

## RESEARCH ARTICLE

# Effects of high-intensity functional training on physical fitness and sport-specific performance among the athletes: A systematic review with meta-analysis

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**Data Availability Statement:** All relevant data are within the paper and its [Supporting information](#) files.

## Abstract

### Objective

This study aims to meta-analyze the impact of high-intensity functional training on athletes' physical fitness and sport-specific performance.

### Methods

A systematic search was conducted in five well-known academic databases (PubMed, Scopus, Web of Science, EBSCOhost, and the Cochrane Library) up to July 1, 2023. The literature screening criteria included: (1) studies involving healthy athletes, (2) a HIFT program, (3) an assessment of outcomes related to athletes' physical fitness or sport-specific performance, and (4) the inclusion of randomized controlled trials. The Physical Therapy Evidence Database (PEDro) scale was used to evaluate the quality of studies included in the meta-analysis.

### Results

13 medium- and high-quality studies met the inclusion criteria for the systematic review, involving 478 athletes aged between 10 and 24.5 years. The training showed a small to large effect size ( $ES = 0.414-3.351$ ; all  $p < 0.05$ ) in improving upper and lower body muscle strength, power, flexibility, and sport-specific performance.

### Conclusion

High-intensity functional training effectively improves athletes' muscle strength, power, flexibility, and sport-specific performance but has no significant impact on endurance and agility. Future research is needed to explore the impact of high-intensity functional training on athletes' speed, balance, and technical and tactical performance parameters.

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## 1 Introduction

High-intensity Functional Training (HIFT) is a cutting-edge training method endorsed by CrossFit [1]. Its primary aim is to generate substantial metabolic demands through rapid and repetitive training with minimal or no rest. Over recent years, this high-intensity training approach has garnered widespread popularity among athletes and the general population globally, owing to its brief duration and effectiveness [2–7]. HIFT is characterized by its emphasis on multi-joint, functional, explosive, and continuous full-body movements within various training programs, combining strength exercises with aerobic and bodyweight exercises [8,9]. Its objective is to optimize athletes' movement efficiency within relatively short periods [10,11]. Unlike traditional training methods that focus on isolated muscle groups and specific movement patterns, HIFT seeks to replicate real-life activities and sports demands by incorporating a wide range of functional movements performed at a high intensity [12].

Physical fitness and sport-specific performance determine athletes' competitive abilities [13]. Specialized sports performance refers to athletes' skill level and effectiveness in specific sports processes. Physical fitness forms the foundation for specialized sports performance, with muscle strength, endurance, and agility positively influencing athletes' movement speed. For example, Chaabene et al. found that upper and lower body muscle strength positively impacted boxers' ability to deliver rapid punches. Basketball players require robust aerobic endurance to sustain performance throughout the game [14], and excellent quadriceps muscle strength can optimize hiking performance [15]. The mobility of the hip joint is crucial for taekwondo athletes' kicking performance. Additionally, Pan et al.'s research revealed that single-handed dinghy competition performance is influenced by athletes' muscle strength, flexibility, power, muscular endurance, and cardiovascular fitness [16]. Developing physical attributes such as muscle strength, power, and endurance is crucial for athletes to achieve outstanding performance in competitions [17,18].

Sport-specific performance is a significant prerequisite for athletes to excel in sport-specific scenarios [19,20]. Scientific training methods enhance athlete performance [21]. A singular traditional training approach may isolate Kinematic chains during training, thereby reducing the effectiveness of improving athletes' specific sports performance [17,22]. Dr. Arthur Steidler drew inspiration from the Kinematic chain theory of mechanical engineer Franz Reuleaux and categorized the human body's motion into the upper limb chain, core chain, and lower limb chain [23]. These chains are interconnected, forming a cohesive unit where force generated in one link is transmitted continuously to the link, following a specific sequence of force generation. This sequence transfers the force along the joints to the distal links, enabling optimal motion performance [24]. HIFT emphasizes functional multi-joint activities that engage multiple muscle groups, joints, planes, and dimensions [25]. Research has shown that the functional multi-joint activities in HIFT effectively enhance general physical fitness parameters and athletic performance in diverse training populations [10,26–29].

HIFT suits individuals with diverse training levels [30]. HIFT is a versatile training modality characterized by constantly varying functional movements [31]. It encompasses high-intensity, short-term, and ever-changing functional training patterns involving whole-body, multi-plane movements [32]. These patterns consist of various exercises with different types and durations, occasionally performed without intervals [33,34]. This training method can be customized in intensity and training patterns to accommodate individuals with varying physical conditions [35–37]. Several studies have investigated the effects of HIFT on various populations, including military personnel [5], firefighters [38], football players [39], recreational runners [40], wrestlers [41], and adolescents [42]. Wilke and Mohr conducted a systematic review with a multilevel meta-analysis [30]. They identified 16 studies that met their inclusion criteria,

although the included studies focused primarily on recreationally active and inactive adults, with limited research on athletes [30].

Glassman claims that HIFT can stimulate neuroendocrine responses, increase testosterone, insulin, and growth hormone, and improve exercise performance [43]. By integrating cardiovascular, neuromotor, and muscle functions through aerobic and anaerobic exercise strategies, HIFT elicits greater muscle recruitment than repetitive high-intensity interval training (HIIT) [30,44]. It develops and enhances muscle strength, power, hypertrophy, and aerobic endurance [27,45,46]. Additionally, HIFT can be tailored to specific sports, training patterns, and athletes' needs [37]. HIFT-based workouts like CrossFit, Fran, and Cindy have gained popularity in fitness communities worldwide [31,47]. As a result, many athletes and coaches have integrated HIFT into their training regimens, aiming to gain a competitive edge.

Given the importance of understanding the impact of HIFT on athletes, conducting a comprehensive systematic review in this area is crucial. Therefore, this systematic review aims to thoroughly evaluate the current body of literature on the effects of HIFT on athletes. Additionally, we aim to critically assess the impact of HIFT on various aspects of athletic performance, such as strength, power, speed, agility, endurance, flexibility, and overall athletic performance in different sports events, through meta-analysis. The findings of this review will provide coaches and athletes with low-cost and efficient training plans in sports training. By examining the available evidence and synthesizing the results, valuable insights into the effectiveness of HIFT as a training method for athletes can be obtained, along with identifying potential areas for future research.

