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SYSTEMATIC REVIEW

Effects of high-intensity functional training on physical fitness in healthy individuals: a systematic review with meta-analysis

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Abstract

The purpose of this study was to conduct a meta-analysis of the effects of high-intensity functional training on the physical fitness of healthy individuals. This system review followed the PRISMA guidelines and has been registered in PROSPERO with the registration number CRD42023475055. As of January 2024, we did a thorough search across five databases: PubMed, Scopus, Web of Science, EBSCOhost, and Cochrane Library. We evaluated the methodological quality of the included study by TEST EX tool and ROB 2 tool. GRADE framework determines the level of certainty of evidence. Meta-analysis of random effects model calculations. 19 high-quality studies were included in this review, involving 911 healthy individuals. Positive effects were observed in improving strength (ES = 1.380; $p<0.001$), power (ES = 1.320; $p<0.001$), speed (ES = 3.093; $p<0.001$), endurance (ES = 1.802; $p<0.001$), and agility (ES = 2.086; $p<0.001$). However, flexibility performance had no significant effect (ES = 0.640; $p=0.092$), which may be attributed to limited articles. Therefore, it is necessary to expand high-quality research to explore the impact of HIFT on the physical fitness in healthy individuals.

Keywords High intensity functional training, CrossFit, Healthy males, Physical fitness, Physical performance

Introduction

Physical health is a pivotal determinant of overall well-being, encompassing qualities related to health and skills. Collectively, these attributes contribute to an individual's effective functioning, enjoyment of leisure, and capacity to meet various life demands. Physical performance is intrinsically linked to bodily health, including muscle strength, endurance, agility, and other parameters [1]. Traditional training methods often isolate muscle groups and specific movement patterns, potentially failing to meet the demands of real-life activities and exercises [2]. In contrast, High-intensity Functional Training (HIFT), inspired by the kinetic Chain Theory, emphasises the importance of the relationship between upper chain, lower chain, and core chain components in generating optimal movement patterns in terms of speed, flexibility, and strength [3]. The kinetic chain theory

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explains how different body parts interact to produce coordinated movements. Feito et al. [4] conducted theoretical research on HIFT and explored its significance in improving physical fitness. HIFT is a form of functional fitness training involving high-intensity, multi-joint, and explosive full-body movements conducted in various programmes. HIFT has gained recognition and promotion from the fitness brand CrossFit, which is being adopted by fitness enthusiasts and clubs worldwide [5]. Its uniqueness lies in integrating muscle strengthening, comprehensive upper and lower body movements, and core stability exercises. It follows a high-intensity, short-term, and constantly shifting functional training paradigm, including multi-planar movements of the entire body. HIFT entails many workouts of varying sorts and lengths, which are occasionally completed without interruption. Combining rapid repetitions of multi-joint movements with minimal rest intervals, HIFT creates a significant metabolic demand, recruiting more muscles. This demand promotes enhanced muscle strength, hypertrophy, and aerobic endurance adaptation. HIFT emphasises the participation of multiple muscle groups, joints, planes, and dimensions in functional multi-joint activities. Research suggests that HIFT positively stimulates the neuroendocrine response and promotes the human body's production of testosterone, insulin, and growth hormone [6].

The applicability of HIFT goes beyond conventional fitness plans. It can be tailored to specific sports, individual physical conditions, and the demands of training time and load. Previous studies indicate that HIFT positively influences the physical performance of diverse populations, including obese individuals [7], older adults [8], adolescents [9], wrestlers [10], gymnasts [11], and recreational runners [12]. Furthermore, there is a previous systematic review of HIFT on the general population, but it only included inactive individuals, and the measured outcomes were limited to strength, endurance, and balance [13]. There is limited focus on the unique fitness needs of healthy individuals. In previous studies, our team conducted multiple systematic reviews of the effects of HIFT on athletic populations. For instance, Wang et al. (2024) explored the effects of functional training on muscle strength, jumping, and functional movement screen in wushu athletes through a systematic review, revealing significant benefits of such training within this group [14]. In a further meta-analysis, Wang et al. (2023) focused on the improvements in physical fitness and sport-specific performance resulting from HIFT across various athletes, showing marked enhancements in key fitness metrics such as strength, power, endurance, speed, agility, and flexibility [15]. While these studies offer valuable insights into athletic development, their limitation lies in not covering non-athlete populations, particularly healthy individuals.

This study aims to bridge that gap by systematically evaluating the overall health impact of HIFT on healthy individuals, with a particular focus on multidimensional metrics such as strength, power, endurance, speed, flexibility, and agility. Compared to our previous research on athletes, the current study expands the scope by addressing the comprehensive health status of healthy populations. HIFT not only plays a role in improving athletic performance, but its potential in enhancing the overall health of the general population remains underexplored. Therefore, through a systematic review and meta-analysis of the latest literature, this study provides new evidence to clarify the health benefits of HIFT in the general population.

Methods

Protocol and registration

The system review adheres to the revised Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria and has been registered on the PROSPERO website. The registration code is CRD42023475055.

Search strategy

As of January 2024, a thorough search has been conducted on articles related to this topic using five electronic databases: Web of Science, PubMed, Scopus, EBSCOhost, and Cochrane Library. The main keywords for searching are: ("high-intensity functional training" OR "high-intensity functional exercise" OR "functional high-intensity interval training" OR "CrossFit") AND ("physical fitness" OR "physical endurance" OR "cardiorespiratory fitness" OR "physical condition" OR "body composition" OR "airborne endurance" OR "endurance" OR "strength" OR "speed" OR "power" OR "agility" OR "balance" OR "coordination" OR "flexibility" OR "reaction time") AND ("healthy adults" OR "young" OR "adults" OR "healthy" OR "individual" OR "adolescent" OR "teen" OR "youngsters" OR "junior" OR "older" OR "men" OR "male" OR "women" OR "female"). Furthermore, we personally looked for references and used Google Scholar to make sure to include relevant papers as much as feasible.

