sciendo

Review Paper

Biomedical Human Kinetics, 16, 113–130, 2024
DOI: 10.2478/bhk-2024-0012

High-intensity interval training programs and their impact on endurance performance in handball players: A systematic review

José Rocha Henrique[1,2], Rodrigo Ramirez-Campillo[3], Francisco Tomás González Fernandez[4], Daniel Castillo[5], Javier Raya-González[6], Piotr Zmijewski[7], Rui Miguel Silva[1,2], Filipe Manuel Clemente[1,2,8]

[1] Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Rua Escola Industrial e Comercial de Nun'Álvares, 4900-347 Viana do Castelo, Portugal; [2] Sport Physical Activity and Health Research & Innovation Center, Viana do Castelo, Portugal; [3] Exercise and Rehabilitation Sciences Institute. School of Physical Therapy. Faculty of Rehabilitation Sciences. Universidad Andres Bello. Santiago, Chile; [4] Department of Physical Education and Sports, Faculty of Sport Sciences, University of Granada, Granada, Spain; [5] Valoración del Rendimiento Deportivo, Actividad Física y Salud y Lesiones Deportivas (REDAFLED), Faculty of Education, University of Valladolid, Soria, Spain; [6] Faculty of Sport Sciences, University of Extremadura, Cáceres, Spain; [7] Józef Piłsudski University of Physical Education, Warsaw, Poland; [8] Gdańsk University of Physical Education and Sport, Gdańsk, Poland

Abstract

Study aim: This systematic review aimed to identify and analyze the available evidence about the effects of high-intensity interval training (HIIT) interventions on endurance performance in handball players.

Material and methods: The search for relevant literature was conducted across prominent databases, including PubMed, Scopus, SPORTDiscus, and Web of Science Core Collection. The eligibility criteria focused on healthy handball players, without restrictions on age, sex, or competitive level, who were exposed to HIIT interventions, either alone or in combination with other training methods. The methodological assessment employed the RoB2 and ROBINS scales. A screening process was executed, evaluating 434 titles, leading to the inclusion of 17 eligible studies in this systematic review, comprising a total of 369 participants.

Results: Most studies on HIIT in handball involved tier-two athletes (trained/developmental) and mostly men. The training frequency typically implemented was twice per week, with a duration between 4 and 12 weeks, with different types of HIIT. There was considerable variation in outcomes across the included studies, with most of them demonstrating a significant positive impact of HIIT on improving endurance performance when compared to controls.

Conclusion: In conclusion, the predominant focus of the overall analyzed studies was on the effects of different HIIT interventions in obtaining positive performance adaptations assessed by field-based tests in handball players.

Keywords: Team sports – Intermittent exercise –HIIT – Endurance – Handball

Introduction

During handball matches, players exhibit elevated heart rates (HR), oxygen uptake (VO2), blood lactate levels, glycogen utilization, and lipid metabolism, highlighting the substantial aerobic and anaerobic demands of the sport [41, 54]. Although there are studies that claim that these attributes do or do not differentiate elite performance and are crucial to success [36, 39], prior studies have recommended the utilization of intermittent exercise to improve the endurance performance of these players [22, 52].

While continuous and interval training has been utilized for years to enhance athletes' aerobic and anaerobic capacities [32, 43], it should be noted that these training modalities stimulate different physiological adaptations [21]. Remarkably, high-intensity interval training (HIIT) has shown to be effective in promoting adaptations in the anaerobic threshold, maximal oxygen uptake (VO_{2max}), and the ability to repeatedly perform high-intensity efforts [35]. Additionally, it offers the advantage of significantly reducing

Author's address Filipe Manuel Clemente, Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Rua Escola Industrial e Comercial de Nun'Álvares, 4900-347 Viana do Castelo, Portugal filipe.clemente5@gmail.com

the time required to observe positive adaptations to training when compared to continuous training [34]. HIIT can elicit physiological responses that enhance the capacity for aerobic energy performance [23], and these improvements can be due to physiological factors, such as an increase in the number of mitochondria, and consequently, an increased VO_{2max} and improved capacity for oxidative metabolism in skeletal [2] However, there is still no consensus statement on how HIIT interventions have the potential to improve endurance performance in handball [23].

Prescription for HIIT consists of the manipulation of up to nine variables, which include the work interval intensity and duration, relief interval intensity and duration, exercise modality, number of repetitions, number of series, as well as the between-series recovery duration and intensity [9], and the manipulation of any of these variables can affect the physiological responses to HIIT [9]. Regarding protocol characterization, interval training is infinitely variable and there is a lack of standardization (both in the scientific literature and amongst practitioners) about the terminology used to describe different approaches [23], however, the most referenced forms of interval training are short and long intervals, repeated sprint training (RST), sprint interval training (SIT) and small sided games (SSGs) [10].

Although HIIT prescription has been recommended in the literature based on percentages of maximum HR, heart rate reserve (HRR), VO_{2max}, and VO2 reserve [51], a previous study highlighted significant inter-individual variations in both relative mean and peak power [51]. Consequently, the cardiopulmonary or metabolic strain, along with the exercise stimuli, differs substantially among subjects [51]. The same authors proposed utilizing indicators such as lactate or ventilatory thresholds for a more effective prescription of interval training [51]. However, in situations characterized by limited resources or many athletes, as often encountered in team sports such as handball, alternative methods like maximal aerobic speed or anaerobic speed reserve are typically favored [51].

Given the limited understanding of how exercise intensity, duration, and frequency impact various physiological responses during interval training, this systematic review aims to offer a comprehensive perspective on the existing evidence concerning the effects of HIIT on endurance performance in handball players.

Methods

This systematic scoping review followed rigorously the guidelines outlined in the PRISMA 2020 framework [50] and the guidelines for reporting systematic reviews in sports sciences [44]. To ensure transparency and preclude bias, a detailed protocol for this review was meticulously registered on the Open Science Framework (OSF) under the code “ osf.io/2rjph” and DOI: 10.17605/OSF.IO/J9MEZ on September 08, 2023.

Eligibility criteria

This systematic scoping review only includes original articles in the form of full text that have been subjected to peer review. No restrictions were added to the language or date of publication. Following the PICOS (i.e., population, intervention/exposure, comparator, outcome, study design) approach, the eligibility criteria were as follows:

(i) Population: handball players from any competitive level, age, or sex.

(ii) Intervention: The review encompassed interventions involving HIIT and/or combined training, where the latter incorporates HIIT as a substantial component, comprising at least 50% of the total training intervention duration, as determined by the exposure time.

(iii) Comparator: This systematic review focused exclusively on studies employing parallel study designs where the intervention group(s) received regular training only, i.e., they were exposed to standard in-field training. Additionally, active control groups were included, receiving specific training interventions that did not encompass high-intensity interval training, irrespective of whether these interventions were volume-equated. In cases of non-randomized studies, passive control groups were also considered for inclusion in the review.

(iv) Outcomes: The primary outcomes considered for inclusion in this review are centered around measures of endurance performance which can be assessed using at least two time points (pre-post). These measures encompass but are not limited to, maximal oxygen uptake (whether measured directly or indirectly), anaerobic threshold, maximal aerobic speed, and performance in field-based maximal tests.

(v) Study design: The scope of this systematic review was intentionally limited to encompass study designs that are parallel, whether or not they involve randomization.

Search strategy

During the search process, Boolean operators AND/OR were judiciously applied to combine keywords and synonyms across all fields to ensure comprehensive coverage. No filters were imposed to maximize the likelihood of identifying relevant studies. A thorough exploration of keywords and synonyms was conducted, employing various combinations to facilitate the most exhaustive search possible.

[Title/Abstract] (Handball* OR “Hand-ball*”)
AND
[All fields] (“high-intensity interval training” OR “interval training” OR “HIIT” OR “intermittent training” OR “resistance interval training” OR “circuit training”)

Table 1. Full search strategy for each database

Database	Specificities of the databases	Search strategy	Titles retrieved (n)
PubMed	None to report	(Handball*[Title/Abstract] OR "Hand-ball*"[Title/Abstract]) AND ("high-intensity interval training" OR "interval training" OR "HIIT" OR "intermittent training" OR "resistance interval training" OR "circuit training")	22
SportDiscus		TI (Handball* OR "Hand-ball*") AND TX ("high-intensity interval training" OR "interval training" OR "HIIT" OR "intermittent training" OR "resistance interval training" OR "circuit training") AND AB (Handball* OR "Hand-ball*" AND TX ("high-intensity interval training" OR "interval training" OR "HIIT" OR "intermittent training" OR "resistance interval training" OR "circuit training")	86 + 104
Scopus	Search for title and abstract also includes keywords	(TITLE-ABS-KEY (handball* OR "Hand-ball*") AND ALL ("high-intensity interval training" OR "interval training" OR "HIIT" OR "intermittent training" OR "resistance interval training" OR "circuit training"))	208
Web of Science	Search for title and abstract also includes keywords and its designated "topic"	Handball* OR "Hand-ball*" (Topic) and "high-intensity interval training" OR "interval training" OR "HIIT" OR "intermittent training" OR "resistance interval training" OR "circuit training" (All Fields)	34

The full search strategy can be observed in the following table 1.

