

# EFFECTS OF A FLYWHEEL ECCENTRIC OVERLOAD TRAINING ON ATHLETIC PERFORMANCE: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Review

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## Abstract:

This study aims to assess the effects of resistance training using flywheel devices—hereafter referred to as flywheel eccentric overload training (FEOT)—compared to conventional resistance training (including external-load resistance training and bodyweight training) on athletic performance, providing theoretical guidance and practical foundations for the scientific development of diverse training regimens. Randomized controlled trials on FEOT interventions (up to January 2024) from five Chinese/English databases were analyzed using Review Manager 5.3 and Stata-SE 15 for meta-analysis, subgroup analysis, and bias assessment. A total of 21 articles were included in this study (14 high-quality, seven moderate-quality based on the methodological assessment). The results of the meta-analysis revealed that, compared to the conventional resistance training, FEOT significantly outperformed in countermovement jump (CMJ; SMD=0.60, 95% CI: 0.26 to 0.95,  $p<.05$ ), change-of-direction performance (COD; SMD=-1.23, 95% CI: -1.89 to -0.57,  $p<.05$ ), and short-distance sprint performance (SMD=-0.56, 95% CI: -0.89 to -0.23,  $p<.05$ ). Subgroup analysis revealed: 1) Compared to the external-load resistance training, FEOT improved CMJ (SMD=0.56, 95% CI: 0.13 to 0.99,  $p<.05$ ), short-distance sprinting (SMD=-0.61, 95% CI: -0.95 to -0.27,  $p<.05$ ), and COD (SMD=-1.34, 95% CI: -2.38 to -0.30,  $p<.05$ ), but not 1RM strength (SMD=0.30, 95% CI: -0.50 to 1.10,  $p>.05$ ). 2) Versus the bodyweight training, FEOT improved CMJ (SMD=0.77, 95% CI: 0.25 to 1.29,  $p<.05$ ) and COD (SMD=-1.16, 95% CI: -2.02 to -0.30,  $p<.05$ ), but not short-distance sprinting (SMD=-0.31, 95% CI: -1.47 to 0.86,  $p>.05$ ). Our conclusions are: 1) compared with the conventional resistance training, FEOT yields greater improvements in CMJ, COD, and short-sprint performance and 2) FEOT outperforms external-load resistance training across CMJ, COD, and short-sprint outcomes, and shows clear advantages over bodyweight training in CMJ and COD, supporting its value as an effective strategy for enhancing explosive lower-limb performance.

**Keywords:** *flywheel training, eccentric overload, athletic performance, external-load resistance training, bodyweight training*

## Introduction

In recent years, flywheel eccentric overload training (FEOT) has become an increasingly important modality in athletic conditioning. FEOT is a form of resistance training that emphasizes eccentric overload through the use of a rotating flywheel device. By providing continuously variable inertial resistance throughout the concentric-eccentric cycle, it elicits greater mechanical tension and neuromuscular stimulation, thereby enhancing strength and power while contributing to injury prevention (de Hoyo, et al., 2015; Hody, Croisier, Bury, Rogister, & Leprince, 2019; Meylan, Nosaka, Green, & Cronin, 2010). Unlike traditional resistance training, which often relies on fixed or free weights, FEOT allows for an *overload* stimulus

specifically during the eccentric phase while maintaining adequate resistance in the concentric phase (Su & Yin, 2022). Thus, FEOT combines the principles of resistance and eccentric training in a single, integrated modality. Researchers evaluated the effects of FEOT on athletic performance of professional handball players and elite soccer players, among others. The results showed that FEOT led to a 5-13% increase in muscle hypertrophy, accompanied by an increase in jumping height and strength (Fernandez-Gonzalo, Lundberg, Alvarez-Alvarez, & de Paz, 2014; Norrbrand, Fluckey, Pozzo, & Tesch, 2008), an 11-39% improvement in maximal voluntary contraction strength (Seynnes, de Boer, & Narici, 2007; Tesch, Ekberg, Lindquist, & Trieschmann, 2004), and significant enhancements

in lower body one-repetition maximum strength, vertical jump height, and short-distance sprint performance (de Hoyo, et al., 2015; Maroto-Izquierdo, García-López, & de Paz, 2017a). FEOT offers dynamic, adaptive resistance and enhances muscle power output by developing the stretch-shortening cycle (SSC) (Su, 2021). With the widespread use of FEOT in sports, it has become a critical component of daily training for athletes.

Currently, a meta-analysis has evaluated the effects of FEOT on athletic performance compared with bodyweight training (Vicens-Bordas, Esteve, Fort-Vanmeerhaeghe, Bandholm, & Thorborg, 2018). In addition, other scholars' meta-analysis has examined the effects of FEOT versus external-load resistance training on outcomes such as muscle strength and jump performance in athletes (Maroto-Izquierdo, et al., 2017b; Raya-González, Prat-Luri, López-Valenciano, Sabido, & Hernández-Davó, 2021a). However, there is no consensus on whether FEOT offers a distinct advantage over conventional resistance training methods, such as bodyweight and external-load resistance training. Therefore, this meta-analysis aims to quantitatively compare FEOT with external-load resistance training and bodyweight training across key athletic performance outcomes—including maximum strength, jump performance, sprint ability, and change of direction—so as to clarify their relative efficacy. This approach should provide evidence-based recommendations for optimized training practices that can benefit athletes by maximizing exercise outcomes.

## Methods

### Literature inclusion and exclusion criteria

The inclusion criteria for the literature were developed based on the PICOST framework (Li, et al., 2014), covering four aspects: types of studies, intervention subjects, interventions, and outcomes. All criteria were reviewed by two independent evaluators, and in cases of disagreement, discussions were held with the third evaluator.

*Literature inclusion criteria.* 1) The included studies were required to be randomized controlled trials (RCTs) published in Chinese or English. 2) The participants should be athletes with prior training experience. 3) The intervention group undergoes training using flywheel devices, while the control group engages in conventional resistance training, such as barbell or machine-based resistance (external-load resistance training) or bodyweight training. 4) The intervention duration must be at least four weeks. 5) The primary outcome measures should include vertical jump height, change-of-direction performance (COD), short-distance sprinting, and one-repetition maximum strength (1RM).

