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REVIEW

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Effects of short sprint interval training on aerobic and anaerobic indices: A systematic review and meta-analysis

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The effects of short sprint interval training (sSIT) with efforts of ≤10 s on maximal oxygen consumption ($\dot{V}O_2$max), aerobic and anaerobic performances remain unknown. To verify the effectiveness of sSIT in physically active adults and athletes, a systematic literature search was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The databases PubMed/MEDLINE, ISI Web of Science, and SPORTDiscus were systematically searched on May 9, 2020, and updated on September 14, 2021. Inclusion criteria were based on PICO and included healthy athletes and active adults of any sex (≤40 years), performing supervised sSIT (≤10 s of "all-out" and non-"all-out" efforts) of at least 2 weeks, with a minimum of 6 sessions. As a comparator, a non-sSIT control group, another high-intensity interval training (HIIT) group, or a continuous training (CT) group were required. A total of 18 studies were deemed eligible. The estimated SMDs based on the random-effects model were −0.56 (95% CI: −0.79, −0.33, $p < 0.001$) for $\dot{V}O_2$max, −0.43 (95% CI: −0.67, −0.20, $p < 0.001$) for aerobic performance, and −0.44 (95% CI: −0.70, −0.18, $p < 0.001$) for anaerobic performance after sSIT vs. no exercise/usual training. However, there were no significant differences ($p > 0.05$) for all outcomes when comparing sSIT vs. HIIT/CT. Our findings indicate a very high effectiveness of sSIT protocols in different exercise modes (e.g., cycling, running, paddling, and punching) to improve $\dot{V}O_2$max, aerobic, and anaerobic performances in physically active young healthy adults and athletes.

KEYWORDS
aerobic fitness, anaerobic fitness, high-intensity interval training, human performance, sprint interval training

1 | INTRODUCTION

Traditionally, high-intensity interval training (HIIT) consists of bouts of cyclic endurance exercises at intensities above the lactate threshold or critical power, interspersed with active or passive rest intervals. The main purpose of HIIT is to complete a greater amount of work at a high-intensity when compared to a single continuous bout at the same intensity until exhaustion.[1] This training modality was initially developed for endurance runners,[2] but, to date, it is commonly used in both individual and team sports,[3] and in clinical practice,[4] to enhance both aerobic and anaerobic fitness components.[5] Although athletes typically combine HIIT with other training modalities for fitness development, there is the consensus that it allows rapid metabolic and neuromuscular adaptations already after a few brief sessions when compared to continuous endurance training methods.[6] For this reason, HIIT has become a very popular training modality, not only in recreational and elite sport but also for health purposes in the general population.

Among the HIIT loading parameters that can be manipulated, intensity appears to be most important as the different HIIT modalities are directly linked to manipulation of internal (e.g., HR) and external (e.g., power) loading parameters.[1,3,7] Thus, in the supramaximal zone (i.e., above the maximal oxygen consumption; $\dot{V}O_2$max) of HIIT intensities, we may refer to the intermittent methods in the classic terminology,[1] which includes HIIT with short intervals. Training at "all-out" maximal effort using repeated-sprint training (RST) and sprint interval training (SIT) are other HIIT modalities following the classification by Buchheit and Laursen.[3] However, there is no consensus regarding the HIIT and SIT definitions in the literature.[1] While RST (≤10 s) and SIT (≤45 s) may refer to "all-out" efforts of varying duration, HIIT with short intervals is commonly performed at non-"all-out" efforts of short duration (≤10 s).[3] For this reason, HIIT protocols as RST and SIT do not require identification of metabolic parameters and power output for training prescription, while HIIT with short intervals requires, at least, the identification of a parameter associated with aerobic power.

Recently, it has been suggested that sessions with less and shorter (i.e., 4–20-s) sprints are a more time-efficient HIIT modality than Wingate-based SIT.[8,9] Particularly, several SIT protocols with repeated short (≤10 s) efforts (sSIT) were shown to exhibit similar aerobic and anaerobic adaptations but better perceptual and enjoyment responses (i.e., "less pain, same gain") than Wingate-based SIT.[10–13] The greater efficiency of these sSIT protocols is related to the fact that the highest mechanical responses are achieved during the first seconds of sprinting bouts,[9] while the reduced glycolytic activity would result in less peripheral fatigue[14] because of the more reliance on the ATP-PCr pathway during the first 10 s of effort[15] Moreover, the acute responses of different sSIT schemes have been described with respect to physical,[10,14] physiological,[10,16,17] and perceptual[10,12] responses. However, there are only a few recent studies examining the physical and physiological adaptations after a number of sessions over only a few weeks, in cycling and running sprints with promising results.[18,19] Therefore, a systematic search of longitudinal studies including any sSIT protocol with both "all-out" and non-"all-out" efforts will aid in verifying the effectiveness of short efforts during different HIIT schemes for physical fitness development. This information is very important to elucidate the chronic adaptations of sSIT when compared to other HIIT/SIT and continuous training (CT) protocols, while expanding the understanding of the loading factors (e.g., intensity and work-to-rest ratio) associated with the more efficient adaptations after different sSIT schemes.

Thus, the aim of this systematic review with meta-analysis was to identify controlled (CTs) and randomized controlled trials (RCTs) that used very short efforts ≤10 s (8) over a minimum of 2 weeks, which is the minimum time required to induce stable adaptations (9), and to verify the effects of these training regimes on measures of aerobic and anaerobic fitness and performance. To avoid the confounding effect of training history (i.e., to be sedentary), age (maturational factors or aging), and clinical conditions (e.g., obese and cardiovascular disease), we decided to only include healthy physically active adults and athletes.

