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SPORTS PERFORMANCE

Effects of high-intensity interval training in men soccer player's physical fitness: A systematic review with meta-analysis of randomized-controlled and non-controlled trials

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ABSTRACT

This systematic review with meta-analysis (SRMA) was conducted to assess the effects of high-intensity interval training (HIIT) programmes on men soccer players' aerobic fitness (maximal oxygen uptake and aerobic performance), repeated sprint ability (RSA), vertical jump height (VJH), and linear sprinting time (ST). An electronic search yielded 1,714 articles, 33 of which were included in the present study. Meta-analyses revealed significant benefits of HIIT compared to controls in maximal oxygen uptake ($p = 0.018$), AP ($p = 0.041$), and RSA ($p = 0.049$). No significant effects were found in terms of ST ($p = 0.080$). The meta-analyses of non-controlled studies revealed significant improvements after HIIT in maximal oxygen uptake ($p = 0.001$), AP ($p = 0.007$), RSA ($p = 0.001$), and ST ($p < 0.001$). However, no significant improvements in VHJ were found ($p = 0.063$). Furthermore, no significant differences were found in sub-group analysis (comparisons between HIIT types). In conclusion, HIIT is effective for improving maximal oxygen uptake, AP, and RSA regardless of the HIIT type. For VHJ and ST outcomes, it seems reasonable to complement the HIIT since it might not be enough to achieve significant changes.

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KEYWORDS
Football; athletic performance; interval training; sprint interval training

Introduction

Soccer is characterized by long periods of low- to moderate-intensity activity interspersed with periods of high-intensity actions, such as single and repeated sprints (Buchheit & Laursen, 2013a; Iaia et al., 2009). Additionally, explosive actions, such as accelerations, decelerations, quick changes of direction, and jumps, often occur in key moments of the match (e.g., scoring situations) (Faude et al., 2012). Therefore, a well-prepared soccer player must be able to endure long periods of low- to moderate-intensity activity (i.e., endurance performance) and sustain periods of explosive match effort intensification (Stolen et al., 2005). Those qualities will help to express performance and guarantee an appropriate physical fitness level for worst-case scenarios during a match (Fereday et al., 2020).

In order to improve endurance as well as single and repeated explosive performance among soccer players, a time-efficient method (i.e., compared to conventional continuous running) generically known as high-intensity interval training (HIIT) has been proposed (Buchheit & Rabbani, 2014). Five main HIIT types have been described (M Buchheit & PBLaursen, 2013b): (i) short-interval HIIT (<45 s of high but not all-out intensity exercise); (ii) long-interval HIIT (2–4 min of high not-maximal intensity exercise); (iii) repeated sprint training (RST: ≤10 s repeated all-out [or nearly all-out] short sprint sequences, with short rest intervals); (iv) sprint interval training (SIT: >20-30 s of long all-out sprints, with longer rest intervals (e.g., 3-min)); and (v) game-based training (e.g., small-sided games [SSGs], usually using similar regimens to long-interval HIIT) (M Buchheit & PBLaursen, 2013b).

Due to the high degree of neuromuscular and metabolic stress imposed by HIIT, meaningful changes in human skeletal muscle can occur – namely, mitochondrial protein content, muscle oxidative capacity, and the maximal activity of key enzymes can change (Fransson et al., 2018; Gibala et al., 2006). Moreover, HIIT can improve fitness variables such as maximal oxygen uptake (VO_2max), aerobic capacity, sprint time (ST), vertical jump height (VHJ), and repeated sprint ability (RSA) (Girard et al., 2011; Toh et al., 2011).

Given the variant properties of each HIIT type, different HIIT types can have different effects on soccer players' physical fitness. Some randomized-controlled studies have attempted to compare the effects of one or two HIIT types (Dellal et al., 2012; Helgerud et al., 2001; FM Impellizzeri et al., 2008; Macpherson & Weston, 2015; Ouerghi et al., 2014). However, such studies are usually limited by small sample sizes (eight to 14 participants per group) (Dellal et al., 2012; Helgerud et al., 2001; FM Impellizzeri et al., 2008; Macpherson & Weston, 2015; Ouerghi et al., 2014). This limitation can be largely overcome using a systematic review and meta-analysis (SRMA) approach. Although some SRMA have examined the effects of HIIT on players' physical fitness (Engel et al., 2018; J Taylor et al., 2015),

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Supplemental data for this paper can be accessed on the publisher's website.

such studies combined athletes from sports other than soccer or were focused on one specific physical fitness outcome (i.e., endurance) (Moran et al., 2019) and did not compare the effects of different HIIT types (Gist et al., 2014; Kunz et al., 2019). Further, previous SRMA have focused only on youth soccer players (Kunz et al., 2019; Moran et al., 2019). Therefore, the effects of different HIIT types on a comprehensive battery of the key physical fitness traits for adult and youth soccer players are yet to be determined. Therefore, the purpose of this SRMA was to assess the effects of different HIIT types on soccer players' physical fitness (i.e., VO_2max, aerobic performance assessed from maximal field based-tests [AP], RSA, VHJ, and ST).

2. Methods

The present SRMA followed the Cochrane Collaboration guidelines (Green & Higgins, 2005). The systematic review strategy was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines (Moher et al., 2009). The protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols with the number INPLASY202060006 and the DOI number 10.37766/inplasy2020.6.0006.

2.1. Information sources

A comprehensive computerized search of the following electronic databases was performed: (i) Web of Science; (ii) Scopus; (iii) SPORTdiscus; and (iv) PubMed. The searching process for relevant publications had no restriction regarding year of publication and included articles retrieved until 16 May 2020. The following search strings were employed: "soccer" OR "football" AND "high-intensity interval training" OR "HIIT" OR "high-intensity intermittent training" OR "interval training" OR "small-sided games" OR "sprint interval training" OR "repeated sprint training" OR "speed endurance training".

2.2. Eligibility criteria

Considering that a non-controlled pre-post study design is the most prevalent for HIIT-related research (J Taylor et al., 2015), this SRMA will focus on both randomized controlled trials and non-controlled trials.

The *a priori* inclusion criteria for this review were as follows: (i) randomized-controlled (active control; passive control) or non-controlled trials (parallel studies) conducted in men soccer players with no restriction of age or competitive level; (ii) isolated (i.e., not combined with other methods) soccer-specific (i.e., running-based) HIIT interventions with no restrictions for duration (e.g., short-intervals, long-intervals, small-sided games, speed endurance training, repeated sprint training and sprint interval training); (iii) a pre-post outcome for physical fitness, including VO_2max, AP, VJH, RSA or ST; (iv) original peer-reviewed articles written in English that provided full-text.

Studies were excluded on the basis that they: (i) were observational studies; (ii) included other sports; (iii) used HIIT combined with other training methods; (iv) used combined HIIT types (e.g., running-based long-interval HIIT combined with small-sided games); (v) used other than running-based HIIT (e.g., cycling, boxing, rowing); (v) were review articles, letters to the editor, errata, invited commentaries or conference abstracts.

A posteriori, studies were excluded if they reported the inclusion of women. This exclusion criterion was adopted considering the low number of studies found during a pilot literature search, and the potential confounding factor of sex on the HIIT-physical fitness interaction.

2.3 Data extraction

A data extraction sheet conceived in Microsoft Excel (Microsoft Corporation, Readmon, WA, USA) was made based on Cochrane Consumers and Communication Review Group's data extraction template (Group CCCR, 2016). The sheet was used to assess inclusion requirements and subsequently tested on ten randomly selected studies (i.e., pilot testing). The process was conducted by two of the authors (FMC and HS). Any disagreement regarding study eligibility was resolved in a discussion between the authors. Full text articles excluded, with reasons, were recorded. All the records were stored in the sheet.

2.4. Data items

The outcomes chosen for this SRMA included VO_2max, AP, RSA, VHJ and ST. Both direct (i.e., gas analysis in a graded exercise test until exhaustion, n = 11) and indirect (e.g., equations applied to field-based tests, n = 4) measures of VO_2max were considered, usually assessed as maximal oxygen uptake, peak oxygen uptake, and expressed as $mL\cdot kg^{-1}\cdot min^{-1}$. For the case of indirect measures of VO_2max (equation estimates from AP), three of the studies (see Table 1) used the Yo-Yo intermittent recovery test and one study used the 12-min Cooper test. The AP included progressive tests until exhaustion (e.g., multistage tests) or time-based tests (e.g., maximum distance covered at a given predefined time) in which the measures of total distance covered (m), maximal velocity achieved ($km\cdot h^{-1}$) or maximal aerobic speed ($m\cdot s^{-1}$) were collected. The VHJ (measured in cm) was usually assessed during a countermovement jump (CMJ) with or without arm swing. The RSA was collected based on the mean time (s) or total time (s) in a series of multiple sprints. The linear ST (s) at different distances was also collected, without including values of partial times.

Additionally, the following information was extracted from the included studies: (i) number of participants (n), age (years), competitive level (if available) and design of the study (randomized-controlled trial or non-controlled trial); (ii) HIIT type (e.g., short-interval HIIT; long-interval HIIT; SSGs; RST; SIT) following the classification of a previous study (M Buchheit & PBLaursen, 2013b); (iii) period of intervention (number of weeks) and number of sessions per week (n/w); and (iv) regimen of intervention (work duration, work intensity, modality, relief duration, relief intensity, repetitions and series, between-set recovery) (M Buchheit & PBLaursen, 2013b).

2.5. Assessment of methodological quality

The Physiotherapy Evidence Database (PEDro) scale was used to assess the methodological quality of the randomized

Table 1. Characteristics of the included studies and outcomes extracted.

Study	Mean age (y)	CL	Design	Outcomes	Tests used in the original studies	Measure extracted from the tests in the original studies
(Arslan et al., 2020)	14.2	Y	NC	AP; RSA; VHJ; ST	AP: YYIRT RSA: 6 × 40-m all out/20s rest VHJ: CMJ ST: linear sprint 30-m	AP: distance (m) RSA: total time during the sprints (s) VHJ: (cm) ST: time (s)
(Beato et al., 2019)	21.0	AS	NC	AP; RSA; ST	AP: YYIRT RSA: 6 × 40-m all out/20s rest ST: linear sprint 20-m	AP: distance (m) RSA: mean time over the sprints (s) ST: time (s)
(Bravo et al., 2008)	17.3 and 24.3	Y and AS	NC	VO_2max; VHJ; ST	VO_2max: Incremental treadmill test VHJ: CMJ ST: linear sprint 10-m	VO_2max: mL·kg^{-1}·min^{-1} VHJ: (cm) ST: time (s)
(Buchheit et al., 2010)	14.5	Y	NC	RSA; VHJ; ST	RSA: 6 × 30-m all-out/20s rest VHJ: CMJ ST: linear sprint 30-m	RSA: mean time over the sprints (s) VHJ: (cm) ST: time (s)
Chtara et al., 2017)	13.6	Y	C	VO_2max; RSA; ST	RSA: 6 × 30-m all-out/20s rest ST: linear sprint 30-m	RSA: mean time over the sprints (s) ST: time (s)
(Dellal et al., 2012)	26.3	AS	C	AP	AP: 30–15$_{IFT}$	AP: VIFT (km·h^{-1})
(Dello Iacono et al., 0000)	18.6	Y	NC	AP; RSA; VHJ; ST	AP: YYIRT RSA: 6 × 25-m/20s rest VHJ: CMJ ST: linear sprint 20-m	AP: distance (m) RSA: mean time over the sprints (s) VHJ: (cm) ST: time (s)
(Eniseler et al., 2017)	16.9	Y	NC	AP; RSA	AP: YYIRT RSA: 6 × 40 m all-out/10s rest	AP: distance (m) RSA: mean time over the sprints (s)
(Faude et al., 2013)	15.9	Y	NC	AP; VHJ	AP: Incremental running protocol VHJ: CMJ	AP: Vpeak (km·h^{-1}) VHJ: (cm)
(Faude et al., 2014)	16.5	Y	NC	AP; VHJ; ST	AP: Multistage endurance test VHJ: CMJ ST: linear sprint 30-m	AP: Vpeak (km·h^{-1}) VHJ: (cm) ST: time (s)
(Harrison et al., 2015)	13.9	Y	NC	VO_2max; AP; VHJ; ST	VO_2max: Incremental treadmill test AP: 30–15$_{IFT}$ VHJ: CMJ ST: linear sprint 20-m	VO_2max: mL·kg^{-1}·min^{-1} AP: V_{IFT} (km·h^{-1}) VHJ: (cm) ST: time (s)
(Helgerud et al., 2001)	18.1	Y	C	VO_2max; ST	VO_2max: Incremental treadmill test ST: linear sprint 40-m	VO_2max: mL·kg^{-1}·min^{-1} ST: time (s)
(Hill-Haas et al., 2009)	14.6	Y	NC	VO_2max; AP; RSA; ST	VO_2max: Incremental treadmill test AP: YYIRT RSA: 12 × 20-m all-out/20s rest ST: linear sprint 20-m	VO_2max: mL·kg^{-1}·min^{-1} AP: distance (m) RSA: total time during the sprints (s) ST: time (s)
(Hostrup et al., 2019)	22	SPS	NC	AP; ST	AP: YYIRT ST: linear sprint 30-m	AP: distance (m) ST: time (s)
(Iaia et al., 2015)	18.5	Y	NC	AP; RSA; ST	AP: YYIRT RSA: 15 × 40-m all-out/30s rest ST: linear sprint 20-m	AP: distance (m) RSA: total time during the sprints (s) ST: time (s)
(Iaia et al., 2017)	17.0	y	NC	AP; RSA; ST	AP: YYIRT RSA: 15 × 40-m all out/30s rest ST: linear sprint 20-m	AP: distance (m) RSA: total time during the sprints (s) ST: time (s)
(F Impellizzeri et al., 2006)	17.2	Y	NC	VO_2max	VO_2max: Incremental treadmill test	VO_2max: mL·kg^{-1}·min^{-1}
(FM Impellizzeri et al., 2008)	17.8	Y	C	VO_2max; AP	VO_2max: Incremental treadmill test AP: YYIRT	VO_2max: mL·kg^{-1}·min^{-1} AP: distance (m)
(Jastrzebski et al., 2014)	15.8	Y	NC	VO_2max; ST	VO_2max: Incremental treadmill test ST: linear sprint 30-m	VO_{2max}: mL·kg^{-1}·min^{-1} ST: time (s)
(Kavaliauskas et al., 2017)	22	AS	C	VO_2max; AP	VO_2max: YYIRT AP: YYIRT	VO_{2max}: mL·kg^{-1}·min^{-1} (estimated) AP: distance (m)

(*Continued*)

Table 1. (Continued).