*Literature exclusion criteria.* 1) Studies that are literature reviews or published in languages other than Chinese or English. 2) Studies with incomplete or non-extractable data. 3) Studies involving untrained healthy adults or elderly individuals. 4) Duplicated publications, studies without full text, or conference papers.

### Literature search

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, two researchers independently and blindly conducted the literature search. The databases searched included: CNKI, Wanfang Data, PubMed, Web of Science, and EBSCO SPORT-Discus. The search covered the period from the establishment of each database to January 2024. Keywords such as *flywheel resistance training*, *flywheel training*, *flywheel exercise*, *eccentric overload*, *isoinertial training*, *isoinertial exercise*, *inertial training*, *gravity-independent training*, *YOYO exercise* were used to conduct the literature search. A secondary search of the reference lists from the retrieved studies was also performed to expand the literature included.

### Data extraction

Based on research requirements, the extracted data from the literature primarily includes the lead author, year of publication, basic information about the participants, intervention content and protocol, as well as relevant outcome measures. The outcome data were extracted from the post-intervention values for both the experimental and control groups. If outcome data were not directly available from the text, contacting the corresponding author was the preferred method for obtaining the necessary information.

### Quality assessment

Assessing the methodological quality of the included studies is a crucial indicator of research rigor. This study utilized the PEDro scale (Physiotherapy Evidence Database), which has a maximum score of 10 points. Each criterion met earns one point (from 11 items, with the first item not included in the total score). Two independent reviewers conducted the evaluations based on the established criteria. High-quality studies scored 9-10 points, moderate-quality studies 6-8 points, fair-quality studies 4-5 points, and studies below four points were considered of low quality (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003).

### Data synthesis and analysis

This study employed either a fixed-effect model or a random-effect model to analyze the included studies based on the degree of heterogeneity. Statis-

tical analysis was performed using Review Manager 5.3 for forest plots and subgroup analysis, while publication bias was assessed with Egger's method via Stata-SE 15. The evidence quality assessment was conducted using the GRADE grading system, which classifies the quality of evidence into four levels: high, moderate, low, and very low. Due to the variations in measurement methods and units, standardized mean difference (SMD) was used to present outcomes, with a 95% confidence interval (CI). Statistical significance was determined by p-values, with  $p \leq .05$  indicating a significant combined effect across studies. Heterogeneity was assessed using the  $I^2$  statistic: 25-50% signified low heterogeneity, 50-75% indicated moderate heterogeneity, and  $I^2 \geq 75\%$  represented high heterogeneity. Forest plots were used to present the statistical significance of the combined effect size (SMD), with  $SMD > 0.5$  indicating a small effect size,  $0.5 \leq SMD < 0.8$  indicating a medium effect size, and  $SMD \geq 0.8$  representing a large effect size (Zheng, 2013).

## Results

### Literature search and screening

A total of 1,420 studies were identified across CNKI, Wanfang Data, PubMed, Web of Science, and EBSCO SPORTDiscus based on the search keywords. After screening titles and abstracts, non-flywheel intervention studies were excluded, leaving 131 relevant studies. Following a full-text review, an additional 110 studies were excluded due to interventions involving elderly subjects, bed rest therapy, rehabilitation, short-term acute effects, non-randomized control trials, and mismatched control interventions. Ultimately, 21 studies met the inclusion criteria, with their characteristics summarized in Table 1 and the full selection process shown in Figure 1.

### Characteristics of the included studies

Among the 21 included studies, a total of 515 athletic individuals were analyzed, 45 females and 470 males. Participants included youth athletes

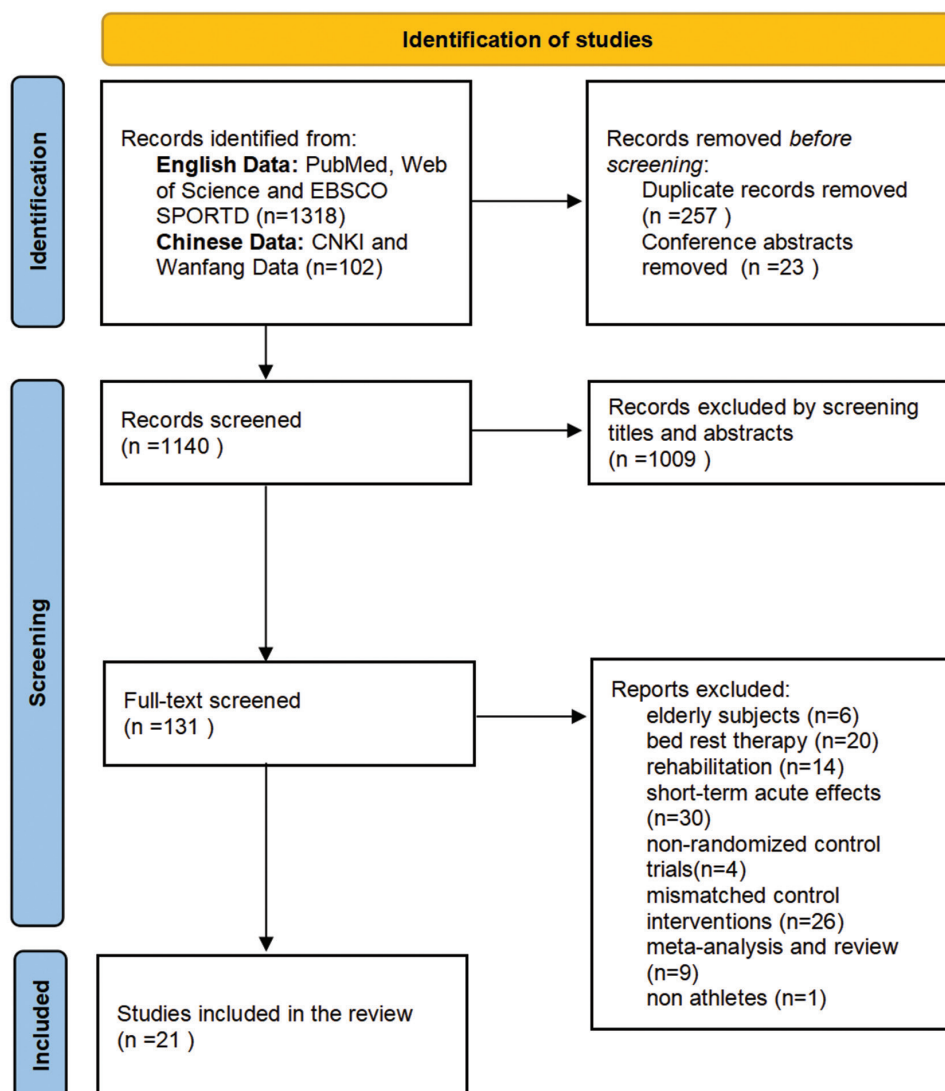


Figure 1. Flowchart of literature search and study selection.