## 2 Methods

### 2.1 Protocol and registration

This Systematic review was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and registered on the International Prospective System Review Register (PROSPERO) website. The registration number is CRD4202343705.

### 2.2 Search strategy

A systematic search of relevant literature was conducted from publication to July 2023 using five renowned academic databases: PubMed, Scopus, Web of Science, EBSCOhost, and Cochrane Library. The search focused on titles, keywords, and abstracts. The main keywords used in retrieving relevant literature on the impact of high-intensity functional training on athletes were: ("high intensity") AND ("functional training" OR "functional exercise" OR "functional workout" OR "power training" OR "CrossFit" OR "extreme conditioning program") AND ("athletes" OR "professional athletes" OR "elite athletes" OR "college athletes" OR "players"). In addition, we manually searched and reviewed potentially relevant literature through Google Scholar and reviewed the article's reference list.

### 2.3 Eligibility criteria

**Table 1** summarizes the inclusion criteria based on the PICOS method used in this study. The PICOS method includes population, intervention, comparison, outcomes, and study design [48]. Therefore, the selected research should meet the following criteria: (1) Full-text peer-reviewed journal articles published in English that describe the impact of high-intensity functional training interventions on athletes; (2) Studies conducted on healthy athletes, regardless of gender or age; (3) Evaluation of at least one outcome related to the physical fitness or performance of athletes; (4) The included studies must be randomized controlled trials.

**Table 1. PICOS eligibility inclusion criteria.**

Category	Inclusion Criteria
Population	Healthy athletes
Intervention	High intensity Functional training
Comparative intervention	Two or multiple groups of controlled trials
Outcome	At least one measure related to physical fitness or sports-specific performance
Study design	Randomized controlled trial

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## 2.4 Study selection

The filtering results from all databases were imported into Endnote x9 software. After removing duplicates, two reviewers (WX and RW) independently screened all English journals based on titles, keywords, or abstracts to assess whether these articles met the inclusion criteria. Subsequently, the reviewers conducted a full-text evaluation of the remaining research. Any discrepancies in the selection between the two reviewers were resolved through consultation with a third reviewer (ZY). The two reviewers extracted data from papers that matched the inclusion criteria (WX and RW), and the final data were reviewed by the third reviewer (ZY). The screening process is illustrated in Fig 1.

## 2.5 Data extraction and synthesis

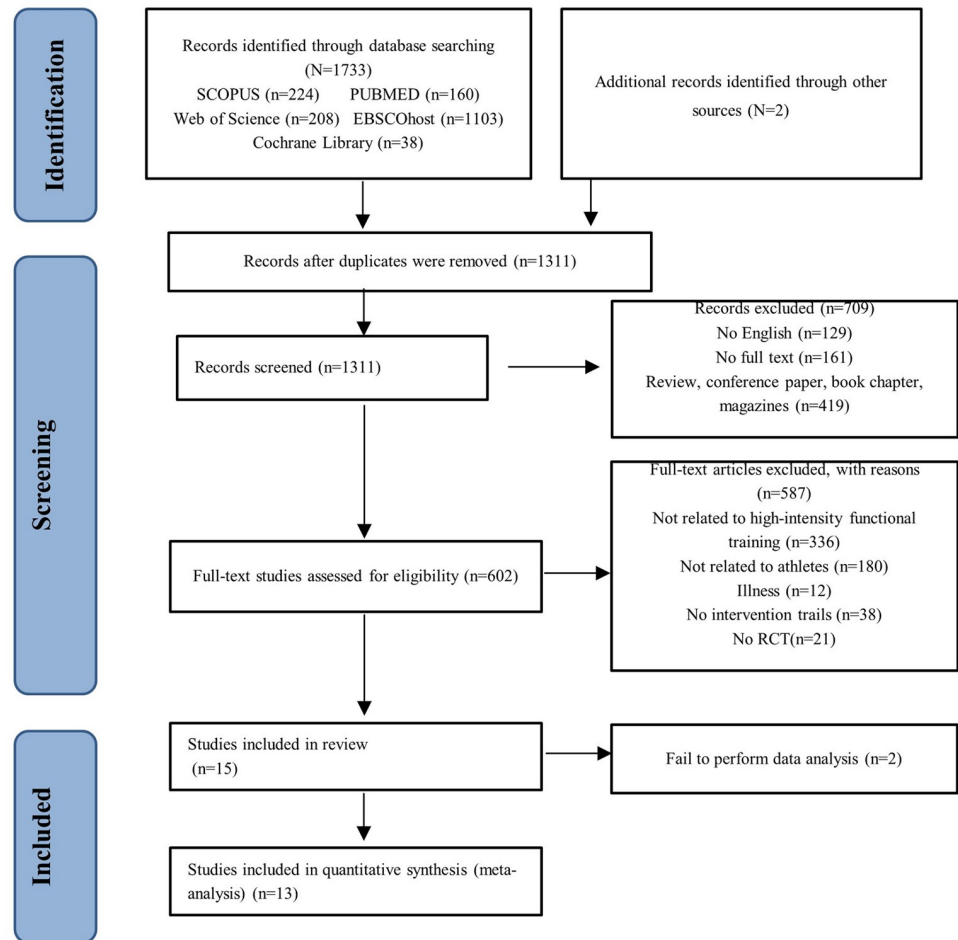
The following data were extracted based on the inclusion criteria: (1) Author and year of publication; (2) Sample size; (3) Characteristics of the participants (such as gender, age, and level of exercise); (4) Intervention characteristics (type, frequency, and duration); (5) Study outcomes. The mean and standard deviation of the included studies were summarized. If the mean and standard deviation of intervention results were not reported in the articles, other data were extracted and converted to mean and standard deviation using established methods [49–52]. The corresponding author was contacted if relevant data were unavailable in the articles.