2 | METHODS

2.1 | Systematic literature search

A systematic literature search was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and was previously registered with the international database of prospectively registered systematic reviews in health and social care (PROSPERO: CRD42020188226).

The databases PubMed/MEDLINE, ISI Web of Science, and SPORTDiscus were systematically searched using a search string that was specifically adapted to the search requirements for each database (see online Supplementary Table 1).

The search was conducted on May 9, 2020, and updated on September 14, 2021. The literature search process was performed independently by two researchers and included saving the online search, removing duplicates and screening titles, abstracts, and full texts. Possible conflicts were solved by consulting a third author. In addition, a gray literature search was performed by screening Google Scholar and the reference lists of previously identified eligible full texts. A flow chart of the search process and the study selection is displayed in Figure 1.

2.2 | Eligibility criteria

Inclusion criteria were defined based on the PICOS criteria.[20] The population included healthy young and

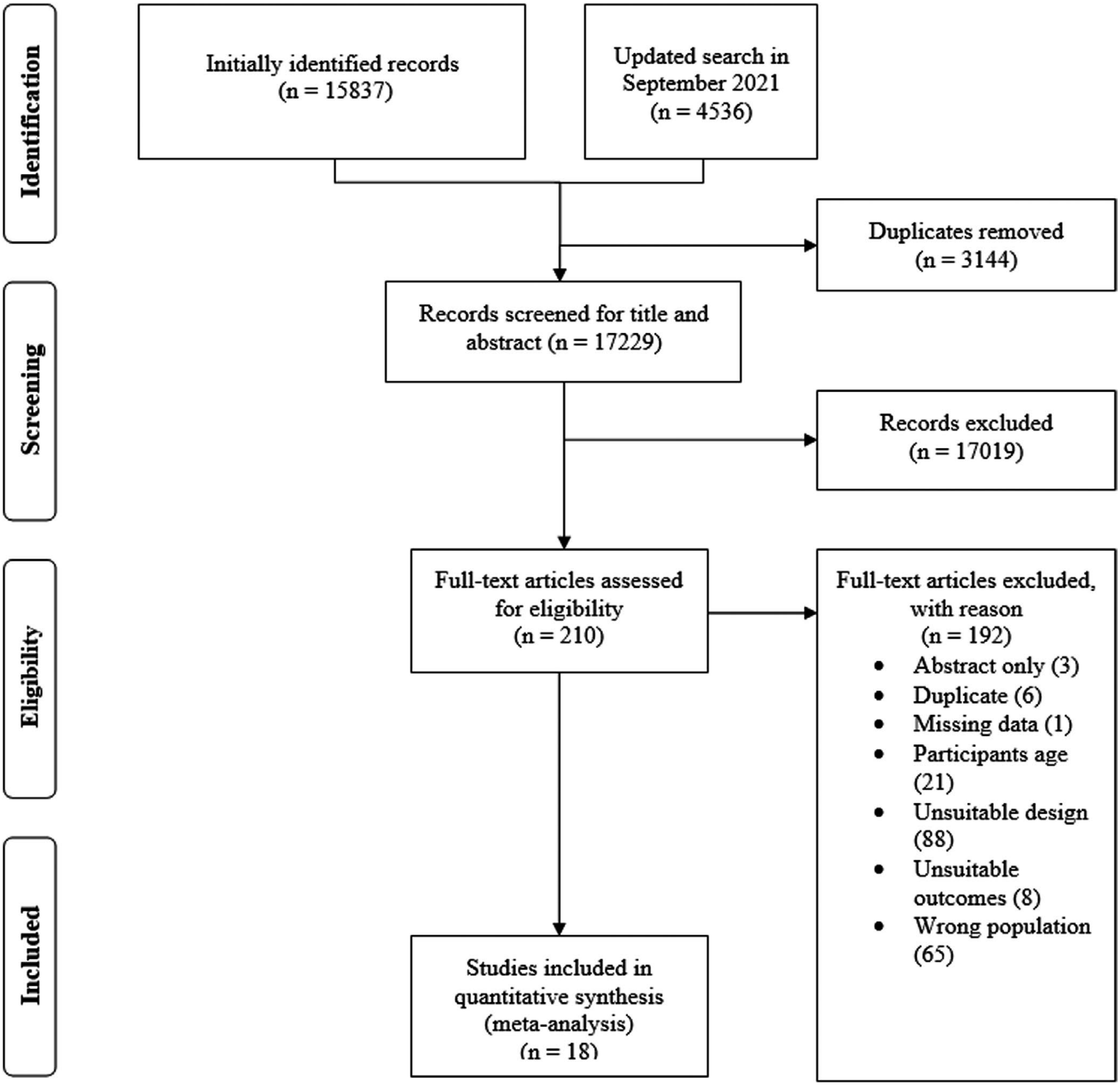

FIGURE 1 Flow chart of the search process and the study selection

middle-aged (18–40 years) athletes and active adults with no restrictions in terms of sex. The intervention had to be comprised of supervised sSIT of at least 2 weeks, with a minimum of 6 sessions. Only CTs and RCTs including a group performing sprints of ≤10 s of duration (or an equivalent distance-based [m] sprint) were included. As a comparator, eligible studies needed to include a non-sSIT control group (either no exercise or continuing their usual training without sSIT) or an endurance training group performing other exercise training regimens such as HIIT, SIT, or CT. The outcomes of interest were defined as aerobic capacity, aerobic performance, and anaerobic performance. For aerobic capacity, measures of peak ($\dot{V}O_2$peak) or maximal oxygen uptake ($\dot{V}O_2$max) were considered. Aerobic performance was defined as the maximal power achieved in a graded exercise test (Pmax), velocity associated with $\dot{V}O_2$max in graded exercise tests (v$\dot{V}O_2$max), completed time in graded exercise tests (GXT time), completed shuttles or distance in aerobic shuttle run tests, time trial performances, and the mean power output during a 3-minute all-out test (MPO). For anaerobic performance, derived measures of Wingate performance (peak power output [PPO]), sprint performance, repeated sprint performance (mean sprint time), and anaerobic shuttle run performance were considered. Exclusion criteria included language other than English and German, non-peer-reviewed articles, abstracts and thesis, cross-sectional studies assessing only acute exercise responses, and observational studies.