from various sports, amateur athletes and professional athletes. The FEOT groups performed exercises such as Bulgarian split squats, lunges, lateral squats, and bilateral squats. Conventional resistance training typically involved barbell exercises, with some studies incorporating bodyweight training (di Cagno, et al., 2020; Fiorilli, et al., 2020; Monajati, Larumbe-Zabala, Goss-Sampson, & Naclerio, 2021; Raya-González, Castillo, de Keijzer, & Beato, 2021b; Sanchez-Sanchez, et al., 2019) and fixed equipment (Maroto-Izquierdo, et al., 2017a). Intervention periods ranged from four to 12 weeks. Outcome measures included countermovement jump (CMJ), short-distance sprints (10 m, 20 m, 30 m, 60 m), 1RM, and COD. Tables 1 and 2 present the basic characteristics of the studies included.

**Quality assessment of the included studies**

Among the 21 studies included, 14 were of relatively high quality ( $\geq 6$  points), and seven were of moderate quality (4-5 points). All studies clearly specified participant inclusion criteria, though few employed blinding methods. Baseline characteristics were consistent across studies. Overall, the methodological quality of the included studies was relatively high (Table 1).

**Meta-analysis: Comparison of FEOT vs. conventional resistance training on CMJ**

Out of the studies included, 18 assessed CMJ as an outcome measure. As shown in Figure 2, the

meta-analysis demonstrated a moderate effect of FEOT on CMJ performance compared with conventional resistance training (SMD=0.60, 95% CI: 0.26 to 0.95,  $p < .05$ ). Subgroup analysis further revealed that FEOT was more effective than bodyweight training (SMD=0.77, 95% CI: 0.25 to 1.29,  $p < .05$ ) and external-load resistance training (SMD=0.56, 95% CI: 0.13 to 0.99,  $p < .05$ ).

**Meta-analysis: Comparison of FEOT vs. conventional resistance training on short-distance sprints**

Eighteen of the included studies evaluated short-distance sprint as an outcome. As shown in Figure 3, the meta-analysis demonstrated a moderate improvement in short-distance sprint performance following FEOT compared with conventional resistance training (SMD=-0.56, 95% CI: -0.89 to -0.23,  $p < .05$ ). Subgroup analysis further revealed that FEOT significantly improved short-distance sprint compared to external-load resistance training (SMD=-0.61, 95% CI: -0.95 to -0.27,  $p < .05$ ), though it showed no significant advantage over bodyweight training (SMD=-0.31, 95% CI: -1.47 to 0.86,  $p > .05$ ).

**Meta-analysis: Comparison of FEOT vs. conventional resistance training on COD**

Nine of the included studies assessed COD ability as an outcome. The meta-analysis (Figure 4) showed that FEOT had a large effect on COD performance compared with conventional resist-

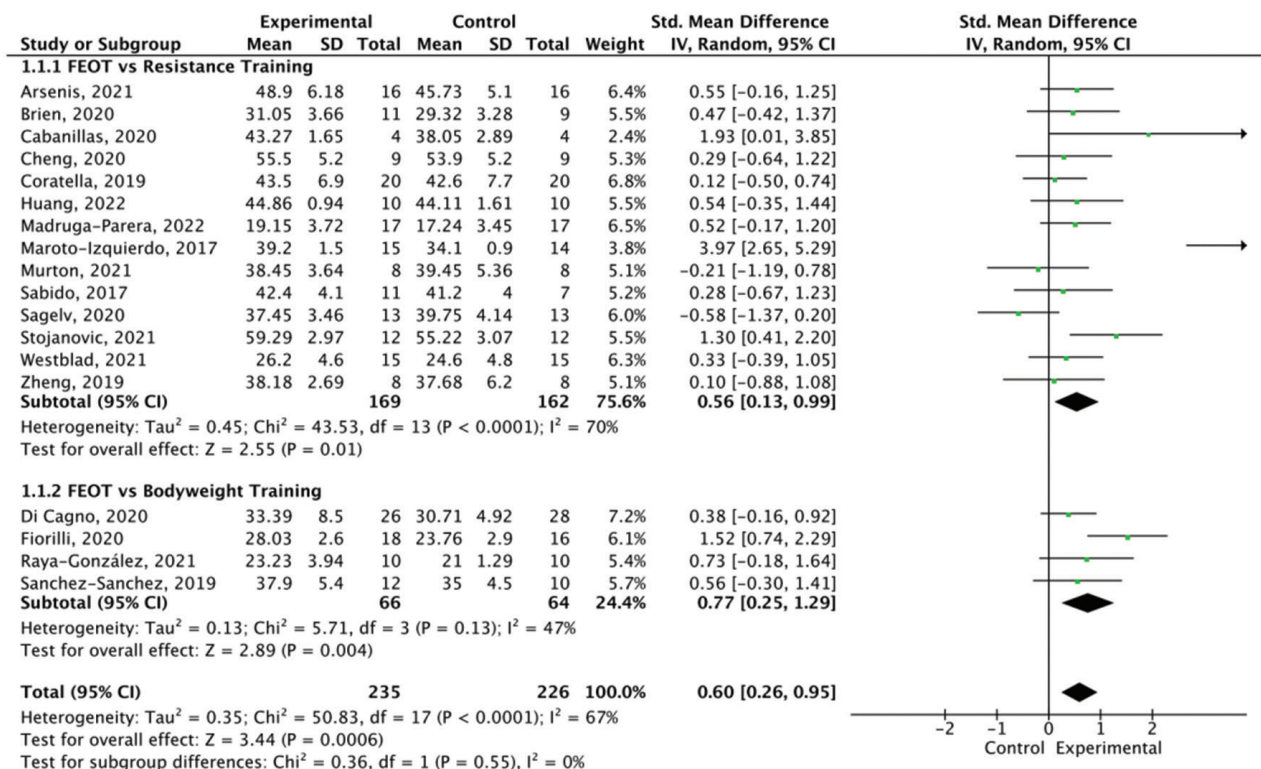


Figure 2. The influence of FEOT and conventional resistance training on CMJ.