## 2.6 Study quality assessment

The Physiotherapy Evidence Database (PEDro) scale, a reliable tool for evaluating the quality of experimental research methodology, was used for study quality assessment [53,54]. The PEDro scale consists of 11 items evaluating randomization, blinding, group comparison, and data analysis [53]. Independent reviewers assessed the quality of articles using a "yes" (1) or "no" (0) rating for each item. The scale ranges from 0 to 10, with higher scores indicating better methodological quality of the article. Articles with a PEDro score of five or higher were deemed to have high methodological quality, while those scoring below five were considered to have poor methodological quality [54]. The quality evaluation and scoring process using the PEDro scale involved two independent reviewers, and any disagreements were settled through discussion with the third reviewer (Table 2).

## 2.7 Statistical analysis

The Comprehensive Meta-Analysis software was used to analyse the data in this systematic review (CMA; Biostat et al., Version 3). The random-effects model was employed for meta-analysis [55], and effect sizes (ES; Hedge's  $g$ ) were calculated using mean and standard deviation. The interpretation of effect size was categorized as follows: trivial effect size ( $<0.2$ ), small effect size ( $0.20$ – $0.6$ ), medium 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 ( $>4.0$ ) [56]. The  $I^2$  statistic was used to evaluate



**Fig 1. Flow chart of PRISMA article screening.**

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the heterogeneity of the included studies, with values less than 50% indicating low heterogeneity, 50–75% indicating moderate heterogeneity, and greater than 75% indicating high heterogeneity [57]. The Chi-squared test was used to evaluate the statistical significance of heterogeneity, with  $p < 0.05$  considered significant. Egger's test was employed to assess publication bias; sensitivity analyses were performed to investigate sources of heterogeneity by removing one study at a time, and the stability of the overall findings was assessed by excluding individual studies [58].

## 3 Results

### 3.1 Study selection

The process of literature screening is outlined in Fig 1. 1,735 articles were initially identified from electronic databases, including 224 from Scopus, 160 from PubMed, 208 from Web of Science, 1,103 from EBSCOhost, and 38 from Cochrane Library (reference = 2). After removing duplicates using Endnote software, 1,311 articles remained for further screening. Among these, 129 were non-English articles, 161 needed full text, and 419 were not journal articles. After screening based on title and abstract, 36 articles were identified as potentially eligible and

Table 2. Methodological quality assessment for inclusion studies.

Study	Eligibility Criteria	Random Allocation	Allocation Concealment	Baseline Comparability	Blind Participants	Blind Therapist	Blind Assessor	Follow-Up	Intention to Treat Analysis	Between Group Comparisons	Point Measure and Variability	Total PEDro Score
Osipov et al. 2019 [67]	1	1	0	0	0	0	0	1	0	1	1	5
Yüksel et al. 2019 [70]	0	1	0	1	0	0	0	1	0	1	1	5
Ambroży et al. 2022 [59]	1	1	0	1	0	0	0	1	0	1	1	6
Kudryavtsev et al. 2023 [63]	1	1	0	1	0	0	0	1	0	1	1	6
Zhu. 2023 [69]	1	1	0	0	0	0	0	1	0	1	1	5
Osipov et al. 2022 [65]	1	1	0	1	0	0	0	1	0	1	1	6
Galimova et al. 2018 [62]	1	1	0	1	0	0	0	1	0	1	1	6
Türker & Yüksel. 2020 [68]	1	1	0	0	0	0	0	1	0	1	1	5
Mischenko et al. 2021 [64]	1	1	0	1	0	0	0	1	0	1	1	6
Caloglu & Yüksel. 2020 [41]	0	1	0	1	0	0	0	1	0	1	1	5
Avetisyan et al. 2022 [60]	1	1	0	1	0	0	0	1	0	1	1	6
Bozdoğan. 2021 [61]	1	1	0	1	0	0	0	1	0	1	1	6
Osipov et al. 2017 [66]	1	1	0	0	0	0	0	1	0	1	1	5

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underwent full-text evaluation. Of these, 336 articles were unrelated to the subject area, 192 were unrelated to healthy athletes, 38 did not involve experimental intervention, and 21 were not randomized controlled trials, resulting in their exclusion. Two articles needed to provide more information for inclusion in the meta-analysis and were also excluded. Finally, 13 articles met the inclusion criteria and were included in the meta-analysis.

### 3.2 Study quality assessment

Detailed information on the quality scores of each included study's PEDro scale is presented in [Table 2](#). The PEDro scale scores ranged from 5 to 6. Seven studies scored 6 points [59–65], while six studies scored 5 points [41,66–70]. These scores indicate that the included articles are of good quality. However, none of the studies met the criteria for allocation concealment, blinding of participants, therapists, and assessors as assessed by the PEDro scale. Two studies did not specify the eligibility criteria for participant inclusion [41,70].

### 3.3 Participant characteristics

[Table 3](#) summarizes the participant characteristics of 13 studies that met the inclusion criteria, and the content included is shown below. (1) Athlete classification: among the 13 articles, there was one article about aerobic gymnasts [69], one article about volleyball players [61], and 11 articles about martial arts athletes [41,59,60,63–68,70]. (2) Gender classification: Eight out of 13 articles investigated male athletes [40,41,59,60,63,65,67,68,70,71], and two articles investigated female athletes [61,64]. However, three studies did not report gender information [62,66,69]. (3) Sample size: the total number of subjects collected in the 13 studies was 530, ranging from 20 to 60, with an average sample size of 35.33 [41,59–61,63–70]. The number of martial arts athletes was the highest, at 432 [41,59,60,63–68,70]. (4) Age: all studies reported the ages of the participants. The age range was between 10 and 24 years old [41,59–61,63–70]. (5) Athlete training level: three studies were on elite athletes [63,65,67], seven studies on professional sports [41,59,61,64,66,68,69], and one study each on amateur athletes [70], junior athletes [60], and college athletes [62], respectively.