Eligibility criteria

This review only included English literature that was not limited by publication year, as articles written in other languages may be difficult to translate. Articles that met the PICOS framework standards were included in this study [16]. The following were the inclusion criteria for this study: (1) Participants were healthy males without age or exercise experience limitations; (2) The intervention project must be high-intensity functional training;

(3) The included studies must include a control group; (4) The examination documented findings about the physical fitness of the participants.

Studies were excluded based on the following criteria: (1) Studies in which participants were female or gender neutral; (2) Participants were unhealthy or have sports injuries; (3) Intervention methods included high-intensity functional training or a combination of high-intensity functional training and psychological intervention; (4) No control group; (5) Lack of results related to physical fitness; And (6) books, chapters, retrospective studies, abstracts, case reports, reviews, or patents.

Study selection

Figure 1 illustrates the selection procedure for these studies. In the first stage, import the search results of all databases into Endnote x9 software to remove duplicate articles. In the second stage, two reviewers (XW and ND) independently assessed every article through the title, keywords, and abstract, using preset inclusion criteria. The reviewers next evaluated the screened publications in full text. Any disputes encountered by two independent reviewers during the article screening and data extraction process will be solved after consulting with

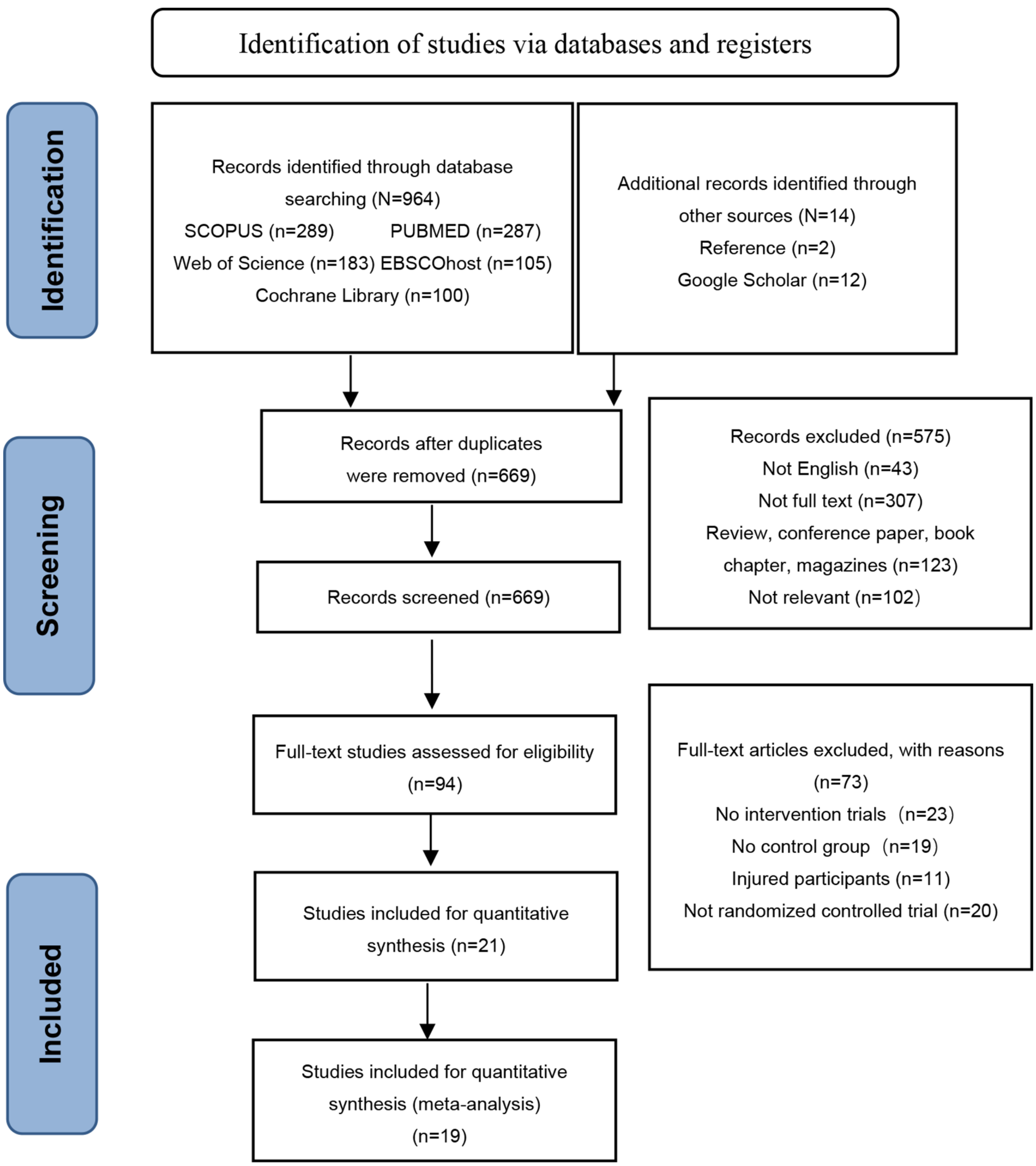

Fig. 1 Flow chart of PRISMA article screening

the third reviewer. (KGS) until a consensus agreement is reached.

Data extraction

Two independent reviewers (XW and ND) used Microsoft Excel tables to extract the data listed below according to inclusion criteria: (1) The first author's name and publication year; (2) Participant characteristics (like sample size, age, and training experience); (3) Intervention features (frequency, duration, and length); (4) Grouping situation; (5) Research results.

Study quality assessment

Two independent reviewers (XW and ND) employed the TESTEX tool (Tool for the Assessment of Study Quality and Reporting in Exercise) to comprehensively assess the quality of all included studies [17]. TESTEX, meticulously designed to evaluate exercise intervention research, encompasses 15 scoring criteria that address both methodological rigour and reporting standards, with a total score ranging from 0 to 15. The evaluation of risk of bias was conducted using the Cochrane-endorsed ROB 2 tool (Risk of Bias 2), which systematically analysed the potential sources of bias in the included randomised controlled trials [18]. ROB 2 examines several domains, including biases stemming from the randomisation process, deviations from intended interventions, incomplete outcome data, the measurement of outcomes, and the selective reporting of results.

Certainty of evidence

The Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) approach analyses and summarises the certainty of evidence. GRADE evaluates the certainty of evidence as very low, low, moderate, or high.