Information sources

On September 08, 2023, the authors FMC and JH initiated the search for pertinent publications across electronic databases, including PubMed, Scopus, SPORTDiscus, and the Web of Science core collection. In addition to these database searches, the review process encompassed the following supplementary methodologies: (i) Manual searches: A thorough examination of the reference lists of included studies was conducted to identify potentially relevant titles; and (ii) Snowballing citation tracking within the Web of Science platform to trace citations and identify relevant sources.

Selection process

The screening process was executed by two authors, JH and FMC, who independently assessed the retrieved records based on their titles and abstracts. Subsequently, the same authors independently evaluated the full texts of the selected studies. Any discrepancies or disagreements that arose between these two authors during the screening process were resolved through joint reanalysis and discussion.

In cases where a consensus could not be reached, a third author, RMS, was consulted to make the final decision. As required, all co-authors were involved in providing their input and opinions to address any uncertainties that arose during the selection of studies, thus contributing to the final decision-making process.

To manage the records and ensure the removal of duplicates, the team employed EndNoteTM 20.4 software, developed by Clarivate^{TM}. Duplicate entries were eliminated using a combination of automated and manual methods as needed.

Extraction of data

A data extraction sheet was employed to assess inclusion requirements and facilitate the systematic data extraction process. This sheet was adapted from the template used by the Cochrane Consumers and Communication Review Group [42]. To ensure its effectiveness, a pilot testing phase was carried out on a randomly selected sample comprising 10% of the studies.

This data extraction process was conducted by two authors, JH and FMC, who were responsible for evaluating the included studies. Any full-text articles that were excluded during this process were meticulously documented along with the specific reasons for their exclusion. The recorded data were organized and managed using a structured form created in Microsoft Excel, developed by Microsoft Corporation in Redmond, WA, USA. This form served as a central repository for the collected information and facilitated subsequent analysis and synthesis of the data.

Data items

The data collection process, conducted by JH and FMC, involved gathering comprehensive information and details about the included studies, which encompassed but were not limited to, the following key elements: authors' identities, the publication year, the study design, the nature of the treatment employed, any existing control group, the implementation of randomization, strategies for blinding (if applicable, instances of injuries observed, citation specifics, the country where data collection occurred, sources of funding, and disclosures of competing interests.

Context-related information included the timing within the season (e.g., off-season, pre-season, in-season). Participant-related information included the number of participants, sex, age, the competitive level (while using the Participant Classification Framework) [35], body mass, height, high-intensity interval training experience, and sport practiced (e.g., handball, para-handball, beach handball).

Intervention-related information included the number of weeks, sessions per week, duration of each session, the total number of sessions within the entire program, and the rest intervals between HIIT sessions. The intensity of the training, as well as any methods used for quantification, was also documented. Moreover, the type of surface on which the training occurred, such as turf, sand, or concrete, was noted. The training regimen, including sets, repetitions, and rest intervals between sets and repetitions, was recorded.

Furthermore, information related to the type of running-based HIIT, such as short or long sprints, repeated sprint training, or sprint interval training, along with data on distance covered, pace, and changes of direction per set, was collected. Additional aspects such as rest intervals between sets, repetitions, and training sessions, as well as details about the training period, tapering strategies, novel program aspects, limitations, considerations, and the potential combination of HIIT with other training methods, were also documented for a comprehensive analysis of the interventions.

Outcomes-related information encompassed various parameters associated with endurance performance. These measures included the following aspects: (i) the direct or indirect assessment of VO_{2max}; (ii) the direct or indirect evaluation of maximal aerobic speed (MAS); (iii) the quantification of distance covered during endurance field-based assessments; (iv) the duration of endurance before exhaustion was reached in a specific test; or (v) the determination of the ventilatory threshold.

Study risk of bias assessment

Utilizing Cochrane's Risk of Bias tool, version 2 (RoB 2), parallel randomized studies underwent comprehensive bias assessment across five domains: randomization process, deviations from intended interventions (inclusive of intention-to-treat analysis), missing outcome data, measurement of outcomes, and selection of the reported results. Conversely, non-randomized studies were subject to a thorough evaluation of bias across seven domains, as outlined by Cochrane's Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I)]. These domains encompassed confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement, and selection of the reported results.

The assessment of bias occurred at both the outcome and study levels, with the most unfavorable scenario per study being reported. In cases where a pre-registered protocol was unavailable, the risk of bias associated with the selection of the reported results was considered to be of at least moderate concern (RoB 2) or moderate risk (ROBINS-I). Two authors, JH and FMC, conducted independent bias assessments, with a third author, RMS, available as an arbitrator whenever necessary. The collective summaries of the risk of bias evaluations were subsequently presented according to the primary outcome measures.

Results

Study identification and selection

The search of databases identified a total of 434 titles. These studies were then exported to reference manager software (EndNoteTM X9, Clarivate Analytics, Philadelphia, PA, USA). Duplicates (175 references) were subsequently removed either automatically or manually. The remaining 259 articles were screened for their relevance based on titles and abstracts, resulting in the removal of a further 183 studies. The full texts of the remaining 76 articles were examined diligently; 61 were rejected, as they did not satisfy the relevant criteria (e.g., HIIT interventions in soccer or other sports), and they were excluded due to several reasons, as described in the PRISMA flow diagram (see Figure 1). Six studies were retrieved by experts, and 4 were included. The 17 studies included in this systematic review provided mean and standard deviation for pre – and post-intervention data for at least one main outcome.

Study characteristics

The characteristics of the 17 studies included in this systematic review and the details of the HIIT programs can be found in Table 2. The included randomized-controlled

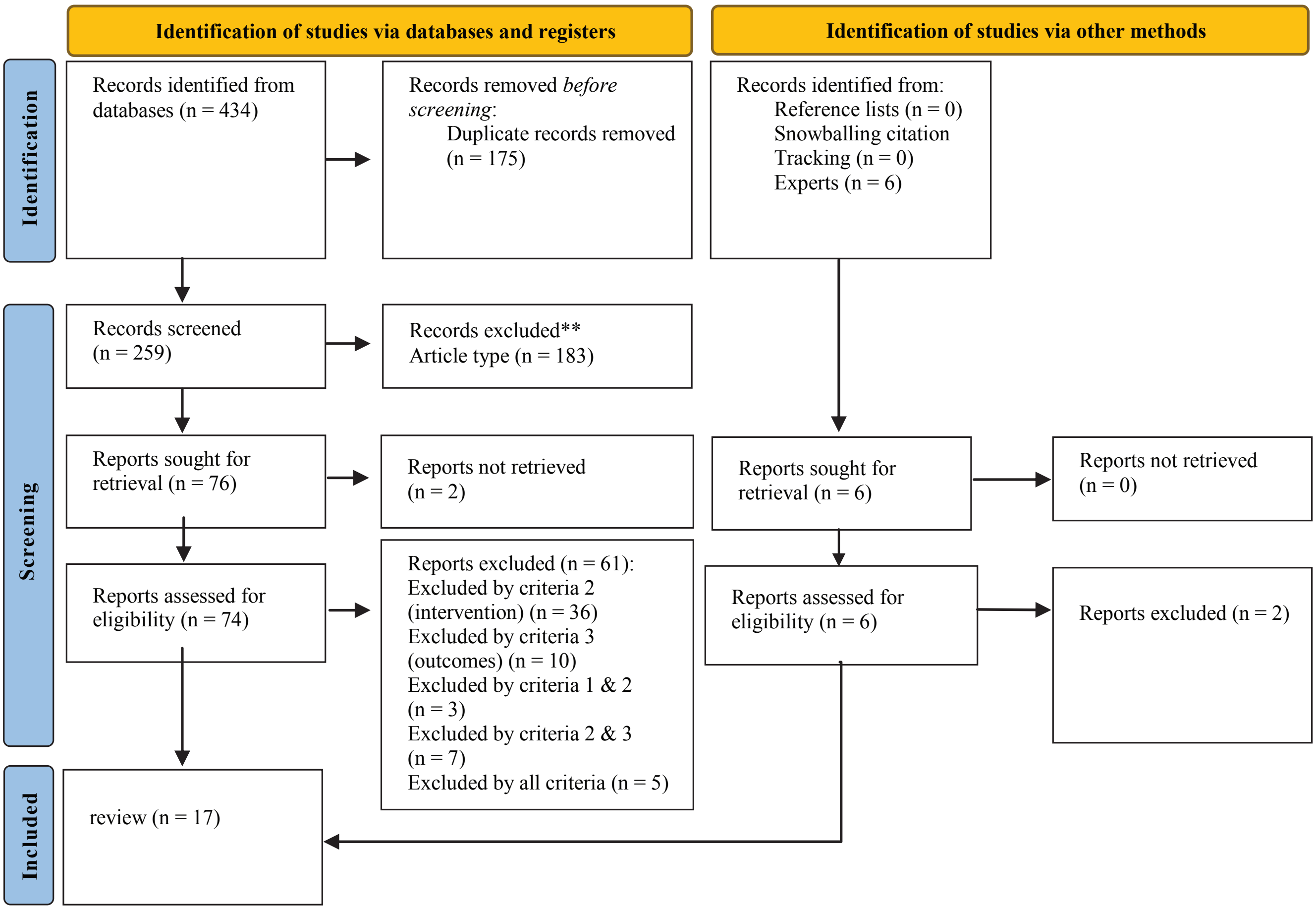

Figure 1. PRISMA 2020 flow diagram

studies involved 14 experimental groups with 158 participants and 10 control groups with 119 participants. The non-randomized controlled studies involved 6 groups and 56 participants, and the quasi-experimental studies involved 2 groups and 36 participants.

