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Effects of high-intensity training on jumping performance among athletes: a systematic review with meta-analysis

Xinzhi Wang[1], Kim Geok Soh[1]✉, Shamsulariffin Samsudin[1], Long Li[2], Chunqing Liu[1], Min Sun[1] & Shuzhen Ma[1,3]✉

This review aims to conduct a meta-analysis of the impact of high-intensity training (HIT) on athlete jumping performance. As of May 2024, we conducted a comprehensive search on PubMed, Web of Science, SCOPUS, and EBSCOhost databases in accordance with the PRISMA guidelines. Use the PEDro scale to evaluate the methodological quality of the included study. Meta-analysis of random effects model calculations. Conduct subgroup analysis (participant age, gender, training experience, intervention length and frequency). 18 high-quality studies met the inclusion criteria, including 490 athletes aged between 6 and 27 years old. The results showed that high-intensity interval training (HIIT) has a moderate effect on athlete jumping performance (ES = 0.918), while high-intensity functional training (HIFT) has a small effect on athlete jumping performance (ES = 0.581). The sub analysis of moderating variables includes 19 datasets. Compared with the control group, HIT has a positive impact on the jumping performance of athletes. The training experience, age, gender, intervention frequency, and intervention length of participants did not have a significant impact on the jumping performance of athletes, indicating the applicability of HIT as a training method. However, more extensive exercise experiments are needed to obtain stronger evidence.

Keywords High-intensity interval training, CrossFit, High-intensity functional training, Athletes, Jumping performance

Physical fitness is intrinsically intertwined with bodily well-being, encompassing diverse facets such as cardiovascular endurance, muscular strength, flexibility, and neuromuscular coordination[1]. Within these aspects, explosive force and jumping proficiency assume pivotal roles across various sports disciplines including track and field, basketball, volleyball, and football[2]. The capacity to exert maximal force in minimal time, often denoted as "rate of force development" (RFD), stands as a critical determinant for executing explosive manoeuvres like jumping, sprinting, and swift directional shifts[3]. Hence, refining jumping prowess has emerged as a primary focus for athletes and Coaches alike, aiming to procure competitive edges within their respective sports fields. Conventional methodologies for enhancing jumping abilities typically prioritize resistance training, plyometric exercises, and movement-specific drills to fortify muscular strength, power, and neuromuscular coordination[4,5]. Although proven efficacious in augmenting jumping capacities, recent attention has veered towards high-intensity training (HIT) as an innovative and auspicious avenue for further amplifying jumping performance[6].

Wahl et al. conducted a theoretical analysis of HIT and found that it helps promote biomechanical changes in athletes, adaptation of the central nervous and endocrine systems, as well as an increase in myoglobin, capillary density, and fibre type characteristics, thereby improving exercise efficiency[1]. Unlike conventional moderate-intensity training modalities, HIT epitomizes brief bursts of maximal or near-maximal exertion, punctuated by fleeting recovery interludes, orchestrated to instigate physiological adaptations and elevate athletic performance[7]. Within myriad sports, including basketball, volleyball, track and field, and gymnastics, jumping prowess assumes paramount significance, where the capacity to generate vertical and horizontal displacement stands as a decisive determinant of triumph[8–10]. The principle of HIT theory suggests that this therapy swiftly and harmoniously stimulates muscle fibres, precipitating neuromuscular adaptations and optimizing the recruitment

[1]Department of Sports Studies, Faculty of Educational Studies, University Putra Malaysia, Serdang 43400, Selangor, Malaysia. [2]Faculty of Physical Education, Ningxia Normal University, Guyuan City 756000, Ningxia, China. [3]College of Public Administration, Guilin University of Technology, 541004 Guilin, China. ✉email: kims@upm.edu.my; msz20210607@126.com

of motor units, thereby empowering athletes to manifest augmented strength in jumping endeavours[6]. Feito et al. underscored the pivotal role of neuromuscular adaptation ensuing HIT interventions in refining jumping performance[11]. Drawing from HIT protocols geared towards bolstering explosive power, such as high-intensity functional training (HIFT), high-intensity interval training (HIIT), and sprint interval training (SIT), which target fast-twitch muscle fibres and incite adaptations conducive to enhanced power output[1]. HIT is an umbrella term that includes various training methods, such as HIIT and HIFT. HIIT is characterized by alternating periods of intense exercise and recovery, typically focusing on cardiovascular fitness and power[12]. In contrast, HIFT emphasizes functional movements that replicate real-life activities or sport-specific motions, targeting strength, power, and mobility[13]. Both forms of training fall under the HIT category but differ in their structure and specific physiological adaptations.

Cumulative research consistently demonstrates that HIT interventions markedly augment maximal strength and power, consequently amplifying jumping performance necessitating both strength and power[14]. HIIT epitomizes a singular modality of training, characterized by brief bouts of high-intensity exertions succeeded by prescribed periods of rest or low-intensity recuperation. Essentially, it encapsulates abbreviated bouts of aerobic/cardiovascular training[11,12,15]. Such regimens, exemplified by SIT and Tabata, wield the potential to augment the anaerobic energy system, fortify muscle endurance, and refine neuromuscular coordination, thereby fostering enhancements in sprinting and jumping capabilities[12,16]. Ojeda-Aravena et al. and Bauer et al. have evidenced that HIIT profoundly enhances peak power output and jumping performance, underscoring its efficacy in fortifying power athleticism among athletes[5,17].

HIFT represents a multifaceted training regimen distinguished by perpetually evolving functional movements, encompassing an array of movement types and durations, interspersed with abbreviated or negligible rest intervals[13,18]. HIFT amalgamates aerobic and anaerobic exercises, eliciting greater muscular recruitment than recurrent HIIT sessions. It aids in fostering the development and refinement of muscle strength and power, fostering muscle hypertrophy[19,20]. HIFT regimens, comprising arduous squats, rigorous pulls, and plyometric drills, have been shown to elicit notable enhancements in muscle strength, power output, and rate of strength development, all pivotal for eliciting explosive jumping prowess[18]. For instance, Mischenko et al. showcased that high-intensity functional training markedly enhances lower body strength and power, consequently augmenting athlete jumping capabilities[21]. Diverse investigations have delved into the ramifications of HIT on myriad facets of athletic performance, spanning strength, explosiveness, speed, and endurance, yielding affirmative outcomes[16,22–24]. Nonetheless, the specific impact of HIT on athlete jumping performance remains relatively underexplored, warranting a comprehensive meta-analysis of extant literature to elucidate the advantages conferred by HIT on athlete jumping prowess.