Data synthesis and statistical analysis

The Cochrane Handbook states that at least two studies are required for meta-analysis [19]. Therefore, we used comprehensive meta-analysis software (CMA; Biostat et al., Version 3). Extract the mean and standard deviation (SD) via the literature. If the mean and SD are not provided in the article, extract other data (such as mode, median, or standard error) and use appropriate methods to convert them into mean and standard deviation. If there is no relevant information in the original article or supplementary materials, we attempt to contact the corresponding author. If the required data cannot be obtained, the study need be excluded. Applying the inverse variance statistical approach and a random effects model, the effect size (ES; Hedge's g) and 95% confidence interval (CI) of the result measurement were determined [20]. The range of effect sizes can be identified by the following explanations: negligible effect sizes (< 0.2), small effect sizes (0.20–0.6), moderate effect sizes (0.6–1.2), large effect sizes (1.2-2.0), very large effect sizes (2.0–4.0), and extremely large effect sizes (> 4.0) [21]. The I^2 statistic assesses the study's heterogeneity, which can be classified into three levels: low, medium, and high. Specifically, 25% or less heterogeneity indicates low heterogeneity, between 25% and 50% indicates lower heterogeneity, between 50 and 75% shows moderate heterogeneity, while more than 75% is called high heterogeneity. The Egger test was used to evaluate the risk of publication bias.

Additional analysis

To investigate the potential impact of moderating factors, subgroup analysis was conducted. Based on the author's discussion and intervention characteristics, the researchers pre-selected relevant heterogeneity sources that may affect training effectiveness: intervention length and gender. Participants were grouped based on the median intervention time (i.e. ≤12 weeks vs. >12 weeks) and gender (male vs. female).

Results

Study selection

Figure 1 illustrates the process of selecting articles for this review. Initially, 964 articles were discovered from the database, including 289 articles discovered through Scopus, 287 articles discovered through PubMed, 183 articles discovered through Web of Science, 105 articles discovered through EBSCOhost, 100 articles discovered through Cochrane Library, and 14 articles discovered through Google Scholar. After manually removing duplicates through Endnote software, 669 articles were retained. Then, by screening the titles and abstracts of these records, it was found that 43 articles were non-English, 307 were not full texts, 123 were not journals, and 102 were not related to the research topic. Then, 94 articles were identified as eligible for full-text analysis. After conducting a full-text review, it was found that 94 articles needed to meet all the inclusion criteria for this system review. Finally, 21 publications fulfilled the inclusion criteria, 19 of which were used in the meta-analysis.

Study quality assessment

The methodological quality of the included studies was assessed using the TESTEX scoring system, with the results presented in Table 1. TESTEX scores ranged from 8 to 12, with an average score of 9, indicating that the majority of studies demonstrated good methodological quality. However, all studies exhibited shortcomings in allocation concealment and implementing blinding, potentially increasing the risk of bias.

Table 1 TESTEX scores for Methodological Quality Assessment of included studies

Study	Testex 1	Testex 2	Testex 3	Testex 4	Testex 5	Testex 6	Testex 7	Testex 8	Testex 9	Testex 10	Testex 11	Testex 12	Result
Bahremand et al., 2023 [26]	1	1	0	1	0	1	0	2	1	0	1	1	9
Garst et al., 2020 [27]	1	1	0	1	0	2	0	2	1	0	1	1	10
Mischenko et al.,2021 [25]	0	1	0	1	0	1	0	2	1	0	1	1	8
Romanova, 2023 [28]	1	1	0	0	0	2	0	2	1	0	1	1	9
Griban, 2021 [21]	0	1	0	1	0	1	1	2	1	0	1	1	9
Yuksel et al., 2019 [24]	0	1	0	1	0	1	0	2	1	0	1	1	8
Ambrozy et al., 2022 [29]	1	1	0	1	0	2	0	2	1	0	1	1	10
Hakim et al., 2021 [30]	1	1	0	1	0	1	0	2	1	0	1	1	9
Kolomiitseva et al., 2020 [31]	1	1	0	1	0	1	0	2	1	0	1	1	9
Hollerbach et al., 2019 [32]	1	1	0	1	0	1	0	2	1	0	1	1	9
Osipov et al., 2022 [22]	0	1	0	1	0	1	0	2	1	0	1	1	8
Yu et al., 2021 [33]	1	1	0	1	0	3	1	2	1	0	1	1	12
Turker & Yuksel., 2020 [10]	1	1	0	1	0	1	0	2	1	0	1	1	9
Caloglu & Yuksel., 2020 [34]	1	1	0	1	0	1	0	2	1	0	1	1	9
Avetisyan et al., 2022 [35]	1	1	0	1	0	1	0	2	1	0	1	1	9
Bozdogan et al., 2021 [36]	1	1	0	1	0	1	0	2	1	0	1	1	9
Osipov et al., 2021 [23]	0	1	0	1	0	1	0	2	1	0	1	1	8
Chukhlantseva et al., 2020 [37]	1	1	0	1	0	1	0	2	1	0	1	1	9
Kudryavtsev et al., 2018 [38]	1	1	0	1	0	1	0	2	1	0	1	1	9