Most of the included studies (~76%) focused on tier 2 competitive-level players, representing those classified as trained/developmental with a local-level representation. Regarding the age of participants, 8 studies included individuals above 18 years old, indicating that the remaining nine focused on youth participants. Twelve of the studies had male participants, 4 had women participants, and 1 had both men and women. In terms of study design, the most common were randomized controlled trials (n = 12), followed by non-randomized controlled trials (n = 3) and quasi-experimental studies (n = 2). The most employed assessment tests included some form of shuttle run/sprint (n = 11), the Yo-Yo intermittent recovery test level 1 (n = 5), and the 30-15 intermittent fitness test (n = 4). The most prevalent outcomes measured were best, mean, or total times during sprints to calculate repeated sprint ability (RSA) (n=8) the distance covered in various tests, mostly 30-15IFT and Yo-Yo intermittent recovery test level (n = 6), MAS, and indirect measurement of VO_{2max} (both n = 4).

The interventions included in this systematic review lasted between 4 and 12 weeks, with 50% lasting 8 weeks. The weekly frequency of the intervention sessions varied from 2 to 4, with most of them (65%) implementing a frequency of 2 sessions per week.

Table 3 presents a summary of the methodological characteristics of the interventions included in this systematic review. The most common formats used were short intervals and small-sided games (both n = 6), followed by long intervals and high-intensity resistance training (both n = 2). The remaining formats (sprint interval training [SIT], repeated sprint training [RST], Tabata, and Mixed) were employed in only one study each. Regarding the number of sets/reps performed in the interventions, it varied from 1 to 12 in sets and 4 to 22 in reps. In the HIIT interventions, the work duration ranged mostly between 5 and 30 seconds, utilized in 11 studies, with rest periods in the same interval being used in a similar number of studies. Regarding SSGs, only one study utilized a 2vs2 playing format, with the majority being 3vs3 and 4vs4, in pitches with dimensions ranging between 20×10m and

Table 2. Characteristics of the included studies and outcomes extracted

Study	N	Mean age	Sex	Competitive level (Tier)	Design	Outcomes	Tests used in the original studies	Measures extracted from the tests in the original studies
Alonso-Fernández et al. [1]	EG: 7 CG: 7	15.2 ± 0.6	F	2	RCT	RSA; Estimated VO_{2max}	RSA: 4 linear sprints with COD Estimated VO_{2max}: 20m shuttle run	RSA: Total time during the sprints (s) Estimated VO_{2max}: ml/kg/min
Balasubramania et al. [3]	EG: 8 CG: 8	22.12 ± 3.22	M	2	RCT	AP	AP: YYIRTL2	AP: distance (m)
Buchheit et al. [11]	HIT: 15 HBT: 17	15.5 ± 0.9	M+F	2	RCT	AP; RSA	AP: 30–15 IFT RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s/14s rest between sprints	AP: V_{IFT} (km/h) RSA: best and mean sprint time (s)
Buchheit et al. [12]	S/A: 7 SIT: 7	15.8 ± 0.9	M	2	nRCT	AP; RSA	AP: 30–15 IFT RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s/14s rest between sprints	AP: V_{IFT} (km/h) RSA: best and mean sprint time (s)
Chittibabu et al. [13]	EG: 15 CG: 15	23.15 ± 3.0	M	2	RCT	Estimated VO_{2max}	Estimated VO_{2max}: multistage (20m shuttle run)	Estimated VO_{2max}: ml/kg/min
Chittibabu et al. [14]	EG: 8 CG: 8	22.12	M	2	RCT	RSA; Estimated VO_{2max}	RSA: 7×30m sprints departing every 25s Estimated VO_{2max}: YYIRTL2	RSA: total time (s) Estimated VO_{2max}: ml/kg/min
Curitianu et al. [16]	T: 9 SI: 9	18–23	F	3	nRCT	Aerobic endurance	Cooper 12-min	distance (m)
Iacono et al. [30]	SI: 9 SSGs: 9	25.6 ± 0.5	M	3	RCT	AP	AP: YYIRTL1	AP: distance (m)
Florin et al. [19]	18	26.94 ± 3.78	M	3	Q-E	MAS	MAS: 30–15 IFT	MAS: km/h
Gaamouri et al. [20]	EG: 15 CG: 13	16.5 ± 0.4	M	2	RCT	RSA; MAS	RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s MAS: 20m shuttle run	RSA: best and mean sprint time (s) MAS: km/h
Hammami et al. [24]	EG: 17 CG: 15	16.6	M	2	RCT	RSA; MAS; Estimated VO_{2max}	RSA: Repeated Sprint T-test Estimated VO_{2max} and MAS: 20m shuttle run	RSA: best, mean and total time (s) Estimated VO_{2max}: ml/kg/min MAS: km/h
Hermassi et al. [27]	EG: 15 CG: 15	17.0 ± 1.2	M	2	RCT	RSA; MAS	RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s MAS: YYIRTL1	RSA: best and total time (s) MAS: m/s
Hermassi et al. [28]	EG: 10 CG: 9	18.5 ± 0.85	M	2	RCT	AP	AP: YYIRTL1	AP: distance (m)

Table 2. Cont.

Study	N	Mean age	Sex	Competitive level (Tier)	Design	Outcomes	Tests used in the original studies	Measures extracted from the tests in the original studies
Bhakti et al. [29]	18	N. D.	M	N. D.	Q-E	Estimated VO_{2max}	Estimated VO_{2max}: 3000m run	VO_{2max}: N. D.
Jurišić et al. [31]	SI: 12 SSGs: 12	16.13	F	2	nRCT	AP	AP: YYIRTL1	AP: distance (m)
Mikalonytė et al. [37]	EG: 12 CG: 12	16.2 ± 1.5	F	2	RCT	AP	AP: YYIRTL1	AP: distance (m)
Viaño-Santasmarinas et al. [52]	SI: 10 LI: 8	22.7 ± 3.9	M	2	RCT	AP; RSA	AP: 30–15 IFT RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s	AP: V_{IFT} (km/h) RSA: best, mean and total time (s)

Note: EG: experimental group; CG: control group; HIT: high-intensity interval training group; HBT: handball-based training group; S/A: sprint and agility group; SIT: sprint interval training; T: tabata; SSGs: small-sided games; SI: short intervals; LI: long intervals; RCT: randomized controlled trial; Q-E: quasi-experimental; RSA: repeated sprint ability; VO2max: maximal oxygen uptake; AP: aerobic performance assessed from field-based tests; MAS: maximal aerobic speed; COD: change of direction; YYIRT: yoyo intermittent recovery test; 30-15IFT: 30–15 intermittent fitness test; V_{IFT}: maximal velocity at 30-15IFT.

40×20m. Regarding the training regimen, the studies utilizing SSGs employed 4 to 12 games per session, lasting between 2 min 25s and 10 min.

Study risk of bias assessment

Tables 4 and 5 provide an assessment of the risk of bias for the randomized studies using the RoB2 instrument. The tables focus on studies that examined endurance performance and VO_{2max}. All of the included studies that analyzed endurance performance had an overall high risk of bias, which was primarily influenced by concerns in dimensions dealing with the selection of the reported results. The main reason for these concerns was the absence of information regarding pre-specified analyses, making it unclear whether the reported results were selectively chosen from a larger set of outcomes.

The other dimension that brought some concerns was dimension 1, which relates to the lack of information provided about the randomization techniques and allocation concealment. Specifically, 10 out of 11 articles analyzed did not provide sufficient details regarding these critical aspects of the study design, and the study by Buchheit et al. [11] had a high risk for this particular dimension. The other dimensions had a low risk of bias but, overall, the assessment of risk of bias indicates that all of the included studies had limitations in key methodological aspects, particularly in the randomization and selection of the reported results. These limitations should be taken into consideration when interpreting the findings and assessing the overall quality of the evidence presented in this systematic review.

Similarly, the assessment of the risk of bias for the four randomized studies that examined VO_{2max} revealed an overall high risk of bias, consistent with the concerns identified for the endurance performance outcome.