### 3.4 Intervention characteristics

[Table 3](#) presents the intervention characteristics of the thirteen included studies, focusing on three aspects: intervention type, frequency, and length. Intervention type: All studies primarily utilized HIFT as the primary intervention method. One study exclusively employed HIFT [61], while ten studies employed CrossFit [41,59,60,62,63,65–67,69,70]. One study combined CrossFit training with other methods like Rope-Skipping and Ki-Bo [64], and another study conducted comparative experiments between classic CrossFit and CrossFit AMRAP [68]. Intervention frequency: Most studies reported intervention frequency, with only one study omitting this information [69]. Among the remaining twelve studies, the intervention frequency ranged from two to four times per week [41,59–67,69,70]. Intervention length: All studies reported the duration of the intervention. The majority of experiments lasted between 4 and 12 weeks [41,59,61,63,65,68–70]. However, one study had a duration of five months [60], another study lasted for six months [66], one study lasted for nine months [64], and one study lasted for ten months [67].

### 3.5 Outcome

**3.5.1 Effect of high-intensity functional training on strength of athletes.** Six out of 13 studies examined the effects of HIFT on muscle strength in athletes [59,60,64,65,69,70]. These



Table 3. Summary of the studies' characteristics included in this review.

Study	Participant	Sex	Age	Exercise level	Intervention characteristics			Outcomes
					Type	Frequency	Length	
Mischenko et al. (2021) [64]	20	F	16–17 years	Professional WTF taekwondo athletes	EG: CrossFit, Rope-skipping, Tai-bo, Ki-bo, and Fightball Training CG: Routine Training	3 times/week	9 months	SS↑ Running 100 m↑ PU↑ 1 min RS↑ SLJ↑ Attack speed↑
Osipov et al. (2019) [67]	31	M	16–17 years	Elite judo athletes	EG: CrossFit Training CG: Circular Training	3 times/week	10 months	Competition score↑
Yüksel et al. (2019) [70]	32	M	21.72 ± 1.40 years	Amateur wrestlers	EG: CrossFit Training CG: Classical Wrestling Training	3 times/week,	8 weeks	Bench press↑ Squat jump↑
Ambroży et al. (2022) [59]	60	M	20.07 ± 1.46 years	Professional kickboxers	EG: CrossFit Training CG: Conventional Kickboxing Training	3 times/week	8 weeks	Dynamic sit-ups↑ SLJ↑ Tapping↑ Cooper test↑ SR↑ Shuttle run 10x5 m↑ Movement speed↑
Kudryavtsev et al. (2023) [63]	44	M	21.06±3.42 years	Elite sambo athletes	EG: CrossFit Training CG: Strength Training	3 times/week	4 weeks	Rank position↑
Zhu. (2023) [69]	24	NR	19.824 ± 0.469 years	Professional aerobic gymnastics athletes	EG: CrossFit training CG: Normal aerobics training	NR	9 weeks	STMB↑ SR↑ Movement performance score↑
Osipov et al. (2022) [65]	53	M	17.22±1.37 years	Elite judo athletes	EG: CrossFit Training CG: Strength Training	4 times/week	8 weeks	Pull up↑
Galimova et al. (2018) [62]	40	NR	18–19 years	College boxer	EG: CrossFit Training CG: Traditional training	4 times/week	12 weeks	Attack strength↑
Türker & Yüksel. (2020) [68]	32	M	20.8 ± 1.15 years	Professional wrestlers	EG1: Classic CrossFit EG2: CrossFit AMRAP	3 times/week	8 weeks	Anaerobic power↑
Caloglu & Yuksel. (2020) [41]	40	M	21.33 ± 1.78 years	Professional wrestlers	EG: CrossFit Training CG: No additional training	3 times/week	8weeks	Anaerobic power↑ Dynamic balance↑
Avetisyan et al. (2022) [60]	20	M	11 ± 0.64 years	Junior judo athletes	EG: CrossFit Training CG: Traditional Training	2 times/week	5 months	Pull-up↑ SLJ↑ Shuttle run time 4 × 10 m↔ Burpees (repetitions in 30 s) ↔

(Continued)



Table 3. (Continued)

Study	Participant	Sex	Age	Exercise level	Intervention characteristics			Outcomes
					Type	Frequency	Length	
Bozdoğan. (2021) [61]	22	F	16.41±1.29 years	Professional Volleyball Players	EG: HIFT CG: Routine training	2 times/week	12 weeks	Shuttle run 10 x 20 m ↑ CMJ ↑
Osipov et al. (2017) [66]	60	NR	20–21 years	Professional martial arts athletes	EG: CrossFit Training CG: Circular and Interval Training	2 times/week	6 months	Competition endurance ↑

M, male; F, female; NR, no record; EG, experiment group; CG, control group; HIFT = high-intensity functional training; SS, side split; PU, pull up; RS, rope skipping; SLJ, standing long jump; SR, sit and reach; STMB, side throw medicine ball; CMJ, counter movement jump. ↑, significant improvement; ↔, no significant difference.