Fig. 2 RoB-2 assessments

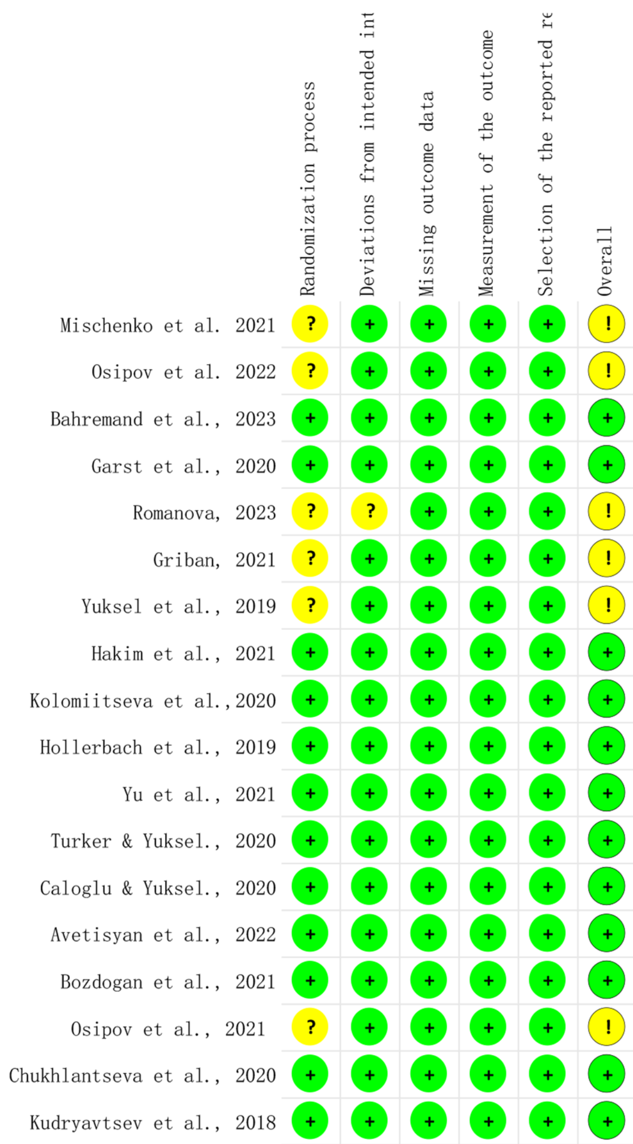

Fig. 3 Risk of overall bias

Additionally, a detailed risk of bias assessment was conducted using the ROB 2 tool, with the findings illustrated in Fig. 2. Figure 3 summarizes the overall risk of bias. Most studies demonstrated a low risk of bias in areas such as missing outcome data, outcome measurement, and selective reporting of results. However, certain studies displayed a degree of bias in the domains of randomisation processes and deviations from intended interventions. This highlights that, although the overall risk of bias was low, these weaknesses in study design and implementation warrant attention to enhance the credibility and reliability of future research.

Certainty of evidence

Table 2 shows the results of GRADE analysis. The GRADE evaluation results report a low level of certainty in the evidence.

Participant characteristics

The participant characteristics of the 19 studies included in this system review were reported in Table 3, as shown below. (1) Sample size: The 19 studies comprised a total of 2215 individuals, with sample sizes ranging from 20 to 92 [10, 19–36]. (2) Age: Participants who meet the criteria reported in studies are aged between 10 and 23 years old [10, 22–39]. (3) Training experience: Ten studies involve athletes [10, 23–25, 29, 30, 35–37], four studies involve cadets [22, 32, 34, 39], two studies involve healthy women [27, 38], two studies involve high school students [31, 32], one study involves middle school students [28], and one study focuses on firelighter recruits [33].

Intervention characteristics

Table 3 summarises the 19 intervention characteristics included in the study. (1) Intervention type: HIFT served as the main intervention strategy in all studies. One study specifically used HIFT intervention [33], while twelve studies used CrossFit training intervention [22, 23, 25,

Table 2 Certainty of evidence for meta-analysed outcomes

Outcomes	Certainty assessment					No of Participants and Studies	Certainty of the Evidence (GRADE)
	Risk of bias	Inconsistency	Indirectness	Imprecision	Risk of publication bias		
Strength performance assessed follow-up: range 5 to 144 weeks	Serious [a]	Not serious	Not serious	Serious [b]	Not serious	659 (14 RCTs)	⨁⨁◯◯ LOW
Power performance assessed follow-up: range 5 to 144 weeks	Serious [a]	Not serious	Not serious	Serious [b]	Not serious	476 (13 RCTs)	⨁⨁◯◯ LOW
Speed performance assessed follow-up: range 8 to 48 weeks	Serious [a]	Not serious	Not serious	Serious [b]	Not serious	186 (5 RCTs)	⨁⨁◯◯ LOW
Endurance performance assessed follow-up: range 8 to 48 weeks	Serious [a]	Not serious	Not serious	Serious [b]	Not serious	321 (9 RCTs)	⨁⨁◯◯ LOW
Agility performance assessed follow-up: range 5 to 48 weeks	Serious [a]	Not serious	Not serious	Serious [b]	Not serious	319 (9 RCTs)	⨁⨁◯◯ LOW
Flexibility performance assessed follow-up: range 8 to 144 weeks	Serious [a]	Not serious	Not serious	Serious [b]	Not serious	254 (6 RCTs)	⨁⨁◯◯ LOW

GRADE, Grading of Recommendations Assessment, Development and Evaluation; RCT, randomized controlled trial. a Downgraded by one level due to average score being moderate (< 9); b Downgraded by one level, as ≥ 800 participants were available for a comparison but there was an unclear direction of the effects. Downgraded by two levels in case of imprecision based on both assessed points

Table 3 Mediation analysis of the impact of HIT on jumping performance

Subgroup	Studies	ES (95%CI)	*P* Value	Q-statistics
Intervention length (week)				
< 12	30	0.727 (0.491 to 0.963)	< 0.001[a]	
≥ 12	36	2.490 (1.884 to 3.095)	< 0.001[a]	
Overall	66	0.960 (0.740 to 1.179)	< 0.001[a]	(Q = 28.271; df (Q) = 1; *P* < 0.001[b])
Sex				
Male	40	1.370 (0.947 to 1.793)	< 0.001[a]	
Female	26	1.941 (1.392 to 2.490)	< 0.001[a]	
Overall	66	1.583 (1.247 to 1.918)	< 0.001[a]	(Q = 2.613; df (Q) = 1; *P* = 0.106)

a = significant difference within a group; b = significant difference between groups

Abbreviations: 95%CI = 95% confidence interval; ES = effect size

27, 29, 30, 32, 34–37, 39]. three study combined CrossFit training with resistance training [24, 26, 38], and the other study carried out comparison tests between CrossFit AMRAP and traditional CrossFit [10]. One study used the CrossFit school challenge [31], and the other used the CrossFit Kids Programme [28]. (2) Intervention frequency: Among the 19 studies, eleven had an intervention frequency of 3 times per week [10, 22, 25–30, 33, 35, 38], four had an intervention frequency of 2 times per week [31, 32, 36, 39], two had an intervention frequency of 4 times per week [23, 24], and one had an intervention frequency of 1 times per week [34]. (3) Intervention length: Seven studies lasted for 8 weeks [10, 23, 25, 27, 30, 31, 35], three studies lasted for 12 weeks [24, 32, 37], the shortest study lasted for 5 weeks [39], one study lasted for 10 weeks [33], one study lasted for 16 weeks [34], one study lasted for 24 weeks [38], one study lasted for 5 months [36], 9 months were spent on two study [26, 28], one study lasted for 12 months [29], and the longest study lasted for three years [22].