Study	Mean age (y)	CL	Design	Outcomes	Tests used in the original studies	Measure extracted from the tests in the original studies
(Los Arcos et al., 2015)	15.5	Y	NC	AP; VHJ	AP: Université de Montréal TrAPt Test	AP: MAS ($km \cdot h^{-1}$)
					VHJ: CMJ	VHJ: (cm)
(Macpherson & Weston, 2015)	25	SPS	C	VO_2max; AP	VO_2max: Incremental treadmill test	VO_{2max}: $mL \cdot kg^{-1} \cdot min^{-1}$
					AP: YYIRT	AP: distance (m)
(Mohr & Krustrup, 2016)	19	U	NC	AP; RSA	AP: YYIRT	AP: distance (m)
					RSA: 5 × 30-m all-out/25 rest	RSA: mean time over the sprints (s)
(Mujika et al., 2009)	18.3	Y	NC	VHJ	VHJ: CMJ	VHJ: (cm)
(Ouerghi et al., 2014)	22.9	AS	C	VO_2max; AP	VO_{2max}: YYIRT	VO_2max: $mL \cdot kg^{-1} \cdot min^{-1}$ (estimated)
					AP: YYIRT	AP: MAS ($km \cdot h^{-1}$)
(Radziminski et al., 2013)	15.1	Y	NC	VO_2max	VO_2max: Incremental treadmill test	VO_2max: $mL \cdot kg^{-1} \cdot min^{-1}$
					ST: linear sprint 30-m	ST: time (s)
(Rey et al., 2019)	12.3	Y	NC	RSA; ST	RSA: 6 × 25-m all-out/25s rest	RSA: mean time over the sprints (s)
					ST: linear sprint at 20-m	ST: time (s)
(Safania et al., 2011)	15.7	Y	NC	VO_2max	VO_2max: estimated at 12-minutes running test	VO_2max: $mL \cdot kg^{-1} \cdot min^{-1}$
(Sanchez-Sanchez et al., 2019)	14.9	Y	C	VO_2max; AP; RSA	VO_2max: estimated at YYIRT	VO_2max: $mL \cdot kg^{-1} \cdot min^{-1}$
					AP: YYIRT	AP: distance (m)
					RSA: 8 × 30-m all out/25s rest	RSA: mean time over the sprints (s)
(Slettaløkken & Rønnestad, 2014)	18–26	SPS	NC	VO_2max; AP	VO_2max: Incremental treadmill test	VO_2max: $mL \cdot kg^{-1} \cdot min^{-1}$
					AP: 20-m shuttle run test	AP: distance (m)
(Sperlich et al., 2011)	13.5	Y	NC	VO_2max; VHJ; ST	VO_2max: Incremental treadmill test	VO_2max: $mL \cdot kg^{-1} \cdot min^{-1}$
					VHJ: CMJ	VHJ: (cm)
					ST: linear sprint 40-m	ST: time (s)
(JM Taylor et al., 2016)	24.1	SPS	NC	AP; VHJ; ST	AP: YYIRT	AP: distance (m)
					VHJ: CMJ	VHJ: (cm)
					ST: linear sprint 20-m	ST: time (s)
(Tønnessen et al., 2011)	16.4	Y	C	AP; RSA; VHJ; ST	AP: Incremental running protocol	AP: final level (n)
					RSA: 10 × 40-m all-out/60s rest	RSA: mean time over the sprints (s)
					VHJ: CMJ	VHJ: (cm)
					ST: linear sprint 40-m	ST: time (s)

N: number of participants in the study; Y: years; CL: competitive level; Y: youth; PS: professional senior; SPS: semi-professional senior; AS: amateur senior; U: universitarian; VO2: maximal oxygen uptake; AP: aerobic performance assessed from maximal field based-tests; RSA: repeated-sprint ability; VHJ: vertical height jump; ST: sprinting time at linear trajectories; *: control group without intervention; CMJ: countermovement jump; YYIRT: Yo-Yo intermittent recovery test; $30\text{–}15_{IFT}$: 30–15 Intermittent Fitness Test; ¶: long-interval HIIT was tested with one (1) session week and one session two in two weeks (0.5); $: the SIT training (described in the original work as speed endurance training and speed endurance maintenance) tested two versions with different recovery periods; RSAmean: mean during repeated sprint ability tes; V_{IFT}: maximal velocity at 30–15 IFT; Vpeak: peak velocity at Multistage endurance test; RSAtotal: total time during the RSA test; MAS: maximal aerobic speed; s: seconds; cm: centimetres; m: metres;

controlled trials included in this SRMA. The scale scores the internal study validity in a range of 0 (high risk of bias) to 10 (low risk of bias). Eleven items are measured in the scale. The criterion 1 is not included in the final score. Points for items 2 to 11 were only attributed when a criterion was clearly satisfied. Two of the authors (FMC and HS) independently scored the articles. Disagreements in the rating between both authors were resolved through discussion. Aiming to control the risk of bias between authors, the Kappa correlation test was used to analyse the agreement level for the included studies. An agreement level of k = 0.84 was obtained.

In the case of the non-randomized trials, the methodological index for non-randomized studies (MINORS) was used (Slim et al., 2003). Twelve items were analysed, in which zero represented cases of no report, one case of report but inadequate, and two in cases of report and adequate. Two of the authors (FMC and HS) independently scored the articles. Disagreements in the rating between both authors were resolved through discussion. Aiming to control the risk of bias between authors, the Kappa correlation test was used to analyse the agreement level for the included studies. An agreement level of k = 0.78 was obtained.

2.6. Summary measures

The analysis and interpretation of results in this SRMA were only conducted in the case of at least three study groups provided baseline and follow-up data for the same measure (García-Hermoso et al., 2019; Moran et al., 2018; Skrede et al., 2019). Means and standard deviations for a measure (VO_2max; AP; RSA; VHJ; ST) of pre-post HIIT interventions were converted to Hedges's *g* effect size (ES). The inverse variance random-effects model for meta-analyses was used because it allocates a proportionate weight to trials based on the size of their individual standard errors (Deeks et al., 2008) and enables analysis while accounting for heterogeneity across studies (Kontopantelis et al., 2013). The ESs were presented alongside 95% confidence intervals (CIs) and interpreted using the following thresholds (Hopkins et al., 2009): <0.2, trivial; 0.2–0.6, small; >0.6–1.2, moderate; >1.2–2.0, large; >2.0–4.0, very large; >4.0, extremely large. All analyses were carried out using the Comprehensive Meta-Analysis programme (version 2; Biostat, Englewood, NJ, USA).

2.7. Synthesis of results

To estimate the degree of heterogeneity between the included studies, the percentage of total variation across the studies due to heterogeneity was used to calculate the I^2 statistic (Higgins, 2003). Low, moderate and high levels of heterogeneity correspond to I^2 values of <25%, 25–75%, and >75%, respectively (Higgins, 2003; Higgins & Thompson, 2002).

2.8. Risk of bias across studies

The extended Egger's test (Egger et al., 1997) was used to assess the risk of bias across the studies. To adjust for publication bias, a sensitivity analysis was conducted using the trim and fill method (Duval & Tweedie, 2000), with L0 as the default estimator for the number of missing studies (Shi & Lin, 2019).

3. Results

3.1. Study identification and selection

The searching of databases identified a total of 1,714 titles. These studies were then exported to reference manager software (EndNote™ X9, Clarivate Analytics, Philadelphia, PA, USA). Duplicates (502 references) were subsequently removed either automatically or manually. The remaining 1,212 articles were screened for their relevance based on titles and abstracts, resulting in the removal of a further 811 studies. The full texts of the remaining 391 articles were examined diligently; 315 were rejected, as they did not satisfy the relevant criteria (e.g., HIIT interventions in soccer). Following the screening procedure, 78 articles were selected for in-depth reading and analysis. After reading full texts, further 45 studies were excluded due to a number of reasons (Figure 1). The 33 studies included in the meta-analysis provided mean and standard deviation for pre- and post-interventions data for at least one main outcome.

3.2. Study characteristics

The characteristics of the 33 studies included in the meta-analysis can be found in Table 1. Additionally, the details of the HIIT programs can be found in Table 2. The included randomized-controlled studies involved 11 individual experimental groups and 107 participants, and 78 participants in the 9 control groups. The included non-controlled studies involved 39 individual groups and 400 participants.

3.3. Methodological quality

Using the PEDro checklist, one study scored 5 points and was classified as being of "moderate" quality, while eight studies achieved 6 points and were therefore considered as being of "high" methodological quality (Table 3). In the case of non-randomized trial, eleven studies were between 16 and 17 points, 12 studies between 18 and 19 points and one study achieved 20 points (Table 4).

3.4. Effects of HIIT on maximal oxygen uptake

A summary of the included studies and results of VO_2max reported before and after HIIT programs are provided in Table 5.

Six controlled studies provided data for VO_2max, involving seven experimental and six control groups (pooled n = 122). There was a significant effect of HIIT on VO_2max (ES = 0.57; 95% CI = 0.10 to 1.03; p = 0.018; I^2 = 40.1%; Egger's test p= 0.103; Figure 2; a funnel plot for bias assessment is available as Supplementary Figure 1). The relative weight of each study in the analysis ranged from 12.1% to 16.8%.

Nine non-controlled studies provided data for VO_2max, involving 14 experimental groups (pooled n = 148). There was a significant effect of HIIT on VO_2max (ES = 0.66; 95% CI = 0.27 to 1.05; p = 0.001; I^2 = 86.8%; Egger's test p= 0.001; Figure 3, bottom). The relative weight of each study in the analysis ranged from 2.4% to 8.1%. After the trim and fill method was applied, the adjusted values remained equal as the observed values (a funnel plot for bias assessment is available as

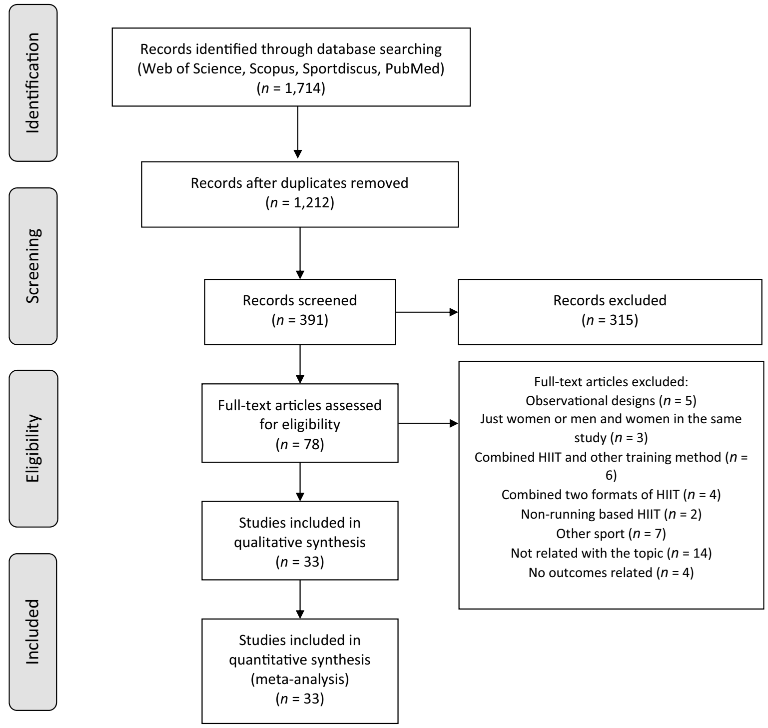


Figure 1. PRISMA flow diagram highlighting the selection process for the studies included in the systematic review and meta-analysis.