This systematic review and meta-analysis endeavour to bridge this lacuna in the literature by scrupulously scrutinizing collective evidence pertaining to the influence of HIT interventions on athlete jumping performance. This scrutiny probes a fundamental inquiry: Can high-intensity training engender superior athlete jumping performance compared to traditional training? Consequently, we aspire that this meta-analysis will furnish invaluable insights into the efficacy of HIT in ameliorating athlete jumping performance.

Methods

Protocol and registration

The system review follows the latest Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and has been registered on the PROSPERO website. The registration number is CRD42024537771.

Search strategy

We collected all data from four databases (Web of Science, PubMed, Scopus, and EBSCOhost) before December 2023. The main keywords of Boolean search strategy were ("high-intensity training" OR "high-intensity exercise" OR "sprint interval training" OR "high-intensity interval training" OR "Tabata" OR "CrossFit" OR "vigorous physical exercise" OR "high-intensity functional training") AND ("physical fitness" OR "fitness, physical" OR "physical" OR "health" OR "fitness" OR "physical training" OR "strength" OR "jumping" OR "power"). In addition, we manually search for all included references and Google Scholar to prevent relevant articles from being overlooked as much as possible.

Eligibility criteria

This review was included in the article according to the PICOS framework standards[25]. The following summarizes the inclusion and exclusion criteria for systematic reviews and meta-analyses. The following were the inclusion criteria for this study: (1) Participants were healthy athletes; (2) The intervention method must be high-intensity training as an alternative to the standard training method, while maintaining an equal overall training volume between the intervention group and the control group; (3) The included studies must include a control group; (4) The evaluation recorded at least one baseline and follow-up measurement related to jumping performance; And (5) The included studies must be randomized controlled trials.

The following were the exclusion criteria: (1) Injured individuals; (2) Physical training without high-intensity training, such as resistance training or plyometric training; (3) Intervention methods include combining high-intensity training with psychological intervention, or using high-intensity training as a supplementary training strategy; (4) No control group; (5) Lack of data to calculate the effect size; And (6) Abstract, oral presentation, reviews, study protocol, observational studies, case report.

Study selection

The article selection process for this system review is shown in Fig. 1. The endnote x9 scheme included the filtering results of all databases. Repetitive studies have been eliminated. Two reviewers (XW and SM) conducted a secondary screening of the title, keywords, and abstract of the articles based on the inclusion criteria. Then, the reviewer conducts a comprehensive evaluation of the remaining papers based on participant characteristics, intervention projects, comparator, and outcomes. Throughout the screening process, any differences between the two reviewers were resolved with the assistance of a third reviewer (KGS).

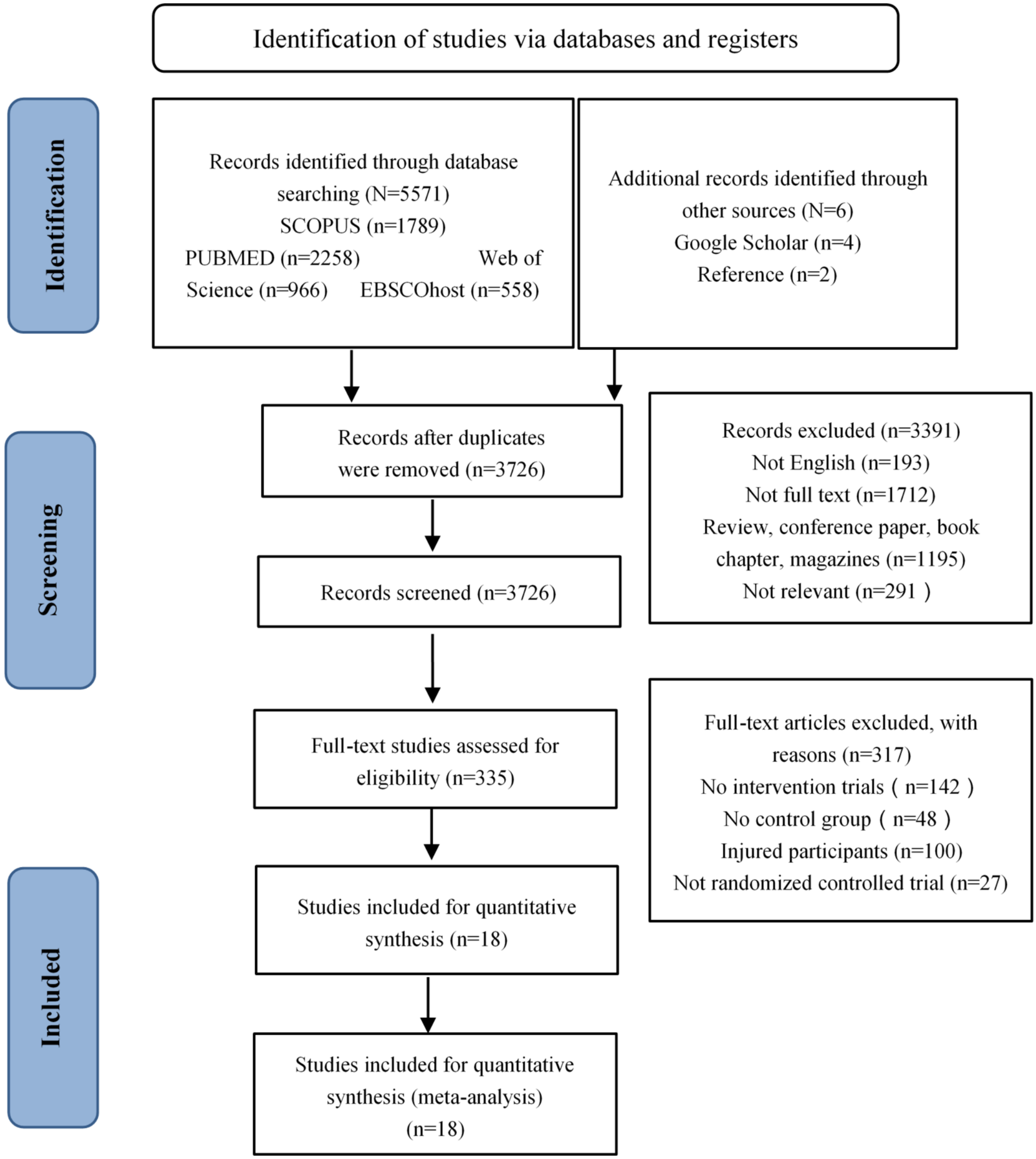


Fig. 1. Flow chart of PRISMA article screening.

