/week	Total sample: 12.5 ± 1.67	Total sample: 146.0 ± 1.1	Total sample: 40.5 ± 9.7	20 (10/10)	6	2	~20/12	670	Mix	No	NR	NR	CMJ
Karagianni et al. (2020) [47]	GFA/Reg./ 3 × 90 min/week	EG: 13.2 ± 1.3 CG: 12.3 ± 1.3	EG: 157.3 ± 6.1 CG: 156 ± 7.3	EG: 52.4 ± 6.6 CG: 51.6 ± 8.5	23 (12/11)	10	2–3	7–9/26	NR	Mix	Yes (S)	NR	H	CMJ, SLCMJ, DJ 20 cm
Ma et al. (2024) [48]	Aero/Reg. 4–5 sessions/week	EG: 16.3 ± 1.2 CG: 16.2 ± 1.4	EG: 161.0 ± 3.0 CG: 161.0 ± 3.0	EG: 52.7 ± 2.4 CG: 52.6 ± 2.5	49 (24/25)	8	2	5/16	2160	Single	No	NR	H	CMJ
Ng et al. (2023) [49]	RG/Rec./ 2 sessions/week	EG: 10.5 ± 1.2 CG: 11.1 ± 1.0	EG: 130.0 ± 9.3 CG: 138.0 ± 9.6	EG: 27.4 ± 7.6 CG: 30.9 ± 6.3	22 (11/11)	6	2	NR/12	1230	Mix	No	NR	NR	CMJ
Nitzsche et al. (2022) [50]	RG/Nat./Int. 3 sessions/week	EG: 12.1 ± 2.9 CG: 12.6 ± 2.3	EG: 147.6 ± 12.8 CG: 148.0 ± 9.1	EG: 37.2 ± 10.2 CG: 37.4 ± 6.7	15 (10/5)	6	3	NR/18	1080	Mix	No	Comp.	NR	CMJ, DJ 30 cm
Taktak et al. (2013) [51]	RG/Int. 6 × 2 h/week	EG: 18.2 ± 2.1 CG: 18.4 ± 2.6	EG: 175.0 ± 3.0 CG: 175.0 ± 3.0	EG: 55.1 ± 2.7 CG: 54.7 ± 2.3	20 (10/10)	4	3	25–35/12	NR	Mix	No	NR	P	CMJ, CMJFA, DJ 30 cm, SJ

Note: RG: Rhythmic gymnastics; GFA: Gymnastics for All; Aero: Aerobic gymnastics; AG: Artistic gymnastics; Reg.: Regional; C.G.: Club Gymnasts; Rec.: Recreational; Nat.: National; Int.: International; sessions: training sessions; h: hours; min: minutes; EG: Experimental group; CG: Control group; Freq.: Frequency; Comb.: combined; FC: Functional core; S: Strength; Type: type of PJT drill. When the term “Mix” was reported, it referred to a training protocol incorporating two or more types of jumping exercises. Comp.: Competitive; Int.: Intensity; P: Progressive; H: High; NR: Not reported.

3.4. Meta-Analysis

Eight studies [44–51] assessed CMJ performance in female gymnasts following PJT (Figure 4). The meta-analysis showed that PJT had a statistically significant moderate effect on improvements in CMJ height compared with the control group ($ES = 0.62$, 95% CI = 0.20 to 1.04, $p = 0.01$), with moderate heterogeneity ($I^2 = 41\%$).

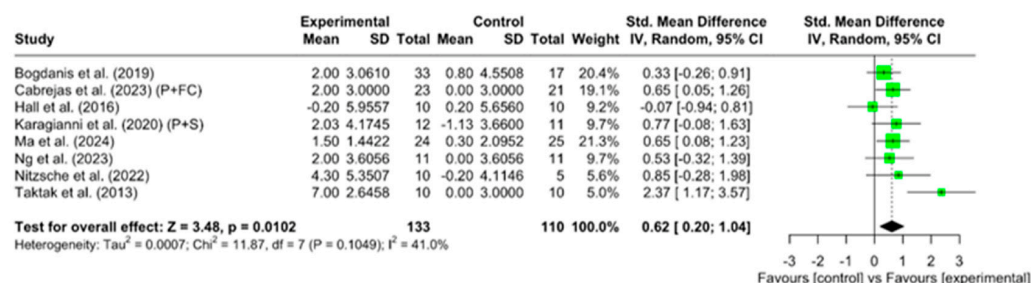


Figure 4. Forest plot of the effects of plyometric jump training (PJT) on countermovement jump (CMJ) in female gymnasts [44–51].