Outcome

Effect of high-intensity functional training on strength of healthy individuals

Fourteen of the nineteen research articles examined the effect of HIFT on the strength healthy individuals [22–26, 28–33, 36, 38, 39]. This meta-analysis's results show that HIFT significantly impacts the strength of healthy individuals (ES = 1.380; 95% CI = 0.770–1.990; $p < 0.001$; Egger test $p = 0.053$; $N = 659$; Fig. 4A). The overall heterogeneity of the effect is moderate (Q = 27.877; I^2 = 42.605%). In the meta-analysis process, the relative weight range for each study is 3.82–6.45%.

Effect of high-intensity functional training on power of healthy individuals

Thirteen discussed how HIFT affected healthy individuals' power [10, 22, 25–27, 29, 30, 33, 35–39]. This meta-analysis's results indicate that HIFT significantly impacts healthy individuals' power (ES = 1.320; 95% CI = 0.537–2.103; $p < 0.001$; Egger test $p = 0.051$; $N = 476$; Fig. 4B). The overall heterogeneity of the effect is moderate (Q = 33.140; I^2 = 60.773%). In the meta-analysis process, the relative weight range for each study was 5.33–7.66%.

Effect of high-intensity functional training on speed of healthy individuals

Four discussed how HIFT affected healthy individuals' speed [26, 29–31]. This meta-analysis's results indicate that HIFT significantly affect healthy individuals' speed (ES = 3.093; 95% CI = 1.432–4.754; $p < 0.001$; Egger test

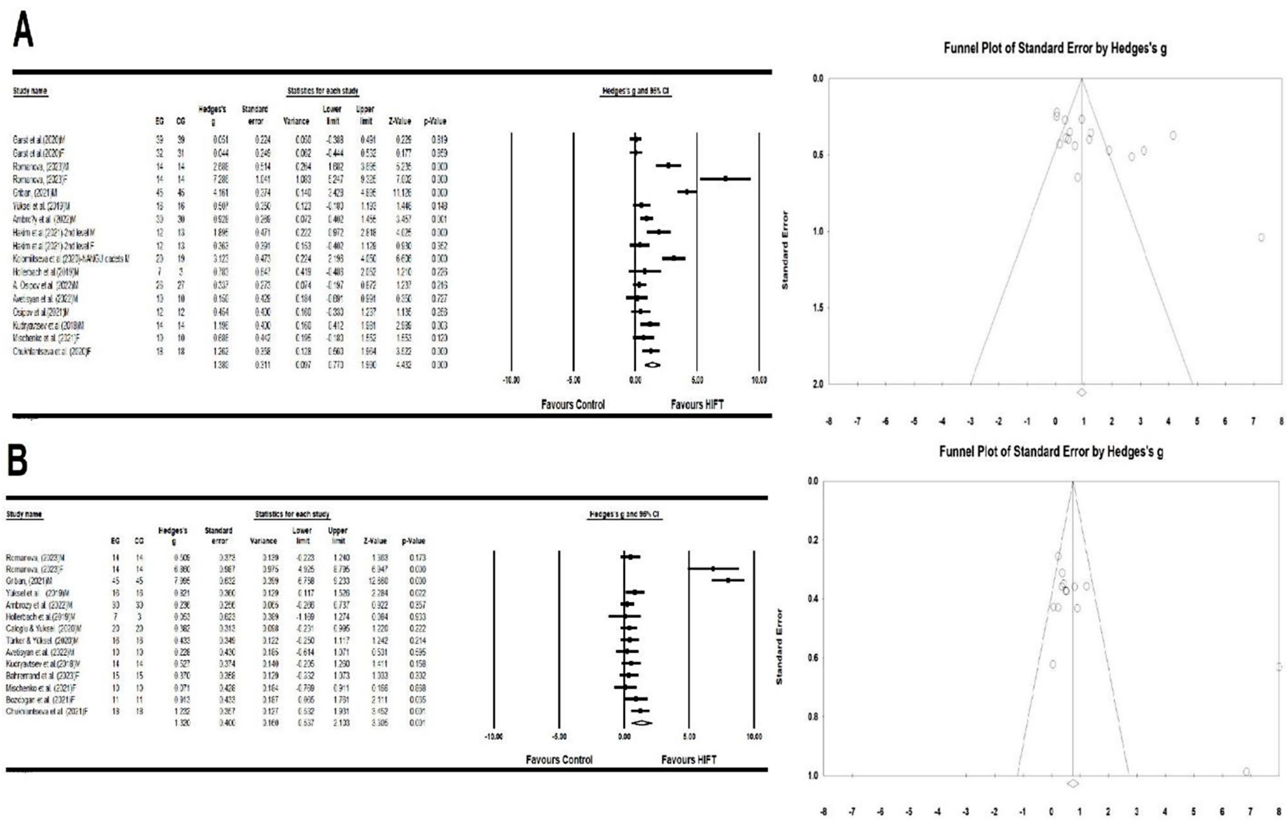

Fig. 4 (**A**) Forest plot and funnel plot of the impact of HIFT on the strength of healthy individuals compared to the control group. (**B**). Forest plot and funnel plot of the impact of HIFT on the power of healthy individuals compared to the control group. The displayed values represent the effect size (Hedges' g) of 95% confidence intervals (CI). The size of the square shown in the figure represents the statistical weight

$p = 0.050$; $N = 186$; Fig. 5A). This meta-analysis's results indicate that the overall heterogeneity of this effect is moderate ($Q = 26.433$; I^2 = 69.084%). In the meta-analysis process, the relative weight range for each study was 8.18–19.42%.