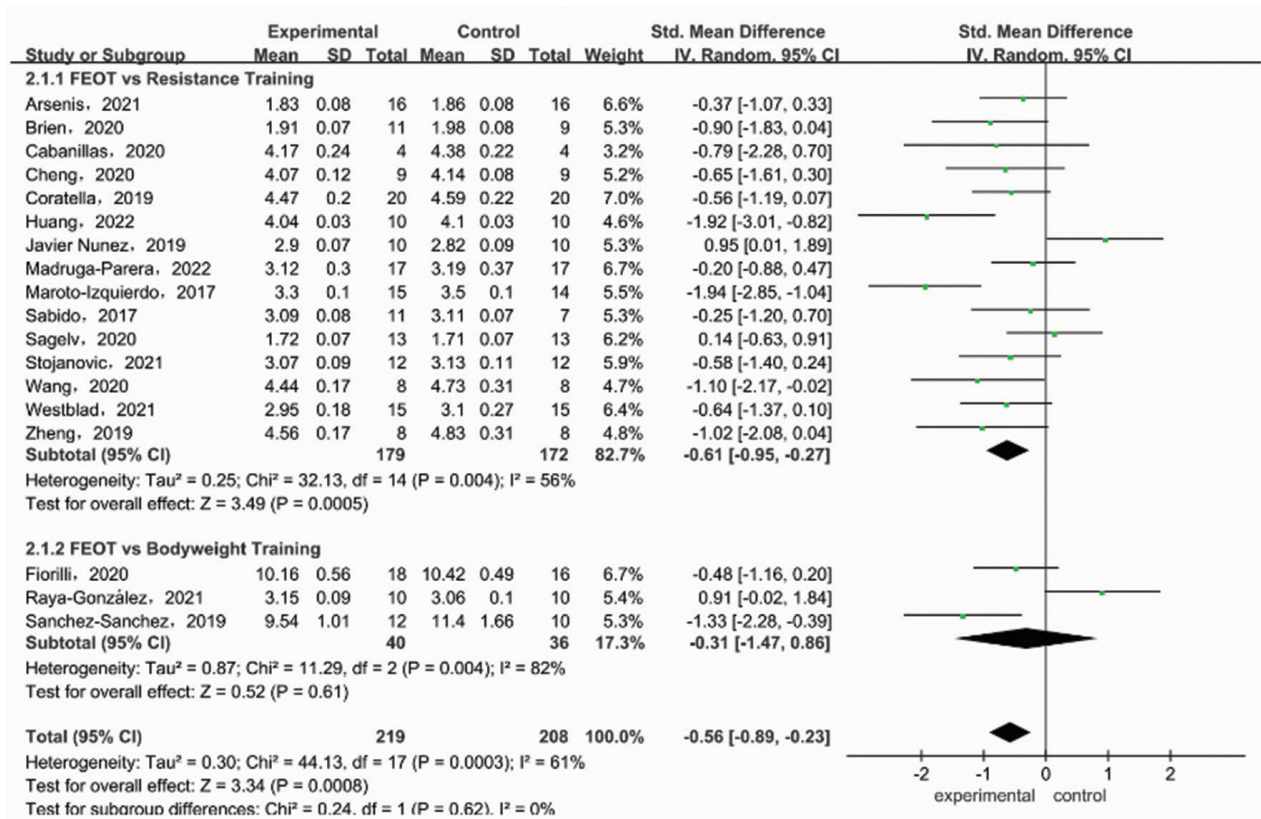


Figure 3. The influence of FEOT and conventional resistance training on sprints.

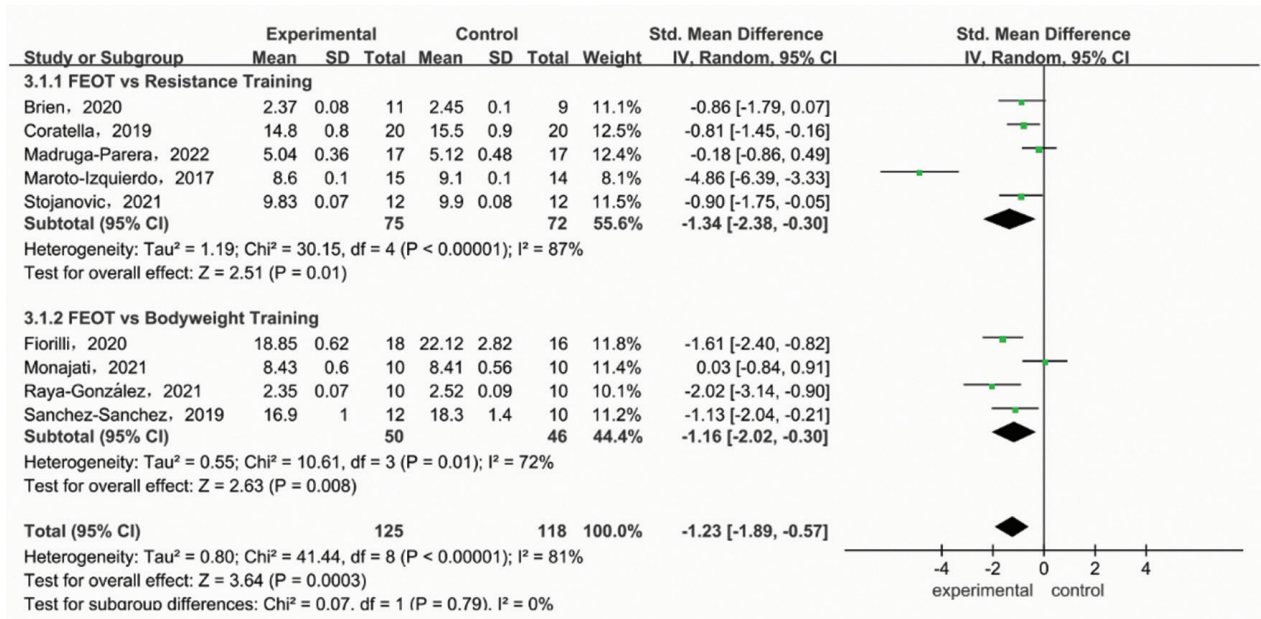


Figure 4. The influence of FEOT and conventional resistance training on COD.

ance training (SMD=-1.23, 95% CI: -1.89 to -0.57, p<.05). Subgroup analysis indicated that FEOT significantly enhanced COD over both the external-load resistance training (SMD=-1.34, 95% CI: -2.38 to -0.30, p<.05) and bodyweight training (SMD=-1.16, 95% CI: -2.02 to -0.30, p<.05).