Three studies [44,45,47] investigated the effects of PJT on female gymnasts' SLCMJ performance (Figure 5). The meta-analysis showed that PJT produced a moderate positive effect on SLCMJ compared with the control group ($ES = 0.68$, 95% CI = -0.29 to 1.65), although this result was not statistically significant ($p > 0.05$). Heterogeneity among the included studies was low to moderate ($I^2 = 26\%$).

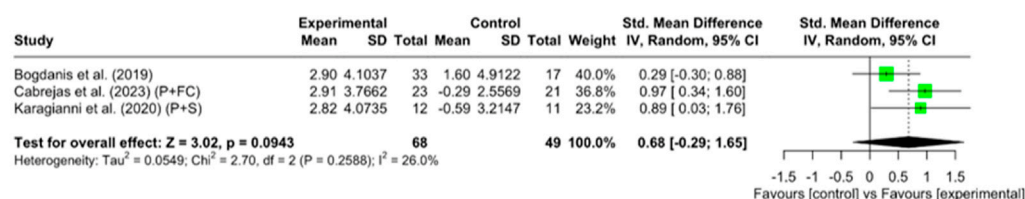


Figure 5. Forest plot of the effects of plyometric jump training (PJT) on single-leg countermovement jump (SLCMJ) in female gymnasts [44,45,47].

Three studies [43,51,52] examined CMJFA performance in female gymnasts following PJT (Figure 6). The meta-analysis showed that PJT had a moderate positive effect on CMJFA compared with the control group ($ES = 1.07$, 95% CI = -1.30 to 3.43), although the result did not reach statistical significance ($p > 0.05$). Heterogeneity among the three studies was moderate ($I^2 = 67.4\%$).

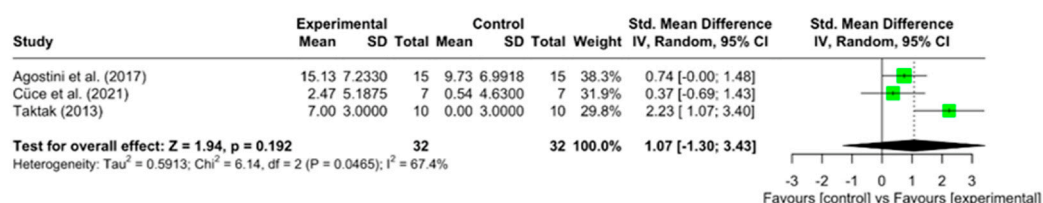


Figure 6. Forest plot of the effects of plyometric jump training (PJT) on countermovement jump with free arms (CMJFA) in female gymnasts [43,51,52].

Four studies [44,47,50,51] assessed DJ performance in female gymnasts following PJT (Figure 7). The meta-analysis showed that PJT had a moderate positive effect on DJ compared with the control group ($ES = 0.68$, 95% CI = -0.50 to 1.86), although the differences were not statistically significant ($p > 0.05$). Heterogeneity was moderate ($I^2 = 68.6\%$).

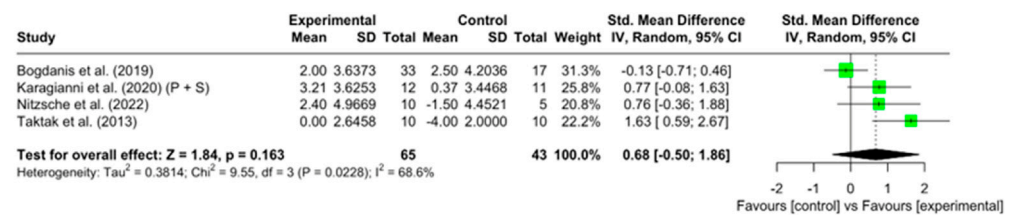


Figure 7. Forest plot of the effects of plyometric jump training (PJT) on drop jump (DJ) in female gymnasts [44,47,50,51].