Data extraction

Two independent reviewers (XW and SM) extracted data based on inclusion criteria, including name, publication year, age, gender, sample size, training experience, sports project, intervention frequency, intervention length, and outcomes. The extracted information and data were verified by a third reviewer (KGS).

Study quality assessment

The two authors (XW, SM) independently used the PEDro scale to evaluate the methodological quality of the article. The PEDro scale is an effective and reliable tool for grading the quality of experimental research methods[26]. The third author (KGS) conducted a cross check on the results, and all three reviewers reached a consensus. The PEDro scale includes 11 items for method quality assessment[27]. For each item that meets the criteria, the total score of the PEDro scale is added by one point, and the maximum score for each article is 10 points. Project 1 was excluded from the study quality assessment. Articles with a total score of 6–10 on the PEDro scale are considered to be of high quality, articles with a total score of 4–5 are considered to be of medium quality, and articles with a total score of ≤ 3 are considered to be of poor quality[26]. Any differences between the two independent reviewers (XW and SM) were resolved through communication with the third reviewer (KGS).

Data synthesis and statistical analysis

At least two studies are required for meta-analysis[28]. Therefore, we only conducted a meta-analysis on studies with three or more reported results data. Extract the mean and standard deviation from articles pre-post intervention. If the data in the article cannot be obtained, we contacted the corresponding author of the article to obtain the corresponding information. If the required data cannot be obtained, the study was excluded. This meta-analysis used inverse variance random-effects model to calculate the effect size (ES; Hedge's g) and 95% confidence interval (95% CI) of the measured results. The following explanations were used to determine: trivial effect size (< 0.2), small effect size (0.20–0.6), moderate effect size (0.6–1.2), large effect size (1.2–2.0), very large effect size (2.0–4.0), and extremely large effect size (> 4.0)[29]. The I^2 statistic was used to evaluate heterogeneity in studies, with 25% or lower indicating low heterogeneity, 25–75% indicating moderate heterogeneity, and over 75% considered high heterogeneity[30]. The Egger test was used to assess the risk of publication bias[31]. In addition, sensitivity analysis was conducted by deleting individual studies. All data analysis was conducted using comprehensive meta-analysis software (CMA; Biostat et al., 3rd version).

Additional analysis

To investigate the potential effects of regulatory factors, subgroup analysis was conducted. Based on the author's discussion and intervention characteristics, we pre-selected relevant heterogeneity sources that may affect training effectiveness: intervention frequency, intervention length, and measurement type. Grouping participants based on median intervention length (i.e. ≤ 6 weeks vs.> 6 weeks), training frequency (i.e. ≤ 3 times vs. > 3 times per week), and measurement type (vertical jumping vs. horizontal jump). If at least three studies provided data for each moderating factor, calculate the median. In addition, the gender (male vs. female), training experience (≥ 5 years vs. < 5 years), and age of athletes (≥ 16 years old vs. < 16 years old) were also considered potential moderating factors.

Results

Study selection

Figure 1 shows the article selection process for this systematic review. Initially, 5571 articles were discovered through database search. In addition, 6 articles were discovered through Google Scholar and Reference List. After manually removing duplicates through Endnote software, 3726 articles were retained. Then, by filtering the titles and abstracts, it was found that 335 articles were identified as meeting the criteria for full-text analysis. However, after conducting a full-text screening, it was found that 317 articles were excluded. Ultimately, 18 articles met all inclusion criteria for this systematic review and meta-analysis.

Study quality assessment

The PEDro checklist was used to evaluate the quality of each article that met the inclusion criteria, and the results in Table 1 showed that the score range of the PEDro scale was 4 to 6. The PEDro scale score for twelve studies is 4[32–34] or 5[5,16,21–23,35–38], indicating moderate methodological quality in the article. The score for six studies is 6[39–44], indicating a high methodological quality of the article. Therefore, the methodological quality of the articles included in this system review was rated as moderate to high.

Participant characteristics

Table 2 reports the characteristics of the participants included in the study, as shown below. (1) Article publication year: The research was published from 2010 to 2023. (2) Sample size: There were a total of 490 participants in 18 studies, with sample sizes ranging from 10 to 60. (3) Age: Participants are between 10 and 27 years old. (4) Gender: Among the eighteen studies, two focused on women[21,35], eight focused on men[16,23,32,36,38–41], five studied mixed genders[5,34,37], and three did not report gender[22,33,42]. (5) Training Program: Two studies involve football players[33,42], three studies involve handball players[22,35,36], two studies involve tennis players[23,32], four studies involve taekwondo players[16,21,37,43], three studies involve judo players[34,40,44], one study involves basketball players[41], one study involves karate players[5], one study involves wrestlers[38], and one study involves Kickboxers[39].

Intervention characteristics

Table 2 presents information on the intervention characteristics of this study, as shown below. (1) Intervention type: HIT is the main intervention method in all studies. Six studies used HIFT as the intervention

Study	N°1	N°2	N°3	N°4	N°5	N°6	N°7	N°8	N°9	N°10	N°11	Total*
Ferrete et al., 2014	1	1	0	1	0	0	0	1	1	1	1	6
Alonso-Fernández et al., 2017	1	1	0	1	0	0	0	0	1	1	1	5
Wang et al., 2022	1	1	0	1	0	0	0	0	0	1	1	4
Wang et al., 2023	0	1	0	1	0	0	0	0	0	1	1	4
Fernandez-Fernandez et al., 2017	1	1	0	1	0	0	0	1	1	1	1	5
Buchheit et al., 2010	1	1	0	1	0	0	0	1	1	1	1	6
Song et al., 2023	1	1	0	1	0	0	0	1	0	1	1	5
Ouergui et al., 2020	0	1	0	1	0	0	0	1	1	1	1	6
Uchoa et al., 2021	0	1	0	1	0	0	0	0	0	1	1	4
Ribeiro et al., 2015	0	1	0	1	0	0	0	0	1	1	1	5
Hammami et al., 2021	0	1	0	1	0	0	0	0	1	1	1	5
Ojeda-Aravena et al., 2021a	1	1	0	1	0	0	0	0	1	1	1	5
Yüksel et al., 2019	0	1	0	1	0	0	0	0	1	1	1	5
Ojeda-Aravena et al., 2021b	1	1	0	1	0	0	0	1	1	1	1	6
Avetisyan et al., 2022	0	1	0	1	0	0	0	1	1	1	1	6
Mischenko et al., 2021	0	1	0	1	0	0	0	0	1	1	1	5
Ambroży et al., 2022	1	1	0	1	0	0	0	1	1	1	1	6
Romanova., 2023	0	1	0	1	0	0	0	0	1	1	1	5