Table 6 provides an assessment of the risk of bias for the non-randomized studies using the ROBINS-I instrument. Two [12, 16] of the three studies presented an overall moderate risk of bias, due to deviations from intended interventions, while the study by Jurišic et al. [31] had an overall low risk of bias, with low risk in all fields.

Table 7 provides an assessment of the risk of bias for the quasi-experimental studies using the Downs and Black modified checklist. The two quasi-experimental studies had an overall low-quality score, which indicates that both studies had poor methodological quality.

Summary of the main results

Tables 8, 9, and 10 provide a summary of the main findings regarding the adaptations induced by HIIT and SSG-based interventions on field-based test outcomes. Studies that measured time in shuttle-sprint tests (the most frequently employed test) have ranged from increases in sprint time of 0.69% [12] to decreases of 7.22% [1].

Table 3. Characteristics of the HIIT programs included

Study	HIIT format	Duration (w)	d/w	Total sessions	Work duration or distance	Work intensity	Relief duration	Relief intensity	Series	Reps	Rest between sets (duration)	Rest between sets (intensity)	SSG format	SSG pitch dimension	SSG area per player (m²)
Alonso–Fernández et al. [1]	SI	8	2	16	20s	>85% HRmax	10s	–	8	–	2min	–	–	–	–
Balasubramania et al. [3]	SSGs	6	3	18	4min	90–95% HRmax	4min	Active	–	4	–	–	4×4	40×20m	–
Buchheit et al. [11]	SI	9	2	17	15s	90–100 % V_{IFT}	15s	Passive	1–2	5	–	–	–	–	–
Buchheit et al. [12]	SIT	4	2	8	30s	All-out	2min	Passive	–	3–5	–	–	–	–	–
Chittibabu et al. [13]	RST	8	3	24	30m	–	15s	Passive	3	10	150s	–	–	–	–
Chittibabu et al. [14]	SSGs	8	3	24	4min	90–95% HRmax	4min	Active	–	4	–	–	4×4	40×20m	–
Curitianu et al. [16]	Tabata + LI	T: 6 LI: 8	4	T: 24 LI: 32	T: 20s LI: 45s	T: All-out LI: N. D.	T: 10s LI: 30s	–	T: 2 LI: 5	–	–	–	–	–	–
Iacono et al. [30]	SI + SSGs	8	2	16	SI: 15s SSGs: 2m25s to 3m10s	SI: 90–95% MAS	SI: 15s	Passive	SI: 12 SSGs: 5	–	SSGs: 1min	Passive	3×3	20×20m	–
Florin et al. [19]	Mixed	8	2–3	20	10s–5min	80–110 % V_{IFT}	10–30s	Passive	2–6	–	3–7min	Active	–	–	–
Gaamouri et al. [20]	HIRT	8	2	16	5s	130% MAS	10s	–	8	2	3–5min	–	–	–	–
Hammami et al. [24]	HIRT	8	2	16	5s	130% MAS	10s	–	8	2	3–5min	–	–	–	–
Hermassi et al. [27]	SI	7	2	14	10–20s	110–130% MAS	10–20s	–	1–4	5–10	3min	–	–	–	–
Hermassi et al. [28]	–	12	2	24	–	All-out	–	–	2	–	3min	–	–	–	–
Bhakti et al. [29]	–	5	4	18	–	–	–	–	–	–	–	–	–	–	–
Jurišić et al. [31]	SI + SSGs	8	2	16	SI: 15s SSGs: 2m25s to 3m10s	SI: 90–95% MAS	SI: 15s	SI: Active	SI: 2 SSGs: 5	–	SI: 3min SSGs: 1min	SI: N.D. SSGs: Passive	3×3	20×20m	–
Mikalonytė et al. [37]	SSGs	10	2	20	10min	–	–	–	3	–	1min	–	2×2, 3×3, 4×4	20×10m, 20×20m	40.7, 54.3
Viaño-Santasmarinas et al. [52]	SI + LI	6	2	12	SI: 10s LI: 3min	SI: 95% V_{IFT} LI: 85% V_{IFT}	SI: 10s LI: 3min	Passive	SI: 2 LI: 5	SI: 22	SI: 5min	SI: Passive	–	–	–

Note: SSGs: small-sided games; SI: short intervals; LI: long intervals; SIT: sprint interval training; RST: repeated sprint training; HIRT: high-intensity resistance training; w: weeks; d: days; T: tabata; HRmax: maximal heart rate; $V_{IFT:}$ maximal velocity at 30-15IFT; MAS: maximal aerobic speed.

Table 4. Assessment of risk of bias for randomized studies for outcome VO_{2max}

Study	D1	D2	D3	D4	D5	Overall
Alonso-Fernández et al. [1]	!	+	+	+	–	–
Chittibabu et al. [13]	!	+	+	+	–	–
Chittibabu et al. [14]	!	+	+	+	–	–
Hammami et al. [24]	!	+	+	+	–	–

Table 5. Assessment of risk of bias for randomized studies for outcome Endurance performance

Study	D1	D2	D3	D4	D5	Overall
Alonso-Fernández et al. [1]	!	+	+	+	–	–
Balasubramanian & Chittibabu [3]	!	+	+	+	–	–
Buchheit et al. [11]	–	+	+	+	–	–
Chittibabu et al. [14]	!	+	+	+	–	–
Iacono et al. [30]	!	+	+	+	–	–
Gaamouri et al. [20]	!	+	+	+	–	–
Hammami et al. [24]	!	+	+	+	–	–
Hermassi et al. [27]	!	+	+	+	–	–
Hermassi et al. [28]	!	+	+	+	–	–
Mikalonytė et al. [37]	!	+	+	+	–	–
Viaño-Santasmarinas et al. [52]	!	+	+	+	–	–

Studies utilizing the Yo-Yo Intermittent Recovery Test Level 1 demonstrated decreases of 10.67% [37] to improvements of 69.2% [28] in distances achieved, and improvements ranging from 3.72% (12) to 9.5% [19] in the velocity in the 30-15 Intermittent Fitness Test. Moreover, when analyzing studies that measured VO_{2max}, the results have shown increases between 6.9% to 137.6% [29], however, this last value should be interpreted with caution, as the study showed a low-quality score and did not specify how they evaluated the athletes.

Discussion

This systematic review aimed to analyze the available evidence regarding the effects of HIIT interventions on endurance performance in handball players. The impact on endurance performance was mainly assessed by evaluating the effects on parameters like VO_{2max}, maximal aerobic speed, and accumulated distances covered in progressive field-based tests. In general, a positive effect was observed on aerobic performance in the subjects that performed a HIIT intervention. In the randomized controlled trials, except the studies by Buchheit et al. [11, 12] and Mikalonytė et al. [37], there was a significant inter-group benefit favorable to the HIIT intervention groups compared to the control groups. All 4 studies [16, 30, 31, 52] with only experimental groups recorded positive effects in both interventions, and the two quasi-experimental studies [19, 29] also recorded improvements.

Effects of high-intensity interval training on handball players' maximal oxygen uptake

Only four studies from this systematic review estimated VO_{2max} through field-based tests, three of them RCTs [1, 13, 14], while the other one [29] was a quasi-

Table 6. Assessment of risk of bias for randomized studies

Study	Bias due to confounding	Bias in selection of participants in the study	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of the reported result	Overall Bias
Buchheit et al. [12]	Low	Low	Low	Moderate	Low	Low	Low	Moderate
Curițianu et al. [16]	Low	Low	Low	Moderate	Low	Low	Low	Moderate
Jurišic et al. [31]	Low	Low	Low	Low	Low	Low	Low	Low

Table 7. Assessment of risk of bias for quasi-experimental studies

Author, year	Reporting (n = 10)	External validity (n = 3)	Internal validity – bias (n = 7)	Internal validity – confounding (n = 6)	Power (n = 1)	Total quality score (n = 27)
Florin et al. [19]	6	0	3	2	0	11
Bhakti [29]	5	0	3	2	0	10

experimental study. Regarding the outcomes, there was considerably greater amplitude in VO_{2max} improvements compared to the results of other parameters. The VO_{2max} results have shown increases between 6.9% [1] to 137.6% [29]. However, the results presented by Bhakti [29] should be interpreted carefully, as the study presented a low quality, had no control group, and there was no information about how the outcome was evaluated. If that study is excluded, the VO_{2max} improvements of the remaining studies presented considerably lower variability, with the experimental groups increasing their VO_{2max} between 6.9% [1] and 9.4% [24], which are much more homogeneous values, and presenting significant increases compared to their control group counterparts. However, other studies also have considerable limitations, given that the study by Chittibabu et al. [13] does not provide the results of the control group, and the other does not provide the pre-post values, only referencing their final results [14].

The reduced number of studies that evaluated the impact of HIIT programs on handball athletes' VO_{2max} has shown similar results to many studies that were included in several systematic reviews and meta-analyses that have studied the impact of different forms of HIIT on VO_{2max} in different populations, including athletes [38, 40, 45, 48, 55]. Regarding acute physiological responses, High-Intensity Interval Training (HIIT) protocols typically exhibit elevated cardiovascular indicators. This includes heightened mean and peak heart rates (HRmean, HRpeak), increased mean oxygen consumption (VO_{2mean}) and maximum oxygen consumption (VO_{2max}), elevated blood lactate and alpha-amylase concentration, augmented ventilation, and carbon dioxide output. Additionally, there's an improved oxygen utilization in the muscle [18, 25]. These responses have been observed across diverse populations and age groups.