Supplementary Figure 2). No significant sub-group difference (between-group p = 0.776) was found between long-interval HIIT (six study groups; ES = 0.69; 95% CI = –0.08 to 1.46; within-group I^2 = 91.1%) and SSGs (6 study groups; ES = 0.83; 95% CI = 0.23 to 1.43; within-group I^2 = 86.3%). Due to reduced number of studies available for robust meta-analyses, one RST study group and one short-interval HIIT study group were not included in the between-group comparison.

3.5. Effects of HIIT on aerobic performance assessed from maximal field based-tests

A summary of the included studies and results of AP reported before and after HIIT programs are provided in Table 6.

Seven controlled studies provided data for AP, involving nine experimental and seven control groups (pooled n = 160). There was a significant effect of HIIT on AP (ES = 0.52; 95% CI = 0.02 to 1.02; p = 0.041; I^2 = 53.9%; Egger's test p= 0.719; Figure 4; a funnel plot for bias assessment is available as Supplementary Figure 3). The relative weight of each study in the analysis ranged from 8.8% to 13.1%.

Fifteen non-controlled studies provided data for AP, involving 25 experimental groups (pooled n = 250). There was a significant effect of HIIT on AP (ES = 0.35; 95% CI = 0.10 to 0.60; p = 0.007; I^2 = 83.5%; Egger's test p= 0.497; Figure 5, bottom; a funnel plot for bias assessment is available as Supplementary Figure 4). The relative weight of each study in the analysis ranged from 2.5% to 4.6%. No significant sub-group difference (between-group p = 0.129) was found between long-interval HIIT (three study groups; ES = –0.56; 95% CI = –1.59 to 0.47; within-group I^2 = 89.7%), RST (6 study groups; ES = 0.54; 95% CI = 0.28 to 0.81; within-group I^2 = 49.4%), short-interval HIIT (3 study groups; ES = 0.78; 95% CI = –0.46 to 2.01; within-group I^2 = 93.8%), SIT (4 study groups; ES = 0.19; 95% CI = –0.06 to 0.44; within-group I^2 = 0.0%), and SSGs (9 study groups; ES = 0.43; 95% CI = –0.07 to 0.94; within-group I^2 = 86.8%).

3.6. Effects of HIIT on repeated-sprint ability

A summary of the included studies and results of RSA reported before and after HIIT programs are provided in Table 7.

Three controlled studies provided data for RSA, involving four experimental and three control groups (pooled n = 71). There was a significant effect of HIIT on RSA (ES = 0.47; 95% CI = 0.00 to 0.93; p = 0.049; I^2 = 0.0%; Egger's test p= 0.907; Figure 6; a funnel plot for bias assessment is available as Supplementary Figure 5). The relative weight of each study in the analysis ranged from 17.2% to 31.6%.

Ten non-controlled studies provided data for RSA, involving 17 experimental groups (pooled n = 182). There was a significant effect of HIIT on RSA (ES = 0.45; 95% CI = 0.19 to 0.71; p = 0.001; I^2 = 79.4%; Egger's test p= 0.022; Figure 7, bottom). The relative weight of each study in the analysis ranged from 4.5% to 6.7%. After the trim and fill method was applied, the adjusted values remained equal as the observed values (a funnel plot for bias assessment is available as Supplementary Figure 6). No significant sub-group difference (between-group p = 0.631) was found between RST (eight study groups; ES = 0.39; 95% CI = 0.20 to 0.57; within-group I^2 = 35.2%), SIT (3 study groups; ES = 0.07; 95% CI = –0.66 to 0.80; within-group I^2 = 82.1%), and SSGs (5 study groups; ES = 0.57; 95% CI = –0.17 to 1.30; within-group I^2 = 89.6%). Due to reduced number of studies available for robust meta-analyses, one short-interval

Table 2. Characteristics of HIIT programs in the included studies.

Study	HIIT format	Duration (w)	d/ w*	Total sessions	Work duration*	Work intensity	Relief duration	Relief intensity	Series*	Reps*	Recovery between sets (duration)	Recovery between sets (intensity)	SSG formats	SSG pitch dimension (length × width)	SSG area per player (m^2)
(Dellal et al., 2012)	siHIIT	6	1–2	9	10–30s	95–100% V_{IFT}	10–30s	NR	2	7–10	5–6 min	Passive	-	-	-
(Faude et al., 2013)	siHIIT	11	2–3	22–33	15–30s	140–125% IAT	15–30s	NR	2	12–15	10 min	Light activity	-	-	-
(Faude et al., 2014)	siHIIT	4	2	8	15s	140% IAT	15s	NR	2	12–15	10 min	NR	-	-	-
(Jastrzebski et al., 2014)	siHIIT	8	2	16	15s	85–90% HRmax	15s	NR	7	6	90s	Active recovery	-	-	-
(Ouerghi et al., 2014)	siHIIT	12	2	24	15s	105–120% MAS	15s	Passive	2	20	3 min	NR	-	-	-
(Arslan et al., 2020)	siHIIT	5	2	10	15s	90–95% V_{IFT}	15s	Passive	2	12–20	NR	NR	-	-	-
(Bravo et al., 2008)	liHIIT	7	2	14	4 min	90–95% HRmax	3 min	Light activity (60–70% HRmax)	-	4	-	-	-	-	-
(Helgerud et al., 2001)	liHIIT	8	2	16	4 min	90–95% HRmax	3 min	50–60% HRmax	-	4	-	-	-	-	-
(FM Impellizzeri et al., 2008)	liHIIT	4	2–3	10	4 min	90–95% HRmax	3 min	Jogging	-	4	-	-	-	-	-
(Los Arcos et al., 2015)	liHIIT	6	2	12	4 min	90–95% HRmax	3 min	50–60% HRmax	-	3	-	-	-	-	-
(Radziminski et al., 2013)	liHIIT	8	2	16	4 min	>90% HRmax	3 min	Light activity	-	5	-	-	-	-	-
(Safania et al., 2011)	liHIIT	6	3	18	4 min	70–95% HRmax	3 min	NR	-	4	-	-	-	-	-
(Slettaløkken & Rønnestad, 2014)	liHIIT	6	1	6	4 min	87–97% HRmax	NR	NR	-	5	-	-	-	-	-
(Slettaløkken & Rønnestad, 2014)	liHIIT	6	0–1	3	4 min	87–97% HRmax	NR	NR	-	5	-	-	-	-	-
(Sperlich et al., 2011)	liHIIT	5	2–3	13	30s-240s	90–95% HRmax	30s-180s	Passive	-	4–12	-	-	-	-	-
(Beato et al., 2019)	RST[e]	2	3	6	30-m	All-out	20s	NR	3	7	4 min	NR	-	-	-
(Beato et al., 2019)	RST[f]	2	3	6	20 + 20-m	All-out	20s	NR	3	7	4 min	NR	-	-	-
(Bravo et al., 2008)	RST	7	2	14	40-m	All-out	20s	Passive	3	6	4 min	Passive	-	-	-
(Buchheit et al., 2010)	RST	10	1	10	15- to 20 m	All-out	14s or 23s	Passive or active (~2 $m \cdot s^{-1}$)	2–3	5–6	NR	NR	-	-	-
(Chtara et al., 2017)	RST	6	2	12	20–30-m	All-out	20s	NR	2–4	5–6	4 min	NR	-	-	-
(Eniseler et al., 2017)	RST	6	2	12	40-m	All-out	20s	Passive	3	6	4 min	NR	-	-	-
(Iaia et al., 2017)	RST[c]	5	2	10	30-m	All-out	15s	Passive	1–3	6	2 min	NR	-	-	-
(Iaia et al., 2017)	RST[d]	5	2	10	30-m	All-out	30s	Passive	1–3	6	2 min	NR	-	-	-
(Kavaliauskas et al., 2017)	RST[£]	6	2	12	10s	All-out	60s	Light activity	-	10	-	-	-	-	-
(Rey et al., 2019)	RST[a]	6	1	6	15 to 30-m	All-out	20s	Passive	2–6	4–6	NR	NR	-	-	-
(Rey et al., 2019)	RST[b]	6	2	12	15 to 30-m	All-out	20s	Passive	2–6	4–6	NR	NR	-	-	-
(Sanchez-Sanchez et al., 2019)	RST[g]	8	2	16	18-m	All-out	18-m	Low-intensity running	3	10	4 min	Passive	-	-	-
(Sanchez-Sanchez et al., 2019)	RST[h]	8	2	16	18-m	All-out	18-m	Low-intensity running	3	10	4 min	Passive	-	-	-

(*Continued*)

Table 2. (Continued).

Study	HIIT format	Duration (w)	d/w*	Total sessions	Work duration*	Work intensity	Relief duration	Relief intensity	Series*	Reps*	Recovery between sets (duration)	Recovery between sets (intensity)	SSG formats	SSG pitch dimension (length × width)	SSG area per player (m^2)
(JM Taylor et al., 2016)	RST	2	3	6	30-m	All-out	20s	Passive	3–4	7	4 min	Passive	-	-	-
(Tønnessen et al., 2011)	RST	10	1	10	40-m	95–100% Maximal Speed	90–120s	NR	2–5	4–5	10 min	NR	-	-	-
(Hostrup et al., 2019)	SIT	10	3	30	6s	All-out	54s	Passive	2–3	6	4 min	NR	-	-	-
(Iaia et al., 2015)	SIT	3	3	9	20s	All-out	120s	Passive	-	6–8	-	-	-	-	-
(Iaia et al., 2015)	SIT	3	3	9	20s	All-out	40s	Passive	-	6–8	-	-	-	-	-
(Macpherson & Weston, 2015)	SIT$^{\$}$	2	3	6	30s	All-out	4 min	Light activity	-	4–6	-	-	-	-	-
(Mohr & Krustrup, 2016)	SIT	4	2	8	30s	All-out	150s	NR	-	8–10	-	-	-	-	-
(Mujika et al., 2009)	SIT	7	1	6	30 m	NR	90s	NR	2–4	4	180s	NR	-	-	-
(Arslan et al., 2020)	SSGs	5	2	10	2.5–4.5 min	NR	2 min	Passive	2	2	NR	NR	2vs.2	20 × 15-m	75 m^2
(Dellal et al., 2012)	SSGs	6	1–2	9	90 to 150s	NR	1.5 to 2 min	NR	-	5	-	-	1vs.1 to 2vs.2	15 × 10 to 20 × 20-m	150 to 100 m^2
(Dello Iacono et al., 0000)	SSGs	8	2	16	4 min	89.7% HRmax	2 min	Passive	-	3–5	-	-	5vs.5	42 × 30-m	126 m^2
(Eniseler et al., 2017)	SSGs	6	2	12	3 min	90–95% HRmax	4 min	Passive	-	4	-	-	3vs.3	18 × 30-m	90 m^2
(Faude et al., 2014)	SSGs	4	2	8	4 min	NR	4 min	Technical activities	-	4	-	-	3vs.3 to 4vs.4	35 × 25-m to 40 × 30-m	145 to 150 m^2
(Harrison et al., 2015)	SSGs	6	2	12	8–11 min	NR	3 min	Passive	-	2	-	-	3vs.3	NR	NR
(Hill-Haas et al., 2009)	SSGs	7	2	14	6–13 min	NR	1–3 min	NR	-	2–6	-	-	2vs.2 to 7vs.7	20 × 15 to 60 × 40-m	75–220 m^2
(F Impellizzeri et al., 2006)	SSGs	12	2	24	4 min	91.3% HRmax	3 min	60–70% HRmax	-	4	-	-	3 vs. 3 to 5 vs. 5	25 × 40 to 35 × 50-m	-
(Jastrzebski et al., 2014)	SSGs	8	2	16	3 min	NR	90s	Active recovery	-	7	-	-	3vs.3	18 × 30-m	90 m^2
(Los Arcos et al., 2015)	SSGs	6	2	12	4 min	NR	3 min	Passive	-	3	-	-	3vs.3 to 4vs.4	NR	85 m^2
(Mohr & Krustrup, 2016)	SSGs	4	2	8	45s	NR	45s	NR	-	8–10	-	-	2vs.2	20 × 20-m	100 m^2
(Radziminski et al., 2013) 77–90 m^2	SSGs	8	2	16	4 min	>90% HRmax	3 min	Light activity	-	5	-	-	3vs.3 or	3vs.3 + 1	18 × 30-m
(Safania et al., 2011)	SSGs	6	3	18	4 min	NR	3 min	NR	-	4	-	-	2vs.2 to 4vs.4	10 × 15 to 40 × 50-m	NR

HIIT: type of high-intensity interval training; siHIIT: short-interval HIIT; liHIIT: long-interval HIIT; RST: repeated sprint training; SIT: sprint interval training; SSGs: small-sided games; W: weeks; d/w: days per week; MAS: maximal aerobic speed; s: seconds; NR: not reported; *: the range between the programs; min: minutes; m: metres; V_{IFT}: maximal velocity at 30–15_{IFT}; IAT: individual anaerobic threshold; $^{£}$: uphill sprint training (gradient of 7%); $^{\$}$: only the first two-weeks of intervention were considered (SIT development); MAS: maximal aerobic speed; HRmax: maximal heart rate; Passive: passive recovery; s: seconds; min: minutes; m: metres; ^{a}: one session week; ^{b}: two-session week; ^{c}: short rest; ^{d}: long rest; ^{e}: straight sprint; ^{f}: with change of direction; ^{g}: group above 48 $mL\cdot kg^{-1}\cdot min^{-1}$ of VO_2max; ^{h}: group below 48 $mL\cdot kg^{-1}\cdot min^{-1}$ of VO_2max

Table 3. Physiotherapy Evidence Database (PEDro) scale ratings.