Five studies from four publications [44,51–53] examined SJ performance in female gymnasts following PJT (Figure 8). The meta-analysis showed that PJT had a moderate positive effect on SJ compared with the control group (ES = 0.64, 95% CI = −0.21 to 1.49), although the result did not reach statistical significance ($p > 0.05$). Heterogeneity was moderate ($I^2 = 54.1\%$).

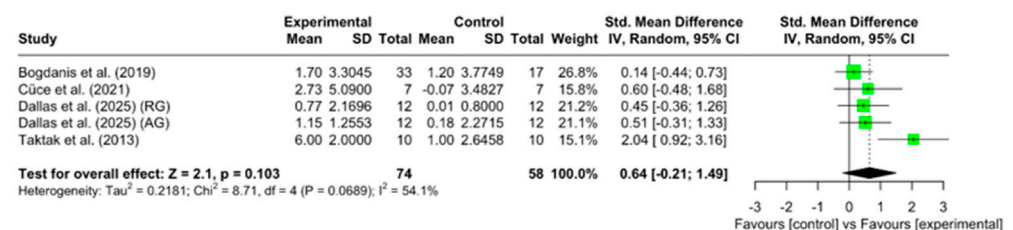


Figure 8. Forest plot of the effects of plyometric jump training (PJT) on squat jump (SJ) in female gymnasts [44,51–53].

The results for SLCMJ, CMJFA, DJ, and SJ suggest the possibility of positive moderate effects, but, due to the wide confidence intervals and limited power of the analyses, they should be interpreted with caution.

3.5. Additional Analyses

For PJT interventions lasting ≤ 7 weeks (4 groups), the meta-analysis showed a non-significant effect on CMJ height compared with the control group (ES = 0.861, 95% CI = −0.755 to 2.478, $p = 0.189$), with moderate heterogeneity observed across studies ($I^2 = 71.8\%$, $p = 0.014$). In contrast, interventions lasting > 7 weeks (4 groups) showed a statistically significant increase in CMJ height in the experimental group compared with the control group (ES = 0.576, 95% CI = 0.274 to 0.878, $p < 0.001$), with very low heterogeneity across studies ($I^2 = 0.0\%$, $p = 0.793$). However, the test for subgroup differences was not statistically significant ($p = 0.58$).

For interventions completing up to 14 sessions (3 groups), the meta-analysis showed a non-significant increase in CMJ height compared with the control group (ES = 0.892, 95% CI = −2.201 to 3.986, $p = 0.340$), with large heterogeneity observed across studies ($I^2 = 81.1\%$, $p = 0.005$). In contrast, PJT interventions exceeding 14 sessions (5 groups) showed a statistically significant improvement in CMJ compared with routine gymnastics training (ES = 0.595, 95% CI = 0.355 to 0.836, $p = 0.002$), with no heterogeneity among studies ($I^2 = 0.0\%$, $p = 0.872$). However, no statistically significant differences were observed between these subgroups ($p = 0.682$).

PJT interventions performed at a frequency of ≤ 2 sessions per week (4 groups) showed no significant differences in CMJ performance compared with the control group (ES = 0.415, 95% CI = −0.036 to 0.866, $p = 0.061$), with no heterogeneity observed across studies ($I^2 = 0.0\%$, $p = 0.576$). Similarly, interventions performed at a frequency of > 2 sessions per week (4 groups) showed non-significant improvements in CMJ performance compared with routine gymnastics training (ES = 1.052, 95% CI = −0.129 to 2.233, $p = 0.066$), with

moderate heterogeneity ($I^2 = 53.8\%$, $p = 0.89$). The subgroup comparison based on PJT frequency was not statistically significant ($p = 0.109$).

4. Discussion

The aim of the present study was to conduct a systematic review and meta-analysis of the effects of supplementary PJT on different vertical jump performances in female gymnasts, compared with routine training control groups. A total of 881 records were initially identified through systematic database and Google Scholar searches. Of these, 11 studies (12 reports) met the inclusion criteria and were included in the meta-analysis. The main finding of the meta-analysis indicates that PJT elicits a moderate positive effect on vertical jump performance in female gymnasts compared with a control condition; however, statistically significant effects were observed only for CMJ. Analysis of moderator variables revealed no significant subgroup differences for training duration, total number of sessions, or training frequency ($p > 0.05$). The certainty of evidence for the meta-analyzed outcomes ranged from very low to low.