HIIT sessions might trigger cardiocirculatory adaptation via cardiovascular adjustments occurring specifically during the recovery periods, and the peripheral and central chronic adaptations generated by different HIIT types are dependent on the metabolic and cardiorespiratory acute responses induced by the training sessions, as there are differences among the acute responses of different forms of HIIT [9, 15].

According to several studies that have analyzed the physiological mechanisms that drive adaptations in maximal oxygen uptake, these improvements might be attributed to increased stroke volume, maximal cardiac output, maximal arteriovenous oxygen difference, plasma volume, left ventricular mass, capillary density, blood flow, maximal citrate synthase activity, skeletal-muscle oxidative enzyme capacity, and mitochondrial content, increased capacity of the central nervous system to recruit motor units and increased red blood cell volume and hemoglobin mass, resulting in higher oxygen carrying capacity [45].

Table 8. Summary of main results for experimental studies with control group

Study	Intervention	Sub-group	Total sessions	Tier	Randomized	N	Outcome	Before Mean ± SD	After Mean ± SD	Before-After (Δ%)
Alonso-Fernández et al. [4]	HIIT	SI	16	2	Yes	7	Total time during sprints (s) Estimated VO_{2max} (ml/kg/min) at 20-m shuttle run test	RSA: 16.76 ± 0.72 VO_{2max}: 43.96 ± 2.8	RSA: 15.55 ± 0.55 VO_{2max}: 46.68 ± 2.60	RSA: –7.22* VO_{2max}: 6.19*
Alonso-Fernández et al. [4]	CG	Warm-up	16	2	Yes	7	Total time during sprints (s) Estimated VO_{2max} (ml/kg/min) at 20-m shuttle run test	RSA: 17.74 ± 1.24 VO_{2max}: 42.73 ± 6.53	RSA: 17.46 ± 1.31 VO_{2max}: 43.27 ± 6.31	RSA: –1.58 VO_{2max}: 1.26
Balasubramania et al. [3]	SSGs	4x4	18	2	Yes	8	Distance (m) at YYIRTL2	–	–	4.56
Balasubramania et al. [3]	CG	CG	18	2	Yes	8	Distance (m) at YYIRTL2	–	–	–
Buchheit et al. [11]	HIIT	SI	17	2	Yes	15	Velocity (km/h) at 30-15IFT Best sprint time (s) at 6 reps of 2×15m all-out shuttle sprints	AP: 17.9 ± 1.8 RSA_b: 6.27 ± 0.42	AP: 18.9 ± 1.3 RSA_b: 6.05 ± 0.37	AP: 5.59* RSA_b: –3.5*
Buchheit et al. [11]	CG	HBT	17	2	Yes	17	Velocity (km/h) at 30-15IFT Best sprint time (s) at 6 reps of 2×15m all-out shuttle sprints	AP: 18.4 ± 1.5 RSA_b: 6.19 ± 0.41	AP: 19.6 ± 1.4 RSA_b: 5.96 ± 0.31	AP: 6.52* RSA_b: –3.7*
Buchheit et al. [12]	HIIT	SIT	8	2	No	7	Velocity (km/h) at 30-15IFT Best sprint time (s) at 6 reps of 2×15m all-out shuttle sprints	AP: 18.8 ± 1.2 RSA_b: 5.79 ± 0.16	AP: 19.5 ± 1.1 RSA_b: 5.83 ± 0.18	AP: 3.72 RSA: 0.69
Buchheit et al. [12]	CG	S+A	8	2	No	7	Velocity (km/h) at 30-15IFT Best sprint time (s) at 6 reps of 2×15m all-out shuttle sprints	AP: 18.8 ± 1.2 RSA_b: 5.84 ± 0.09	AP: 18.5 ± 1.3 RSA_b: 5.72 ± 0.13	AP: –1.6 RSA: –2.05
Chittibabu et al. [13]	HIIT	RST	24	2	Yes	15	Estimated VO_{2max} (ml/kg/min) at 20-m shuttle run test	50.02	56.71	11.79**
Chittibabu et al. [13]	CG	CG	24	2	Yes	15	Estimated VO_{2max} (ml/kg/min) at 20-m shuttle run test	–	50.88	–
Chittibabu et al. [14]	SSGs	4x4	24	2	Yes	8	Total time (s) at 7×30m sprints Estimated VO_{2max} (ml/kg/min) at YYIRTL2	–	–	RSA: –4.19** VO_{2max}: 8.83**
Chittibabu et al. [14]	CG	CG	24	2	Yes	8	Total time (s) at 7×30m sprints Estimated VO_{2max} (ml/kg/min) at YYIRTL2	–	–	No changes
Gaamouri et al. [20]	HIIT	HIRT	16	2	Yes	15	Best sprint time (s) at 6 reps of 2×15m all-out shuttle sprints Velocity (km/h) 20-m shuttle run test	RSA_b: 6.42 ± 0.31 MAS: 14.9 ± 0.6	RSA_b: 6.03 ± 0.19 MAS: 15.9 ± 0.5	RSA: –6 ± 2.5** MAS: 7.2 ± 3.3**

Table 8. Cont.

Study	Intervention	Sub-group	Total sessions	Tier	Randomized	N	Outcome	Before Mean ± SD	After Mean ± SD	Before-After (Δ%)
Gaamouri et al. [20]	CG	Standard in-season regimen	16	2	Yes	13	Best sprint time (s) at 6 reps of 2×15m all-out shuttle sprints Velocity (km/h) 20-m shuttle run test	RSA_b: 6.48 ± 0.26 MAS: 15 ± 0.7	RSA_b: 6.41 ± 0.25 MAS: 15.2 ± 0.6	RSA_b: –1.1 ± 0.4 MAS: 1.6 ± 4.4
Hammami et al. [24]	HIIT	HIRT	16	2	Yes	17	Best total time (s) at Repeated Sprint T-test Estimated VO_{2max} (ml/kg/min) and Velocity (km/h) at 20-m shuttle run test	RSA_b: 11.3 ± 0.7 MAS: 14.8 ± 0.6 VO2max: 47.8 ± 2.5	RSA_b: 10.5 ± 0.6 MAS: 15.9 ± 0.5 VO_{2max}: 52.2 ± 1.9	RSA: –6.9 ± 1.3** MAS: 7.5 ± 3.3** VO_{2max}: 9.4 ± 4.1**
Hammami et al. [24]	CG	Standard handball and physical training	16	2	Yes	15	Best total time (s) at Repeated Sprint T-test Estimated VO_{2max} (ml/kg/min) and Velocity (km/h) at 20-m shuttle run test	RSA_b: 11.2 ± 0.4 MAS: 15.0 ± 0.7 VO2max: 48.4 ± 2.9	RSA_b: 11.1 ± 0.4 MAS: 15.3 ± 0.6 VO_{2max}: 50.0 ± 2.6	RSA_b: – 1.3 ± 0.6 MAS: 2.1 ± 4.3 VO_{2max}: 3.6 ± 8.2
Hermassi et al. [27]	HIIT	SI	14	2	Yes	15	Best time (s) at 6 reps of 2×15m all-out shuttle sprints Velocity (m/s) at YYIRTL1	RSA_b: 6.24 ± 0.09 MAS: 4.56 ± 0.27	RSA_b: 6.06 ± 0.10 MAS: 5.74 ± 0.30	RSA: –2.9** MAS: 25.9**
Hermassi et al. [27]	CG	Handball training	14	2	Yes	15	Best time (s) at 6 reps of 2×15m all-out shuttle sprints Velocity (m/s) at YYIRTL1	RSA_b: 6.19 ± 0.10 MAS: 4.47 ± 0.17	RSA_b: 6.15 ± 0.08 MAS: 4.34 ± 0.10	RSA_b: –0.6 MAS: –2.9*
Hermassi et al. [28]	HIIT	-	24	2	Yes	10	Distance (m) at YYIRTL1	1156 ± 261	1956 ± 318	69.2**
Hermassi et al. [28]	CG	Standard in-season regimen	24	2	Yes	9	Distance (m) at YYIRTL1	1333 ± 272	1129 ± 312	–15.3**
Mikalonytė et al. [37]	SSGs	Mixed	20	2	Yes	12	Distance (m) at YYIRTL1	1256 ± 401.0	1122 ± 354.0	–10.67**
Mikalonytė et al. [37]	CG	Simulated match	20	2	Yes	12	Distance (m) at YYIRTL1	1100 ± 510.0	1272 ± 532.0	15.63**