	N.º1*	N.º2	N.º3	N.º4	N.º5	N.º6	N.º7	N.º8	N.º9	N.º10	N.º11	Total**
(Dellal et al., 2012)	0	1	0	1	0	0	0	1	1	1	1	6
(Chtara et al., 2017)	0	1	0	1	0	0	0	1	1	1	1	6
(Helgerud et al., 2001)	1	1	0	1	0	0	0	1	1	1	1	6
(FM Impellizzeri et al., 2008)	0	1	0	1	0	0	0	1	1	1	1	6
(Kavaliauskas et al., 2017)	0	1	0	0	0	0	0	1	1	1	1	5
(Macpherson & Weston, 2015)	1	1	0	1	0	0	0	1	1	1	1	6
(Ouerghi et al., 2014)	0	1	0	1	0	0	0	1	1	1	1	6
(Sanchez-Sanchez et al., 2019)	1	1	0	1	0	0	0	1	1	1	1	6
Tonnessen et al (Tønnessen et al., 2011)	1	1	0	1	0	0	0	1	1	1	1	6

*: PEDRro scale items number; **: the total number of points from a possible maximal of 10; N.º1: eligibility criteria were specified; N.º2: subjects were randomly allocated to groups; N.º3: allocation was concealed; N.º4: the groups were similar at baseline regarding the most important prognostic indicators; N.º5: there was blinding of all subjects; N.º6: there was blinding of all therapists who administered the therapy; N.º7: there was blinding of all assessors who measured at least one key outcome; N.º8: measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups; N.º9: all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat"; N.º10: the results of between-group statistical comparisons are reported for at least one key outcome; and N.º11: the study provides both point measures and measures of variability for at least one key outcome.

Table 4. Methodological index for non-randomized studies (MINORS).

	N.º1*	N.º2	N.º3	N.º4	N.º5	N.º6	N.º7	N.º8	N.º9	N.º10	N.º11	N.12	Total**
(Arslan et al., 2020)	2	1	2	2	0	2	2	0	1	2	2	2	18
(Beato et al., 2019)	2	1	2	2	0	2	0	0	1	2	2	2	16
(Bravo et al., 2008)	2	1	2	2	0	2	0	0	1	2	2	2	16
(Buchheit et al., 2010)	2	1	2	2	0	2	1	2	1	2	2	2	19
(Dello Iacono et al.)	2	1	2	2	0	2	2	0	1	2	2	2	18
(Eniseler et al., 2017)	2	1	2	2	0	2	2	0	1	2	2	2	18
(Faude et al., 2013)	2	2	2	2	0	2	0	0	2	2	2	2	18
(Faude et al., 2014)	2	0	2	2	0	2	0	0	2	2	2	2	16
(Harrison et al., 2015)	2	1	2	2	0	2	2	0	1	2	2	2	18
(Hill-Haas et al., 2009)	2	1	2	2	0	2	0	0	1	2	2	2	16
(Hostrup et al., 2019)	2	1	2	2	0	2	1	0	1	2	2	2	17
(Iaia et al., 2015)	2	1	2	2	0	2	2	0	1	2	2	2	18
(Iaia et al., 2017)	2	1	2	2	0	2	1	0	1	2	2	2	17
(F Impellizzeri et al., 2006)	2	1	2	2	0	2	0	0	1	2	2	2	16
(Jastrzebski et al., 2014)	2	1	2	2	0	2	0	0	1	2	2	2	16
(Los Arcos et al., 2015)	2	1	2	2	0	2	2	0	1	2	2	2	18
(Mohr & Krustrup, 2016)	2	1	2	2	0	2	2	0	1	2	2	2	18
(Mujika et al., 2009)	2	2	2	2	0	2	0	0	1	2	2	2	17
(Radziminski et al., 2013)	2	1	2	2	0	2	0	0	1	2	2	2	16
(Rey et al., 2019)	2	1	2	2	0	2	2	2	1	2	2	2	20
(Safania et al., 2011)	2	1	2	2	0	2	2	0	1	2	2	2	18
(Slettaløkken & Rønnestad, 2014)	2	2	2	2	0	2	2	0	1	2	2	2	19
(Sperlich et al., 2011)	2	0	2	2	0	2	1	0	2	2	2	2	17
(JM Taylor et al., 2016)	2	1	2	2	0	2	2	0	1	2	2	2	18

*: MINORS scale items number; N.º1: A clearly study aimed; N.º 2: Inclusion of consecutive patients; N.º 3: Prospective collection of data; N.º 4: Endpoints appropriate to the aim of the study; N.º 5: Unbiased assessment of the study endpoint; N.º 6: Follow-up period appropriate to the aim of the study; N.º 7: Loss to follow less than 5%; N.º 8: Prospective calculation of the study size; N.º 9: An adequate control group; N.º10: Contemporary groups; N.º 11: Baseline equivalence of groups; N.º 12: Adequate statistical analyses; **: the total number of points from a possible maximal of 24.

HIIT study group was not included in the between-group comparison.

3.7. *Effects of HIIT on vertical height jump*

A summary of the included studies and results of VJH reported before and after HIIT programs are provided in Table 8.

Sixteen experimental groups (pooled n = 167) provided data for VJH. There was a non-significant effect of HIIT on VJH (ES = 0.25; 95% CI = −0.01 to 0.51; p = 0.063; I^2 = 79.4%; Egger's test p= 0.000; Figure 8, bottom). The relative weight of each study in the analysis ranged from 1.7% to 7.3%. After the trim and fill method was applied, the adjusted values were ES = 0.35, 95% CI = 0.08 to 0.63 (a funnel plot for bias assessment is available as Supplementary Figure 7). No significant sub-group difference (between-group p = 0.665) was found between long-interval HIIT (three study groups; ES = 1.07; 95% CI = −0.29 to 2.43; within-group I^2 = 92.9%), RST (4four study groups; ES = 0.21; 95% CI = −0.01 to 0.44; within-group I^2 = 0.0%), short-interval HIIT (three study groups; ES = 0.14; 95% CI = −0.67 to 0.96; within-group I^2 = 90.0%), and SSGs (five study groups; ES = 0.28; 95% CI = −0.18 to 0.74; within-group I^2 = 77.0%). Due to reduced number of studies available for robust meta-analyses, one SIT group was not included in the between-group comparison.

3.8. *Effects of HIIT on sprint time*

A summary of the included studies and results of ST reported before and after HIIT programs are provided in Table 9.

Three controlled studies provided data for ST, involving three experimental and three control groups (pooled n = 61).

Table 5. Summary of the included studies and results of VO_2max ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$) reported before and after HIIT programs.

Study	HIIT Format	Design	N	Before Mean±SD	After Mean±SD	Before-after (Δ%)
(Jastrzebski et al., 2014)	siHIIT	NC	11	55.7 ± 5.2	56.9 ± 5.6	2.2
(Ouerghi et al., 2014)	siHIIT	C	8	53.3 ± 4.5	57.3 ± 4.0	7.5
(Bravo et al., 2008)	liHIIT	NC	13	52.8 ± 3.2	56.3 ± 3.1	6.6
(Helgerud et al., 2001)	liHIIT	C	9	58.1 ± 4.5	64.3 ± 3.9	10.7
(FM Impellizzeri et al., 2008)	liHIIT	C	11	56.6 ± 2.5	58.9 ± 3.0	4.1
(Radziminski et al., 2013)	liHIIT	NC	11	56.2 ± 8.7	55.3 ± 6.1	−1.6
(Safania et al., 2011)	liHIIT	NC	10	34.0 ± 1.4	43.5 ± 1.4	27.9
(Slettaløkken & Rønnestad, 2014)[@]	liHIIT	NC	9	65.6 ± 2.1	64.3 ± 1.3	−2.0
(Slettaløkken & Rønnestad, 2014)[¶]	liHIIT	NC	8	63.4 ± 5.9	64.0 ± 5.9	0.9
(Sperlich et al., 2011)	liHIIT	NC	9	55.1 ± 4.9	58.9 ± 4.7	6.9
(Bravo et al., 2008)	RST	NC	13	55.7 ± 2.3	58.5 ± 4.1	5.0
(Kavaliauskas et al., 2017)	RST	C	7	48.8 ± 3.4	50.2 ± 3.2	2.9
(Sanchez-Sanchez et al., 2019)	RST[g]	C	10	51.2 ± 2.8	51.6 ± 2.8	0.8
(Sanchez-Sanchez et al., 2019)	RST[h]	C	10	44.1 ± 2.8	44.7 ± 2.8	1.3
(Macpherson & Weston, 2015)	SIT	C	14	52.7 ± 4.7	54.3 ± 3.4	3.0
(Harrison et al., 2015)	SSGs	NC	10	55.9 ± 3.0	57.1 ± 3.5	2.1
(Hill-Haas et al., 2009)	SSGs	NC	10	59.3 ± 4.5	58.9 ± 5.5	−0.7
(F Impellizzeri et al., 2006)	SSGs	NC	14	57.7 ± 4.2	61.8 ± 4.5	7.1
(Jastrzebski et al., 2014)	SSGs	NC	11	52.5 ± 5.2	57.0 ± 5.4	8.6
(Radziminski et al., 2013)	SSGs	NC	9	58.6 ± 6.9	63.3 ± 8.0	8.0
(Safania et al., 2011)	SSGs	NC	10	34.2 ± 1.6	42.9 ± 1.4	25.4

@: one liHIIT session every week; ¶: one liHIIT session two every two weeks; HIIT: type of high-intensity interval training; siHIIT: short-interval HIIT; liHIIT: long-interval HIIT; RST: repeated sprint training; SIT: sprint interval training; SSGs: small-sided games; C: controlled; NC: non-controlled; [g]: group above 48 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ of VO_2max; [h]: group below 48 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ of VO_2max; N: number of participants per group; SD: standard deviation.

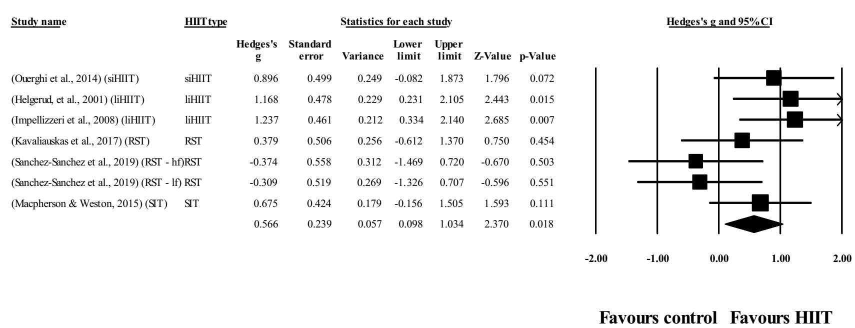


Figure 2. Forest plot of changes in maximal oxygen consumption, in men soccer players participating in high-intensity interval training (HIIT) compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study.

There was a non-significant effect of HIIT on ST (ES = 0.48; 95% CI = −0.06 to 1.02; p = 0.080; I^2 = 15.1%; Egger's test p= 0.691; Figure 9; a funnel plot for bias assessment is available as Supplementary Figure 8). The relative weight of each study in the analysis ranged from 32.9% to 34.2%.