2.3 | Data extraction

Data extraction was performed independently by two authors. The following data were extracted from each included study: (1) the general characteristics (e.g., author(s), year of publication and aim of the study); (2) participants information (i.e., sample size, sex, training status, and age); (3) intervention data for all groups (i.e., intervention duration, types of interventions, and training loads); and (4) specific outcomes (e.g., measures of $\dot{V}O_2$max and PPO). If the mean and standard deviation of the respective groups were not reported, authors of primary studies were contacted to provide baseline and postintervention data. In case data were presented within a graphic and no additional data were provided upon request, mean and standard deviation were extracted using WebPlotDigitizer (Pacifica, California, USA, Version: 4.4).[21]

2.4 | Data synthesis and analyses

Standardized mean differences (SMD) were calculated, and an inverse variance-weighted random-effects model was fitted to the effect sizes (ES). Meta-analyses were performed using R (3.6.2), RStudio (1.2.5033), and the metafor packages (version 2.4.0).[22] Effect sizes were calculated for *pre-test and post-test control group designs* using the raw score standardization recommended previously[23,24] Furthermore, exact sampling variance of the effect sizes was computed according to previous recommendations.[24]

Heterogeneity (i.e., τ^2) was estimated using the restricted maximum-likelihood estimator (REML).[25] In addition, in order to complete heterogeneity analyses, the Q-test for heterogeneity[26] and the I^2 statistic[27] were calculated. Studentized residuals and Cook's distances were examined to assess whether studies may be outliers and influential.[28] Studies with a studentized residual larger than the $100 \times (1\text{–}0.05 / (2 \times k))^{th}$ percentile of a standard normal distribution were declared potential outliers (i.e., using a Bonferroni correction with two-sided $\alpha = 0.05$ for k studies included in the meta-analyses). Studies with a Cook's distance larger than the median plus six times the interquartile range of the Cook's distances were considered influential. In case a study was identified as a potential outlier or overly influential, a sensitivity analysis was performed. A trim-and-fill-contour funnel plot was provided to estimate the number of studies potentially missing from the meta-analysis (Figure S1–S3). The rank correlation test[29] and the regression test,[30] using the standard error of the observed outcomes as predictor, were used to check for funnel plot asymmetry.

Effect sizes from studies with more than two intervention or control groups were combined in accordance with the recommendations of the Cochrane handbook.[31] In the case of multiple measurements for the same outcome, only one measure was included in the analysis. For aerobic performance, this was based on the following hierarchy: Pmax, $v\dot{V}O_2$max, GXT time, completed shuttles or distance in aerobic shuttle-run tests, time trial performance, and mean power output (MPO). For anaerobic performance, it was based on the following hierarchy: Wingate performance (PPO), repeated sprint performance (mean sprint time), sprint performance, and completed anaerobic shuttle runs.

When ≥3 studies were available, subgroup analyses were conducted for exercise intensity ("all-out" vs. non-"all-out"). For specific justification of exclusion of individual studies, please refer to the online Supplementary Table 2.

2.5 | Assessment of methodological quality

The risk-of-bias assessment for the included studies was carried out independently using the PEDro scale by two reviewers. The PEDro scale has previously been rated as a valid measure of the methodological quality of randomized trials.[32] Studies with scores >6 were considered to be of "high quality," studies with scores 4 – 5 were considered to be of "medium quality," and studies that scored less than 4 were considered to be of "low quality." The following sources of bias were considered: selection (sequence generation and allocation concealment), performance (blinding of participants/personnel), detection (blinding outcome assessors), attrition (incomplete outcome data), reporting (selective reporting), and other potential bias (e.g., recall bias). The risk-of-bias assessments for the included studies are shown in online Supplementary Table 3. The mean score for the PEDro scale criteria 2 – 11 was 3.8/10, that is, medium quality.

3 | RESULTS

3.1 | Study characteristics

The database search identified 15,837 potentially eligible articles in the initial search and 4,536 in the updated search. After further screening and eligibility assessment, a total of 18 studies were included in the final analyses (see Figure 1). The characteristics of studies, participants, and training interventions are summarized in online Supplementary Table 4. The meta-analysis included a total of 438 participants, of whom 239 performed supervised sSIT, 107 participants performed no exercise or no additional sSIT, 49 performed HIIT as control condition, 45 performed other SIT modality as control condition, and 13 performed CT as control condition. Of the included studies, cycling was the most common mode of exercise (8 studies),[13,19,33–38] followed by running (6 studies).[11,39–43] Additionally, boxing exercise,[44] canoe paddling,[45] functional fitness exercises,[46] handcycling,[47] and squatting + cycling[19] were also assessed by one study each. In 12 of the included studies, sSIT was performed at maximal possible intensity ("all-out"),[11,13,19,34,37,38,40,41,44–47] while 5 studies assessed the effect of non-"all-out" high-intensity efforts,[33,36,39,42,43] and one study gave no further description about the intensity.[35]

3.2 | $\dot{V}O_2$max

Twelve studies were included in the quantitative analysis of sSIT vs. no exercise or usual training. The SMD ranged from −2.12 to 0.33. The estimated SMD based on the random-effects model was −0.56 (95% CI: −0.79, −0.33, $p < 0.001$). The forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 2. The Q-test revealed that the true outcomes are homogenous ($Q(11) = 14.81$, $p = 0.192$, $\tau^2 = 0.00$, $I^2 = 0.00\%$). The regression test indicated funnel plot asymmetry ($p = 0.046$) but not the rank correlation test ($p = 0.381$) (Figure S1A).