Effect of high-intensity functional training on endurance of healthy individuals

Nine discussed how HIFT affected healthy individuals' endurance [26, 29–34, 37, 38]. This meta-analysis's results show that HIFT significantly impacts the endurance of healthy individuals (ES = 1.820; 95% CI = 0.169–2.625; $p < 0.001$; Egger test $p = 0.054$; $N = 321$; Fig. 5B). The overall heterogeneity of this effect is low ($Q = 11.007$; I^2 = 9.150%). In the meta-analysis process, the relative weight range for each study was 7.64–10.09%.

Effect of high-intensity functional training on agility of healthy individuals

Seven discussed how HIFT affected healthy individuals' agility [26,29–33,36,38,39]. The results showed that HIFT significantly impacted agility in healthy individuals (ES = 2.086; 95% CI = 1.112–3.060; $p < 0.001$; Egger test $p = 0.053$; $N = 319$; Fig. 6A). The overall heterogeneity of this effect is moderate ($Q = 26.418$; I^2 = 62.147%). In the meta-analysis process, the relative weight range for each study was 5.66–10.13%.

Effect of high-intensity functional training on flexibility of healthy individuals

Six discussed how HIFT affected healthy individuals' flexibility [22, 26, 30, 31, 33, 38]. This meta-analysis's findings show that HIFT has no significant effect on the flexibility of healthy individuals (ES = 0.640; 95% CI = -0.105-1.385; $p = 0.092$; Egger test $p = 0.057$; $N = 254$; Fig. 6B). The overall heterogeneity of this effect is moderate ($Q = 22.012$; I^2 = 61.257%). In the meta-analysis process, the relative weight range for each study was 2.45–18.16%.

Effect of moderator variables

Table 3 shows the analysis results of mediating variables. The subgroups analysed in this study include intervention time (< 12 weeks and ≥ 12 weeks) and gender (male and female). For intervention length, studies with intervention time < 12 weeks showed moderate efficacy (ES = 0.727, 95% CI: 0.491–0.963, $p < 0.001$), and studies with intervention time ≥ 12 weeks also showed moderate efficacy (ES = 0.960, 95% CI: 0.740–1.179, $p < 0.001$). For

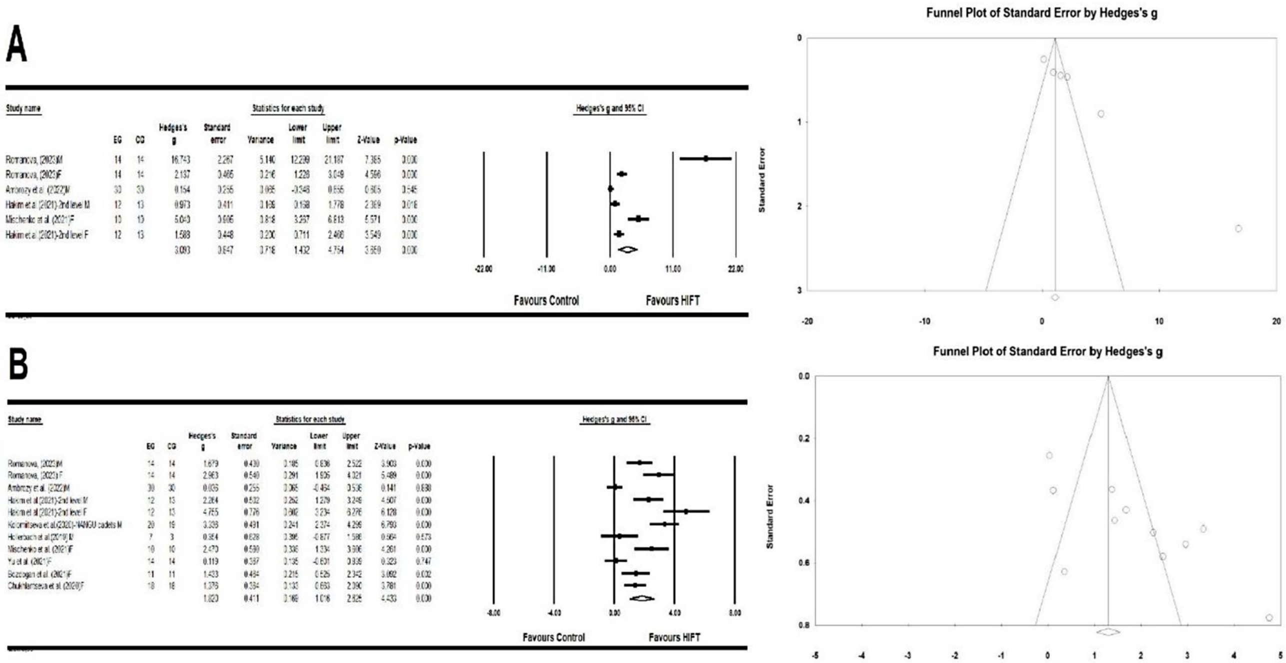

Fig. 5 (**A**). Forest plot and funnel plot of the impact of HIFT on the speed of healthy individuals compared to the control group. (**B**). Forest plot and funnel plot of the impact of HIFT on the endurance of healthy individuals compared to the control group. The displayed values represent the effect size (Hedges' g) of 95% confidence intervals (CI). The size of the square shown in the figure represents the statistical weight