Table 1. Methodological quality assessment for inclusion studies. Note: A detailed explanation for each PEDro scale item can be accessed at https://www.pedro.org.au/english/downloads/pedro-scale. *From a possible maximal punctuation of 10.

method[21,32,37,38,40,45], while twelve studies used HIIT for intervention[5,16,22,23,33–36,41–44]. Moreover, three out of these twelve HIIT interventions used sprint as the intervention method[16,41,44]. One study combines squat, deep jumps, CMJ, and sprint as the intervention method[42], One study combines jumping and sprinting as the intervention method[36], One study uses tabata as the intervention method[35], and high-intensity training for specific sports such as tennis[22], basketball[16], judo[23,34], taekwondo[43], and karate[5]. (2) Intervention frequency: Among the eighteen studies, one intervention frequency was once a week[41], seven interventions frequency was twice a week[16,22,35,36,40,42,44], seven interventions frequency was three times a week[5,21,34,37,38,43,45], one intervention frequency was four times a week[33], and two interventions frequency was five times a week[23,32]. (3) Intervention duration: Five studies lasted for 4 weeks[5,32,41,43,44], three studies lasted for 6 weeks[16,33,34], five studies lasted for 8 weeks[22,35,36,38,45], one study lasted for 10 weeks[23], one study lasted for 26 weeks[42], one study lasted for 20 weeks[40], one study lasted for 36 weeks[21], and the longest study lasted for 48 weeks[37].

Effect of high-intensity training on jumping performance

This meta-analysis's results indicate that the impact of HIT on athlete jumping performance has a moderate effect size (ES = 0.819; 95% CI = 0.532–1.106; p < 0.001; Egger's test p = 0.214; N = 502; Fig. 2). The overall heterogeneity of this effect is low (Q = 23.179; I^2 = 9.4%). In the meta-analysis process, the relative weight range for each study is 3.33–6.26%.

Effect of high-intensity interval training on jumping performance

The impact of HIIT on athlete jumping performance has a moderate effect size (ES = 0.918; 95% CI 0.516–1.319; p < 0.001; Egger's test p = 0.675; N = 242; Fig. 3). The overall heterogeneity of this effect is low (Q = 15.651; I^2 = 4.157%). During the analysis process, the relative weight of each study ranged from 5.17 to 7.24%.

Effect of high-intensity functional training on jumping performance

The main impact analysis of the impact of HIFT on jumping performance, there was a small effect size (ES = 0.581; 95% CI 0.307–0.856; p < 0.001; Egger test p = 0.533; N = 210; Fig. 4). The overall heterogeneity of this effect is low (Q = 4.978; I^2= 0.000%). During the analysis process, the relative weight of each study ranged from 9.26 to 29.05%.

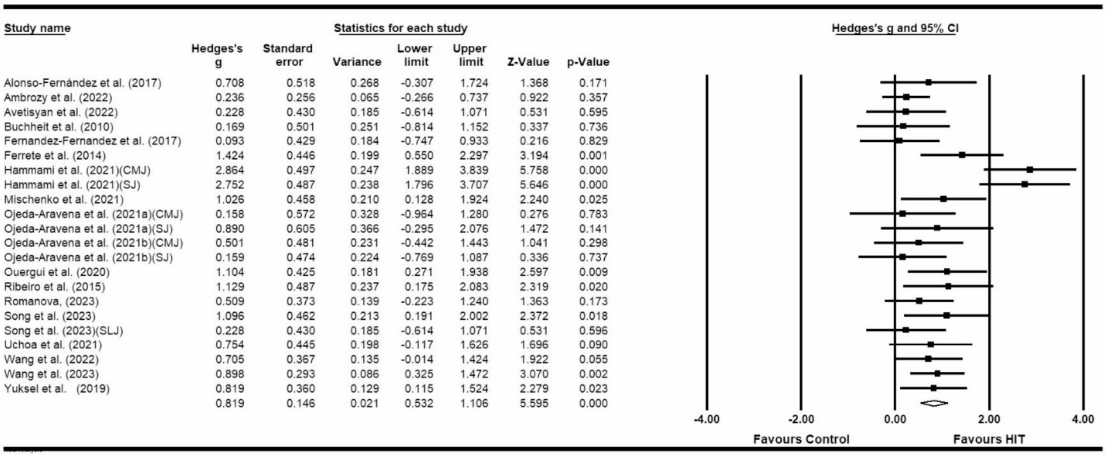
Effect of moderator variables

The results of the mediation variable analysis are shown in Table 3. The subgroups analysed are jump tests (vertical and horizontal jump tests), participant training experience (< 5 years and ≥ 5 years), intervention frequency (< 3 times per week and ≥ 5 times per week), intervention length (< 6 weeks and ≥ 6 weeks), gender (male and female), and age (< 16 years and ≥ 16 years). For the measurement results, the Vertical jumping test showed a moderate effect size (ES = 0.994, 95% CI 0.632–1.356, p < 0.001), while the Horizontal jumping test showed a smaller effect size (ES = 0.394, 95% CI 0.067–0.720, p = 0.018). For training experience, participants with less than five years of training experience showed moderate effect size (ES = 0.816, 95% CI 0.484–1.148, p < 0.001), while participants with five years of training experience and above also showed moderate effect size (ES = 0.932, 95% CI 0.403–1.461, p = 0.001). For intervention frequency, studies with less than 3 interventions