For the quantitative analysis of differences in $\dot{V}O_2$max of sSIT vs. HIIT/SIT/CT, eight studies were included in the final analysis. The SMD ranged from −0.64 to 0.39. The estimated SMD based on the random-effects model was 0.05 (95% CI: −0.19, 0.30, $p = 0.676$). The forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 3. The Q-test revealed that the true outcomes are homogenous ($Q(7) = 4.700$, $p = 0.696$, $\tau2 = 0.00$, $I2 = 0.00\%$). Neither the rank correlation nor the regression test indicated any funnel plot asymmetry ($p = 0.905$ and $p = 0.537$, respectively) (Figure S1B).

3.3 | Aerobic performance

Ten studies were included in the quantitative analysis of sSIT vs. no exercise or usual training. The SMD ranged from −1.24 to −0.04. The estimated SMD based on the random-effects model was −0.43 (95% CI: −0.67, −0.20, $p < 0.001$). The forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 4. The Q-test revealed that the true outcomes are homogenous ($Q(9) = 9.44$, $p = 0.398$, $\tau^2 = 0.00$, $I^2 = 0.00\%$). Neither the rank correlation nor the regression test indicated any funnel plot asymmetry ($p = 0.601$ and $p = 0.155$, respectively) (Figure S2A).

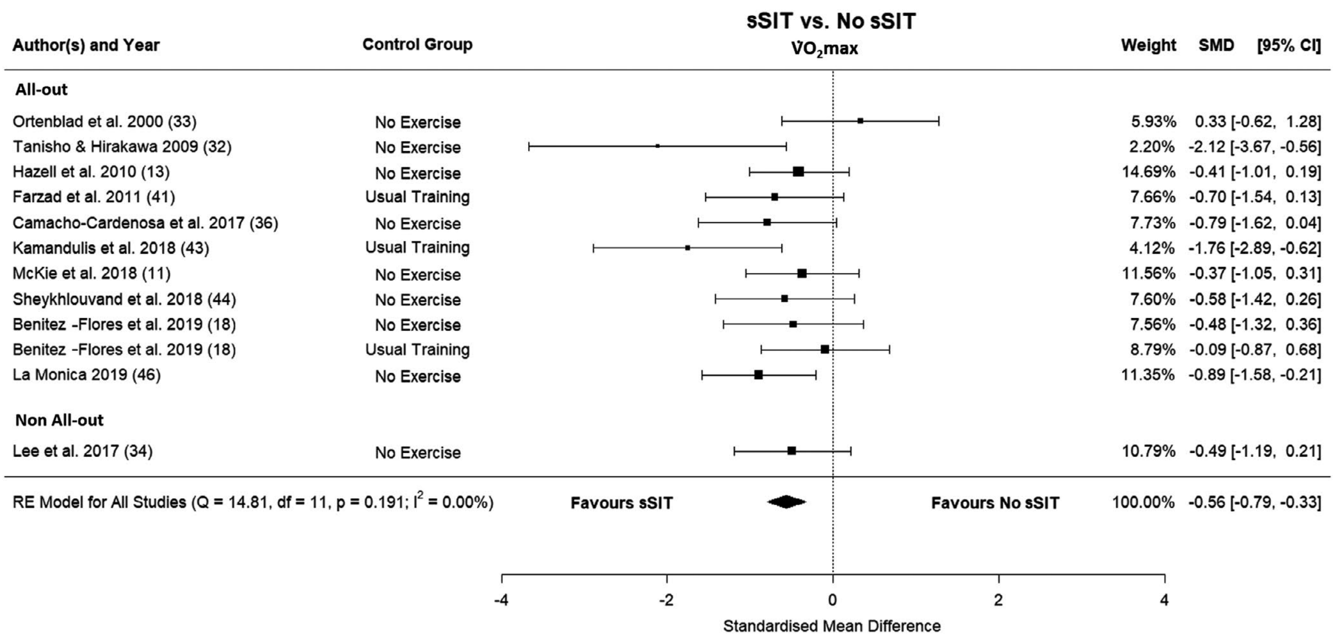

FIGURE 2 Forest plot showing the differences in effect sizes in $\dot{V}O_2$max of sSIT compared to no sSIT. CI, confidence interval; RE Model, random-effects model; SMD, standardized mean difference; sSIT, short sprint interval training; $\dot{V}O_2$max, maximal oxygen consumption