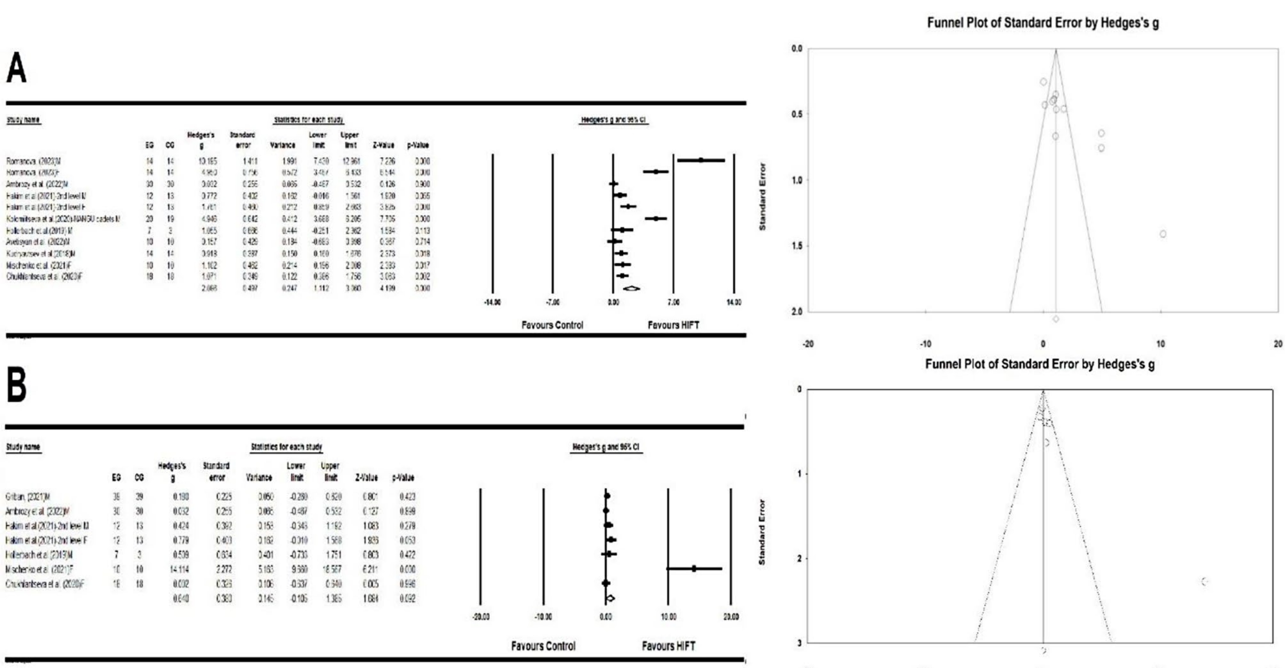

Fig. 6 (**A**). Forest plot and funnel plot of the impact of HIFT on the agility of healthy individuals compared to the control group. (**B**). Forest plot and funnel plot of the impact of HIFT on the flexibility of healthy individuals compared to the control group. The displayed values represent the effect size (Hedges' g) of 95% confidence intervals (CI). The size of the square shown in the figure represents the statistical weight

gender, studies focusing on males (ES = 1.370, 95% CI: 0.947–1.793, $p < 0.001$) and studies focusing on females (ES = 1.941, 95% CI: 1.392–2.490, $p < 0.001$) both showed large efficacy. The Q statistic of subgroup analysis showed a significant difference in intervention length ($p < 0.001$). Further subgroup analysis showed no significant difference in Q-statistics between genders ($P = 0.106$).

Discussion

Effect of high-intensity functional training on strength of healthy individuals

Muscle strength is critical for individuals' health [40]. HIFT theory emphasises the effectiveness of HIFT in increasing muscle strength [41]. This study investigates how HIFT affects healthy individuals' strength performance through meta-analysis (ES = 1.380). Fourteen studies evaluated the strength performance of middle and high school students, firelighter advisors, cadets, writers, judo athletes, and taekwondo athletes after HIFT training. These results agree with the systematic review by Wilke et al., who reported a positive impact of HIFT on the strength [13]. However, Wilke et al. only focused on the control group of inactivity, strength, endurance, or balance exercise. Interestingly, Ambrozy et al. (2022) contrasted traditional Taekwondo instruction with high-intensity CrossFit exercise and found that, compared to the control group, the CrossFit training group had no significant effect on the pull-up of atoms [30]. However, push-ups were significantly different. According to a report by Barfield et al. [42], high-intensity functional training can significantly improve participants' lower limb muscle strength. Research has shown that strength training, such as squatting or hard pulling, can significantly enhance individuals' ability to generate strength [41]. Glassman's research found that HIFT can activate the neuroendocrine system, increasing testosterone, insulin, and growth hormones [6]. In addition, studies have shown a noteworthy affirmative relationship between the increase in strength parameters and serum testosterone concentration [43]. Therefore, our meta-analysis results indicate that HIFT effectively improves the strength performance of healthy individuals.

Effect of high-intensity functional training on power of healthy individuals

Power is usually related to factors such as speed, agility, and strength and is crucial for the rapid and robust movement of the human body [44]. This study explored the impact of HIFT on the power performance of healthy individuals through meta-analysis (ES = 1.320). Thirteen studies evaluated the power performance of Cadets, Firefighter Recruits, Judo athletes, Wrestlers, and Taekwondo athletes after HIFT training and achieved significant improvements. These results align with those obtained by Claudino et al.'s systematic review. Claudino et al. found that short-term HIFT intervention has a positive impact on power [45]. Newman et al. contrasted the effects of HIFT and standard military physical training interventions on the physical fitness of ROTC cadets and found that after 10 weeks of training intervention, HIFT had a better effect on the power of ROTC cadets [46]. The strength speed curve shows that various training techniques may increase each region's strength growth pace, optimizing power development. Adam et al.'s study found that HIFT athletes perform better in power than endurance and strength athletes [47]. HIFT without sufficient rest promotes the release of synthetic metabolic hormones [6]. HIFT theory emphasises combining strength training with aerobic and weight training, which generates a significant metabolic demand through rapid and repetitive training with fewer intervals [48].

Effect of high-intensity functional training on speed of healthy individuals

The term "speed" describes the human body's capacity for rapid movement, encompassing displacement, action, and reaction speeds [49]. This meta-analysis explores the impact of HIFT on the speed performance of healthy individuals (ES = 3.093). As individuals' bodies develop, several vital factors can cause changes in their speed performance [50]. However, it is interesting that several studies that were not grouped by gender have found that HIFT has a positive impact on the speed performance of healthy individuals [26, 46, 51]. For example, Newman et al. investigated the effect of HIFT on the physical fitness of ROTC cadets and found that compared to the control group, HIFT had a more significant improvement in the speed performance of ROTC Cadets [46]. Studies have shown that HIFT programs can effectively enhance the recruitment of exercise units, optimize the speed of muscle contraction, and enable the human body to quickly generate maximum strength and speed [52]. Similar to high-intensity interval training, HIFT theory emphasises short-term, high-intensity, explosive, and continuous whole-body exercise that specifically recruits and stimulates these fast muscle fibres to rapidly produce energy through anaerobic energy pathways using stored adenosine triphosphate (ATP) and creatine phosphate, thereby helping to improve speed performance [13].