Study	Participants characteristics					Intervention	Comparator	Outcomes
	N	Sex	Age	Sport	Exp			
Ferrete et al., 2014	24	NR	8.3 ± 0.3 years	Soccer	1.75 years	Freq.: 2 times/week Time: 30 min Length: 26 weeks	EG: Combined strength and high-intensity training (e.g., squat, deep jumps, CMJ, and sprint) CG: No extra training group	CMJ↑
Alonso-Fernández et al., 2017	14	14 F	15.2 ± 0.6 years	Handball	at least 5 years	Freq.: 2 times/week Time: NR Length: 8 weeks	EG: High-intensity interval training (e.g., tabata) CG: Usual training	CMJ↑
Wang et al., 2022	30	NR	19.8 ± 0.4 years	Soccer	12.014 ± 0.499 years	Freq.: 4 times/week Time: NR Length: 6 weeks	EG: Hight-intensity interval training group (NR) CG: Traditional aerobic resistance training group	Bounce height↑
Wang et al., 2023	50	50 M	19.96 ± 1.49 years	Tennis	7.725 ± 1.07 years	Freq.: 5 times/week Time: NR Length: 4 weeks	EG: Hight-intensity functional training program (e.g., CrossFit) CG: Routine training program	RUOFVJ↑
Fernandez-Fernandez et al., 2017	20	NR	14.8 ± 0.1 years	Tennis	6 ± 1.2 years	Freq.: 2 times/week Time: NR Length: 8 weeks	EG: Mixed high-intensity intermittent runs and tennis-specific training (e.g., tennis) CG: Tennis-specific drills only training	CMJ↑
Buchheit et al., 2010	14	14 M	15.8 ± 0.9 years	Handball	NR	Freq.: 1 times/week Time: 60 min Length: 4 weeks	EG: Hight-intensity interval training group (e.g., sprint) CG: Speed/agility (S/A) training	CMJ↑
Song et al., 2023	30	30 M	25.7 ± 2.0 years	Basketball	8.5 ± 2.1 years	Freq.: 2 times/week Time: 30 min Length: 6 weeks	EG1: Hight-intensity interval training group (e.g., Basketball-specific sprint) EG2: Hight-intensity interval training group (e.g., sprint) CG: Traditional training group	CMJ↑ SLJ↑
Ouergui et al., 2020	24	18 F/6 M	16 ± 1 years	Taekwondo	2–7 years	Freq.: 2 times/week time: NR length: 4 weeks	EG: Hight-intensity interval training group (e.g., repeated sprint) CG: Control group	CMJ↑
Uchoa et al., 2021	20	5 F/15 M	17.4 ± 2.9 years	Judo	a minimum of 2 years	Freq.: 3 times/week Time: 60 min Length: 6 weeks	EG: Hight-intensity interval training group (e.g., uchi-komi without throwing) CG: Auto-oriented uchi-komi training group	CMJ↑
Ribeiro et al., 2015	18	18 M	21.7 ± 5.0 years	Brazilian Jiu-Jitsu	at least two years	Freq.: 5 times/week Time: 60 min Length: 10 weeks	EG: Hight-intensity interval training group (e.g., Brazilian Jiu-Jitsu) CG: Traditional training group	CMJ↑
Hammami et al., 2021	32	32 M	16.6 ± 0.5 years	Handball	at least 5 years	Freq.: 2 times/week Time: 30 min Length: 8 weeks	EG: Combined HIIT with plyometric exercise (e.g., horizontal jump, sprint) CG: Regular training	CMJ↑ SJ↑
Ojeda-Aravena et al., 2021a	10	6 M/4F	15.2 ± 1.6 years	Karate	at least 3 years	Freq.: 3 times/week Time: 90 min Length: 4 weeks	EG: Hight-intensity interval training group (e.g., Karate) CG: Usual training	CMJ↑ SJ↑
Yuksel et al., 2019	32	32 M	21.72 ± 1.40 years	Wrestling	NR	Freq.: 3 times/week Time: 20 min Length: 8 weeks	EG: Hight-intensity functional training group (e.g., CrossFit) CG: Classical wrestling practice program	SJ↑
Ojeda-Aravena et al., 2021b	16	5 F/11 M	17.4 ± 2.9 years	Taekwondo	6 ± 1.9 years	Freq.: 3 times/week Time: 90 min length: 4 weeks	EG: Hight-intensity interval training group (e.g., Taekwondo) CG: Traditional training group	CMJ↑ SJ↑
Avetisyan et al., 2022	20	20 M	11 ± 0.64 years	Judo	an average of 3 years	Freq.: 2 times/week Time: 20 min Length: 20 weeks	EG: Hight-intensity functional training group (e.g., CrossFit) CG: Traditional training program	SLJ↑
Mischenko et al., 2021	20	20 F	16–17 years	Taekwondo	NR	Freq.: 3 times/week Time: 95 min Length: 36 weeks	EG: Hight-intensity functional training group (e.g., CrossFit, Rope-skipping, Tai-bo, Ki-bo, and Fightball) CG: Routine wrestling training	SLJ↑
Ambroży et al., 2022	60	60 M	20.07 ± 1.46 years	Kickboxing	8.1 ± 4.24 years	Freq.: 3 times/week Time: 10 min Length: 8 weeks	EG: Hight-intensity functional training group (e.g., CrossFit) CG: Conventional kickboxing training program	SLJ↑
Romanova., 2023	56	28 F/28 M	10–12 years	Taekwondo	3 weeks	Freq.: 3 times/week Time: NR Length: 48 weeks	EG: Hight-intensity functional training group (e.g., CrossFit) CG: Circular training program	SLJ↑

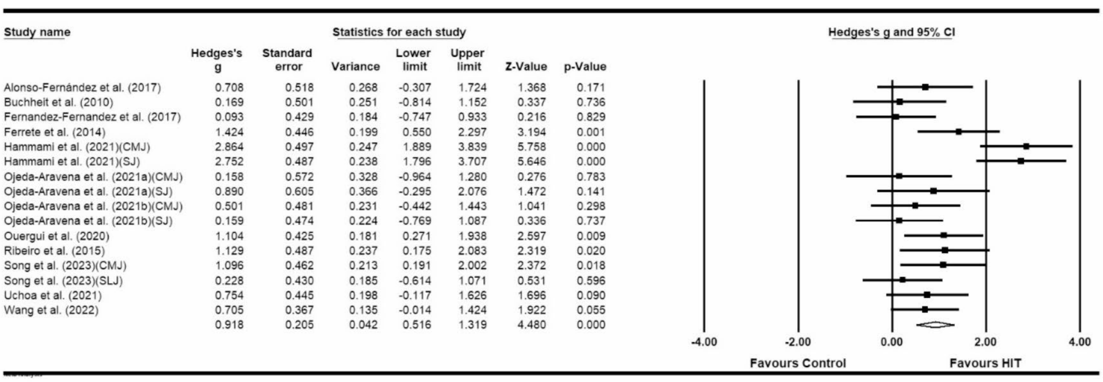
Table 2. Summary of the studies' characteristics included in this review. *M* male, *F* female, *NR* no record, *Exp* experience, *EG* experiment group, *CG* control group, *Freq* frequency, *CMJ* countermovement jump, *SLJ* standing long jump, *RUOFVJ* run-up one-foot vertical jump touch height.