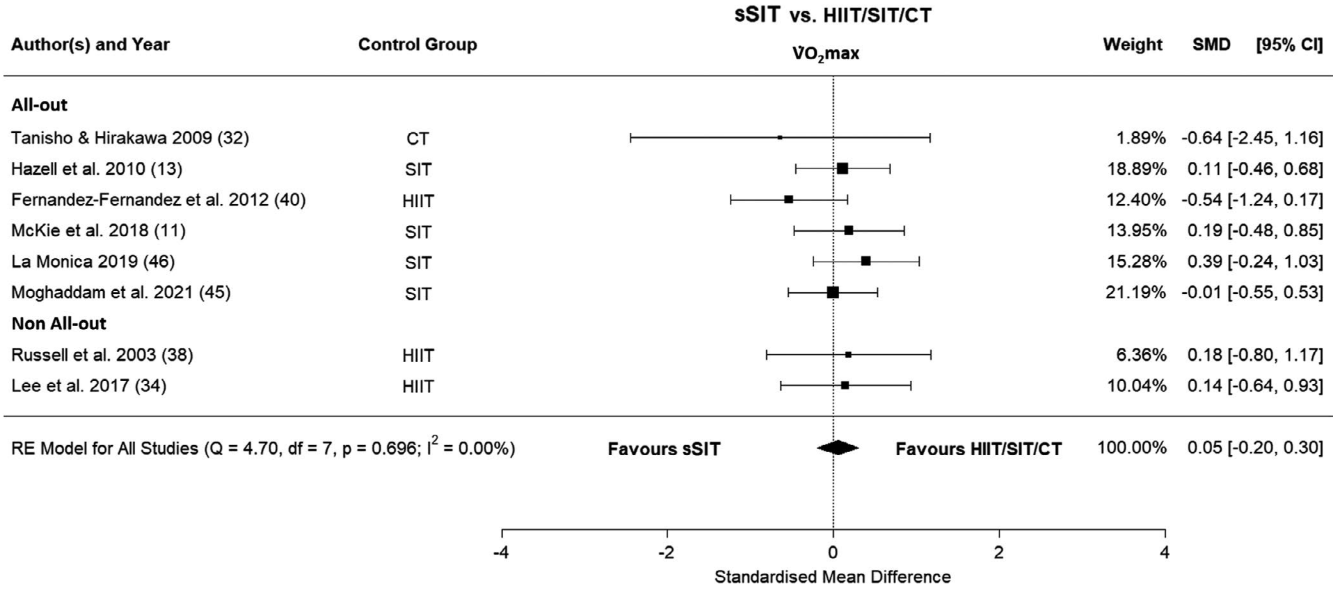

FIGURE 3 Forest plot showing the differences in effect sizes in $\dot{V}O_2$max of sSIT compared to HIIT/SIT/CT. CI, confidence interval; CT, continuous training; HIIT, high-intensity interval training; RE Model, random-effects model; SMD, standardized mean difference; sSIT, short sprint interval training; $\dot{V}O_2$max, maximal oxygen consumption

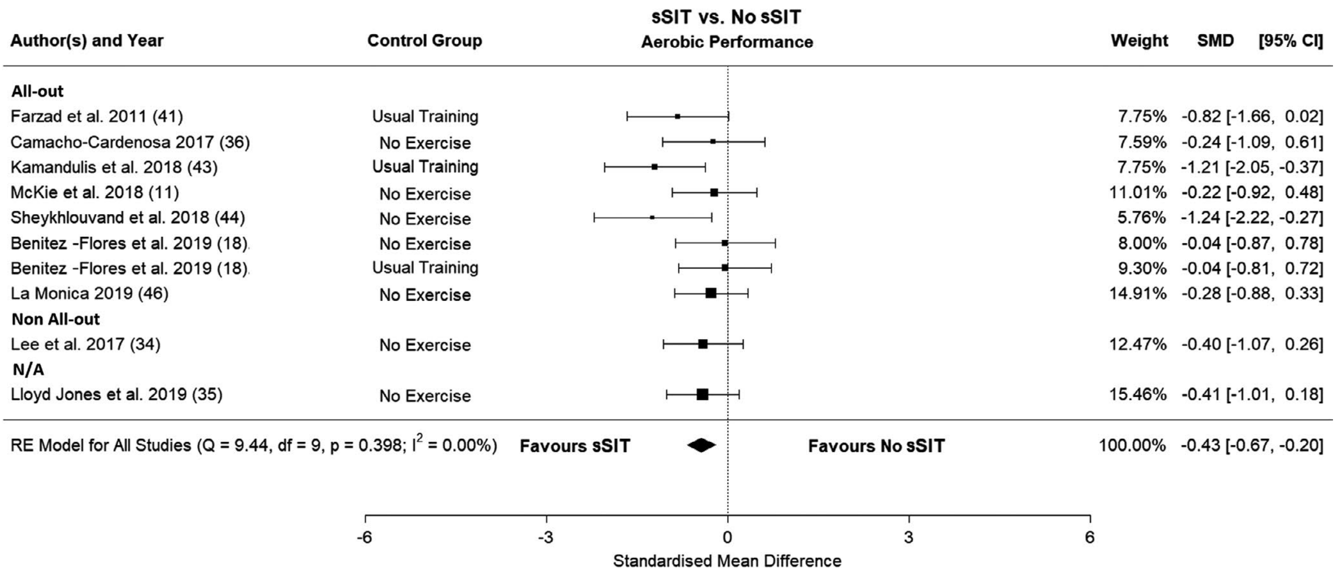

FIGURE 4 Forest plot showing the differences in effect sizes in aerobic performance of sSIT compared to no sSIT. CI, confidence interval; N/A, not available; RE Model, random-effects model; SMD, standardized mean difference; sSIT, short sprint interval training; $\dot{V}O_2$max, maximal oxygen consumption

For the quantitative analysis of differences in aerobic performance of sSIT vs. HIIT/SIT/CT, seven studies were included in the final analysis. The SMD ranged from −0.02 to 0.93. The estimated SMD based on the random-effects model was 0.15 (95% CI: −0.12, 0.42, $p = 0.281$). The forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 5. The Q-test revealed that the true outcomes are homogenous ($Q(6) = 2.86$, $p = 0.826$, $\tau^2 = 0.00$, $I^2 = 0.00\%$). Neither the rank correlation nor the regression test indicated any funnel plot asymmetry ($p = 0.381$ and $p = 0.320$, respectively) (Figure S2B). The subgroup analysis revealed no statistical differences ($p > 0.05$).