CG: control group; HIIT: high-intensity interval training; SSGs: small-sided games; SI: short intervals; HBT: handball-based training; SIT: sprint interval training; S+A: sprint+agility; RST: repeated sprint training; HIRT: high-intensity resistance training; s: seconds; m: meters; VO_{2max}: maximal oxygen uptake; YYIRT: yoyo intermittent recovery test; 30-15IFT: 30-15 intermittent fitness test; RSA: repeated sprint ability; AP: aerobic performance assessed from field-based tests; MAS: maximal aerobic speed; *: significant intra-group differences; **: significant intra and inter-group differences

Table 9. Summary of main results for experimental studies with two intervention groups

Study	Intervention	Sub-group	Total sessions	Tier	Randomized	N	Outcome	Before Mean ± SD	After Mean ± SD	Before-After (Δ %)
Curitianu et al. [16]	HIIT	LI	32	3	No	9	Distance (m) at 12-min Cooper test	2385 ± 47.6	2553.1 ± 70.4	7.05*
Curitianu et al. [16]	HIIT	Tabata	24	3	No	9	Distance (m) at 12-min Cooper test	2388.5 ± 57.8	2545.1 ± 60.1	6.55*
Iacono et al. [30]	HIIT	SI	16	3	Yes	9	Distance (m) at YYIRTL1	1297.8 ± 300	1601.1 ± 192	23.3*
Iacono et al. [30]	SSGs	3×3	16	3	Yes	9	Distance (m) at YYIRTL1	1364.4 ± 397	1723.3 ± 327	26.3*
Jurišić [31]	HIIT	SI	16	2	No	12	Distance (m) at YYIRTL1	563.33 ± 73.28	723.33 ± 86.06	28.40*
Jurišić [31]	SSGs	3×3	16	2	No	12	Distance (m) at YYIRTL1	520.00 ± 61.49	611.67 ± 100.35	17.63*
Viaño-Santasmarinas et al. [52]	HIIT	SI	12	2	Yes	10	Velocity (km/h) at 30-15IFT Mean time (s) at 6 reps of 2×15m all-out shuttle sprints	AP: 16.77 ± 1.69 RSA_m: 6.10 ± 0.26	AP: 18.13 ± 1.74 RSA_m: 5.94 ± 0.17	AP: 8.18* RSA: –2.51*
Viaño-Santasmarinas et al. [52]	HIIT	LI	12	2	Yes	8	Velocity (km/h) at 30-15IFT Mean time (s) at 6 reps of 2×15m all-out shuttle sprints	AP: 16.58 ± 2.28 RSA_m: 6.18 ± 0.33	AP: 17.91 ± 2.35 RSA_m: 6.06 ± 0.29	AP: 8.19* RSA: –1.87*

HIIT: high-intensity interval training; SSGs: small-sided games; SI: short intervals; LI: long intervals; m: meters; s: seconds; YYIRT: yoyo intermittent recovery test; 30-15IFT: 30-15 intermittent fitness test; RSA: repeated sprint ability; AP: aerobic performance assessed from field-based tests; *: significant intra-group differences; **: significant intra and inter-group differences.

Table 10. Summary of main results for quasi-experimental studies (no control group)

Study	Intervention	Sub-group	Total sessions	Tier	Randomized	N	Outcome	Before Mean ± SD	After Mean ± SD	Before-After (Δ %)
Florin et al. [19]	HIIT	Mixed	20	3	No	18	Velocity (km/h) at 30-15IFT	17.21 ± 0.81	18.83 ± 0.38	9.5*
Bhakti [29]	HIIT	–	18	N. D.	No	18	VO_{2max} (N. D.)	1.17	2.78	137.6*

HIIT: high-intensity interval training; VO_{2max}: maximal oxygen uptake; 30-15IFT: 30-15 intermittent fitness test; *: significant intra-group differences.

Effects of high-intensity interval training on handball players' endurance performance

Except for the studies by Buchheit et al. [8, 12] and Mikalonytė et al. [37] all intervention groups have shown improvements in their field-based tests after high-intensity interval training. These improvements happened with different types of HIIT protocols, namely short intervals [1, 11, 30, 31, 52], long intervals [16, 52], SSGs [3, 14, 30, 31], and other forms of HIIT [19, 20, 24, 28]. The Yo-Yo Intermittent Recovery Test Level 1 presented results that ranged from decreases of 10.67% [37] to improvements of 69.2% [28] in the experimental groups. Regarding the improvements recorded in the study by Hermassi et al. [28] despite it being the study with the longest duration of all those presented in this systematic review (12 weeks), it is hard to justify the magnitude of the improvements, since the intervention comprised circuit training with a mix of exercises that were not very specific to the test.

However, it must be said that high-intensity circuit training has shown acute physiological responses like increased oxygen consumption, heart rate, and lactate values that might explain the results [33]. In contrast, the study by Mikalonytė et al. [37] is the only one present in this systematic review that has shown negative results from a HIIT intervention, specifically small-sided games, which is quite unexpected since team/intermittent sports players usually display superior performance in the YYIRT [5], and the players in the control group that performed match simulation recorded improvements of 15.63% in the same test. While the improvements of the subjects that participated in the match simulation are not surprising due to handball demands and their relationship with the YoYo test [5, 26], small-sided games would also be expected to cause some positive results due to their acute physiological responses needed and their appropriateness to improve handball players' physical fitness [6].

Studies that evaluated RSA by measuring time in shuttle-sprint tests have shown decreases of 7.22% [1] to increases of 0.69% [12]. Although different forms of sprint training have been shown to improve repeated sprint ability [7], this was not the case with the intervention of Buchheit et al. [12] was the only one in this systematic review with a negative effect. Curiously, this study by Buchheit et al. [12] is present in the aforementioned review as having a positive effect, but that is not the case since the best time in the shuttle sprints changed from 5.79 to 5.83 seconds. Repeated Sprint Ability has been widely considered a relevant fitness component in team sports [7, 17], and specifically in handball, it has been deemed extremely important, especially for wings [53]. RSA is a complex fitness component that depends on both metabolic and neural factors, and HIIT is considered one of the main strategies to improve this ability [7].

Concerning the physiological mechanisms underlying these results, the enhancements can be attributed to various adaptations favoring an increased dependence on aerobic metabolism for ATP resynthesis. These include heightened mitochondrial respiratory capacity, quicker oxygen uptake kinetics, an accelerated post-sprint muscle reoxygenation rate, an elevated lactate threshold, and an increased VO_{2max}. These factors are associated with an improved capacity to withstand fatigue during repeated sprints [7]. During repeated sprinting, the relative contribution of anaerobic glycogenolysis is reduced when subsequent sprints are performed, which is partially explained by an increase in aerobic metabolism [49].

Furthermore, the degradation and resynthesis rate of PCr is related to performance decrement, and a loss of muscle purine nucleotides may also occur during subsequent sprints [49]. The exercise protocol, including factors like exercise mode, sprint duration, number of repetitions, recovery duration, type of recovery, and training status, can markedly influence the relative contribution of energy systems during repeated sprint exercise. Additionally, the sprint duration plays a significant role in shaping the relative energy system contribution in the turnover of skeletal muscle ATP [49]. Normally, if athletes want to increase their RSA, they can do it by improving their muscle strength/power and, consequently, their acceleration and maximum speed, or by improving their endurance ability to improve the final sprints [7]. Finally, velocity in field-based tests has shown improvements in all the interventions present in this systematic review. Velocity at the 30-15IFT has shown improvements between 3.72% and 9.5%, and maximal aerobic speed recorded increases between 7.2% [20] and 25.9% [24].

Furthermore, the significance of rest intervals between sets should not be underestimated. The duration of rest periods plays a pivotal role in shaping motor skills and influencing ATP resynthesis during training. For instance, contrasting scenarios, such as a maximal 40-meter run with a 45-second interval emphasizing maximal power, and a similar run with a 15-second interval emphasizing anaerobic endurance, can provide valuable insights into the effects of varying rest durations. In the context of the 17 studies included in this systematic review, it became evident that demographic characteristics play a significant role in the responses to different HIIT formats. For instance, the heterogeneity in the improvements in VO_{2max} and sprint performance offers valuable insights into the programming of HIIT interventions, considering biological individuality, age, and gender of handball practitioners [53]. The endurance improvements were observed across different types of HIIT protocols, including short intervals, long intervals, and small-sided games. The overall endurance improvements shown among the analyzed studies could be attributed to the increased aerobic metabolism, mitochondrial respiratory capacity, quicker oxygen uptake kinetics, and elevated lactate threshold, which are common among HIIT protocols [2].

Despite the diversity of interval training regimens, there are benefits to all of them [53]. However, as the authors emphasize, coaches must be careful while choosing a specific form of interval training, as the manipulation of a single variable can have a direct impact on metabolic, cardiopulmonary, and neuromuscular responses to exercise [53]. It is also worth noting that physiological adaptations in response to interval training are dependent not only on the intensity of the exercise but also on the subsequent rest intervals; and excessive HIIT prescription might result in detrimental effects, which makes exercise intensity monitoring extremely important to guarantee the previously mentioned benefits of this type of exercise.