per week showed moderate effectiveness (ES = 1.095, 95% CI 0.459–1.732, $p = 0.001$), and studies with 3 or more interventions per week also showed moderate effectiveness (ES = 0.645, 95% CI 0.415–0.875, $p < 0.001$). For intervention length, studies with interventions < 6 weeks showed moderate effect sizes (ES = 0.683, 95% CI 0.339–1.026, $p < 0.001$), and studies with interventions ≥ 6 weeks also showed moderate effect sizes (ES = 0.967, 95% CI 0.562–1.373, $p < 0.001$). For gender, studies that focused on males (ES = 1.040, 95% CI 0.474–1.605, $p < 0.001$), studies that focused on females (ES = 0.937, 95% CI 0.228–1.646, $p = 0.010$), and studies that focused on both males and females (ES = 0.633, 95% CI 0.270–0.996, $p = 0.001$) all showed moderate effects. In terms of age, studies focusing on athletes under 16 years old showed moderate effect size (ES = 0.514, 95% CI 0.190–0.838, $p = 0.002$), while studies focusing on athletes over 16 years old showed moderate effect size (ES = 0.982, 95% CI 0.592–1.372, $p < 0.001$). The Q-statistics of subgroup analysis showed a significant difference in jump



Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Alonso-Fernández et al. (2017)	0.708	0.518	0.268	-0.307	1.724	1.368	0.171
Ambrozy et al. (2022)	0.236	0.256	0.065	-0.266	0.737	0.922	0.357
Avetisyan et al. (2022)	0.228	0.430	0.185	-0.614	1.071	0.531	0.595
Buchheit et al. (2010)	0.169	0.501	0.251	-0.814	1.152	0.337	0.736
Fernandez-Fernandez et al. (2017)	0.093	0.429	0.184	-0.747	0.933	0.216	0.829
Ferrete et al. (2014)	1.424	0.446	0.199	0.550	2.297	3.194	0.001
Hammami et al. (2021)(CMJ)	2.864	0.497	0.247	1.889	3.839	5.758	0.000
Hammami et al. (2021)(SJ)	2.752	0.487	0.238	1.796	3.707	5.646	0.000
Mischenko et al. (2021)	1.026	0.458	0.210	0.128	1.924	2.240	0.025
Ojeda-Aravena et al. (2021a)(CMJ)	0.158	0.572	0.328	-0.964	1.280	0.276	0.783
Ojeda-Aravena et al. (2021a)(SJ)	0.890	0.605	0.366	-0.295	2.076	1.472	0.141
Ojeda-Aravena et al. (2021b)(CMJ)	0.501	0.481	0.231	-0.442	1.443	1.041	0.298
Ojeda-Aravena et al. (2021b)(SJ)	0.159	0.474	0.224	-0.769	1.087	0.336	0.737
Ouergui et al. (2020)	1.104	0.425	0.181	0.271	1.938	2.597	0.009
Ribeiro et al. (2015)	1.129	0.487	0.237	0.175	2.083	2.319	0.020
Romanova, (2023)	0.509	0.373	0.139	-0.223	1.240	1.363	0.173
Song et al. (2023)	1.096	0.462	0.213	0.191	2.002	2.372	0.018
Song et al. (2023)(SLJ)	0.228	0.430	0.185	-0.614	1.071	0.531	0.596
Uchoa et al. (2021)	0.754	0.445	0.198	-0.117	1.626	1.696	0.090
Wang et al. (2022)	0.705	0.367	0.135	-0.014	1.424	1.922	0.055
Wang et al. (2023)	0.898	0.293	0.086	0.325	1.472	3.070	0.002
Yuksel et al. (2019)	0.819	0.360	0.129	0.115	1.524	2.279	0.023
	0.819	0.146	0.021	0.532	1.106	5.595	0.000

Fig. 2. Forest plot of the impact of HIT on jumping performance of athletes compared to the control group. The displayed values represent the effect size (Hedges' g) of 95% confidence intervals (Cl). The size of the square shown in the figure represents the statistical weight.



Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Alonso-Fernández et al. (2017)	0.708	0.518	0.268	-0.307	1.724	1.368	0.171
Buchheit et al. (2010)	0.169	0.501	0.251	-0.814	1.152	0.337	0.736
Fernandez-Fernandez et al. (2017)	0.093	0.429	0.184	-0.747	0.933	0.216	0.829
Ferrete et al. (2014)	1.424	0.446	0.199	0.550	2.297	3.194	0.001
Hammami et al. (2021)(CMJ)	2.864	0.497	0.247	1.889	3.839	5.758	0.000
Hammami et al. (2021)(SJ)	2.752	0.487	0.238	1.796	3.707	5.646	0.000
Ojeda-Aravena et al. (2021a)(CMJ)	0.158	0.572	0.328	-0.964	1.280	0.276	0.783
Ojeda-Aravena et al. (2021a)(SJ)	0.890	0.605	0.366	-0.295	2.076	1.472	0.141
Ojeda-Aravena et al. (2021b)(CMJ)	0.501	0.481	0.231	-0.442	1.443	1.041	0.298
Ojeda-Aravena et al. (2021b)(SJ)	0.159	0.474	0.224	-0.769	1.087	0.336	0.737
Ouergui et al. (2020)	1.104	0.425	0.181	0.271	1.938	2.597	0.009
Ribeiro et al. (2015)	1.129	0.487	0.237	0.175	2.083	2.319	0.020
Song et al. (2023)(CMJ)	1.096	0.462	0.213	0.191	2.002	2.372	0.018
Song et al. (2023)(SLJ)	0.228	0.430	0.185	-0.614	1.071	0.531	0.596
Uchoa et al. (2021)	0.754	0.445	0.198	-0.117	1.626	1.696	0.090
Wang et al. (2022)	0.705	0.367	0.135	-0.014	1.424	1.922	0.055
	0.918	0.205	0.042	0.516	1.319	4.480	0.000

Fig. 3. Forest plot of the impact of HIIT on jumping performance of athletes compared to the control group. The displayed values represent the effect size (Hedges' g) of 95% confidence intervals (Cl). The size of the square shown in the figure represents the statistical weight.