Sixteen non-controlled studies provided data for ST, involving 25 experimental groups (pooled n = 267). There was a significant effect of HIIT on ST (ES = 0.30; 95% CI = 0.19 to 0.41; p < 0.001; I^2 = 33.0%; Egger's test p= 0.011; Figure 10, bottom). The relative weight of each study in the analysis ranged from 3.0% to 5.6%. After the trim and fill method was applied, the adjusted values remained equal as the observed values (a funnel plot for bias assessment is available as Supplementary Figure 9). No significant sub-group difference (between-group p = 0.366) was found between long-interval HIIT (three study groups; ES = 0.15; 95% CI = −0.10 to 0.40; within-group I^2 = 0.0%), RST (9 study groups; ES = 0.40; 95% CI = 0.25 to 0.55; within-group I^2 = 7.6%), short-interval HIIT (3 study groups; ES = 0.43; 95% CI = −0.04 to 0.89; within-group I^2 = 65.9%), SIT (3 study groups; ES = 0.23; 95% CI = −0.07 to 0.52; within-group I^2 = 0.0%), and SSGs (7 study groups; ES = 0.20; 95% CI = −0.06 to 0.45; within-group I^2 = 54.3%).

3.9. *Adverse effects*

Among the included studies, none reported soreness, pain, fatigue, injury, damage or adverse effects related to the HIIT interventions.

4. Discussion

4.1. *Effects of HIIT on maximal oxygen uptake*

Overall, HIIT had favourable effects on VO_2max. In the case of controlled trials, slight improvements were observed in comparison to control groups. Interestingly, among the controlled studies, those testing short or long-interval HIIT (Bravo et al., 2008; Helgerud et al., 2001; Ouerghi et al., 2014) had moderate to large benefits, while RST (Kavaliauskas et al., 2017) and SIT (Macpherson & Weston,

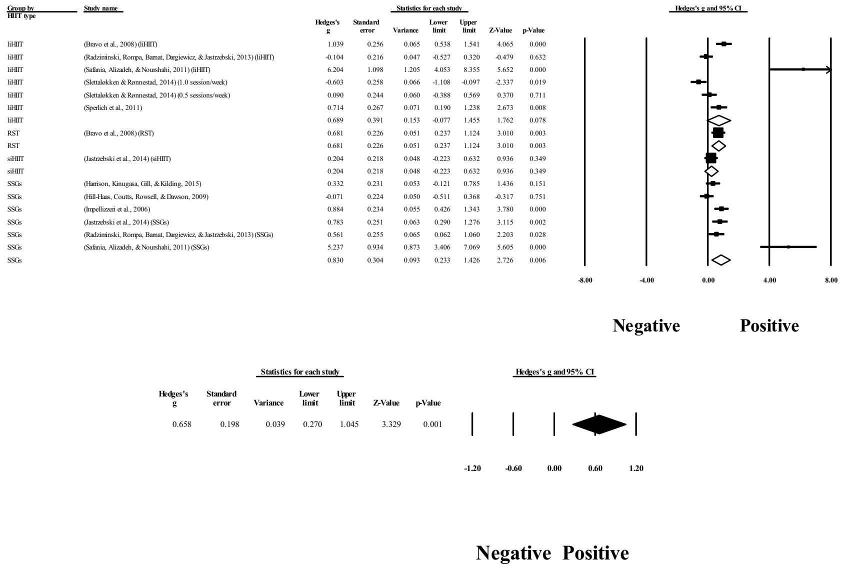


Figure 3. Forest plot on the effects of high-intensity interval training (HIIT) on maximal oxygen consumption in men soccer players from non-controlled trials. Upper figure: individual studies results (the size of the plotted squares reflects the statistical weight of the study). Bottom figure: overall results. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI).

Table 6. Summary of the included studies and results of aerobic performance assessed from maximal field based-tests reported before and after HIIT programs.

Study	HIIT Format	Design	N	Before Mean±SD	After Mean±SD	Before-after (Δ%)
(Dellal et al., 2012)	siHIIT	C	8	19.4 ± 0.5	20.7 ± 1.2	6.7
(Faude et al., 2013)	siHIIT	NC	20	17.05 ± 1.1	17.30 ± 0.9	1.5
(Faude et al., 2014)	siHIIT	NC	10	17.8 ± 1.0	17.3 ± 1.0	−2.8
(Ouerghi et al., 2014)	siHIIT	C	8	16.0 ± 1.5	17.6 ± 1.0	10.0
(Arslan et al., 2020)	siHIIT	NC	10	1240 ± 75	1484 ± 74	19.7
(FM Impellizzeri et al., 2008)	liHIIT	C	11	1890 ± 180	2100 ± 200	11.1
(Los Arcos et al., 2015)	liHIIT	NC	8	16.8 ± 0.9	17.1 ± 1.0	1.8
(Slettaløkken & Rønnestad, 2014)[@]	liHIIT	NC	9	2531 ± 106	2327 ± 96	−8.1
(Slettaløkken & Rønnestad, 2014)[¶]	liHIIT	NC	8	2335 ± 390	2213 ± 345	−5.2
(Beato et al., 2019)	RST[e]	NC	18	1642 ± 365	1822 ± 461	11.0
(Beato et al., 2019)	RST[f]	NC	18	1686 ± 359	1811 ± 260	7.4
(Eniseler et al., 2017)	RST	NC	9	2307 ± 252	2480 ± 159	7.5
(Iaia et al., 2017)	RST[c]	NC	9	1000 ± 169	1111 ± 171	11.1
(Iaia et al., 2017)	RST[d]	NC	10	1016 ± 217	1072 ± 156	5.5
(Kavaliauskas et al., 2017)	RST	C	7	1468 ± 409	1643 ± 382	11.9
(Sanchez-Sanchez et al., 2019)	RST[g]	C	10	1764 ± 334	1798 ± 335	2.0
(Sanchez-Sanchez et al., 2019)	RST[h]	C	10	914 ± 330	985 ± 337	8.1
(JM Taylor et al., 2016)	RST	NC	8	1830 ± 274	2269 ± 201	24.0
(Tønnessen et al., 2011)	RST	C	10	12.0 ± 1.2	12.6 ± 1.2	5.0
(Hostrup et al., 2019)	SIT	NC	8	1910 ± 557	1940 ± 553	1.6
(Iaia et al., 2015)[£]	SIT	NC	6	927 ± 185	1020 ± 155	10.0
(Iaia et al., 2015)[#]	SIT	NC	7	989 ± 226	1026 ± 210	3.7
(Macpherson & Weston, 2015)	SIT	C	14	1523 ± 493	1799 ± 292	18.1
(Mohr & Krustrup, 2016)	SIT	NC	9	680 ± 68	693 ± 52	1.9
(Arslan et al., 2020)	SSGs	NC	10	1284 ± 152	1472 ± 99	14.6
(Dellal et al., 2012)	SSGs	NC	8	19.5 ± 0.9	20.5 ± 1.2	5.1
(Dello Iacono et al.)	SSGs	NC	10	1646 ± 138	1990 ± 176	20.9
(Eniseler et al., 2017)	SSGs	NC	10	2320 ± 388	2432 ± 336	4.8
(Faude et al., 2014)	SSGs	NC	9	17.5 ± 1.0	17.8 ± 0.7	1.7
(Harrison et al., 2015)	SSGs	NC	10	18.1 ± 1.3	19.1 ± 1.4	5.5
(Hill-Haas et al., 2009)	SSGs	NC	10	1488 ± 345	1742 ± 362	17.1
(Los Arcos et al., 2015)	SSGs	NC	7	17.0 ± 0.8	16.9 ± 0.8	−0.6
(Mohr & Krustrup, 2016)	SSGs	NC	9	978 ± 57	858 ± 48	−12.3

[£]: 120s passive recovery; [#]: 40s passive recovery; @: one liHIIT session every week; ¶: one liHIIT session every two weeks; HIIT: type of high-intensity interval training; siHIIT: short-interval HIIT; liHIIT: long-interval HIIT; RST: repeated sprint training; SIT: sprint interval training; SSGs: small-sided games; [a]: one session per week; [b]: two session per week; [c]: short rest; [d]: long rest; [e]: straight sprint; [f]: with change of direction; [g]: group above 48 $mL \cdot kg^{-1} \cdot min^{-1}$ of VO_2max; [h]: group below 48 $mL \cdot kg^{-1} \cdot min^{-1}$ of VO_2max; C: controlled; NC: non-controlled; N: number of participants per group; SD: standard deviation.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
(Ouerghi et al., 2014) (siHIIT)	0.876	0.497	0.247	-0.099	1.851	1.762	0.078
Dellal et al (2012) (siHIIT)	1.028	0.657	0.431	-0.259	2.314	1.565	0.118
(Impellizzeri et al., 2008) (liHIIT)	1.634	0.489	0.239	0.675	2.593	3.338	0.001
(Tønnessen et al., 2011) (RST)	0.282	0.431	0.185	-0.562	1.126	0.655	0.513
(Kavaliauskas et al., 2017) (RST)	0.385	0.506	0.256	-0.606	1.376	0.762	0.446
(Sanchez-Sanchez et al., 2019) (RST - high-fitness)	-0.721	0.570	0.325	-1.839	0.397	-1.264	0.206
(Sanchez-Sanchez et al., 2019) (RST - low-fitness)	-0.619	0.528	0.279	-1.654	0.415	-1.173	0.241
(Macpherson & Weston, 2015) (SIT)	0.988	0.437	0.191	0.131	1.844	2.261	0.024
Dellal et al (2012) (SSGs)	0.771	0.640	0.410	-0.485	2.026	1.203	0.229
	0.522	0.255	0.065	0.022	1.021	2.047	0.041

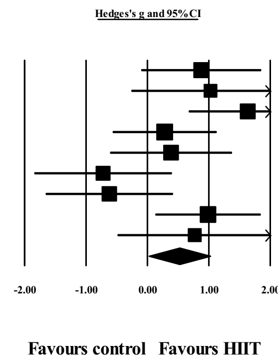
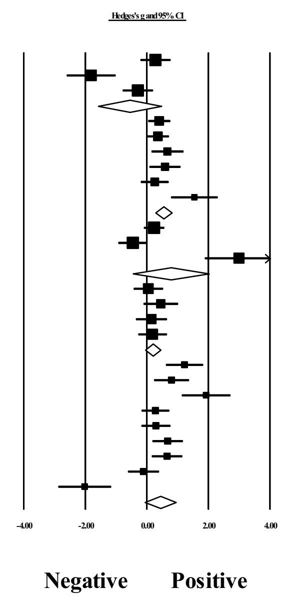


Figure 4. Forest plot of changes in aerobic performance assessed from maximal field based-tests measured in men soccer players participating in high-intensity interval training (HIIT) compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study.

Group by HIIT type	:	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
liHIIT	(Los Arcos et al., 2015) (liHIIT)	0.279	0.249	0.062	-0.210	0.767	1.117	0.264
liHIIT	(Slettaløkken & Rønnestad, 2014) (1.0 session/week)	-1.812	0.405	0.164	-2.605	-1.019	-4.477	0.000
liHIIT	(Slettaløkken & Rønnestad, 2014) (0.5 sessions/week)	-0.292	0.250	0.062	-0.782	0.198	-1.168	0.243
liHIIT		-0.561	0.524	0.275	-1.588	0.466	-1.071	0.284
RST	(Beato et al., 2019) (straight sprint)	0.401	0.182	0.033	0.045	0.758	2.206	0.027
RST	(Beato et al., 2019) (with change of direction)	0.361	0.181	0.033	0.007	0.714	1.997	0.046
RST	(Eniseler, ?ahan, Özcan, & Dinler, 2017) rst	0.669	0.263	0.069	0.153	1.185	2.543	0.011
RST	(Iaia et al., 2017) (short rest)	0.590	0.257	0.066	0.086	1.093	2.296	0.022
RST	(Iaia et al., 2017) (long rest)	0.256	0.228	0.052	-0.192	0.703	1.121	0.262
RST	(Taylor, Macpherson, McLaren, Spears, & Weston, 2016)	1.543	0.385	0.149	0.788	2.298	4.004	0.000
RST		0.540	0.135	0.018	0.275	0.806	3.995	0.000
siHIIT	(Faude, Schnittker, Schulte-Zurhausen, Müller, & Meyer, 2013)	0.233	0.169	0.028	-0.097	0.564	1.384	0.166
siHIIT	(Faude, Steffen, Kellmann, & Meyer, 2014) (siHIIT)	-0.457	0.238	0.056	-0.923	0.008	-1.925	0.054
siHIIT	(Arslan, Orer, & Clemente, 2020) (siHIIT)	2.994	0.565	0.319	1.887	4.101	5.300	0.000
siHIIT		0.779	0.630	0.397	-0.456	2.014	1.237	0.216
SIT	(Hostrup et al., 2019)	0.048	0.244	0.059	-0.429	0.526	0.197	0.844
SIT	(Iaia et al., 2015) (120s passive recovery)	0.451	0.285	0.081	-0.107	1.009	1.583	0.113
SIT	(Iaia et al., 2015) (40s passive recovery)	0.147	0.256	0.066	-0.355	0.650	0.573	0.566
SIT	(Mohr & Krustrup, 2016) (SIT)	0.187	0.236	0.056	-0.275	0.648	0.791	0.429
SIT		0.192	0.127	0.016	-0.056	0.440	1.515	0.130
SSGs	(Arslan, Orer, & Clemente, 2020) (SSGs)	1.224	0.308	0.095	0.619	1.828	3.969	0.000
SSGs	(Dellal, Varliette, Owen, Chirico, & Pialoux, 2012) (SSGs)	0.801	0.289	0.083	0.236	1.367	2.776	0.006
SSGs	(Dello Iacono, Beato, & Unnithan)	1.925	0.402	0.161	1.138	2.712	4.793	0.000
SSGs	(Eniseler, ?ahan, Özcan, & Dinler, 2017) SSG	0.279	0.229	0.052	-0.170	0.728	1.217	0.224
SSGs	(Faude, Steffen, Kellmann, & Meyer, 2014) (SSGs)	0.294	0.239	0.057	-0.175	0.763	1.228	0.219
SSGs	(Harrison, Kinugasa, Gill, & Kilding, 2015)	0.675	0.253	0.064	0.180	1.170	2.671	0.008
SSGs	(Hill-Haas, Coutts, Rowsell, & Dawson, 2009)	0.656	0.251	0.063	0.164	1.148	2.612	0.009
SSGs	(Los Arcos et al., 2015) (SSGs)	-0.109	0.256	0.065	-0.610	0.392	-0.425	0.671
SSGs	(Mohr & Krustrup, 2016) (SSGs)	-2.023	0.437	0.191	-2.879	-1.167	-4.631	0.000
SSGs		0.433	0.258	0.067	-0.074	0.939	1.674	0.094



Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
0.345	0.128	0.016	0.095	0.596	2.707	0.007

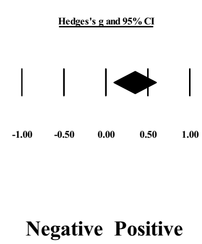


Figure 5. Forest plot on the effects of high-intensity interval training (HIIT) on aerobic performance assessed from maximal field based-tests measured in men soccer players from non-controlled trials. Upper figure: individual studies results (the size of the plotted squares reflects the statistical weight of the study). Bottom figure: overall results. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI).

2015) had smaller benefits. VO_2max improvements seem to be elicited by working at intensities closer to VO_2max, in which the high aerobic demands signal peripheral adaptations (e.g., increased skeletal muscle mitochondrial content and capillary density) and central adaptations (e.g., maximal stroke volume, maximal cardiac output, and blood volume) (MacInnis & Gibala, 2017). However, the type of HIIT used elicits different acute responses that may explain different levels of adaptations found in the results (Figures 2 and 3). For example, short-interval HIIT seems to stimulate a large spectrum of responses, namely metabolic load (oxygen transport and utilization), anaerobic glycolytic energy contribution, neuromuscular strain, and load, while long-interval HIIT seems to be more closely associated with the stress of the anaerobic system and neuromuscular strain and load (Buchheit & Laursen, 2013a). The

Table 7. Summary of the included studies and results of repeated sprint ability before and after HIIT programs.

Study	HIIT Format	Design	N	Before Mean±SD	After Mean±SD	Before-after (Δ%)
(Arslan et al., 2020)	siHIIT	NC	10	38.2 ± 1.7	34.9 ± 1.5	−8.6
(Beato et al., 2019)	RST[e]	NC	18	7.46 ± 0.19	7.40 ± 0.20	−0.8
(Beato et al., 2019)	RST[f]	NC	18	7.50 ± 0.21	7.48 ± 0.21	−0.3
(Buchheit et al., 2010)	RST	NC	10	6.35 ± 0.20	6.18 ± 0.14	−2.7
(Chtara et al., 2017)	RST	C	12	6.53 ± 0.13	6.42 ± 0.14	−1.7
(Eniseler et al., 2017)	RST	NC	9	7.13 ± 0.17	7.13 ± 0.21	0.0
(Iaia et al., 2017)	RST[c]	NC	9	92.91 ± 4.66	90.47 ± 4.24	−2.6
(Iaia et al., 2017)	RST[d]	NC	10	91.45 ± 4.35	88.22 ± 4.65	−3.5
(Rey et al., 2019)	RST[a]	NC	14	4.20 ± 0.17	4.12 ± 0.20	−1.9
(Rey et al., 2019)	RST[b]	NC	13	4.20 ± 0.20	4.08 ± 0.19	−2.9
(Sanchez-Sanchez et al., 2019)	RST[g]	C	10	4.40 ± 0.33	4.26 ± 0.23	3.0
(Sanchez-Sanchez et al., 2019)	RST[h]	C	10	4.77 ± 0.41	4.76 ± 0.40	0.3
(Tønnessen et al., 2011)	RST	C	10	5.42 ± 0.18	5.30 ± 0.14	−2.2
(Iaia et al., 2015)[£]	SIT	NC	6	86.09 ± 6.30	83.97 ± 4.72	−2.5
(Iaia et al., 2015)[#]	SIT	NC	7	83.81 ± 2.37	84.65 ± 2.27	2.2
(Mohr & Krustrup, 2016)	SIT	NC	9	4.45 ± 0.05	4.36 ± 0.14	−2.0
(Arslan et al., 2020)	SSGs	NC	10	37.8 ± 1.5	35.6 ± 1.2	−5.8
(Dello Iacono et al.)	SSGs	NC	10	5.48 ± 0.14	5.23 ± 0.10	−4.6
(Eniseler et al., 2017)	SSGs	NC	10	7.12 ± 0.17	7.22 ± 0.20	1.4
(Hill-Haas et al., 2009)	SSGs	NC	10	42.1 ± 1.1	42.0 ± 1.4	−0.2
(Mohr & Krustrup, 2016)	SSGs	NC	9	4.41 ± 0.07	4.35 ± 0.22	−1.4

[£]: 120s passive recovery; [#]: 40s passive recovery; HIIT: type of high-intensity interval training; siHIIT: short-interval HIIT; liHIIT: long-interval HIIT; RST: repeated sprint training; SIT: sprint interval training; SSGs: small-sided games; [a]: one session per week; [b]: two sessions per week; [c]: short rest; [d]: long rest; [e]: straight sprint; [f]: with change of direction; [g]: group above 48 $mL\cdot kg^{-1}\cdot min^{-1}$ of VO_2max; [h]: group below 48 $mL\cdot kg^{-1}\cdot min^{-1}$ of VO_2max; C: controlled; NC: non-controlled; N: number of participants per group; SD: standard deviation

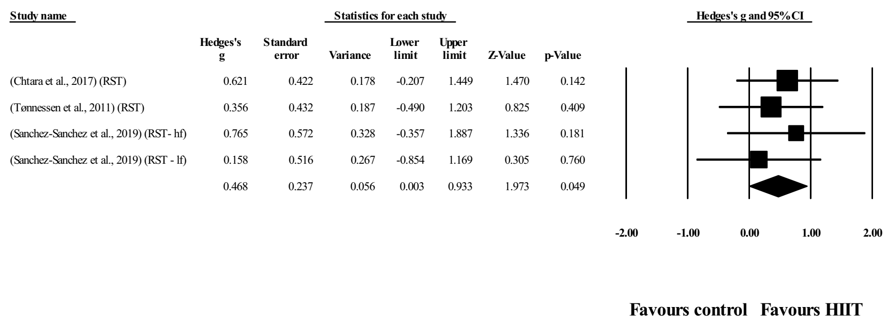


Figure 6. Forest plot of changes in repeated sprint ability, in men soccer players participating in high-intensity interval training (HIIT) compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study.

RST that implies repeated all-out efforts also seem to elicit the oxygen system but primarily focuses on the anaerobic system (higher rate of anaerobic energy turnover) (Iaia et al., 2009) and neuromuscular participation due to the greatest power required during sprints (Mendez-Villanueva et al., 2008). The SIT is also more focused on neuromuscular load, power output, and the anaerobic system, considering the levels of blood lactate accumulation (MacDougall et al., 1998). These differences in acute responses could explain the different magnitudes of adaptations observed between the different types of training considered in the current SRMA. This justifies the greater improvements of short and long-interval HIIT on VO_2max than RST and SIT, which can be more appropriate for developing other physical qualities.

The additional analysis made with the non-controlled studies (Figure 3) confirmed greater magnitudes of benefits regarding long-interval HIIT and SSGs when compared to other HIIT types (despite the small number of studies associated with short-interval HIIT and RST in this section). Interestingly, SSGs prescribed with similar regimens as long-interval HIIT (two to five bouts of 2–4 min of intense effort) also reveals moderate improvements in VO_2max, thus confirming previous findings that have compared the efficacy of running-based exercises and SSGs (Moran et al., 2019).

In our comparisons, both HIIT types (long-interval HIIT and SSGs) were effective in improving VO_2max, and no significant differences were found between them. This could be interesting for those who want to choose the most effective HIIT types to implement in practical scenarios. Even though the majority of studies have been conducted on youth players (Table 1), it seems that coaches may choose between long-interval HIIT and SSGs to improve players' VO_2max taking into account the idea behind the training intervention, granting technical proficiency

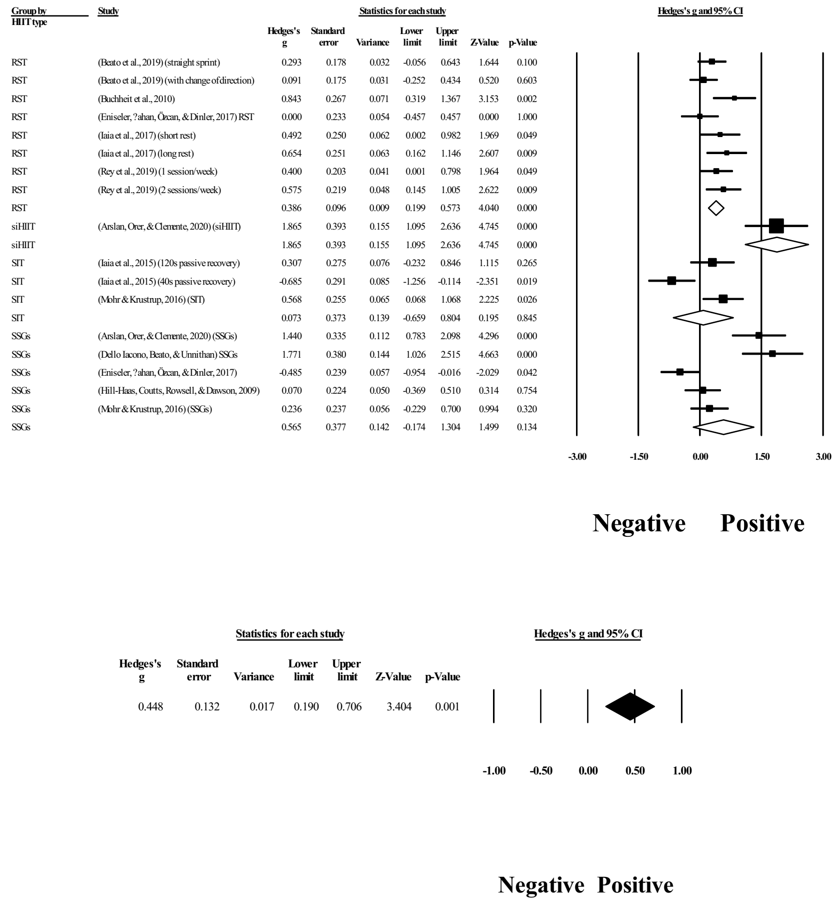


Figure 7. Forest plot on the effects of high-intensity interval training (HIIT) on repeated sprint ability in men soccer players from non-controlled trials. Upper figure: individual studies results (the size of the plotted squares reflects the statistical weight of the study). Bottom figure: overall results. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI).

and tactical awareness while choosing SSGs, but finely controlling the physiological responses while implementing long-interval HIIT. Additionally, although one study has included a group with small VO_2max levels at the baseline (~34 mL·Kg·min^{-1}) (Safania et al., 2011), the remaining studies related to long-interval HIIT and SSGs displayed players' baseline values between ~53 and 65 mL·Kg·min^{-1}, thus suggesting that even in cases of moderate to high VO_2max baseline levels, long-interval HIIT and SSGs seem to be effective enough to elicit favourable adaptations. The only exceptions of no improvement were noted after long-interval intervention involving a single training session per week and very high players' baseline VO_2max level (65.6 mL·Kg·min^{-1}) (Slettaløkken & Rønnestad, 2014), and a study using SSGs in a sample with 59.3 mL·kg·min^{-1} as baseline VO_2max (Hill-Haas et al., 2009).