**Meta-analysis: Comparison of FEOT vs. conventional resistance training on 1RM**

Among the included studies, eight selected 1RM as an outcome measure. The meta-analysis forest plot (Figure 5) indicated that FEOT did not significantly improve 1RM compared with external-load resistance training (SMD=0.30, 95% CI: -0.50 to 1.10, p>.05).

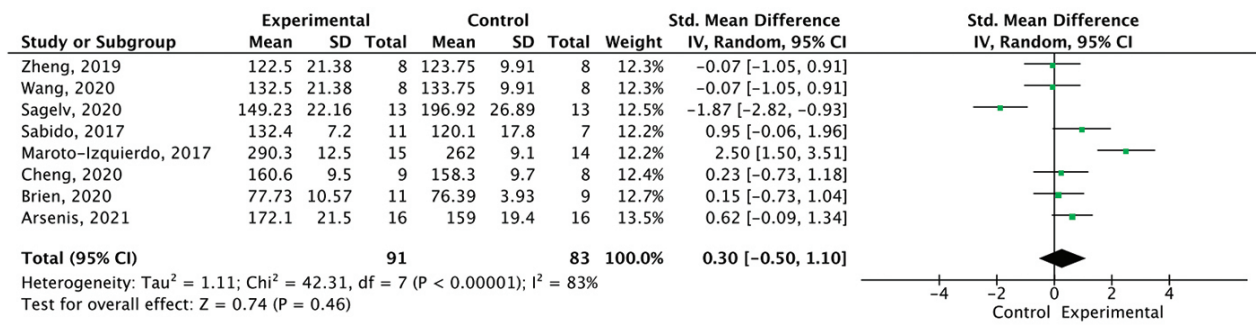


Figure 5. The influence of FEOT and conventional resistance training on IRM.

**Publication bias assessment**

If the included literature exceeds ten studies, a publication bias test is required (Zhou & Fang, 2002). In the present review, 18 studies reported CMJ performance, 18 studies assessed short-distance sprint ability, 13 studies evaluated COD performance, and 10 studies examined IRM strength. Egger’s regression test was applied to these outcomes to detect potential small-study effects (Table 3).

The results indicated that CMJ (p=.063), short-distance sprint (p=.280), and IRM strength (p=.940) all presented p-values greater than 0.05, suggesting no statistically significant evidence of publication bias. In contrast, COD performance showed a statistically significant intercept (p=.017). However, this finding should be interpreted with caution. Although COD included more than ten effect sizes, the number of independent studies remained relatively limited—effectively fewer than ten—which reduces the stability of Egger’s test. Given the known susceptibility of regression-based bias tests to inflated Type I error when study numbers are small, the apparent publication bias for COD is likely influenced by sample-size limitations and therefore has lower inferential value.

**GRADE evidence quality assessment**

The quality of evidence for each outcome was evaluated using the GRADE approach (Table 4).

The certainty of evidence regarding the effects of FEOT on CMJ, short-distance sprint, and IRM was rated as low, whereas the evidence for COD was rated as very low. Most of the included randomized controlled trials were exercise-training interventions in which blinding of participants and trainers was not feasible. This inherent limitation led to downgrading the risk of bias domain by one level.

**Discussion and conclusions**

**The influence of FEOT on jump performance**

This study found that FEOT significantly enhances jump performance compared to external-load resistance training (SMD=0.56, 95% CI: 0.13 to 0.99, p<.05) and bodyweight training (SMD=0.77, 95% CI: 0.25 to 1.29, p<.05). From the 18 studies included in Figure 2, 16 demonstrate that FEOT outperforms conventional resistance training methods in improving jump capacity. FEOT stores rotational inertia energy after the concentric phase, leading to a greater *overload* in the eccentric phase. This motion replicates the SSC mode, where muscles repeatedly and rapidly complete concentric-eccentric actions. Research by scholars worldwide has shown that the SSC movement pattern significantly enhances jump performance (Li, Yu, & Yang, 2019; Xu, Yin, Huang, et al., 2018). For instance,

Table 3. Meta-analysis of Egger’s test result

Outcome	Parameter	Coefficient	Std. error	t-value	Egger’s p-value	95% CI
CMJ	Intercept (Bias)	2.889	1.939	1.99	.063	[-0.19, 6.60]
	Slope	-0.786	0.674	-1.17		[-2.21, 0.64]
short-distance sprint	Intercept (Bias)	-2.245	2.009	-1.12	.280	[-6.50, 2.01]
	Slope	0.412	0.870	0.47		[-1.43, 2.26]
COD	Intercept (Bias)	-7.7261	2.4906	-3.10	.017	[-13.62, -1.84]
	Slope	2.2545	1.0779	2.09		[-0.29, 4.80]
1RM	Intercept (Bias)	0.7416	9.3522	0.08	.940	[-23.30, 24.78]
	Slope	0.0165	4.3139	0.00		[-11.07, 11.11]

Note. Egger’s test evaluates small-study effects. A p-value of <.05 indicates potential publication bias.