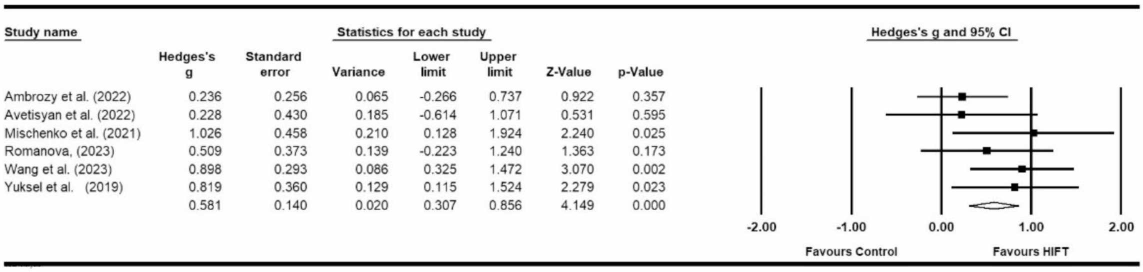


Fig. 4. Forest plot of the impact of HIFT on jumping performance compared to the control group. The displayed values represent the effect size (Hedges' g) of 95% confidence intervals (Cl). The size of the square shown in the figure represents the statistical weight.

Subgroup	Studies	ES (95% CI)	*P* value	Q-statistics
Measurement tested				
Vertical jumping	17	0.994 (0.632–1.356)	< 0.001[a]	
Horizontal jump	5	0.394 (0.067–0.720)	0.018[a]	
Overall	22	0.640 (0.405–0.875)	< 0.001[a]	(Q = 5.833; df (Q) = 1; *P* = 0.016)[b]
Training experience (year)				
< 5	8	0.816 (0.484–1.148)	< 0.001[a]	
≥ 5	11	0.932 (0.403–1.461)	0.001[a]	
Overall	19	0.849 (0.567–1.130)	< 0.001[a]	(Q = 0.132; df (Q) = 1; *P* = 0.716)
Intervention frequency (per week)				
< 3	10	1.095 (0.459–1.732)	0.001[a]	
≥ 3	12	0.645 (0.415–0.875)	< 0.001[a]	
Overall	22	0.697 (0.481–0.913)	< 0.001[a]	(Q = 1.701; df (Q) = 1; *P* = 0.192)
Intervention length (week)				
< 6	7	0.683 (0.339–1.026)	< 0.001[a]	
≥ 6	15	0.967 (0.562–1.373)	< 0.001[a]	
Overall	22	0.802 (0.539–1.064)	< 0.001[a]	(Q = 1.101; df (Q) = 1; *P* = 0.294)
Sex				
Male	10	1.040 (0.474–1.605)	< 0.001[a]	
Female	2	0.937 (0.228–1.646)	0.010[a]	
Male & Female	7	0.633 (0.270–0.996)	0.001[a]	
Overall	19	0.781 (0.500–1.061)	< 0.001[a]	(Q = 1.625; df (Q) = 2; *P* = 0.444)
Age (year)				
< 16	8	0.514 (0.190–0.838)	0.002[a]	
≥ 16	14	0.982 (0.592–1.372)	< 0.001[a]	
Overall	22	0.705 (0.456–0.954)	< 0.001[a]	(Q = 3.268; df (Q) = 1; *P* = 0.071)

Table 3. Mediation analysis of the impact of HIT on jumping performance. [a]Significant difference within a group; [b]significant difference between groups. *95%CI* 95% confidence interval, *ES* effect size.

test results ($P = 0.016$). Further subgroup analysis showed no significant differences in Q-statistics for training experience ($P = 0.716$), intervention frequency ($P = 0.192$), intervention length ($P = 0.294$), gender ($P = 0.444$), and age ($P = 0.071$).

Discussion

This meta-analysis examined the impact of HIT on athlete jumping performance. Principal findings indicate that in the study based on HIT replacing traditional training, juxtaposed with control group, HIT engenders a moderate yet statistically significant upsurge in athlete jumping performance. The increase in jumping performance attributable to HIT resonates with antecedent investigations. Ferrete et al. reported that a 26-week HIT regimen augments the reverse jumping proficiency of adolescent soccer athletes.

Moreover, this meta-analysis discerned that, compared to the control group, HIIT exerts a notable and moderate impact on athlete jumping performance (ES = 0.918). The systematic review assessed the jumping prowess of handball, soccer, basketball, taekwondo, judo, tennis, and karate athletes post-HIIT training, eliciting substantial enhancements. The theoretical underpinning of HIIT lies in the principles of overload and adaptation, coupled with the concept of interval training, renowned for its efficacy in refining both aerobic and anaerobic physical fitness[11]. Myriad studies attest to the capacity of HIIT regimens to refine neuromuscular coordination and motor unit recruitment, thereby amplifying the velocity of force generation and development during explosive movement such as jumping[12,17]. Additionally, adaptations in anaerobic energy metabolism induced by HIIT, encompassing augmented phosphocreatine stores and heightened lactate tolerance, bolster the capacity to sustain high-intensity exertion during jumping tasks, delay the occurrence of fatigue[1,15]. Numerous studies evidence supports the positive impact of HIIT on athlete jumping performance. For instance, Engel et al. ascertained, through their meta-analysis, a significant enhancement in jumping performance across diverse athletic sports post-HIIT intervention. Furthermore, individual investigations have underscored the favourable outcomes of HIIT on jumping abilities. Ojeda-Aravena et al. investigated the effect of a 4-week HIIT intervention on the vertical jumping performance of karate athletes, discerning noteworthy improvements in both squat jump and countermovement jump metrics.

This study analysed the effects of various high-intensity training methods on athletes' jumping performance. According to the principle of training specificity, the similarity between training content and the target sport influences training outcomes. We found that studies employing plyometric-based training typically demonstrated more pronounced improvements in jumping performance, likely due to the high correlation between the explosive power demands of plyometric exercises and jump performance. In contrast, high-intensity training focused on sprints or tennis may exhibit a weaker effect on jump performance, as these movement patterns do not fully align with those required for jumping. This underscores the importance of selecting appropriate high-intensity training types to enhance target performance outcomes.