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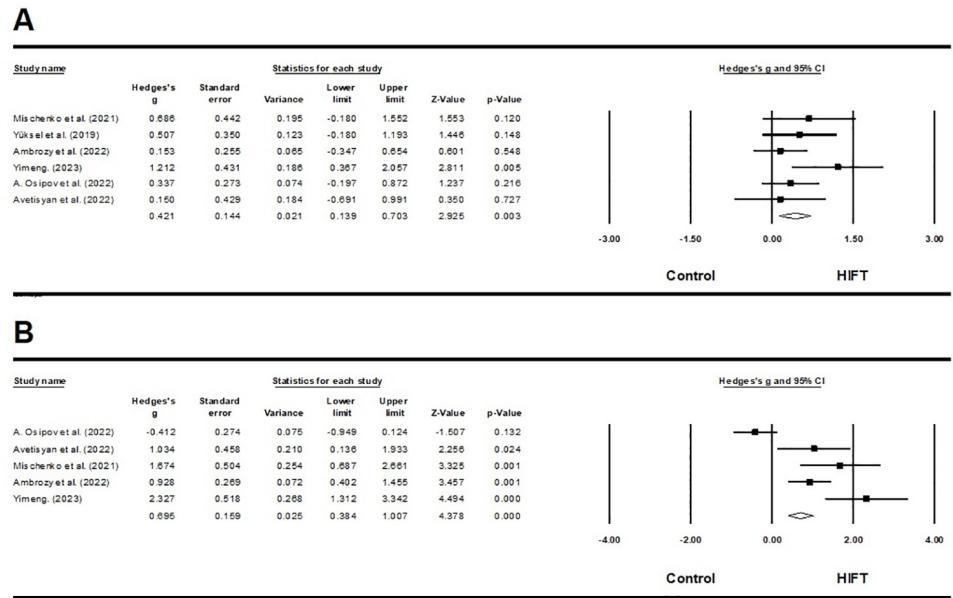
studies used various methods to evaluate strength indicators, including squats, bench presses, pull-ups, side throw medicine balls, and leg lifts. The results of this meta-analysis indicate that HIFT has a small effect on upper body muscle strength, in athletes (ES = 0.414; 95% CI = 0.14–0.683;  $p = 0.003$ ; Egger test  $p = 0.170$ ;  $N = 209$ ; Fig 2A). There was low heterogeneity in the overall effect ( $Q = 5.044$ ;  $I^2 = 0.872\%$ ). The relative weight of each study ranged from 9.69% to 29.03% during the analysis process. Furthermore, HIFT also significantly impacted lower body muscle strength, in athletes (ES = 1.051; 95% CI = 0.126–1.977;  $p = 0.026$ ; Egger test  $p = 0.160$ ;  $N = 177$ ; Fig 2B). There was low heterogeneity in the overall effect ( $Q = 3.781$ ;  $I^2 = 0.00\%$ ). Each study's relative weight ranged from 18.37% to 21.91% during the analysis.

**3.5.2 Effect of high-intensity functional training on power of athletes.** Seven studies investigated the impact of HIFT on power in a total of 184 male martial arts athletes, 20 female martial arts athletes, and 22 female volleyball athletes [41,59–61,64,68,70]. The main methods used to evaluate power included the squatting jump, standing long jump, and Anaerobic Power Test. The results of this meta-analysis indicate that HIFT has a small effect on power, among athletes (ES = 0.499; 95% CI = 0.239–0.758;  $p < 0.001$ ; Egger test  $p = 0.084$ ;  $n = 226$ ; Fig 3). In addition, low heterogeneity in the overall effect ( $Q = 4.676$ ;  $I^2 = 0.00\%$ ) was also reported. Each study's relative weight ranged from 9.37% to 26.83% during the analysis.

**3.5.3 Effect of high-intensity functional training on endurance of athletes.** Four studies investigated the impact of HIFT on the endurance of 22 female volleyball athletes and 100 female martial arts athletes [59–61,64]. The results of this meta-analysis indicate that HIFT has a moderate but no significant effect on endurance (ES = 0.798; 95% CI = -0.352–1.949;  $p = 0.174$ ; Egger test  $p = 0.274$ ;  $N = 122$ ; Fig 4). There was low heterogeneity in the overall effect ( $Q = 3.765$ ;  $I^2 = 20.245\%$ ). Each study's relative weight ranged from 22.67% to 27.57% during the analysis.

**3.5.4 Effect of high-intensity functional training on agility of athletes.** Three studies investigated the impact of HIFT on the agility of 80 male and 20 female martial arts athletes [59,60,64]. The results of this meta-analysis indicate that HIFT has no significant effect on athletes' agility performance (ES = 0.247; 95% CI = -0.443–0.537;  $p = 0.482$ ; Egger test  $p = 0.601$ ;  $N = 100$ ; Fig 5). There was low heterogeneity in the overall effect ( $Q = 2.307$ ;  $I^2 = 13.315\%$ ). Each study's relative weight ranged from 27.96% to 42.08% during the analysis.

**3.5.5 Effect of high-intensity functional training on flexibility of athletes.** Three studies investigated the impact of HIFT on the flexibility of 24 aerobic gymnasts and 80 martial arts athletes [59,64,69]. The results of this meta-analysis indicate that HIFT has a large

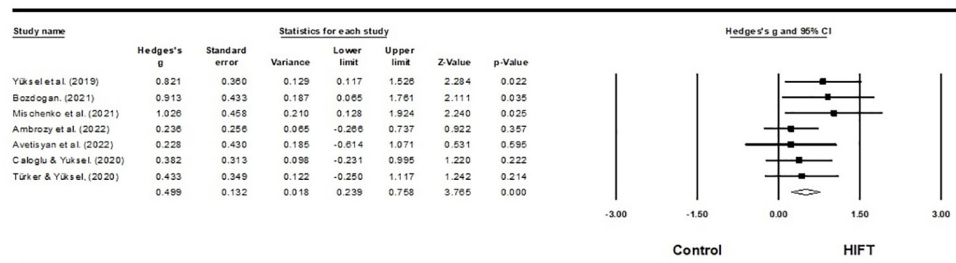


**Fig 2.** A. Forest plot of the effects of HIFT and control group on upper body strength. The displayed result is an effect size of 95% CIs. HIFT = high-intensity functional training. B. Forest plot of the effects of HIFT and control group on lower body strength. The displayed result is an effect size of 95% CIs. HIFT = high-intensity functional training.

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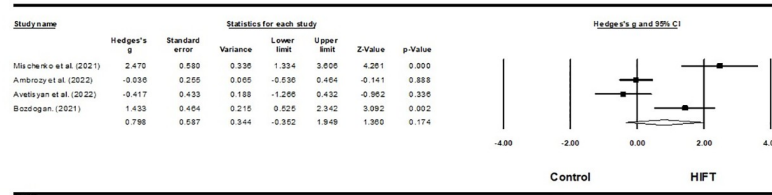
effect on athletes' flexibility performance (ES = 3.167; 95% CI = 0.477–5.857;  $p = 0.021$ ; Egger test  $p = 0.029$ ;  $N = 104$ ; Fig 6). High heterogeneity exists in the overall effect ( $Q = 15.409$ ;  $I^2 = 87.021\%$ ). Each study's relative weight ranged from 19.39% to 40.79% during the analysis.