3.4 | Anaerobic performance

Nine studies were included in the quantitative analysis of sSIT vs. no exercise or usual training. The SMD ranged from −1.73 to −0.07. The estimated SMD based on the

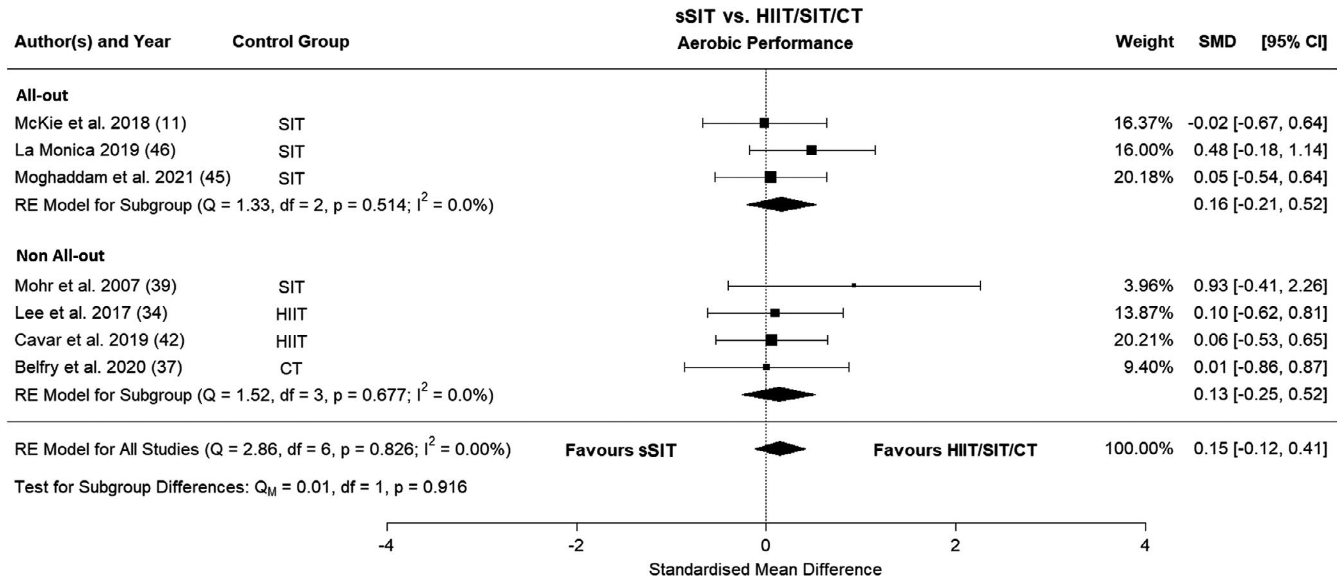

FIGURE 5 Forest plot showing the differences in effect sizes in aerobic performance of sSIT compared to HIIT/SIT/CT. CI, confidence interval; CT, continuous training; HIIT, high-intensity interval training; RE Model, random-effects model; SMD, standardized mean difference; sSIT, short sprint interval training; $\dot{V}O_2$max, maximal oxygen consumption

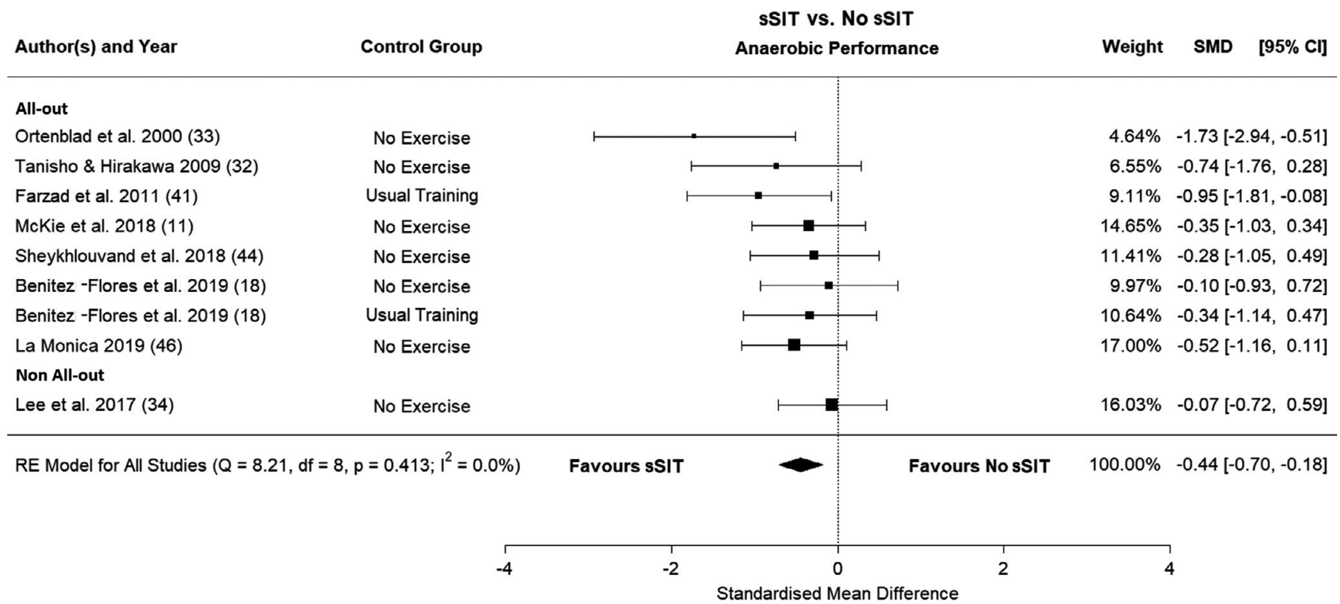

FIGURE 6 Forest plot showing the differences in effect sizes in anaerobic performance of sSIT compared to no sSIT. CI, confidence interval; RE Model, random-effects model; SMD, standardized mean difference; sSIT, short sprint interval training; $\dot{V}O_2$max, maximal oxygen consumption

random-effects model was −0.44 (95% CI: −0.70, −0.18, $p < 0.001$). The forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 6. The Q-test revealed that the true outcomes are heterogeneous (Q(8) =8.21, $p = 0.413$, $\tau^2 = 0.00$ $I^2 = 0.00\%$). The regression test indicated funnel plot asymmetry ($p = 0.039$) but not the rank correlation test ($p = 0.119$) (Figure S3A).