The present meta-analysis demonstrated a statistically significant effect of PJT on CMJ height in female gymnasts, with a moderate effect magnitude compared with controls. The CMJ test was the most frequently reported outcome among the included studies and was assessed under standardized conditions with hands placed on the hips, thereby isolating the contribution of the lower limbs to vertical displacement (i.e., jump height). The included studies showed moderate heterogeneity ($I^2 = 41\%$). The magnitude of the effect ($ES = 0.62$) is consistent with previous meta-analyses in female adolescent team-sport athletes, which also report moderate, significant effect on CMJ height following plyometric interventions [54]. PJT-induced improvements in lower-limb explosive strength (as reflected by vertical jump performance) may be mediated by a combination of structural and neuromuscular adaptations, including an increased proportion of type IIx muscle fibers, greater tendon stiffness, more efficient motor unit recruitment, improved intermuscular coordination, and more refined stretch-reflex regulation [55–57]. These findings suggest that although routine gymnastics training already incorporates a considerable number of jumping exercises designed to improve physical fitness across age-group development [58,59], the inclusion of additional structured PJT programs yields greater benefits. However, Feng et al. [60] demonstrated that cluster-based plyometric training, which involves performing repetitions within sets with short intra-set rest intervals, can produce greater improvements in CMJ performance and reactive strength index (RSI) than traditional plyometric training in young female artistic gymnasts (approximately 15 years of age). This may be attributed to reduced fatigue accumulation and better maintenance of power output during repeated efforts, although the underlying mechanisms were not directly examined in the study. Similarly, Zhao et al. [61] showed that young competitive vaulting female gymnasts (7.53 ± 0.45 years) exhibited significant dominant–non-dominant lower-limb asymmetries, particularly in CMJ-derived power, as well as in balance and muscle activation. Higher levels of CMJ power asymmetry ($>10.4\%$) were associated with reduced ground reaction force, while asymmetries exceeding 14.8% were associated with lower run-up velocity, suggesting that these power imbalances may negatively influence vaulting performance. Furthermore, the CMJ appears to be a sensitive and practically useful measure for differentiating the physical fitness profiles of gymnasts across apparatus specializations, with floor exercise and vault specialists demonstrating significantly superior performance, highlighting the greater importance of lower-limb explosive strength in these events [62].

The SLCMJ also showed a moderate effect magnitude ($SMD = 0.68$), although the result did not reach statistical significance. This test was performed in a similar manner to the CMJ but using a single-leg take-off and landing. Heterogeneity across studies was

low to moderate. SLCMJ performance relies on efficient SSC utilization, rapid transition from eccentric to concentric muscle action, and coordinated triple extension, all of which are key targets of PJT [3]. The interventions included in the analyzed studies [44,45,47] comprised both unilateral and bilateral plyometric exercises. Zhang et al. [63] showed that the effects of unilateral and bilateral PJT on athletic performance are task-specific. Unilateral plyometric interventions were particularly effective in improving single-leg jump performance, sprint speed, and change-of-direction ability, whereas bilateral PJT was more effective for enhancing bilateral jump performance. Similarly, another study [64] reported that unilateral plyometric exercises produced faster improvements in both single-leg and double-leg jump performance compared with bilateral protocols in women.

Evidence from the present meta-analysis indicates a moderate effect magnitude, although not statistically significant, of PJT on CMJFA performance in female gymnasts, suggesting potentially meaningful but inconsistent adaptations. Stojanović et al. [11] reported a large but also not significant effect of PJT on CMJFA in a female athlete sample including mainly team sports, with high heterogeneity ($I^2 = 92.68\%$) across analyzed studies. CMJFA performance is strongly dependent on intersegmental coordination, particularly the precise timing between arm downswing and lower-limb extension, which enhances net vertical impulse through a more effective transfer of momentum from the upper to the lower body and improved utilization of the SSC mechanism. Recent biomechanical evidence confirms that coordinated arm swing increases peak ground reaction force, reduces braking-phase inefficiencies, and increases take-off velocity, making CMJFA more technically demanding [65]. However, in gymnastics disciplines, take-offs coordinated with arm swing are an integral component of jumps, leaps, and vaulting actions [66]. Furthermore, Gateva [67] demonstrated that CMJFA height, used as an important diagnostic tool for assessing physical fitness, is significantly correlated with back muscle strength in rhythmic gymnasts.