Establishing the link for the practice, the analysis of training prescription (Table 2) revealed that long-interval HIIT varied from four to eight weeks, with the majority of interventions applying one to two sessions/week and the regimen consisting of 3–5 bouts of work at 87–95% of HR_{max} or 90–95% V_{IFT}. Relief intervals of 3 min with light activities (e.g., jogging) occurred in the majority of cases. Considering SSGs, the interventions had similar regimens to long-interval HIIT, while one vs. one to four vs. four games were contested in most cases. These regimens seem to be effective enough to increase VO_2max in soccer players.

4.2. Effects of HIIT on aerobic performance assessed from maximal field based-tests

The synthesis of controlled studies revealed significant moderate benefits on field-based AP after HIIT. Among the controlled studies (Figure 4), the exception (in which the intervention was not favourable compared to the control condition) was a study implementing RST (Sanchez-Sanchez et al., 2019). The remaining interventions (short-interval HIIT, long-interval HIIT, and SSGs) showed that the intervention was favourable, as did one study that examined SIT (Macpherson & Weston, 2015). Overall, these studies reveal that regardless of the HIIT type, this type of training seems to effectively improve aerobic performance during field-based tests. Consistently with the observations related to VO_2max, RST does not appear to be as effective as short and long-interval HIIT and SSGs to improve AP, and this fact deserves consideration while implementing this kind of training in soccer players. Nonetheless, more studies are still warranted on this topic.

Considering the non-controlled studies, significant improvements in field-based aerobic performance were

Table 8. Summary of the included studies and results of vertical height jump before and after HIIT programs.

Study	HIIT Format	Design	N	Before Mean±SD	After Mean±SD	Before-after (Δ%)
(Faude et al., 2013)	siHIIT	NC	20	38.0 ± 4.0	36.3 ± 5.0	−4.5
(Faude et al., 2014)	siHIIT	NC	10	38.5 ± 4.0	37.3 ± 4.0	−3.1
(Arslan et al., 2020)	siHIIT	NC	10	28.2 ± 2.0	30.6 ± 1.8	8.5
(Bravo et al., 2008)	liHIIT	NC	13	48.5 ± 3.8	48.1 ± 3.8	−0.8
(Los Arcos et al., 2015)	liHIIT	NC	8	42.8 ± 4.6	42.4 ± 4.8	−0.9
(Sperlich et al., 2011)	liHIIT	NC	9	26.0 ± 0.5	29.0 ± 0.6	11.5
(Bravo et al., 2008)	RST	NC	13	46.1 ± 3.5	46.1 ± 3.0	0.0
(Buchheit et al., 2010)	RST	NC	10	35.5 ± 5.8	38.0 ± 7.0	7.0
(JM Taylor et al., 2016)	RST	NC	8	41.9 ± 3.8	42.5 ± 5.1	1.4
(Tønnessen et al., 2011)	RST	C	10	35.2 ± 3.9	37.9 ± 5.7	7.7
(Mujika et al., 2009)	SIT	NC	10	42.4 ± 6.0	42.7 ± 5.9	0.7
(Arslan et al., 2020)	SSGs	NC	10	28.5 ± 2.5	31.3 ± 1.9	9.8
(Dello Iacono et al.)	SSGs	NC	10	42.1 ± 5.2	45.8 ± 5.2	8.8
(Faude et al., 2014)	SSGs	NC	9	38.1 ± 4.7	37.5 ± 4.6	−1.6
(Harrison et al., 2015)	SSGs	NC	10	33.2 ± 6.2	33.8 ± 6.4	1.8
(Los Arcos et al., 2015)	SSGs	NC	7	42.7 ± 2.4	42.0 ± 2.8	−1.6

£: 120s passive recovery; #: 40s passive recovery; HIIT: type of high-intensity interval training; siHIIT: short-interval HIIT; liHIIT: long-interval HIIT; RST: repeated sprint training; SIT: sprint interval training; SSGs: small-sided games; C: controlled; NC: non-controlled; n: number of participants per group; N: number of participants per group; SD: standard deviation.

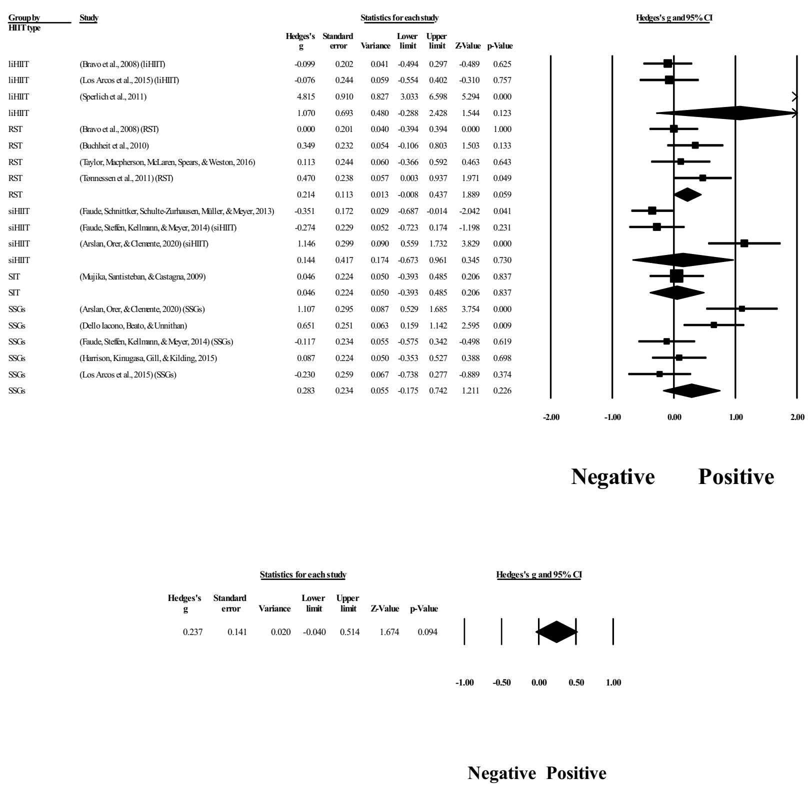


Figure 8. Forest plot on the effects of high-intensity interval training (HIIT) on vertical jump height in men soccer players from non-controlled trials. Upper figure: individual studies results (the size of the plotted squares reflects the statistical weight of the study). Bottom figure: overall results. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI).

observed after HIIT, although the magnitudes were rated as small. Additional sub-group analysis comparing different HIIT types did not reveal significant differences. These sub-group comparisons included long-interval HIIT, RST, SIT, and SSGs. Interestingly, some parallel studies included in this section tested different HIIT types. In particular, comparisons of SSGs vs. short- and long-interval HIIT were tested (Arslan et al., 2020; Dellal et al., 2012; Faude et al., 2014; Los Arcos et al., 2015). In one study conducted on amateur players, no significant differences were found between SSGs and short-interval HIIT, even though both groups had improved their final velocity at 30–15_{IFT} test (V_{IFT}) by ~5% (Dellal et al., 2012). Also, in a study that compared short-interval HIIT to SSGs in youth players, the results revealed that both interventions improved aerobic performance in YYIRT (~13% for SSG group and 16% for

Table 9. Summary of the included studies and results of sprint time before and after HIIT programs.

Study	HIIT Format	Design	N	Before Mean±SD	After Mean±SD	Before-after (Δ%)
(Faude et al., 2014)	siHIIT	NC	10	4.12 ± 0.13	4.09 ± 0.11	−0.7
(Jastrzebski et al., 2014)	siHIIT	NC	11	4.66 ± 0.22	4.62 ± 0.22	−0.9
(Arslan et al., 2020)	siHIIT	NC	10	5.00 ± 0.34	4.66 ± 0.29	−6.8
(Bravo et al., 2008)	liHIIT	NC	13	1.77 ± 0.06	1.77 ± 0.06	0.0
(Helgerud et al., 2001)	liHIIT	C	9	5.58 ± 0.16	5.56 ± 0.15	−0.4
(Radziminski et al., 2013)	liHIIT	NC	11	4.80 ± 0.28	4.77 ± 0.24	−0.6
(Sperlich et al., 2011)	liHIIT	NC	9	6.41 ± 0.37	6.23 ± 0.39	−2.8
(Beato et al., 2019)	RST[e]	NC	18	2.94 ± 0.11	2.92 ± 0.11	−0.7
(Beato et al., 2019)	RST[f]	NC	18	2.96 ± 0.12	2.90 ± 0.10	−2.0
(Bravo et al., 2008)	RST	NC	13	1.77 ± 0.06	1.76 ± 0.06	−0.6
(Buchheit et al., 2010)	RST	NC	10	4.70 ± 0.12	4.60 ± 0.19	−2.1
(Chtara et al., 2017)	RST	C	12	4.68 ± 0.09	4.57 ± 0.07	−2.4
(Iaia et al., 2017)	RST[c]	NC	9	3.30 ± 0.09	3.25 ± 0.06	−1.5
(Iaia et al., 2017)	RST[d]	NC	10	3.29 ± 0.08	3.21 ± 0.08	−2.4
(Rey et al., 2019)	RST[a]	NC	14	3.31 ± 0.15	3.23 ± 0.21	−2.4
(Rey et al., 2019)	RST[b]	NC	13	3.28 ± 0.15	3.23 ± 0.22	−1.5
(JM Taylor et al., 2016)	RST	NC	8	2.96 ± 0.10	2.85 ± 0.18	−3.7
(Tønnessen et al., 2011)	RST	C	10	5.21 ± 0.21	5.15 ± 0.20	−1.2
(Hostrup et al., 2019)	SIT	NC	8	4.34 ± 0.16	4.30 ± 0.12	−0.9
(Iaia et al., 2015)[£]	SIT	NC	6	2.84 ± 0.08	2.83 ± 0.12	−0.4
(Iaia et al., 2015)[#]	SIT	NC	7	2.91 ± 0.09	2.87 ± 0.10	−1.4
(Arslan et al., 2020)	SSGs	NC	10	5.15 ± 0.32	4.81 ± 0.31	−6.6
Dello Iacono et al.)	SSGs	NC	10	2.79 ± 0.09	2.76 ± 0.10	−1.1
(Faude et al., 2014)	SSGs	NC	9	4.13 ± 0.13	4.13 ± 0.11	0.0
(Harrison et al., 2015)	SSGs	NC	10	3.33 ± 0.27	3.24 ± 0.24	−2.7
(Hill-Haas et al., 2009)	SSGs	NC	10	3.26 ± 0.12	3.24 ± 0.17	−0.6
(Jastrzebski et al., 2014)	SSGs	NC	11	4.61 ± 0.25	4.67 ± 0.25	1.3
(Radziminski et al., 2013)	SSGs	NC	9	4.91 ± 0.29	4.89 ± 0.40	−0.4

[£]: 120s passive recovery; [#]: 40s passive recovery; HIIT: type of high-intensity interval training; siHIIT: short-interval HIIT; liHIIT: long-interval HIIT; RST: repeated sprint training; SIT: sprint interval training; SSGs: small-sided games; [a]: one session per week; [b]: two sessions per week; [c]: short rest; [d]: long rest; [e]: straight sprint; [f]: with change of direction; C: controlled; NC: non-controlled; N: number of participants per group; SD: standard deviation.

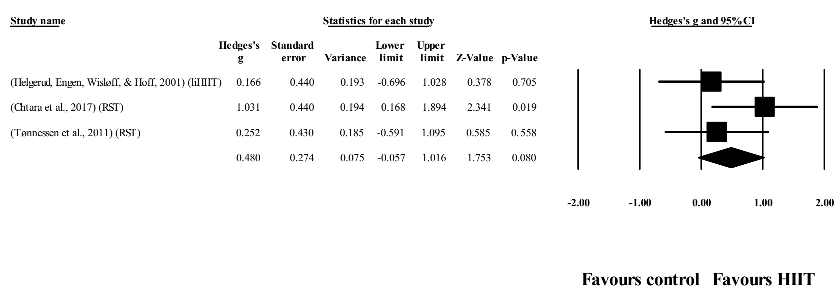


Figure 9. Forest plot of changes in sprint time, in men soccer players participating in high-intensity interval training (HIIT) compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study.

short-interval HIIT) without any significant changes found between the two interventions (Arslan et al., 2020). Comparing short-interval HIIT and SSGs, significant improvements were also found regarding individual anaerobic thresholds in both groups, while no significant differences between interventions were found (Faude et al., 2014). Finally, one study that compared long-interval HIIT and SSGs in youth players found that neither intervention promoted significant benefits, and no significant differences were found between them (Los Arcos et al., 2015). Therefore, it seems reasonable to assume that, overall, SGGs have similar effects as short and long-interval HIIT on aerobic performance.