For the quantitative analysis of differences in anaerobic performance of sSIT vs. HIIT/SIT/CT, eight studies were included in the final analysis. The SMD ranged from −0.64 to 0.74. The estimated SMD based on the random-effects model was 0.07 (95% CI: −0.25, 0.39, $p = 0.672$). The forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 7. The Q-test revealed that the true outcomes appear to be homogenous, but some heterogeneity may still be present (Q(7) =10.76, $p = 0.149$, τ2 = 0.07, I2 = 35.32%). Neither the rank correlation nor the regression test indicated any funnel plot asymmetry ($p =$

0.548 and $p = 0.407$, respectively (Figure S3B). The subgroup analysis did not reveal a statistically significant difference ($p > 0.05$).

4 | DISCUSSION

This is the first meta-analysis evaluating the effects of sSIT (≤ 10-s sprints) on $\dot{V}O_2$max and measures of aerobic and anaerobic performances in different exercise modes in healthy adults and athletes. From the current results, it can be suggested that sSIT is an excellent means to develop $\dot{V}O_2$max and both aerobic and anaerobic performances in physically active individuals and athletes after short training periods of ≥2 weeks and that the effects of sSIT are similar to other continuous or HIIT/SIT protocols.

Our results confirm a high time efficiency of sSIT to increase $\dot{V}O_2$max in different populations after a short training period of ≥2 weeks, when compared to nonexercise or usual training regimens of physically active adults and athletes. Importantly, this effectiveness is similar to other more time-consuming endurance training methods including CT, HIIT, or traditional SIT in diverse populations (95% CI: −0.28, 0.26, $p = 0.951$). This finding further expands our current knowledge on the high effectiveness of low-volume traditional SIT to improve $\dot{V}O_2$max after only a few weeks of training.[8,9,48,49] Interestingly, the exercise modes used included punching,[44] paddling,[45] and functional fitness exercises,[46] apart from the more typically used cycling[13,19,33-38] and running.[11,39-43] Of note, although with a limited number of studies, it appears that non-"all-out" efforts may also be sufficient to induce significant improvements of $\dot{V}O_2$max after 4[36] and 6 weeks[43] of training. However, the lower intensity during non-"all-out" efforts was associated with a higher volume including 40 – 48 efforts during training.[36,43] Meanwhile, the other studies with "all-out" efforts only completed 6—36 efforts of diverse duration and work-to-rest ratios.[11,13,19,38,40,41,44-46] Therefore, while the high time efficiency (i.e., rapid $\dot{V}O_2$max improvements after a few sessions) of different protocols of sSIT has been confirmed, the most optimal dose response in terms of intensity (non-"all-out" vs. "all-out"), volume (number of sprints and sessions), and work-to-rest ratios in terms of $\dot{V}O_2$max improvements are yet to be defined.

Regarding aerobic performances, a number of sSIT protocols appeared to improve several performance parameters in studies using incremental[33,36,39,44,45] and time-trial tests,[11,40] while others did not find significant improvements.[34,42,47] Therefore, the positive effects of sSIT protocols on improving $\dot{V}O_2$max are accompanied by an increased endurance performance. However, the SMD was slightly greater for HIIT/SIT/CT protocols. Similar to $\dot{V}O_2$max improvements, the variety of protocols and exercise modes used limits our interpretation. In this regard, it is interesting to note that the most effective protocols for endurance performance enhancements involved athletes of different sports such as boxing,[44] wrestling,[40] and canoe polo,[45] who completed very short (3 – 6 s) "all-out" efforts with reduced recovery intervals (i.e., 10 s), totaling 12–36 repetitions per session. In addition, the included studies used different exercise modes than cycling and running, including punching,[44] paddling,[45] handcycling,[47] and functional exercises[46] with