The present findings suggest that incorporating PJT into standard gymnastics practice may provide additional benefits for DJ performance in female gymnasts. However, the lack of statistical significance, together with the imprecision indicated by wide confidence intervals, requires cautious interpretation of this effect. The trend toward improved outcomes in the experimental groups is consistent with the theoretical premise that plyometric exercises enhance SSC efficiency; however, the magnitude and reliability of this effect appear to vary considerably across studies. This variability is reflected in the moderate heterogeneity ($I^2 = 68.6\%$). The DJ was performed with gymnasts standing upright on an elevated platform of predetermined height (20–30 cm), instructed to step off the box without an initial jump, and to keep their hands on their hips to eliminate the influence of arm swing. Upon ground contact, an immediate maximal vertical jump was executed, with the aim of minimizing ground contact time while maximizing jump height, thereby emphasizing SSC efficiency [44,47,50,51]. The results reported by Marina and Torrado [68] indicated that vertical jump tests, such as CMJ, CMJFA, and SJ, demonstrated stable reliability in children aged 8–10 years, whereas plyometric tasks such as the DJ showed evidence of learning effects and lower test–retest consistency. Importantly, gymnastics training at this developmental stage does not appear to enhance the reliability of these performance measures, although it is associated with higher overall vertical jump performance. Pasacantando et al. [69] showed that young rhythmic gymnasts (12.15 ± 2.26 years) exhibited significant lower-limb asymmetries during drop vertical jumps, with greater concentric force production in the preferred limb and higher braking-phase force absorption in the non-preferred limb, highlighting the influence of sport-specific unilateral demands and the importance of addressing these asymmetries for musculoskeletal health. The study by Dallas et al. [70] showed that both types of warm-up plyometric exercises (double

tuck jumps and leg-blocking actions) improved DJ performance in young female artistic gymnasts (10.10 ± 2.17 years), increasing jump height, flight time, and take-off velocity shortly after exercise. The more sport-specific exercise (leg-blocking action) produced stronger effects, supporting its use in warm-ups to enhance jumping performance. The study by Moeskops et al. [71] showed that elite female gymnasts demonstrate a higher proportion of “good” SSC function than recreational athletes, reflected in a significantly greater RSI and a ground-contact strategy characterized by later peak braking force and a shorter propulsive phase. These findings indicate that DJ kinetic variables can effectively distinguish competitive level and help inform training targets.

The present findings indicate that the inclusion of PJT alongside standard gymnastics practice may have a moderate effect size magnitude on SJ performance in female gymnasts; however, the overall effect did not reach statistical significance, warranting cautious interpretation. The moderate level of heterogeneity ($I^2 = 54.1\%$) further suggests variability across studies. The SJ test was performed from a static half-squat position with approximately 90° knee flexion, an upright trunk, feet shoulder-width apart, and hands placed on the hips throughout the movement to eliminate the influence of arm swing. From this position, gymnasts executed a maximal vertical jump without any preparatory countermovement, ensuring a purely concentric action for vertical jump performance as assessed by jump height [44,51–53]. Both DJs and SJs, when used as conditioning exercises, have been shown to effectively enhance CMJ performance in elite rhythmic gymnasts (18.25 ± 2.55 years). DJs elicited an earlier increase in performance at 30 s post-exercise, whereas SJs produced a greater potentiation effect at 9 min post-exercise. Additionally, higher maximal strength levels were positively associated with greater post-activation performance enhancement responses for both protocols [72].