Table 4. GRADE evidence quality assessment

Outcome measures	Included studies	Studies design	1	2	3	4	5	Evidence Quality
CMJ	18	RCT	0	0	-1	-1	0	Low
Short-distance sprint	18	RCT	0	0	-1	-1	0	Low
COD	9	RCT	-1	0	-1	-1	0	Very low
1RM	8	RCT	0	-1	-1	-1	0	Low

Note. 1 indicates publication bias; 2 indicates imprecision; 3 indicates risk of bias; 4 indicates inconsistency; 5 indicates indirectness.

plyometric training, a common exercise for jump improvement, leverages SSC. Short-duration SSC exercises can improve the rate of force development (RFD) and enhance rapid muscle power by optimizing neuromuscular activation. Comparative analysis of training outcomes between FEOT and plyometric exercises—both utilizing SSC mechanisms—is essential because these modalities elicit distinct neuromuscular loading patterns despite sharing SSC characteristics. Understanding their differential effects on strength, power, and muscle hypertrophy can help practitioners select the most appropriate method based on specific performance goals, athlete profiles, and training phases. Fiorilli et al. (2020) investigated the effects of knee extension and squatting exercises with flywheel devices versus plyometric exercises on jump performance in soccer players. Their results showed that FEOT produced substantially greater improvements ( $30.33 \pm 4.29$  cm vs.  $25.47 \pm 3.91$  cm), corresponding to a large effect size (Cohen's  $d=1.18$ ). Similarly, Di Cagno et al. (2020) reported that after six weeks, fencers in the flywheel group achieved greater improvements in jump performance compared with those in the bodyweight group ( $33.39 \pm 8.50$  cm vs.  $30.71 \pm 4.92$  cm). These findings further support that FEOT yields superior jump-related adaptations relative to conventional resistance training modalities, reinforcing its effectiveness for enhancing explosive lower-limb performance.

### The influence of FEOT on short-distance sprints

Short-distance sprinting ability reflects explosive power, primarily determined by the magnitude of power output and the recruitment of muscle fibers during contraction. This study found that FEOT significantly improves short-distance sprinting ability compared to external-load resistance training, with a medium effect size (SMD=-0.61, 95% CI: -0.95 to -0.27,  $p<.05$ ). However, our meta-analysis showed that, compared to bodyweight training, FEOT does not show a significant advantage in enhancing short-distance sprint performance (SMD=-0.31, 95% CI: -1.47 to 0.86,  $p>.05$ ). It is important to note that the term *bodyweight training* in our pooled analysis encompasses several distinct training formats (primarily plyo-

metric training and sprint training in the included trials). Heterogeneity among these control protocols (differences in exercise selection, volume and intensity) likely contributed to the wide confidence interval and non-significant pooled result. Therefore, the absence of a significant effect versus bodyweight training should be interpreted with caution and may reflect intervention heterogeneity and limited study numbers. Of the 15 studies comparing FEOT with external-load resistance training, 13 indicated that FEOT was more effective in enhancing short-distance sprint performance. FEOT has been shown to improve the rate of force development and power output in muscles. During flywheel training, trainees pull on a rope connected to a rotating flywheel, generating kinetic energy as the flywheel accelerates. In the concentric phase, the muscles work to resist the rope's force, increasing stored energy. As the concentric phase ends and the rope disengages, the flywheel recoils, pulling the rope back and driving eccentric muscle contraction. This rapid shift results in eccentric overload, generating higher peak eccentric force and power due to the compressed timeframe of kinetic energy dissipation (Kaux, et al., 2013; Lepley, Wojtys, & Palmieri-Smith, 2015). This mechanism is not only a mechanical description but has direct implications for sprint and strength performance. Eccentric overload increases the peak eccentric force, enhances the RFD, and promotes neuromuscular adaptations such as improved motor-unit recruitment and stretch-reflex potentiation. These adaptations are strongly associated with short-distance sprinting, which depends on rapid force generation during ground contact; and maximal strength development, which benefits from increased eccentric force capacity. Previous studies have demonstrated that FEOT improves RFD and muscle power to a greater extent, thereby contributing to performance outcomes in explosive tasks (O'Brien, Browne, & Earls, 2020; Sabido, Hernández-Davó, Botella, Navarro, & Tous-Fajardo, 2017). Therefore, the mechanical characteristics of FEOT—particularly its ability to generate superior eccentric loading—provide a plausible physiological rationale for its observed effects on sprint, jump, and strength-related measures. In external-load resistance training, maximal eccentric force can only be

achieved under maximum load; however, at this intensity, movement speed significantly decreases, limiting rate of force development. Studies indicate no significant advantage of FEOT over bodyweight training in enhancing short-distance sprint capacity, with three papers included in this analysis. Fiorilli et al. (2020) and Sanchez-Sanchez et al. (2019) found that FEOT outperformed bodyweight training like horizontal jumps and high-intensity intermittent sprints. However, Raya-González et al. (2021b) observed that bodyweight training surpassed FEOT in sprint improvements. Currently, evidence does not conclusively support flywheel training's superiority in sprint performance, highlighting a need for further research to clarify this relationship.

### The influence of FEOT on COD

Change-of-direction ability is a key component of agility and reflects an athlete's overall physical qualities. Improvements in speed, strength, and coordination positively transfer to enhance agility. This synergy across physical attributes supports COD proficiency (Chen, Yin, & Peng, 2021). This study found that FEOT produced a large effect size in improving COD ability compared to both the external-load resistance training (SMD=-1.34, 95% CI: -2.38 to -0.30,  $p<.05$ ) and bodyweight training (SMD=-1.16, 95% CI: -2.02 to -0.30,  $p<.05$ ). The essence of COD movement lies in the functional transition of lower limb muscles from eccentric to concentric contraction, while maintaining trunk stability as a core foundation (Chen, et al., 2021). Key factors influencing COD ability include the nervous system's responsiveness to external changes, movement speed, balance maintenance, and the capacity for eccentric overload contractions (Guo & Yu, 2021). FEOT can enhance the nervous system's ability to recruit motor units, thereby improving rapid neuromuscular responses. Núñez, Suarez-Arrones, Cater, and Mendez-Villanueva (2017) compared immediate barbell lifting speed and eccentric force between flywheel and barbell deadlifts, finding superior outcomes in the flywheel group. In the short term, neural factors such as motor unit activation, firing rate, and motor unit synchronization likely play a primary role (Su & Yin, 2022). Eccentric contractions greatly influence movement efficiency in COD, as deceleration is essential for COD, with eccentric muscles playing a critical role in slowing down. Flywheel training's unique eccentric overload effect enhances eccentric force development, supporting rapid deceleration to improve COD ability. The specific acceleration-

deceleration and braking pattern of FEOT aligns with performance needs in competition, potentially explaining its efficacy in enhancing COD performance.

