HALL, A.J., ASPE, R.R., CRAIG, T.P., KAVALIAUSKA, M., BABRAJ, J. and SWINTON, P.A. 2023. The effects of sprint interval training on physical performance: a systematic review and meta-analysis. Journal of strength and conditioning research [online], 37(2), pages 457-481. Available from: https://doi.org/10.1519/JSC.0000000000004257

The effects of sprint interval training on physical performance: a systematic review and meta-analysis.

HALL, A.J., ASPE, R.R., CRAIG, T.P., KAVALIAUSKA, M., BABRAJ, J. and SWINTON, P.A.

2023

OpenAIR @RGU

This document was downloaded from https://openair.rgu.ac.uk

CC BY NC

Title: The Effects of Sprint Interval Training on Physical Performance: A Systematic Review and Meta-Analysis

ABSTRACT

The present study aimed to synthesise findings from published research and through meta-analysis quantify the effect of sprint interval training (SIT) and potential moderators on physical performance outcomes (categorised as aerobic; anaerobic; mixed aerobic/anaerobic; or muscular force) with healthy adults, in addition to assessing the methodological quality of included studies and the existence of small study effects. Fifty-five studies were included (50% moderate methodological quality, 42% low methodological quality), with 58% comprising an intervention duration of ≤4 weeks and an array of different training protocols. Bayesian meta-analysis of standardized mean differences (SMD) identified a medium effect of improved physical performance with SIT ($ES_{0.5}$ = 0.52 [95%CrI: 0.42 to 0.62]). Moderator analyses identified overlap between outcome types with the largest effects estimated for anaerobic outcomes ($ES_{0.5}$ = 0.61 [95%CrI: 0.48 to 0.75]). Moderator effects were identified for intervention duration, sprint length, and number of sprints performed per session, with larger effects obtained for greater values of each moderator. A substantive number of very large effect sizes (41 SMDs >2) were identified with additional evidence of extensive small study effects. This meta-analysis demonstrates that short-term SIT interventions are effective for developing moderate improvements in physical performance outcomes. However, extensive small study effects, likely influenced by researchers analysing many outcomes, suggests potential overestimation of reported effects. Future research should analyse fewer a priori selected outcomes and investigate models to progress SIT interventions for longer-term performance improvements.

Key Words: SIT; High Intensity Interval Training; Methodological Quality; Aerobic Training; Anaerobic Training

1. INTRODUCTION

Interval training is considered a time efficient approach to exercise that can produce physical performance benefits [1] that are at least equivalent to those obtained with traditional endurance training [2, 3]. Interval training involves repeated bouts of intense exercise interspersed with recovery periods of low intensity activity or rest [4]. Two of the most frequently investigated forms of interval training include high-intensity interval training (HIIT) and sprint interval training (SIT). HIIT has been defined as repeated short-to-long bouts of exercise performed at a power output or velocity within the severe-intensity domain (between the second ventilatory threshold and maximal oxygen consumption ($\dot{V}O_{2max}$) [5]. Therefore, HIIT requires 'near maximal' efforts that elicit an intensity ≥ 80% of maximal heart rate (HR_{max}) or $\dot{V}O_{2max}$ [6]. HIIT is frequently performed using a range of exercise modes including running [7], cycling [8], rowing [9], and swimming [10]; resulting in wide applicability to trained and untrained populations. In contrast, SIT is defined by exercise performed at a power output or velocity above $\dot{V}O_{2max}$ (i.e. 'all-out' efforts in the extreme-intensity domain) necessitating short bouts of exercise [5]. Within research studies, SIT is most often performed on a cycle ergometer allowing a controlled application of training intensity through the application of substantive resistance over 6 to 30 second intervals [11-13]. The potential for SIT to generate large physiological improvements in a time efficient manner has resulted in uptake by athletes, thus becoming its own stand-alone training modality, where research findings have identified improvements in performance measures of competitive runners [14], cyclists [15], triathletes [16], and ice hockey players [17].

Whilst previous research has demonstrated there may be overlap between adaptations produced from both HIIT and SIT [18], differences are likely to exist for a selection of both aerobic and anaerobic outcomes, and delineation between the two training methods is important for future

understanding. Additionally, Viana et al. [19] identified the importance of careful evaluation of acute programme variables when comparing findings from studies either within or across forms of interval training. Creation of an interval training session is complex and first involves the manipulation of several interconnected acute program variables including interval intensity, work interval duration, recovery intensity, recovery duration, exercise modality, number of repetitions, number of series, series duration, time between series and between series recovery intensity [20]. Individual sessions can then be altered within a training microcycle and progressed over longer periods of time to create overload and continued adaptations. However, current knowledge regarding the effects of acute program variables and their interaction is in the early stages, particularly with regards to SIT and the range of different outcomes that may be of interest to athletes.