**3.5.6 Effect of high-intensity functional training on sport-specific performance of athletes.** Seven studies investigated the impact of HIFT on the sport performance of 24 aerobic gymnasts and 255 martial arts athletes [59,62–64,66,67,69]. The results of this meta-analysis indicate that HIFT has a large effect on athletes' sport-specific performance (ES = 3.351; 95% CI = 1.780–4.922;  $p = 0.000$ ; Egger's test  $p = 0.005$ ;  $N = 279$ ; Fig 7). There is no significant heterogeneity in the overall effect ( $Q = 6.784$ ;  $I^2 = 11.554\%$ ). Each study's relative weight ranged from 12.73% to 15.25% during the analysis.



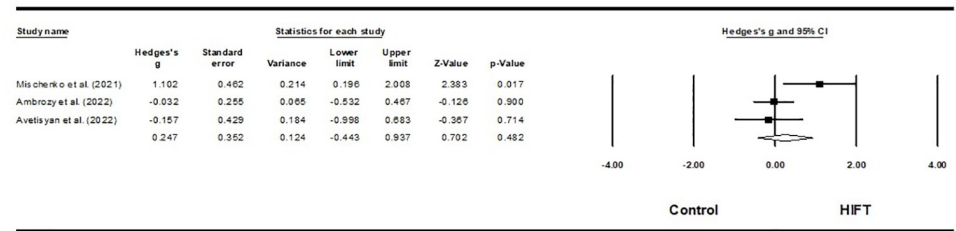
**Fig 3.** Forest plot of the effects of HIFT and control group on power. The displayed result is an effect size of 95% CIs. HIFT = high-intensity functional training.

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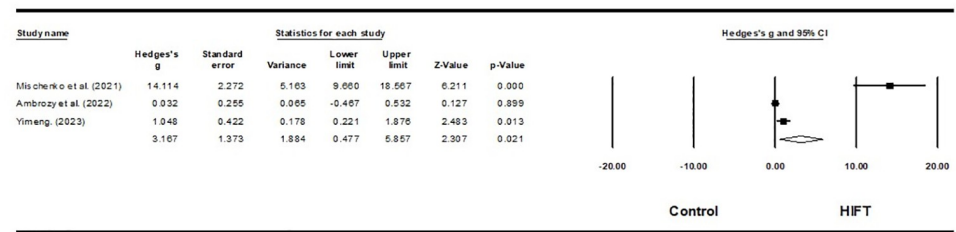
**Fig 4. Forest plot of the effects of HIFT and control group on endurance.** The displayed result is an effect size of 95% CIs. HIFT = high-intensity functional training.

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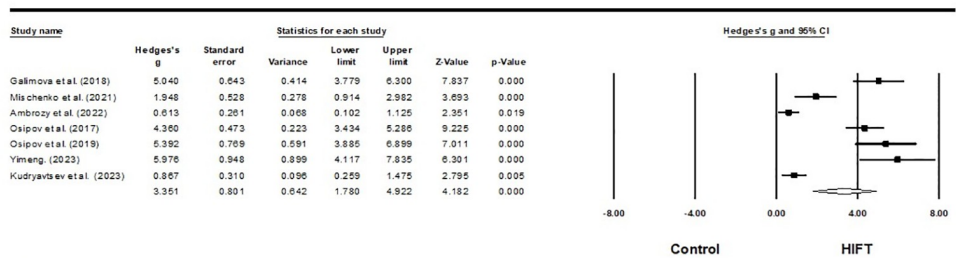
**Fig 5. Forest plot of the effects of HIFT and control group on agility.** The displayed result is an effect size of 95% CIs. HIFT = high-intensity functional training.

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**Fig 6. Forest plot of the effects of HIFT and control group on flexibility.** The displayed result is an effect size of 95% CIs. HIFT = high-intensity functional training.

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**Fig 7. Forest plot of the effects of HIFT and control group on sport-specific performance.** The displayed result is an effect size of 95% CIs. HIFT = high-intensity functional training.

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## 4 Discussion

### 4.1 Effect of high-intensity functional training on muscle strength of athletes

Numerous studies have indicated that combining resistance training and endurance training may lead to interference effects and impact athletes' training outcomes [72–76]. However, when athletes engage in HIFT training, this interference effect may not be observed [77]. A meta-analysis was conducted to assess the effects of HIFT on both upper-body muscle strength (ES = 0.414) and lower-body muscle strength (ES = 1.051). In this systematic review, six studies evaluated athletes' upper-body muscle strength in taekwondo, wrestling, judoka, and aerobic gymnastics. These findings are consistent with De Sousa et al., who investigated the effects of HIFT on lower limb muscle strength in young men [78]. Barfield et al. 2012 suggested that HIFT training is more effective in enhancing participants' lower limb muscle strength than upper limb strength. In contrast to previous reports, Heinrich et al. found through 1RM testing that the experimental group showed more significant improvement in upper limb muscle strength after HIFT intervention [10]. During muscle contraction, c-Jun N-terminal kinase (JNK) is activated. HIFT training stimulates an increase in JNK activity, promoting protein synthesis, which may increase muscle strength [79]. Previous research has demonstrated that the weightlifting component in HIFT training plans can significantly increase participants' muscle strength [10,78,80]. During the HIFT training process, participants often reach the point of muscle failure, increasing muscle strength at various repetition levels. Yüksel et al. found that eight weeks of HIFT improved the push-up performance of amateur wrestlers [70].