### The influence of FEOT on 1RM

This study found that FEOT did not demonstrate a significant advantage over external-load resistance training in enhancing 1RM. 1RM development is primarily influenced by factors such as muscle cross-sectional area, the excitability of the central nervous system, and muscle coordination (Tian & Liu, 2012). The meta-analysis by Maroto-Izquierdo et al. (2017b) found that FEOT offers a significant advantage over external-load resistance training in enhancing muscle hypertrophy. However, differences in stimulation effects across lower limb muscles and variability in muscle selection for testing may lead to discrepancies in results. Additionally, since 1RM performance involves multiple joints, the involvement of core stabilizers like the *erector spinae* and hip extensors influences outcomes (Walker, et al., 2016). In external-load resistance training, core engagement provides body support and stability, which is comparatively lower in FEOT.

### Conclusion

In conclusion, our meta-analysis indicates that FEOT is effective in enhancing athletic performance compared with conventional resistance training modalities. Specifically, FEOT produces superior improvements in jump performance (CMJ), change-of-direction ability, and short-distance sprint performance. When compared with external-load resistance training, FEOT consistently shows greater benefits across these outcomes, while compared with bodyweight training, FEOT demonstrates clear advantages in CMJ and COD performance. These findings support the use of FEOT as an efficient and practical training strategy for improving explosive lower-limb performance in athletes.

Nevertheless, some limitations should be considered. The number of studies included for certain outcomes was relatively small, and study protocols varied in terms of training duration and frequency, which may contribute to heterogeneity. Future high-quality, large-scale randomized trials are warranted to confirm these results, explore optimal FEOT protocols, and further clarify FEOT comparative efficacy across different athletic populations and performance metrics.

Table 1. Characteristics of the studies included in the meta-analysis

Author (year)	Number	Age	Training experience	Control intervention	Outcome measures	PEDro
Madruga-Parera, et al. (2022)	M=34	15.9±1.3	Handball players	external-load resistance training	CMJ; COD; 20m	6
Arsenis, et al. (2021)	M=32	20.9±1.2	Well-trained athletes	external-load resistance training	1RM; CMJ; 10m	6
Fiorilli, et al. (2020)	M=34	13.2±1.2	Football players	bodyweight training	CMJ; COD; 60m	7
di Cagno, et al. (2020)	M=54	17.3±1.9	Fencers	bodyweight training	CMJ	7
Murton, et al. (2023)	M=16	18.0±1.0	Rugby players	external-load resistance training	CMJ	7
Raya-González, et al. (2021b)	M=20	U16	Football players	bodyweight training	CMJ; COD, 20m	7
Núñez, et al. (2019)	M=20	17±1	Football players	external-load resistance training	20m	6
Monajati, et al. (2021)	M=10, W=10	22.6±2.3	Volleyball players	bodyweight training	COD	5
Westblad, et al. (2021)	M=15, W=15	13±1.3	Young athletes	external-load resistance training	20m; CMJ	5
Stojanović, et al. (2021)	M=24	17.5±0.5	Youth basketball players	external-load resistance training	20m; CMJ; COD	6
Sagelv, et al. (2020)	M=26	23±3.15	Football players	external-load resistance training	10m; CMJ; 1RM	7
O'Brien, et al. (2020)	W=20	23.6±6	Basketball players	external-load resistance training	1RM; 10m; CMJ; COD	6
Cabanillas, et al. (2020)	M=8	18-25	Professional athletes	external-load resistance training	CMJ; 30m	4
Sanchez-Sanchez, et al. (2019)	M=22	22.5±2.2	Team sport athletes	bodyweight training	COD; CMJ; 20m	6
Sabido, et al. (2017)	M=18	23.8±3.8	Handball players	external-load resistance training	CMJ; 1RM; 20m	4
Coratella, et al. (2019)	M=40	23±4	Football players	external-load resistance training	COD; 30m; CMJ	6
Maroto-Izquierdo, et al. (2017a)	M=29	19.8±1	Handball players	external-load resistance training	1RM; CMJ; 20m; COD	6
Zheng (2019)	M=16	16.5±0.5	Judo athletes	external-load resistance training	CMJ; 30m; 1RM	6
Huang (2022)	M=20	U19	Football players	external-load resistance training	CMJ; 30m	4
Cheng (2020)	M=18	21.4±1.2	Sprinters	external-load resistance training	30m; CMJ; 1RM	5
Wang (2020)	M=16	Unknown	Sanda athletes	external-load resistance training	30m; 1RM	5

Note. W: women; M: men; CMJ: countermovement jump; COD: change-of-direction performance; 1RM: one-repetition maximum strength; m: meter.