Previous systematic reviews and meta-analyses have attempted to synthesise an increasing evidence base focusing on SIT performed on a cycle ergometer and its effects on aerobic capacity [5, 21-24] and sprint power [23]. These evidence synthesis studies have generally included data from healthy individuals between the ages of 18 and 45, who were either sedentary or engaged in moderate frequency recreational activities [5, 21-24]. Additionally, previous evidence synthesis studies have chosen to focus on a restricted range of outcome variables and SIT protocols. Rosenblat et al. [5] meta-analysed results from studies directly comparing HIIT and SIT interventions with time-to-exhaustion tests. The analysis was restricted to six studies that met the inclusion criteria, with the primary analysis identifying no differences between the forms of interval training. Sloth et al. [21] and Gist et al. [22] both investigated the effectiveness of SIT interventions to improve $\dot{V}O_{2max}$. Gist et al. [22] restricted their analysis to SIT interventions employing the popular repeated Wingate protocol comprising four to six ‘all-out’ 30 s sprints with approximately 4 mins recovery. The meta-analysis included sixteen studies

and compared SIT interventions with either traditional endurance training or no-exercise controls. When analysed separately, the results demonstrated a moderate effect (d = 0.69 [95%CI: 0.46 to 0.93]) of SIT compared with no-exercise controls, and no effect (d = 0.04 [95%CI: -0.17 to 0.24]) of SIT when compared to traditional endurance training. Similar findings were obtained in the meta-analysis conducted by Sloth et al. [21], which included twenty-one studies with a wider range of SIT protocols (10- to 30-s sprints) incorporating either non-controlled or no-exercise-controlled designs. Sloth et al. [21] also reported a moderate effect (d = 0.63 [95%CI: 0.39 to 0.87]) of SIT to improve $\dot{V}O_{2max}$. In contrast, Weston et al. [23] acknowledged that SIT performed on a cycle ergometer had the potential to improve sprint performance as well as aerobic capacity. The authors' meta-analysed results from sixteen studies including either controlled or non-controlled designs that measured power produced during a maximum 30 s sprint. The analysis was restricted to SIT studies employing the repeated Wingate protocol, with results demonstrating that SIT interventions had an unclear effect on improvements in peak (+1.8% [90%CL: ±5.0]) and mean (+2.2% [90%CL: ±10.3]) power.

Given the work of previous meta-analyses, Vollaard et al. [24] stated that it was surprising that there had been minimal attempt to identify "optimal" protocols. As a result, the authors investigated the modifying effects of maximum number of sprints, intervention duration, number of sessions, sprint duration, recovery time, and sprint resistance on $\dot{V}O_{2max}$ in thirty-four studies. The results indicated a possible small modifying effect of the maximum number of sprints, with decreased improvements with additional sprints [24]. All other programme variables were found to exert unclear or trivial effects [24]. However, the meta-analysis conducted by Vollaard et al. [24] included a limited number of data points and only focused on a single outcome variable. The inclusion of a limited number of outcome measures in previous

meta-analyses is no longer reflective of the research area with studies investigating a range of outcomes including those that assess anaerobic [25], neural [26], and force production systems [27].

Given the recent increase in the number of diverse SIT protocols to improve a range of fitness parameters associated with physical performance and sporting activity, there is a need to synthesise the available evidence and identify which protocols are most effective. This would provide athletes, practitioners and researchers with a practical framework for SIT prescriptions targeting specific training outcomes. Therefore, the aim of this systematic review and meta-analysis was to perform a comprehensive synthesis of the published research and quantify the effect of SIT and potential moderators on a range of physical performance measures collected from healthy adults. Additionally, assessment of the overall research quality was made to combine with the meta-analytic findings to better inform current practice and future research.