Muscle strength plays a crucial role in various movements performed by taekwondo athletes, such as horizontal kicks, whirlwind kicks, and rapid movements [81,82]. Mischenko et al. reported that female taekwondo athletes significantly improved in modified pull-ups after nine months of HIFT intervention [64]. Interestingly, one study included in this review compared the effects of high-intensity CrossFit training with traditional taekwondo training and found that the CrossFit training group significantly impacted athletes' pull-ups and push-ups. However, there was no significant difference in pull-ups compared to the control group, and push-ups showed significant statistical differences [59]. A recent study demonstrated that nine weeks of CrossFit training improved aerobic gymnasts' side-throw medicine ball performance [69]. Osipov et al. reported that eight weeks of HIFT significantly improved muscle strength performance in elite judo athletes, but no significant statistical difference was observed in lower limb strength compared to the control group in the squat test [65]. Therefore, the results of our meta-analysis indicate that HIFT is an effective method for enhancing athletes' upper and lower limb muscle strength performance.

### 4.2 Effect of high-intensity functional training on power of athletes

Numerous studies suggest that HIFT training may directly lead to improvements in power by enhancing muscle strength [10,78,83]. The meta-analysis revealed that HIFT had a significantly moderate impact on athletes' strength performance compared to the control group (ES = 0.499). Compared to traditional strength training, these improvements in power measurement align more closely with the principle of training specificity [84–86]. The effectiveness of power training for athletes can be enhanced by modifying the prescription of HIFT training [32,46]. Power refers to the ability of the human body to generate maximum force explosively following rapid muscle contractions, and it can increase with the duration of force development [87]. According to the force-velocity curve, different training methods within various ranges can enhance the rate of force development at each point on the curve, thereby

maximizing the benefits of power development [88,89]. Previous meta-analyses have also indicated that strength training improves adolescent athletic performance [90]. Within this systematic review, six studies evaluated the impact of HIFT on the strength performance of male Wushu athletes and female volleyball athletes, and significant improvements were observed. Current research suggests that HIFT can effectively enhance athletes' strength. These findings are consistent with the findings of Adami et al. The latter compared the physiological characteristics of HIFT, endurance, and power athletes and discovered the role of HIFT in enhancing male power [91]. Adami et al. examined the physiological characteristics of 20 HIFT athletes and found that they performed remarkably well in power-related aspects [92]. Notably, Caloglu and Yuksel found that eight weeks of HIFT positively impacted the power indicators of wrestlers [41]. Furthermore, numerous studies across different sports have demonstrated the effectiveness of HIFT in enhancing athletes' power ability [60,61,64,68,70]. Thus, our meta-analysis provides robust evidence supporting the positive impact of HIFT on athletes' power ability.

### 4.3 Effect of high-intensity functional training on endurance of athletes

Endurance is crucial for athletes to maintain high-level sports performance over an extended period [93]. The meta-analysis indicates that HIFT has a medium impact on the endurance performance of athletes (ES = 0.831). For sports with longer competitive durations, endurance directly determines athletes' outcomes in competitions, especially in sports like soccer [94], swimming [95], cycling [96], basketball [97], boxing [98], and judo [99]. HIFT is an effective alternative to traditional endurance training methods [91,100]. Training at high intensities with various movement patterns effectively promotes musculoskeletal, metabolic adaptations [101]. The human body adapts by increasing muscle fiber size and quantity to meet the demands of high-intensity loads, as well as enhancing the cardiovascular system's oxygen delivery capacity, thereby improving athletes' endurance levels for sustained exercise [102–104]. Four studies included in this systematic review examined the effects of HIFT on the endurance performance of martial arts athletes. This positive impact can be attributed to enhancing muscle endurance, lactate tolerance, and cardiorespiratory function in athletes following high-intensity functional training. Specifically, the short and intense aerobic interval training common in HIFT and the multi-mode high-intensity repetitive training help improve the cardiovascular system's adaptability, effectively delivering oxygen and nutrients to muscle tissues while also delaying lactate accumulation and enhancing athletes' lactate tolerance. Previous research has shown that cardiorespiratory function, exercise economy, and lactate may influence athletes' performance [105]. Additionally, Armstrong and Barker found that elite young athletes exhibit more substantial cardiorespiratory function [102]. Adami et al. found that HIFT effectively enhances athletes' endurance capacity [91]. Green et al. conducted a cross-sectional assessment of physiological differences among HIFT, endurance, and strength participants and found similar endurance performance between HIFT participants and endurance-trained athletes [106]. However, Gavanda et al. discovered that compared to traditional strength and endurance training, HIFT can effectively improve endurance capacity in adolescents [107]. This result aligns with the findings of Bozdoğan's study, which reported the positive effects of twelve weeks of high-intensity training on the aerobic endurance of volleyball athletes [61]. Ambroży et al. assessed the Cooper test results of 60 male taekwondo athletes and observed significant improvements in the 12-minute non-stop running performance following the intervention of HIFT [59].

#### 4.4 Effect of high-intensity functional training on agility of athletes

Agility is the ability of athletes to react quickly in a short period [108]. Our meta-analysis indicates that the impact of HIFT on athletes' agility performance can be considered negligible ( $ES = 0.247$ ). HIFT typically involves various fast and explosive movements, especially clean and jerk, and box jump training [26]. These movements require rapid force generation after cutting off the force, enhancing the neural capacity for quick reactions, and enabling the body to respond accurately in fast-paced environments [109]. Gary Grey's "Chain Reaction Exploratory Theory" is strongly linked to agility training for athletes [110]. Agility is typically demonstrated by an athlete's ability to control body posture and rapidly change directions [111]. Crucial factors affecting agility include speed, muscle strength [112,113], and balance [114,115]. Possessing good agility helps athletes perform various actions more quickly in competitions, better control their body posture, and easily demonstrate personal skills, thereby increasing their competitive advantage [116]. HIFT emphasizes multi-joint and high-intensity movements, which positively affect the human body's neural-muscular coordination and proprioceptive abilities [31]. Three studies included in this systematic review evaluated the agility performance of volleyball and martial arts athletes. These findings are consistent with the results reported by Carvutto et al. Carvutto et al. reported significant improvements in athletes' agility performance, although there was no statistically significant difference compared to the control group [71]. Additionally, Hovsepian et al. found significant improvements in agility performance for both the experimental and control groups of athletes after HIFT training, although there were no statistically significant differences between the two groups [14]. However, Ambroży et al. discovered that after eight weeks of HIFT, the shuttle run performance of taekwondo athletes had improved, and the study also highlighted the significant correlation between the enhancement of shuttle run performance and hip joint rotation speed as a specific quality [59]. Rapid movement is essential in combat and defence as the foundation for achieving technical and tactical goals [117].