Effect of high-intensity functional training on endurance of healthy individuals

Endurance is an essential component of physical health and profoundly impacts individuals' health. This study explored the impact of HIFT on the endurance performance of healthy males through meta-analysis (ES = 1.820). Nine studies evaluated the endurance performance of high school students, firefighter recruits, and taekwondo athletes after HIFT training and achieved significant improvements. These results are consistent with Wilke et al.'s systematic review findings. Wilke et al. found that HIFT has a positive impact on endurance, and compared to NEX, women seem to have a stronger response to HIFT [13]. Heinrich and colleagues compared the effects of HIFT and weight training on the physical fitness of high school students and found that after nine months of training intervention, HIFT had a better impact on the endurance of high school students [51]. The core of HIFT theory is the integration of high-intensity functional exercise, which typically challenges the cardiovascular and respiratory systems in various and constantly changing patterns, promoting oxygen delivery and increasing the efficiency of cardiac pumping to meet metabolic needs, enabling individuals participating in HIFT to maintain high-intensity exercise for more an extended period. The HIFT theory involves both aerobic and anaerobic energy pathways, emphasizing a dual metabolic requirement that leads to increased mitochondrial density and efficiency-enhanced glycolytic pathways, allowing individuals to maintain high-intensity exercise and delay fatigue during HIFT exercise [53].

Effect of high-intensity functional training on agility of healthy individuals

Agility is the ability to change direction quickly and accurately. This study explored the impact of HIFT on agile performance in healthy individuals through meta-analysis (ES = 2.086). Seven studies evaluated the agility performance of high school students, firefighters, cadets, judo athletes, and taekwondo athletes after HIFT training, and achieved significant improvements. These results are in agreement with those of Cataldi et al. Cataldi et al. observed a substantial improvement in agility performance in healthy adolescents after 8 weeks of HIFT intervention when compared to the control group [54]. The HIFT program includes fast and explosive movements, such as burpee, clean and jerk, and box jumping training. HIFT theory emphasises adaptability and multifunctionality to help balance muscle development, particularly for males who frequently engage in fast, explosive sports activities. The multi-joint and high-intensity exercise characteristics of HIFT contribute to the development of neuromuscular coordination and proprioceptive abilities in the human body [41]. Hakim et al. found that the agility performance of high school students significantly improved after eight weeks of CrossFit training [31]. In addition, Romanova et al. found that after one year of HIFT, Taekwondo athletes significantly improved their agility performance [29].

Effect of high-intensity functional training on flexibility of healthy individuals

Flexibility refers to the range of motion around the joints, playing a crucial role in maintaining the optimal movement mode of the human body and preventing injury. This study explored how HIFT affected the flexibility performance of healthy individuals through meta-analysis (ES = 0.640). Six studies evaluated the flexibility performance of middle school students, high school students, firelighter recruiters, and taekwondo athletes after HIFT training, and comparison to the control group, the results did not reveal any statistically significant differences. It is worth noting that the HIFT theory emphasises functional movements across multiple muscle groups, joints, planes, and dimensions, particularly jerks and squats, which may help improve joint flexibility in healthy individuals [55]. However, it is interesting that several studies that were not grouped by gender have found a positive impact of HIFT on the flexibility of healthy individuals [56, 57]. For example, a study reported the positive impact of nine weeks HIFT on the flexibility and quality of aerobic gymnasts [11]. Cosgrove et al. found in their report that, compared to the control group, the flexibility performance of adult individuals significantly improved after six weeks of HIFT intervention [56]. Similarly, the study by Zagdhuren et al. found that after six months of HIFT, the flexibility of healthy individuals was significantly improved compared to the control group [57].

Effect of moderator variables

The subgroup analysis results from our systematic review offer crucial insights into the varying effects of HIFT training on physical fitness of healthy individuals. Our meta-analysis reveals that the duration of HIFT intervention plays a significant role in enhancing physical performance, indicating that individuals can achieve substantial improvements in fitness through HIFT programs of varying lengths. Furthermore, our gender-based analysis demonstrates that HIFT interventions significantly enhance physical fitness across healthy individuals of different genders.

Limitations

This systematic review and meta-analysis provide valuable insights into the physical development of healthy individuals, but it should be acknowledged that there are also some limitations:

1. This review only includes research on healthy individuals, and the number of studies included is limited, which may restrict the generalizability of the findings.
2. The research intervention methods included in this review include different types of HIFT projects, such

as classic CrossFit, AMRAP-based CrossFit, CrossFit kids' program, and CrossFit school challenge. This variability may have impacted the consistency of intervention strategies and their comparative effects.
3. The outcome indicator analysed in this review is the physical fitness of healthy individuals, without specifically studying body composition or skill performance, leaving gaps in understanding HIFT's effects on these critical areas.
4. The inclusion of research in this review is limited to studies written in English, which may limit the representativeness and comprehensiveness of the research results.

Conclusions

This systematic review and meta-analysis summarise some positive effects of HIFT on the physical fitness of healthy individuals. It is worth noting that HIFT has shown significant effects in terms of strength, power, endurance, speed, and agility. However, no significant impact has been observed on healthy individuals' flexibility performance, which may be attributed to limited articles. Subgroup analysis suggests that longer HIFT interventions (≥ 12 weeks) appear to be more effective in improving physical fitness. To more comprehensively validate the potential effects of HIFT on physical fitness, particularly its impact on flexibility performance, further high-quality research is necessary. Moreover, to ensure the comparability and reliability of research findings, it is recommended to adopt consistent and standardized data measurement methods and to conduct an in-depth exploration of specific HIFT training protocols. This will contribute to a more precise assessment of HIFT's impact on the physical fitness of healthy individuals.

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Declarations

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