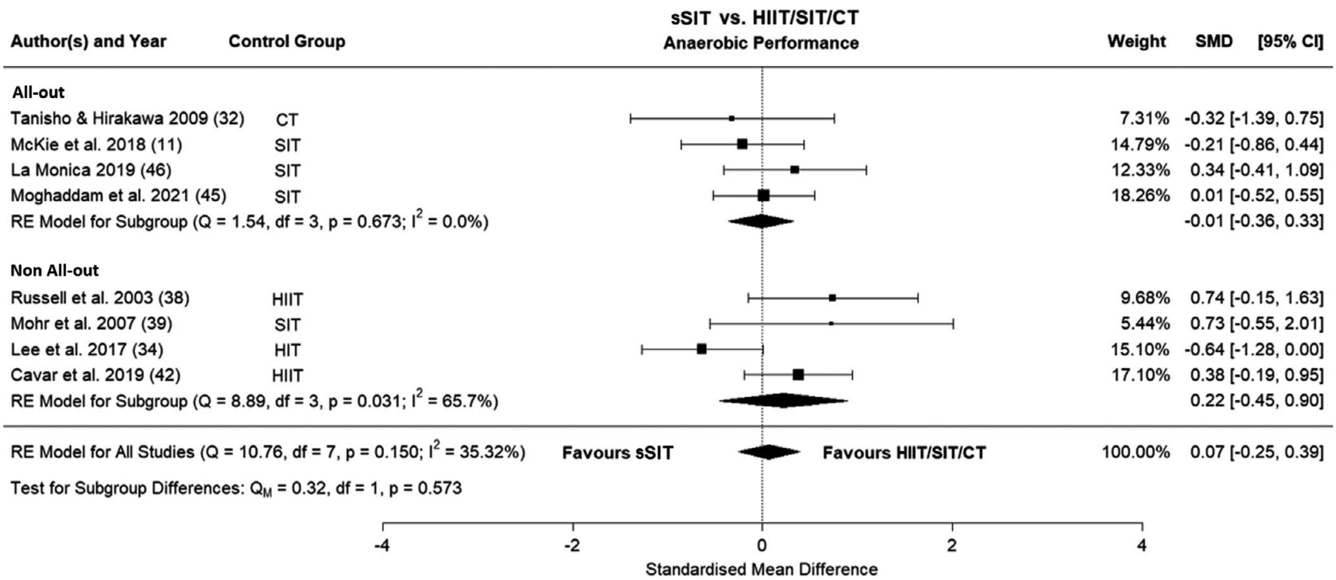

FIGURE 7 Forest plot showing the differences in effect sizes in anaerobic performance of sSIT compared to HIIT/SIT/CT. CI, confidence interval; CT, continuous training; HIIT, high-intensity interval training; RE Model, random-effects model; SMD, standardized mean difference; sSIT, short sprint interval training, $\dot{V}O_2$max, maximal oxygen consumption

diverse results. For instance, the study by La Monica et al.[47] included 2 and 4 minutes of recovery between the 10-s "all-out" hand cycling bouts and did not exhibit significant improvements in aerobic performance, thus reinforcing the need for short recovery intervals to favor aerobic adaptations. Therefore, it is suggested that the limited effectiveness of sSIT protocols to improve endurance performances may be more related to the duration of recovery intervals rather than to the exercise mode used and probably to the physical status of participants. Further studies should assess other protocol designs to simultaneously improve $\dot{V}O_2$max and endurance performances in different tests and populations with different training statuses.

As expected, from the current meta-analysis, it can be suggested that sSIT protocols are excellent means to improve anaerobic performances when compared to no exercise/usual training regimens. Furthermore, the differences with other HIIT/SIT protocols are negligible. Of note, these similar anaerobic performances between sSIT and HIIT/SIT protocols were evident, despite half (4/8) of the included mSIT studies were performed with non-"all-out" efforts.[36,39,42,43] Meanwhile, this high effectiveness for the enhancement of anaerobic performances reinforces the superiority of sSIT protocols when compared to traditional SIT protocols of longer sprints, as similar outcomes can be achieved with less effort in terms of psychological[50] and physiological[8] strains (i.e., "same gain with less pain"), probably as a result of the lower glycolytic activation.[19] As observed with $\dot{V}O_2$max and aerobic performance gains, the improvements in anaerobic performances also occurred after training with different exercise modes. Therefore, sSIT protocols can be confidently used to enhance anaerobic performances in different exercise modes.

4.1 | Strengths and limitations of the meta-analysis

As with the majority of other exercise science-related meta-analyses, the main limitation of the current systematic review with meta-analysis is the heterogeneity of studies with respect to sample characteristics and training history, exercise modes, loading parameters and protocols, and performance outcomes measures. However, with our inclusion criteria we have limited the sprints to both "all-out" and non-"all-out" efforts ≤10 s, independently of diverse HIIT and SIT definitions proposed by different authors, thus providing enough studies comparing sSIT to other training modalities, therefore, allowing a quantitative analysis of the selected outcomes.

4.2 | Perspective

This systematic review clearly shows the high efficiency of sSIT of "all-out" and non-"all-out" efforts to improve $\dot{V}O_2$max and both aerobic and anaerobic performances in different exercises. Therefore, for a better understanding of what factors are related to these performance enhancements, further comparisons should be made with different sSIT and HIIT/SIT protocols of equated loads but differing in sprint duration (4–10 s)[19] and work-to-rest ratios[36,47] in different exercise modes. In this regard, the combination of different exercises as in the concurrent training group (cycling +squatting) of the study by Benítez-Flores et al.[19] should be further explored. In addition, we only included healthy active adults and athletes; therefore, the applicability of sSIT protocols to other populations such as elderly people[51] and clinical populations[52] requires more research. Of note, to allow appropriate comparisons, further studies should better elaborate on participants' characteristics and training background to verify whether training status also affects performance outcomes. Furthermore, although non-"all-out" efforts seem to be also effective, the supposedly superiority of "all-out" efforts to optimize the dose-response and, thus, the efficiency of this training method for rapid physiological adaptations needs to be confirmed. Meanwhile, the use of non-"all-out" efforts prior to commencing with "all-out" efforts in a periodized fashion would seem an appropriate strategy for nonathletic populations. In this regard, attention should be paid to individual responses[53] to identify what factors are related to heterogeneity in these responses.

5 | CONCLUSIONS

Our data suggest the effectiveness of sSIT protocols comprised of exercise bouts of ≤10 s, to enhance both $\dot{V}O_2$max and aerobic and anaerobic performances, making sSIT a powerful time-efficient means to enhance physical fitness and performance within only few weeks and with a reduced exercise dose. Importantly, this effectiveness has been proven in different exercise modes such as cycling and running, as well as sport-specific exercises such as paddling and punching. Further studies should elaborate on the loading parameters and rest periods associated with optimal adaptations in diverse populations.

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DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

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