#### 4.5 Effect of high-intensity functional training on flexibility of athletes

Flexibility refers to the ability of muscles and joints to stretch, which is crucial for increasing the range of motion and muscle elasticity in the human body [118,119]. Our meta-analysis has demonstrated that HIFT significantly impacts athletes' flexibility performance ( $ES = 3.167$ ), which refers to the specific range of muscle activity or muscle activity ability [119]. Through comprehensive multi-joint training, muscles and joints undergo adaptive changes due to stretching and compression, which enhances athletes' joint stability and muscle elasticity [120]. The sit-and-reach test is commonly used to measure flexibility [121]. Three studies included in this systematic review examined the impact of HIFT on the flexibility performance of aerobic gymnastics and martial arts athletes. These findings align with the results of Chizewski et al., who found that a seven-week HIFT training program effectively improved athletes' flexibility [38]. Good flexibility is beneficial for enhancing muscle efficiency [69]. Stretching exercises help increase muscle elasticity, activate the nervous system, and prevent sports injuries [122]. Furthermore, multiple studies emphasize the importance of flexibility for athletes' performance [122–127]. It is noteworthy that HIFT incorporates various functional movements, particularly clean and jerks, squats, and lunges, which may be crucial factors in improving athletes' joint flexibility [77]. Research conducted by Cosgrove et al. demonstrates that after six months of HIFT, both adult males and females showed improved flexibility [128]. Similarly, Zagdsuren et al. found that after ten weeks of HIFT, the flexibility of both men and women significantly increased [129].



#### 4.6 Effect of high-intensity functional training on sport-specific performance of athletes

Sport-specific performance refers to athletes' proficiency and effectiveness in specific sports processes, forming the foundation for achieving outstanding competition results [130]. Our meta-analysis has revealed that HIFT significantly impacts athletes' sport-specific performance ( $ES = 3.351$ ). The mastery of sport-specific techniques and the skillful application of tactics enable athletes to better leverage their technical advantages and make informed decisions [131]. For example, fast attacking speed allows athletes to seize opportunities when opponents' defences still need to be established [132]. Strong attacking power enables athletes to execute more powerful offensive actions, exerting pressure on opponents [133]. This systematic review includes seven studies examining the impact of HIFT on athletes' technical performance. De Sousa et al.'s research demonstrated that HIFT significantly improved vertical jump performance in male individuals [78]. Hermassi et al. indicated that HIFT programs effectively enhanced the vertical jump performance of high-level handball athletes [83]. Similarly, Hilal and Alsulan found that HIFT plans effectively improved the shooting accuracy of five-a-side soccer players [39]. Previous research has shown that HIFT enhances athletes' speed and attack accuracy [134]. The development of overall physical fitness is crucial for athletes to utilize techniques effectively and enhance their competitive performance [135,136]. Mischenko et al. discovered that young women WTF taekwondo athletes significantly increased their attack speed and combat endurance after nine months of HIFT [64]. Özgür et al. reported that taekwondo athletes' vertical jump performance significantly improved after HIFT training [137]. Galimova et al. reported that a twelve-week HIFT program significantly improved the attacking power of university boxers [62]. Additionally, Pawlak et al. (2015) found that a 12-week HIFT intervention significantly enhanced firefighters' performance in simulated firefighting tasks.

#### 5 Limitations

This meta-analysis has several limitations that should be acknowledged:

1. The minimal number of studies ( $n = 13$ ) included in this review may restrict the generalizability of the findings. Ideally, a meta-analysis should include at least three studies for each analysis, but some of the analyses in this review were based on fewer studies.
2. Only one study met the inclusion criteria for screening literature. Therefore, the analysis of this outcome was limited.
3. The training protocols used in the included studies varied, with different types of HIFT, such as CrossFit, Fan, and Cindy, which may lead to some degree of inconsistency in the results.
4. Some studies needed to provide detailed information on the training protocols, including the duration of each training session, which could have influenced the results.
5. This meta-analysis focused primarily on overall physical abilities and did not specifically examine technical performance or combat ability, which are essential aspects of athletes' overall performance.

#### 6 Conclusions

In conclusion, this systematic review and meta-analysis suggest that HIFT positively impacts athletes' physical abilities and specific performance in sports such as aerobic gymnastics,



volleyball, taekwondo, judoka, sambo, and wrestling. HIFT effectively improves athletes' muscle strength, power, flexibility, and sport-specific performance but has no significant impact on endurance and agility. HIFT can stimulate neuroendocrine responses [43], triggering increased recruitment of muscles [30,44], consequently enhancing athletic performance. Coaches, trainers, and athletes can refer to the results of this meta-analysis to guide training programs and optimize performance results. However, due to the limited number of studies and the heterogeneity in training protocols, further research is needed to explore the potential variables that affect athletes' physical fitness and specialized performance in the HIFT intervention process. Additionally, future studies should investigate the effects of the HIFT intervention program on athletes' speed, balance, and technical and tactical performance parameters to understand better its impact on overall physical fitness and specialized abilities.

## 7 Practical application

The results of this systematic review and meta-analysis have significant implications for athletes, coaches, and sports professionals seeking to improve athletes' physical fitness and specific sports performance. Additionally, this training program requires a relatively short time commitment and recruits more muscle groups than single-mode HIIT training [31]. The diversity and dynamism of HIFT training contribute to athletes' rapid adaptation to specialized movements. The current systematic review includes limited studies, and no subgroup analysis of gender, age, or training variables was conducted. This review suggests that coaches and trainers incorporate this mode into athletes' training plans, with a frequency of at least two sessions per week and a duration of at least four weeks. Additionally, considering additional training strategies targeting specific aspects such as endurance, agility, speed, and balance, as well as technical and tactical performance, are recommended.

## Supporting information

**S1 Checklist. PRISMA 2020 checklist.**  
(DOCX)

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