Table 2. Experimental designs of the studies included in the meta-analysis

Author (Year)	Intervention	Intervention load	Duration	Frequency
Madruga-Parera, et al. (2022)	FEOT: Side lunges, lunge squats, and step-over lunges performed with a flywheel device; CON: Side lunges, lunge squats, and step-over lunges performed with rope resistance.	The load for FEOT and CON is set at 3 sets of 8-12 repetitions, with an intensity of RPE 6-9.	8 weeks	2/week
Arsenis, et al. (2021)	FEOT: Half-squats using a flywheel device; CON: half-squats using a barbell. Duration is 15-30 minutes.	FEOT: 3-6 sets of 5-6 repetitions, with an intensity of 0.097 kg·m <sup>2</sup> ; CON: 3-6 sets of 5-6 repetitions, with an intensity of 80% OPL.	8 weeks	2/week
Fiorilli, et al. (2020)	FEOT: Flywheel linear sprints and knee extension exercises; CON: Horizontal jump exercises.	FEOT: 4 sets of 7 repetitions, with an intensity of RPE 17; CON: 3-4 sets of 7-10 repetitions, with an intensity of RPE 17.	6 weeks	2/week
di Cagno, et al. (2020)	FEOT: Perform lunges and half-squats using a flywheel; CON: Perform drop jumps, lunge jumps, and lunge squats.	FEOT: 3-4 sets of 7-9 repetitions; CON: 1-3 sets of 7 repetitions, both with an intensity of RPE 5-6.	6 weeks	2/week
Murton, et al. (2023)	FEOT and CON utilize a flywheel and barbell for squats, Romanian deadlifts, and Bulgarian split squats.	FEOT intensity: 0.05 kg·m <sup>2</sup> ; CON intensity: unspecified. Both groups perform a load of 3-5 sets of 6-8 repetitions.	6 weeks	2/week
Raya-González, et al. (2021b)	FEOT consists of flywheel side lunge exercises; CON includes external-load resistance training, endurance, and sprint exercises.	FEOT: 2-4 sets of 8-10 repetitions, with an intensity of 0.025 kg·m <sup>2</sup> ; CON: as planned by the strength and conditioning coach.	4 weeks	2/week
Núñez, et al. (2019)	FEOT includes flywheel squats and lunge exercises; CON includes barbell lunges and squat exercises.	FEOT: 2-3 sets of 6 repetitions, with an intensity based on Mean MPV; CON: 2-3 sets of 4-6 repetitions, with an intensity of 30-40% of 1RM.	10 weeks	1/week
Monajati, et al. (2021)	FEOT involves flywheel exercises including squats, single-leg squats, lunges, and leg curls; CON includes single-leg jumps, single-leg landings, lunge jumps, and single-leg raises.	FEOT intensity: 0.13 kg·m <sup>2</sup> to 0.22 kg·m <sup>2</sup> ; CON intensity: body weight. Both groups perform a load of 2 sets of 8 repetitions.	9 weeks	1/week
Westblad, et al. (2021)	FEOT involves squats using a flywheel device; CON involves squats using a barbell.	FEOT intensity: 0.025 kg·m <sup>2</sup> ; CON intensity: 10-30 kg. Both groups perform a load of 4 sets of 6 repetitions.	6 weeks	2/week
Stojanović, et al. (2021)	FEOT involves performing half-squats and Romanian single-leg squats using a flywheel device; CON involves performing half-squats and Romanian single-leg squats using a barbell.	FEOT: 2-4 sets of 8 repetitions, with an intensity of 0.075 kg·m <sup>2</sup> ; CON: 2-4 sets of 8 repetitions, with an intensity of 80% 1RM.	8 weeks	2/week
Sagelv, et al. (2020)	FEOT involves performing squats using a flywheel device; CON involves performing squats using a free barbell.	FEOT: 3-4 sets of 6 repetitions, with an intensity of 0.0125-0.1 kg·m <sup>2</sup> ; CON: 3-4 sets of 8 repetitions, with an intensity of 70-85% 1RM.	6 weeks	2/week
O'Brien, et al. (2020)	FEOT involves performing squats using a flywheel device, while CON involves performing squats using a barbell.	FEOT: 4 sets of 10 repetitions at an intensity of 0.075 kg·m <sup>2</sup> ; CON: 4 sets of 8 repetitions at an intensity of 65% 1RM.	4 weeks	2/week
Cabanillas, et al. (2020)	FEOT involves performing squats using a flywheel device, while CON involves performing squats using a barbell.	FEOT: 4-6 sets of 10 repetitions at an intensity of 0.0332 kg·m <sup>2</sup> ; CON: 4-6 sets of 10 repetitions, with unspecified intensity.	8 weeks	1/week

Sanchez-Sanchez, et al. (2019)	FEOT involves flywheel-based lunge and single-leg half squat exercises; CON consists of 26 minutes of high-intensity interval training.	FEOT consists of 2-3 sets of 6 repetitions with an intensity of 0.05-0.27 kg·m <sup>2</sup> ; CON includes 2 sets of 8 repetitions at 90-100% of maximum heart rate.	5 weeks	2/week
Sabido, et al. (2017)	FEOT involves performing half squats and lunge exercises using a flywheel; CON maintains the regular external-load resistance training program.	FEOT involves 2-4 sets of 8 repetitions at an intensity of 0.05 kg·m <sup>2</sup> ; CON maintains the regular training routine.	7 weeks	1/week
Coratella, et al. (2019)	FEOT involves performing squat exercises using a flywheel; CON involves performing squat exercises with a barbell.	FEOT: Intensity of 0.11 kg·m <sup>2</sup> ; CON: Intensity of 80% 1RM. Both groups perform 3-6 sets of 8 repetitions.	8 weeks	1/week
Maroto-Izquierdo, et al. (2017a)	FEOT: Performing seated leg extensions using a flywheel; CON: Performing seated leg extensions using a fixed machine.	FEOT: Intensity set at 0.145 kg·m <sup>2</sup> ; CON: Intensity set at 7RM. Both groups perform 4 sets of 7 repetitions.	6 weeks	2/week
Zheng (2019)	FEOT involves flywheel squat exercises; CON involves barbell squat exercises.	FEOT: intensity of 0.035–0.05 kg·m <sup>2</sup> ; CON: intensity of 80% 1RM. Both groups perform 4 sets of 8 repetitions.	4 weeks	2-3/week
Huang (2022)	FEOT performs single-leg squats using a flywheel; CON performs single-leg squats using a barbell.	FEOT: intensity of 0.028–0.082 kg·m <sup>2</sup> ; CON: intensity of 80% 1RM. Both groups perform 4 sets of 4–6 repetitions.	8 weeks	2-3/week
Cheng (2020)	FEOT performs flywheel squat exercises; CON performs barbell squat exercises.	FEOT: intensity at 0.028–0.082 kg·m <sup>2</sup> ; CON: intensity at 50% 1RM. Both groups perform 4 sets of 8 repetitions.	8 weeks	3/week
Wang (2020)	FEOT performs flywheel squat exercises; CON performs barbell squat exercises.	FEOT: intensity of 0.05–0.095 kg·m <sup>2</sup> ; CON: intensity of 80% 1RM. Both groups perform 4 sets of 7 repetitions.	12 weeks	3/week

Note. FEOT: flywheel eccentric overload training; CON: conventional resistance training; RPE: rating of perceived exertion; OPL: optimal power load; MPV: mean propulsive velocity.

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### Author Contributions

Yuetong Wang was responsible for selecting topics, collecting literature, organizing the extracted data and writing papers. Yuying Su was responsible for searching literature, extracting data and writing papers. Canzhong Ji was responsible for selecting topics, extracting data, reviewing and modifying papers. All authors read and approved the final manuscript. Yuetong Wang and Yuying Su contributed equally to the work.