Implementing these recommendations is challenging due to limited knowledge about the physiological mechanisms and adaptations induced by interval training, as well as the communication between metabolic pathways within cells [2]; and there are insufficient data to determine the responsiveness of mitochondrial adaptations to changes in the duration or frequency of interval training.

Study limitations and future research

The main limitations of this systematic review are the relatively low number of studies for each parameter, the quality of some of those studies, and the fact that most of them (13 out of 17) have been done with tier 2 athletes. The combination of these factors prevents any strong conclusions from being reached.

Given these limitations, and the lack of studies about the use of MAS in a handball context, more research on the topic should be done before reaching any conclusions. The aim of future research should also involve assessing the effects of individualizing training loads based on positional requirements. It is crucial to evaluate the disparities in internal and external load between playing positions and to characterize the training demands in the days preceding competitive events for professional handball players, aiming for better training optimization. Furthermore, an assessment of training designed to improve effectiveness during matches in the worst-case scenarios of high-performance handball players is warranted, given the significant differences between playing positions, with effect sizes ranging from moderate to very large (0.7–5.1 ES).

While most of the studies in this systematic review have presented positive effects from the HIIT interventions, there are still many uncertainties regarding the best type(s) of HIIT, the ideal volume, intensity, and frequency, and if there is any benefit in general forms of HIIT (e.g., SI, LI, SIT, RST) compared to more specific types like small-sided games since the studies in this systematic review that compared general vs specific forms of HIIT presented mixed results. Given this, more research on these topics must be carried out before providing any specific recommendations.

Conclusion

This systematic review underscores a significant diversity in methodological approaches among the included studies, encompassing seven distinct types of High-Intensity Interval Training (HIIT) conducted over periods ranging from 4 to 12 weeks. While these varied formats consistently demonstrate positive impacts on assessed endurance performance parameters, the current body of evidence falls short of providing specific recommendations regarding the optimal selection of a particular HIIT format, including its most advantageous volume, intensity, and frequency.

It is noteworthy that a positive trend emerges, indicating that engaging in some form of HIIT twice a week holds potential benefits for enhancing endurance performance markers in handball players. However, for more definitive and tailored guidance, future studies must undertake a comparative analysis of diverse HIIT formats, exploring variations in volumes, intensities, and frequencies. This imperative research will contribute to a more nuanced understanding, enabling precise recommendations to optimize HIIT for endurance gains in the context of handball training.

Conflict of interest: Authors state no conflict of interest.

References

1. Alonso-Fernández D., Lima-Correa F., Gutierrez-Sánchez F., De Vicuña O.A.G. (2017) Effects of a high-intensity interval training protocol based on functional exercises on performance and body composition in handball female players. *J. Hum. Sport Exerc.,* 12: 1186-1198. DOI: 10.14198/jhse.2017.124.05
2. Atakan M.M., Li Y., Koşar Ş.N., Turnagöl H.H., Yan X. (2021) Evidence-based effects of high-intensity interval training on exercise capacity and health: A review with historical perspective. *Int. J. Environ. Res. Public Health*, 18: 1-27. DOI: 10.3390/ijerph18137201
3. Balasubramanian C.M., Chittibabu B. (2014) Effect of handball specific aerobic training on aerobic capacity and maximum exercise heart Rate of male handball players. *Int. J. Phys. Educ. Fit. Sports*, 3: 85-91. DOI: 10.26524/14210
4. Balsalobre-Fernández C., Marchante D., Baz-Valle E., Alonso-Molero I., Jiménez S.L., Muñóz-López M. (2017) Analysis of wearable and smartphone-based technologies

for the measurement of barbell velocity in different resistance training exercises. *Front. Physiol.,* 8: 1-10. DOI: 10.3389/fphys.2017.00649

5. Bangsbo J., Iaia F.M., Krustrup P. (2008) The Yo-Yo intermittent recovery test: a useful tool for evaluation of physical performance in intermittent sports. *Sports Med.,* 38: 37-51. DOI: 10.2165/00007256-200838010-00004
6. Bělka J., Hůlka K., Šafář M. (2023) Small-sided games versus continuous endurance training in female handball players. *J. Hum. Kinet*., 88: 151-161. DOI: 10.5114/jhk/163070
7. Bishop D., Girard O., Mendez-Villanueva A. (2011) Repeated-sprint ability part II: Recommendations for training. *Sports Med.*, 41: 741-756. DOI: 10.2165/11590560-000000000-00000
8. Buchheit M. (2008) The 30-15 intermittent fitness test: accuracy for individualizing interval training of young intermittent sport players. *J. Strength Cond. Res.*, 22: 365-374. DOI: 10.1519/JSC.0b013e3181635b2e
9. Buchheit M., Laursen P.B. (2013) High-intensity interval training, solutions to the programming puzzle: Part I: Cardiopulmonary emphasis. *Sports Med.*, 43: 313-338. DOI: 10.1007/s40279-013-0029-x
10. Buchheit M., Laursen P.B. (2013) High-intensity interval training, solutions to the programming puzzle: Part II: Anaerobic energy, neuromuscular load and practical applications. *Sports Med.*, 43: 927-954. DOI: 10.1007/s40279-013-0066-5
11. Buchheit M., Laursen P.B., Kuhnle J., Ruch D., Renaud C., Ahmaidi S. (2009) Game-based training in young elite handball players. *Int. J. Sports Med.*, 30: 251-258. DOI: 10.1055/s-0028-1105943
12. Buchheit M., Mendez-Villanueva A., Quod M., Quesnel T., Ahmaidi S. (2010) Improving acceleration and repeated sprint ability in well-trained adolescent handball players: Speed versus sprint interval training. *Int. J. Sports Physiol. Perform.*, 5: 152-164. DOI: 10.1123/ijspp.5.2.152
13. Chittibabu B. (2013) Effect of handball-specific repeated-sprint training on aerobic capacity of male handball players. *Int. J. Phys. Educ. Fit. Sports*, 2: 04-07.
14. Chittibabu B. (2014) Effect of small-sided handball game on aerobic capacity and repeated sprint ability of male handball players. *Turkish J. Sport Exerc.*, 16: 22-22. DOI: 10.15314/TJSE.201428101
15. Cipryan L., Tschakert G., Hofmann P. (2017) Acute and post-exercise physiological responses to high-intensity interval training in endurance and sprint athletes. *J. Sports Sci. Med.*, 16: 219-229.
16. Curiţianu I.M., Turcu I., Alexe D.I., Alexe C.I., Tohănean D.I. (2022) Effects of tabata and HIIT programs regarding body composition and endurance performance among female handball players. *Balneo PRM Res. J.*, 13: 1-8. DOI: 10.12680/balneo.2022.500
17. Dardouri W., Selmi M.A., Sassi R.H., Gharbi Z., Rebhi A., Yahmed M.H., Moalla W. (2014) Relationship between repeated sprint performance and both aerobic and anaerobic fitness. *J. Hum. Kinet.*, 40: 139-148. DOI: 10.2478/hukin-2014-0016
18. Falz R., Fikenzer S., Holzer R., Laufs U., Fikenzer K., Busse M. (2019) Acute cardiopulmonary responses to strength training, high-intensity interval training and moderate-intensity continuous training. *Eur. J. Appl. Physiol.*, 119: 1513-1523. DOI: 10.1007/s00421-019-04138-1
19. Florin C., Constantin R., Adrian G. (2013) Improve maximal aerobic speed in handball seniors through intermittent effort. *Ovidius Univ. Ann. Ser. Phys.*, 13: 73-77.
20. Gaamouri N., Hammami M., Shephard R.J., Chelly M.S., Knechtle B., Suzuki K., Gaied S. (2023) Effects of brief periods of combined plyometric exercise and high intensity running training on the fitness performance of male U17 handball players. *Int. J. Sports Sci. Coach.*, 18: 801-811. DOI: 10.1177/17479541221090932
21. Gaamouri N., Hammami M., Shephard R.J., Chelly M.S., Knechtle B., Suzuki K., Gaied S. (2023) Effects of brief periods of combined plyometric exercise and high intensity running training on the fitness performance of male U17 handball players. *Int. J. Sports Sci. Coach.,* 18: 801-811. DOI: 10.1177/17479541221090932
22. García-Sánchez C., Navarro R.M., Karcher C., de la Rubia A. (2023) Physical demands during official competitions in elite handball: a systematic review. *Int. J. Environ. Res. Public Health*, 20: 1-30. DOI: 10.3390/ijerph20043353
23. Gibala M.J. (2021) Physiological basis of interval training for performance enhancement. *Exp. Physiol.*, 106: 2324-2327. DOI: 10.1113/EP088190
24. Hammami M., Gaamouri N., Ramirez-campillo R., Shephard R.J., Bragazzi R.L., Chelly M.S., Knechtle B., Gaied S. (2021) Effects of high-intensity interval training and plyometric exercise on the physical fitness of junior male handball players. *Eur. Rev. Med. Pharmacol. Sci.*, 25: 7380-7389. DOI: 10.26355/eurrev_202112_27434
25. Harris N.K., Dulson D.K., Logan G.R.M., Warbrick I.B., Merien F.L.R., Lubans D.R. (2017) Acute responses to resistance and high-intensity interval training in early adolescents. *J. Strength Cond. Res.*, 31: 1177-1186. DOI: 10.1519/JSC.0000000000001590
26. Hermassi S., Hoffmeyer B., Irlenbusch L., Fieseler G., Noack F., Delank K.S., Gabbett T.J., Chelly M.S., Schwesig R. (2018) Relationship between the handball-specific complex-test and intermittent field test performance in professional players. *J. Sports Med. Phys. Fitness,* 58: 8-16. DOI: 10.23736/S0022-4707.16.06842-0
27. Hermassi S., Ingebrigtsen J., Schwesig R., Fieseler G., Delank K.S., Chamari K., Shephard R.J., Chelly M.S. (2018) Effects of in-season short-term aerobic and high-