Some parallel studies included in this section also tested different strategies that share the same HIIT type (Beato et al., 2019; Iaia et al., 2017). One study compared straight line vs. RST with changes of direction and reported no significant improvements for either group and no significant changes between them regarding the aerobic performance on the YYIRT (Beato et al., 2019). Comparing RST in players with high and low aerobic fitness levels, it was found that only RST was effective in low-aerobic fitness players, and none of the intervention groups performed better than a control group that engaged in soccer-specific training (Sanchez-Sanchez et al., 2019). Possibly, the fact that RST taxes more anaerobic systems and a greater neuromuscular load and strain than the oxygen system chain may explain the reduced effectiveness of this method to significantly improve aerobic capacity (M Buchheit & PBLaursen, 2013c). Also, a study that tested two RST interventions and compared variations in resting time revealed that

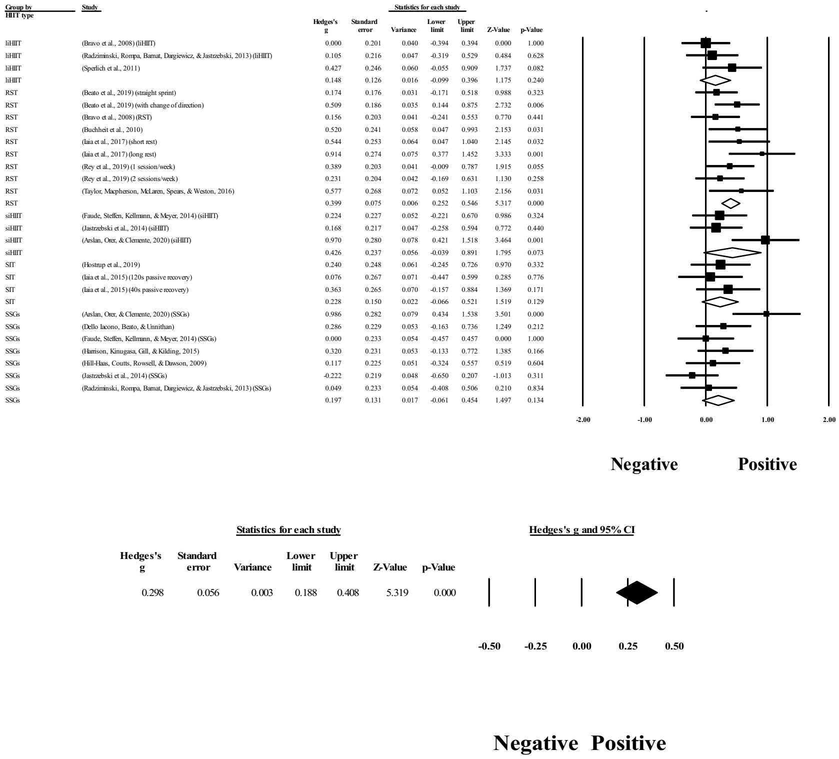


Figure 10. Forest plot on the effects of high-intensity interval training (HIIT) on sprint time in men soccer players from non-controlled trials. Upper figure: individual studies results (the size of the plotted squares reflects the statistical weight of the study). Bottom figure: overall results. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI).

shorter rests (15 s) had greater efficacy than longer rests (30 s) in improving aerobic performance at YYIRT (Iaia et al., 2017). In fact, the period of rest might aid the general understanding of the adaptations promoted by training, particularly considering that shorter periods might elicit a greater taxing of both aerobic and anaerobic metabolisms (M Buchheit & PBLaursen, 2013c). Nonetheless, RST does not seem to be the most suited training strategy to promote gains in aerobic endurance in soccer players.

4.3. Effects of HIIT on repeated-sprint ability

Randomized controlled trials revealed a significant beneficial effect of HIIT in RSA when compared to control groups. In this case, only RST interventions were included in the analysis (Chtara et al., 2017; Sanchez-Sanchez et al., 2019; Tønnessen et al., 2011). The RST interventions included in the randomized controlled trials varied from six to 10 weeks, and one to two sessions/week during which working intervals involved 18 to 40-m sprints performed 10 to 16 times per set. Because RST involves aerobic and anaerobic pathways, the capacity of improving RSA is expected, specifically when compared to control groups (Buchheit, 2012). Moreover, one possible explanation for the improvements is the similarity between RST and the specific RSA tests. Thus it is reasonable to expect improvements, and this should be highlighted and carefully interpreted (Buchheit, 2012). Nevertheless, it is important to note that some studies did not find any positive effect of performing RST on RSA in soccer (Haugen et al., 2014, 2015) and futsal players (Soares-Caldeira et al., 2014). Therefore, more controlled studies need to be conducted before concluding upon the effectiveness of RST on RSA, especially after considering that short-interval HIIT showed superior effects in the improvement of RSA than RST in team sports players (Buchheit et al., 2008).

The analysis of non-controlled studies revealed significant improvements in RSA from HIIT. No significant differences between RST, SIT, and SSGs were found, thus suggesting that all of them are equally effective in improving RSA. In nature, RST and SIT are highly similar to the RSA tests, and they are expected to improve sprinting speed (Buchheit, 2012). Interestingly, even considering that SSGs may not involve enough sprinting during typical external load demands (Clemente, 2020), significant improvements at RSA were also found. In a parallel study that compared SIT and SSGs (Mohr & Krustrup, 2016) over four weeks, similar benefits were found (~1.5–2%). However, the fatigue index was improved only to SIT in comparison to SSGs (Mohr & Krustrup, 2016). Oppositely, a study comparing RST and SSGs interventions revealed that SSGs led to significant decreases in the best time during RSA, while no significant changes were found for RST (Eniseler et al., 2017). However, in the same study, it was found that SSGs improved RSA decrements after the intervention, suggesting a greater capacity to recover between sprints (Eniseler et al., 2017). Finally, a parallel study that compared short-interval HIIT and SSGs revealed that both interventions contributed to improvements in RSA and that there were no significant differences between interventions (Arslan et al., 2020).

Within the same HIIT type, some parallel studies tested the variations of training regimens in RST. Comparing RST using straight running or running with a change of direction, improvements in RSA were found only in the group exposed to changes of direction. This can be explained by the neuromuscular load and tension promoted by the change of direction, also contributing such stimulus for improving acceleration (Beato et al., 2019). In a different approach, a study comparing short vs. long rest intervals during RST revealed that longer rest periods might improve RSA total time, while unclear findings were found regarding decrements in RSA (Iaia et al., 2017). A study comparing the effects of resting periods (120 vs. 40 s) during SIT (Iaia et al., 2015) found that longer periods (120 s) led to meaningful improvements in RSA total time, while short periods led to very likely impairments in this outcome. Possibly, the decreased running performance was due to fatigue, which could justify the decreases associated with shorter periods (Iaia et al., 2015).

4.4. Effects of HIIT on vertical height jump

The included HIIT studies indicated no significant effects on VHJ. Additionally, sub-group comparisons (long-interval HIIT vs. RST vs. SSGs) revealed no differences between HIIT types. Despite sprinting being associated with short contact time and dependence from reactive strength (Suchomel et al., 2016), it seems plausible that VHJ is not the main target of HIIT. However, and interestingly, comparing SIT with contrast training (heavy-light resistance with soccer-specific drills for speed and power development), no significant changes were found for VJH, and no differences were observed among interventions (Mujika et al., 2009).

By comparing different HIIT types, parallel studies have revealed that short-interval HIIT and SSGs implemented in youth soccer had positive effects on VHJ, though there was no significant difference between them (Arslan et al., 2020). Comparing long-interval HIIT and SSGs in youth players, no significant changes in time were found among interventions (Los Arcos et al., 2015). Similar trends of no benefits and no differences between interventions were found in a study comparing RST and SSGs (Faude et al., 2014).

Based on the trivial effects of HIIT (independent of the type), it seems reasonable to utilize more specific training that allows improvements in the stretch-shortening cycle and reactive strength, thus potentially complementing HIIT interventions. Even considering the considerable neuromuscular strain and load promoted by RST and SIT (Buchheit & Laursen, 2013a), no meaningful benefits were found in this SRMA – for that reason, it can be assumed that the inefficacy of HIIT to develop VHJ.

4.5. Effects of HIIT on sprint time

The analysis of randomized controlled trials did not reveal significant benefits of HIIT in comparison to a control condition regarding sprinting time. Despite that, small effects were beneficial to HIIT groups. Among the included studies, two of them used RST (Chtara et al., 2017; Tønnessen et al., 2011), and one used long-interval HIIT (Helgerud et al., 2001). Because long-interval HIIT works at submaximal speeds, no meaningful changes in sprinting time are to be expected. However, in the RST, the work is centred on speed endurance at all-out intensity, and the results of the individual studies revealed significant improvements in 40-m maximum sprint (Tønnessen et al., 2011) and 30-m sprint (Chtara et al., 2017). More specifically, when comparing RST vs. plyometric training vs. control, the most significant improvements were found for RST (Chtara et al., 2017). Thus, it might be prudent to assume that HIIT can produce different effects on sprinting time, depending on the type and the level of players.

The analysis of non-controlled studies revealed significant improvements in sprinting time after HIIT interventions. No significant differences were found between HIIT types (i.e., long-interval HIIT, RST, SIT, and SSGs). Some parallel studies compared different HIIT types. A study comparing short-interval HIIT and SSGs revealed the positive effects of both interventions on sprinting time, and no changes were found between the interventions (Arslan et al., 2020). Nevertheless, two studies comparing short-interval HIIT and SSGs in youth players revealed no significant improvements in any of the groups and no differences between them (Faude et al., 2014; Jastrzebski et al., 2014). Similarly, in a study that compared SSGs and long-intervals interventions in youth players, it was found that neither intervention yielded significant improvements in sprinting time, and there were no differences among them (Radziminski et al., 2013). In the particular case of SSGs, it may be unlikely to observe maximal sprint in smaller formats and pitch dimensions, and in cases of longer field dimensions, there is often a poor frequency of sprinting stimulus (Djaoui et al., 2017). Thus, it is recommended to use running-based drills to promote enough stimulus to achieve the maximal sprint (Castagna et al., 2017; Clemente, 2020).

In a study that compared long-interval HIIT and RST interventions in youth soccer players, no significant improvements were found in sprinting performance for any of the groups, and no differences were observed between the groups (Bravo et al., 2008). Two RST interventions (one using straight sprinting and other using sprinting with a change of direction) revealed no significant improvements in 20-m sprint. However, RST with a change of direction yielded significant improvements in 10-m sprinting, which is mainly justified by the greater neuromuscular tension promoted by RST with a change of direction and the transfer for acceleration (Beato et al., 2019). Furthermore, a comparison of two different RST interventions (short vs. long resting intervals) revealed that the group exposed to longer rest intervals exhibited unclear small benefits, possibly because they were given more time for recovery, thus allowing them to maintain greater performance at each bout (Iaia et al., 2017).

4.6. Potential limitations, directions for future research, and practical implications

There are some potential limitations to the current SRMA. One of them is the limited number of studies per each HIIT type. Another is the limited number of randomized controlled studies. These facts limited the sub-group analysis and did not permit an examination of the effects of controlled interventions on VHJ. Another potential limitation relates to the relatively reduced number of participants among the included studies. Considering reduced sample sizes are common in the sports science literature (Abt et al., 2020), it was not surprising to find that most included studies comprised between 8 and 10 participants per experimental (or control) group. In this sense, some of our meta-analyses were conducted with a relatively reduced sample size (e.g., $n = 61$), potentially limiting inferences towards other soccer players. Future studies in the field of HIIT in soccer are encouraged to follow recently published recommendations (Abt et al., 2020) to increase the sample size.

From the results of this SRMA, it can be highlighted that VO_2max, field-based aerobic performance, or RSA can be elicited by different HIIT types and – with SSGs among them. This may allow coaches to decide the best type of HIIT for each moment of the season. The majority of the studies involved one or two sessions a week. Thus, we may suggest that this schedule should be maintained during regular weeks to ensure positive adaptations or maintenance. However, HIIT does not seem to elicit positive adaptations in VHJ and, in some cases, in sprinting time. Therefore, it could be beneficial to add complementary training to improve reactive strength/plyometrics (for improving VHJ and the stretch-shortening cycle), sprinting training (closer to maximal velocity), and other strength and power training methods that help to improve sprinting.

5. Conclusions

The current SRMA indicates that randomized controlled trials have revealed the significant beneficial effects of HIIT (overall) on VO_2max, field-based aerobic performance, and RSA. No significant benefits were found in terms of sprinting time. Considering the analysis of non-controlled trials (parallel studies), HIIT (overall) was found to produce significant improvements in VO_2max, field-based aerobic performance, RSA, and sprinting, although no significant improvements were found for VHJ.

Sub-group analysis (i.e., comparisons between HIIT types) revealed no significant differences in any of the outcomes. However, more research should be conducted to test this idea and, possibly, greater analysis to responder profile of players is necessary, aiming to adjust HIIT type to human variability. Nevertheless, coaches can use HIIT methods as part of their regimens and should perhaps vary the HIIT type throughout the season to foster stimulus variability, but also keep in mind that some specificities exist across the HIIT strategies in terms of adaptation.

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Disclosure statement

No conflicts of interest.

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