The present meta-analysis showed that plyometric interventions lasting longer than 7 weeks significantly improved vertical jump performance (CMJ) in female gymnasts, with a small effect size and no heterogeneity ($I^2 = 0.0\%$), whereas shorter interventions showed non-significant but moderate effects with substantial variability ($I^2 = 71.8\%$). Similarly, interventions involving more than 14 sessions produced significant improvements (small effect) with highly consistent results ($I^2 = 0.0\%$), while protocols with up to 14 sessions showed non-significant moderate effects and considerable heterogeneity ($I^2 = 81.1\%$). Importantly, no statistically significant subgroup differences were observed for either intervention duration or number of sessions. Regarding training frequency, interventions performed >2 times per week showed a moderate positive effect ($ES = 1.052$), whereas lower-frequency interventions demonstrated a small effect ($ES = 0.415$). However, neither subgroup reached statistical significance, and no significant subgroup differences were identified ($p > 0.05$). A previous meta-analysis examining the effects of plyometric training on CMJ and DJ performance in gymnasts, which combined male and female participants and excluded rhythmic gymnasts, also reported no significant subgroup differences according to training characteristics (i.e., duration, number of sessions, and frequency), likely due to the small number of reports and high heterogeneity across studies [24]. However, Ma et al. [19] showed that an 8-week jumping interval training program in youth female aerobic gymnasts led to significant improvements in CMJ performance, with twice-weekly training producing greater gains than once-weekly training, although both frequencies were effective in eliciting positive adaptations compared with control conditions.

Moderate heterogeneity observed for the outcomes may be attributed to differences in participant characteristics and intervention design across studies. In particular, variability in gymnastic discipline, age, competitive level, training duration, weekly training frequency, and specific characteristics of the plyometric jump training (PJT) protocols may have contributed to the observed heterogeneity. Importantly, two of the included studies [45,47] im-

plemented combined training interventions, where PJT was supplemented with functional core or strength training. This limits the ability to attribute the observed effects exclusively to PJT, as the additional training stimuli may have also influenced the outcomes.

Limitations

Several limitations of the present systematic review and meta-analysis should be acknowledged. The number of studies included in the meta-analyses for each jump modality was relatively small. Limited sample sizes may reduce statistical power, increase uncertainty around ES estimates, and limit robust assessment of publication bias or small-study effects. As fewer than ten studies were available for any single outcome, formal statistical tests for publication bias (e.g., Egger's test) were not feasible [41].

Differences in intervention characteristics (e.g., exercise selection, intensity, progression) and participant characteristics (e.g., age, training level) may have contributed to heterogeneity across studies, and variability in training protocols may have influenced the observed outcomes.

Future well-controlled experimental studies with larger sample sizes and more standardized training protocols are needed to strengthen the evidence base and allow for more precise meta-analytic estimates.

5. Conclusions

This systematic review and meta-analysis demonstrate that PJT produces a moderate positive effect on vertical jump performance (CMJ, SLCMJ, CMJFA, SJ, and DJ) in female gymnasts, including athletes from rhythmic gymnastics, Gymnastics for All, aerobic gymnastics, and artistic gymnastics, compared with routine gymnastics training alone. Importantly, these effects were observed in addition to routine gymnastics training, which already includes a substantial volume of jumping-based activities. However, the certainty of the evidence ranged from very low to low across the analyzed outcomes, indicating limited confidence in the estimated effects. Therefore, the findings should be interpreted with caution, particularly for outcomes based on small sample sizes, wide confidence intervals, and non-significant pooled effects. Plyometric training-related moderator variables, including training duration (≤ 7 vs. > 7 weeks), total number of sessions (≤ 14 vs. > 14 sessions), and training frequency (≤ 2 vs. > 2 sessions per week), do not appear to meaningfully influence the effects.

PJT appears to be a practical and effective strategy for improving vertical jump performance in female gymnasts, although not all observed effects reached statistical significance. However, further research is needed to refine optimal training parameters. Overall, these findings support the inclusion of PJT as a complement to standard gymnastics practice while also highlighting the need for higher-quality, discipline-specific research in female gymnasts.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app16136763/s1>: PRISMA 2020 Checklist [73].

Author Contributions: All authors (K.S.-P. and T.P.-I.) participated in conceptualization, methodology, data collection, formal analysis, data curation, writing—original draft preparation, and writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the University of Physical Culture, Kraków, Poland, grant number 398/BS/INoS/2025. The APC was financed within the program of the Minister of Science in Poland under the name 'Regional Excellence Initiative' in the years 2024–2027 (project number: RID/SP/0027/2024/01) in the amount of PLN 4,053,904.00.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on RODBUK, University of Physical Culture in Krakow, Faculty of Physical Education. <https://akf.rodbuk.pl/dataset.xhtml?persistentId=doi:10.58145/AKF/LCC9TN> (accessed on 30 June 2026).

Conflicts of Interest: The authors declare no conflicts of interest.

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