intensity interval training program on repeated sprint ability and jump performance in handball players. *J. Sports Med. Phys. Fitness,* 58: 50-56. DOI: 10.23736/S0022-4707.16.06770-0
28. Hermassi S., Laudner K., Schwesig, R. (2020) The effects of circuit strength training on the development of physical fitness and performance-related variables in handball players. *J. Hum. Kinet.,* 71: 191-203. DOI: 10.2478/hukin-2019-0083
29. Bhakti Y.H. (2022) Improve Vo2max and arm strength of handball athletes. *Int. Conf. Sci., Edu. Techn*., 8(1): 1273-1278.
30. Iacono A.D., Eliakim A., Meckel Y. (2015) Improving fitness of elite handball players: small-sided games vs. high-intensity intermittent training. *J. Strength Cond. Res.*, 29: 835-843. DOI: 10.1519/JSC.0000000000000686
31. Jurišic M.V., Jakšic D., Trajkovic N., Rakonjac D., Peulic J., Obradovic J. (2021) Effects of small-sided games and high-intensity interval training on physical performance in young female handball players. *Biol. Sport*, 38: 359-366. DOI: 10.5114/biolsport.2021.99327
32. Leal J.M., Galliano L.M., Del Vecchio F.B. (2020) Effectiveness of high-intensity interval training versus moderate-intensity continuous training in hypertensive patients: a systematic review and meta-analysis. *Curr. Hypertens. Rep.,* 22: 1-13. DOI: 10.1007/s11906-020-1030-z
33. Marín-Pagán C., Blazevich A.J., Chung L.H., Romero-Arenas S., Freitas T.T., Alcaraz P.E. (2020) Acute physiological responses to high-intensity resistance circuit training vs. Traditional strength training in soccer players. *Biology*, 9: 1-12. DOI: 10.3390/biology9110383
34. Mazoochi M., Fateminezhad S.E., Mazoochi T. (2013) Effects of continuous and interval training on different fitness parameters in athletes. *World Appl. Sci. J.*, 28: 312-315. DOI: 10.5829/idosi.wasj.2013.28.03.81183
35. McKay A.K.A., Stellingwerff T., Smith E.S., Martin D.T., Mujika I., Goosey-Tolfrey V.L., Sheppard J., Burke L.M.. (2022) Defining training and performance caliber: a participant classification framework. *Int. J. Sports Physiol. Perform*. 17: 317-331. DOI: 10.1123/ijspp.2021-0451
36. Michalsik L.B., Madse K., Aagaard P. (2015) Physiological capacity and physical testing in male elite team handball. *Sports Med*., 55: 1503-1516.
37. Mikalonytė R., Paulauskas R., Abade E., Figueira B. (2022) Effects of small-sided games vs. simulated match training on physical performance of youth female handball players. *PLoS One*, 17: 1-12. DOI: 10.1371/journal.pone.0273574
38. Milanović Z., Sporiš G., Weston M. (2015) Effectiveness of high-intensity interval training (HIT) and continuous endurance training for VO_{2max} improvements: a systematic review and meta-analysis of controlled trials. *Sports Med.*, 45: 1469-1481. DOI: 10.1007/s40279-015-0365-0
39. Nikolaidis P.T., Ingebrigtsen J. (2013) Physical and physiological characteristics of elite male handball players from teams with a different ranking. *J. Hum. Kinet.*, 38: 115-124. DOI: 10.2478/hukin-2013-0051
40. Oliveira-Nunes S.G., Castro A., Sardeli A.V., Cavaglieri C.R., Chacon-Mikahil M.P.T. (2021) HIIT vs. SIT: what is the better to improve VO_{2max}? a systematic review and meta-analysis. *Int. J. Environ. Res. Public Health*, 18: 7-9. DOI: 10.3390/ijerph182413120
41. Póvoas S., Ascensão A., Magalhães J., Seabra A.T., Krustrup P., Soares J.M.C., Rebelo A.N. (2014) Analysis of fatigue development during elite male handball matches. *J. Strength Cond. Res.*, 28: 2640-2648. DOI: 10.1519/JSC.0000000000000424
42. Prictor M., Hill S. (2013) Cochrane consumers and communication review group: Leading the field on health communication evidence. *J. Evid. Based. Med.*, 6: 216-220. DOI: 10.1111/jebm.12066
43. Ramos J.S., Dalleck L.C., Tjonna A.E., Beetham K.S., Coombes J.S. (2015) The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a systematic review and meta-analysis. *Sports Med.*, 45: 679-692. DOI: 10.1007/s40279-015-0321-z
44. Rico-González M., Pino-Ortega J., Clemente F.M., Arcos A.L. (2022) Guidelines for performing systematic reviews in sports science. *Biol. Sport*, 39: 463-471. DOI: 10.5114/biolsport.2022.106386
45. Rosenblat M.A., Granata C., Thomas S.G. (2022) Effect of interval training on the factors influencing maximal oxygen consumption: a systematic review and meta-analysis. *Sports Med.*, 52: 1329-1352. DOI: 10.1007/s40279-021-01624-5
46. Sandford G.N., Laursen P.B., Buchheit M. (2021) Anaerobic speed/power reserve and sport performance: scientific basis, current applications, and future directions. *Sports Med.*, 51: 2017-2028. DOI: 10.1007/s40279-021-01523-9
47. Schoenmakers P.P.J.M., Hettinga F.J., Reed K.E. (2019) The moderating role of recovery durations in high-intensity interval training protocols. *Int. J. Sports Physiol. Perform.*, 14: 859-867. DOI: 10.1123/ijspp.2018-0876
48. Sloth M., Sloth D., Overgaard K., Dalgas U. (2013) Effects of sprint interval training on VO_{2max} and aerobic exercise performance: A systematic review and meta-analysis. *Scand. J. Med. Sci. Sports*, 23: 341-352. DOI: 10.1111/sms.12092
49. Spencer M., Bishop D., Dawson B., Goodman C. (2005) Physiological and metabolic responses of repeated-sprint activities specific to field-based team sports. *Sports Med.*, 34: 1025-1044. DOI: 10.2165/00007256-200535120-00003
50. Tricco A.C., Lillie E., Zarin W., O'Brien K.K., Colquhoun H., Levac D., et al. (2018) PRISMA extension

for scoping reviews (PRISMA-ScR): Checklist and explanation. *Ann. Intern. Med.*, 169: 467-473. DOI: 10.7326/M18-0850

51. Tschakert G., Hofmann P. (2013) High-intensity intermittent exercise: Methodological and physiological aspects. *Int. J. Sports Physiol. Perform.*, 8: 600-610. DOI: 10.1123/ijspp.8.6.600
52. Viaño-Santasmarinas J., Rey E., Carballeira S., Padrón-Cabo A. (2018) Effects of high-intensity interval training with different interval durations on physical performance in handball players. *J. Strength Cond. Res.*, 32: 3389-3397. DOI: 10.1519/JSC.0000000000001847
53. Wagner H., Finkenzeller T., Würth S., Von Duvillard S.P. (2014) Individual and team performance in team-handball: A review. *J. Sports Sci. Med.*, 13: 808-816.
54. Wagner H., Sperl B., Bell J., Duvillard S. (2019) Testing specific physical performance in male team handball players and the relationship to general tests in team sports. *J. Strength Cond. Res.*, 33: 1056-1064. DOI: 10.1519/JSC.0000000000003026
55. Wen D., Utesch T., Wu J., Robertson S., Liu J., Hu G., Chen H. (2019) Effects of different protocols of high intensity interval training for VO_{2max} improvements in adults: A meta-analysis of randomised controlled trials. *J. Sci. Med. Sport*, 22: 941-947. DOI: 10.1016/j.jsams.2019.01.013

Received 20.12.2023
Accepted 01.02.2024

Acknowledgements

Javier Raya-González was supported by a Ramón y Cajal postdoctoral fellowship (RYC2021-031072-I) given by the Spanish Ministry of Science and Innovation, the State Research Agency (AEI), and the European Union (NextGenerationEU/PRTR).