HIFT epitomizes a high-intensity training methodology underscored by its emphasis on augmenting overall motor proficiency and functional capacities[47]. This meta-analysis showed that compared to the control group, HIFT had a significant small impact on athlete jumping performance (ES = 0.581). The theory of HIFT emphasizes functional movement through imitating multi-joint, multi-planar movements of real-life activities[48]. Although this type of training includes exercises such as jump box and plyometric training[20], its overall focus is broader and not as effective in targeting explosive power as high-intensity interval training. In addition, athletes accustomed to traditional training modalities or specific sports-related strength and conditioning may experience an initial learning curve when introduced to HIFT. Movements such as kettlebell swings, Turkish get-ups, or burpees, commonly used in HIFT, may be unfamiliar to some athletes and require a period of adaptation. This adaptation period could reduce the immediate effectiveness of HIFT for improving jump performance, especially in the short-term, leading to smaller observed effects.

Although the effect is relatively small, HIFT still has practical value for athletes, especially those who require high-level overall functional fitness in addition to explosive power. In sports where multi joint, whole-body coordination, endurance, and jumping ability are equally important (such as mixed martial arts, rugby, or basketball), HIFT can provide comprehensive training stimulation. The influence of HIFT on athlete jumping capabilities can be ascribed to its emphasis on explosive power, multi-joint movements, and its efficacy in eliciting neuromuscular coordination, strength enhancement, and muscle hypertrophy[49]. By amalgamating advanced modalities such as box jumps, depth jumps, and rebounding exercises, HIFT regimens task athletes with engendering maximal force in minimal time, thereby refining their capacity to generate explosive power during jumping[20,50]. In comparison with HIIT, there exists a paucity of study exploring the impact of HIFT on jumping proficiency. Six studies underscored the positive outcomes of HIFT interventions on the jumping performance of wrestlers, judoka, kickboxers, tennis players, and taekwondo athletes. These findings align with those of Ambrozy et al.[45], who scrutinized the effect of HIFT on the jumping performance of amateur wrestlers, noting significant improvements in standing long jump performance following an 8-week HIFT intervention.

Subgroup analysis outcomes, evaluated through our systematic review, furnish invaluable insights into the disparate effects of HIT on athlete jumping performance across various subpopulations. Our meta-analysis elucidates that HIT exerts a significant impact on both vertical and horizontal jump assessments, with vertical jumps exhibiting a moderate effect and horizontal jumps demonstrating a more subdued impact. This indicates that HIT may wield particular efficacy in refining athletes' vertical jumping performance. Furthermore, analyses predicated on participant training experience underscore that both novice athletes (with less than 5 years of training experience) and seasoned athletes (with 5 years or more of training experience) accrue benefits from HIT interventions, with both cohorts manifesting moderate efficacy. This emphasized the versatility of HIT as a training modality capable of enhancing athlete jumping performance across varying proficiency levels. Concerning intervention frequency, HIT interventions conducted at lower and higher frequencies (i.e., less than 3 times per week and 3 or more times per week) elicit a moderate effect on jumping performance enhancement.

This implies that provided the intensity and calibre of training are upheld, the frequency of HIT sessions may not markedly influence its efficacy in augmenting jumping abilities. Similarly, the duration of HIT interventions appears not to significantly impact their effectiveness in enhancing jumping performance, suggesting that athletes can realize meaningful enhancements in jumping abilities across diverse durations of HIT programs. Additionally, our analyses grounded in gender and age demographics indicate that HIT intervention strategies exert a discernible effect on enhancing the jumping performance of athletes across different genders and age brackets.

Overall, despite discernible variances in the magnitude of impact noted across diverse subgroups, our subgroup analysis indicates that HIT generally proves efficacious in augmenting athlete jumping performance across varied contexts. Nevertheless, additional research is needed to deepen our comprehension of the precise factors influencing the efficacy of HIT intervention on jumping abilities, encompassing optimal training frequency, duration, and length, as well as potential differences between male and female athletes.

The methodological quality assessment of this systematic review highlights that primary discrepancies were concentrated in the implementation of follow-up and intention-to-treat (ITT) analysis, potentially introducing attrition and selection bias in the final sample analysis. Although the methodological quality of included studies ranged from moderate to high, most were of sufficient quality to substantiate the conclusions drawn in this review. The high consistency of results across studies further indicates a positive impact of high-intensity training on jump performance. Consequently, we recommend that future research designs aim to minimise biases, such as through establishing detailed follow-up protocols and incorporating ITT analysis, which can reduce selection bias and more accurately reflect the true effects of interventions.

Limitations

There are several limitations to this system review. Firstly, this review only includes English articles sourced from PubMed, Web of Science, SCOPUS, and EBSCOhost databases, potentially overlooking relevant publications from other sources. Secondly, a majority of studies lack precise delineation of intervention durations, precluding analysis of intervention duration within this review. Thirdly, this review does not encompass other sports pertinent to jumping performance, such as badminton, volleyball, and gymnastics. Fourthly, owing to a limited number of studies, this systematic review only compares HIT against traditional control groups, omitting comparisons with alternative training modalities like plyometric training and small-sided games. Fifthly, this system review excludes studies that use HIT as an additional training load. The results only apply to situations where HIT is used as a substitute for traditional training methods, and caution should be exercised when applying these findings to environments where HIT is added to existing training schemes. Sixthly, the binary approach employed in moderating variable analysis, involving median segmentation of continuous data, may engender residual ambiguity and diminish statistical robustness. Lastly, given the scarcity of studies focused specifically on female, the applicability of our meta-analysis results to the female population may be limited.

Conclusions

This systematic review and meta-analysis results indicate that compared to the control group, HIT has a positive impact on athlete jumping performance. The training experience, age, gender, intervention frequency, and intervention length of participants did not have a significant impact on the jumping performance of athletes, indicating the applicability of HIT as a training method. However, in order to fully determine the positive impact of HIT theory on jumping performance, it is necessary to conduct research on a wider range of movements.

Data availability

All relevant data are within the paper and its Supporting information files. The corresponding authors can be contacted for more information.

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Author contributions
XW and SM conducted literature screening and data analysis. XW was responsible for writing the manuscript. KGS supervised the entire writing process. All authors have reviewed the content of the article. LL, SS, and SM provided software support, CL and MS were responsible for the validation section.

Declarations

Competing interests
The authors declare no competing interests.

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Correspondence and requests for materials should be addressed to K.G.S. or S.M.

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