2. METHODS

2.1 Search strategy

This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement [28]. A three-step search strategy was employed, firstly, an initial limited search was performed in MEDLINE and SportDiscuss followed by an analysis of the text words contained in the resulting titles, abstracts, keywords and index terms used to describe the publications. Secondly, a search strategy tailored to each information source (MEDLINE, Web of Science, SPORTDiscuss) was developed based on the identified keywords and index terms (e.g. “sprint interval training”, “high intensity interval training”, “high intensity intermittent training”, “HIIT”, “interval exercise”, “high intensity training”, “high intensity exercise”, “high intensity aerobic interval training”, and “aerobic interval training”) and executed. Finally, the reference lists of all included studies as well as forward citation tracking using Google Scholar were searched for additional sources. Searches were limited to the years 2000 – February 2020 and to the English language. The full electronic search strategy including limits, can be found in Electronic Supplementary Material Appendix S1.

2. 2 Inclusion criteria

Studies were included in this review if they satisfied the following population, intervention, comparator, outcome (PICO) criteria – **Population:** Young to middle-aged adults (mean age 18-45), not suffering from any acute or chronic disease. Studies that specifically recruited overweight or obese participants were excluded. **Intervention:** A minimum of 2 weeks duration comprising maximum intensity (‘all-out’) sprints on a resistance bike. Interventions comprising sprints greater than 30 seconds duration were not considered maximum intensity and therefore were excluded. Studies incorporating combined training interventions (e.g. SIT

plus strength training or aerobic training) or combined supplement interventions (e.g. SIT plus creatine supplementation) were excluded. **Comparator:** Cohort, non-randomised and randomised controlled (no exercise or habitual physical activity) designs. Where studies compared relevant SIT groups with other modes of exercise, data from SIT groups were included. **Outcome:** Three outcome categories were defined and included: 1) Aerobic (e.g. VO_{2max}, incremental time, oxygen consumption [O_2], respiratory exchange ration [RER]); 2) Anaerobic (e.g. Wingate peak power, Wingate mean power); and 3) Mixed aerobic/anaerobic (e.g. total work across critical power test measures, peak power across repeated tests).

2.3 Study selection

Search results were imported to Proquest® Refworks and duplicates were removed. Titles and abstracts of all sources were screened by two independent reviewers (AH & TC) for relevance to the review questions. Full-text manuscripts were retrieved for articles that potentially met the inclusion criteria and were screened independently by the same two reviewers. At each stage of the screening process disagreements were resolved by discussion and inclusion of a third reviewer (PS). Articles identified from hand-searching of reference lists were assessed for relevance based on their titles and abstracts with those meeting inclusion criteria added to the full-text screening stage. Full-text studies that did not meet the inclusion criteria were excluded and reasons for their exclusion documented (Electronic Supplementary Material Appendix S2).

2.4 Data extraction

A bespoke data extraction tool was piloted on 10 studies by two independent reviewers and discussed within the research team prior to full data extraction. Data extraction was completed independently by two authors (AH & TC) and discrepancies resolved through discussion.

Reviewers were not blinded to manuscript authors or journals. Data regarding study type (controlled, uncontrolled), participant characteristics (sex, age, body mass, number), training parameters (intervention duration, total number of training sessions, exercise bike used, number of sprint repetitions within training intervention, sprint duration, recovery duration, applied sprint resistance), and training outcome measures were extracted. All extracted outcome data were assigned to a single outcome category. Where data were presented in figures or percentage change units, the corresponding author was contacted for the original information. Where this was not made available, data within figures were extracted through graph digitiser software (DigitizeIt, Germany), with data expressed in percentage change units omitted from extraction.

2.5 Evaluation of methodological quality

Methodological quality and risk of bias were evaluated by three independent reviewers (TC, RA, MK) with agreement reached on each item by at least two reviewers. The quality of each review outcome category was assigned using a strategy based on the recommendations of the Grading of Recommendations Assessment Development and Evaluation (GRADE) working group [29]. Each individual study was initially appraised using a modified version of the Downs and Black Checklist [30], which was specifically tailored for use in this study (Electronic Supplementary Material Appendix S3). The modified checklist comprised 23 outcomes for comparator studies and 19 outcomes for non-comparator studies after removal of items relating to group differences. A total of four domains were evaluated including: (1) reporting; (2) internal validity – bias; (3) internal validity – confounding; and (4) statistical power. A total of five items were added to both checklists and included: “Were familiarization sessions of training completed?”, “Were familiarization sessions of testing completed?” (internal validity – bias); “Were number of sessions attended reported?”, “Was a minimum number of sessions

for inclusion reported" (reporting); and "If a power calculation was completed, was this adjusted to account for multiple outcome variables?" (statistical power). Scoring for the additional questions employed the same protocol for the original questions: Yes = 1, No = 0, Unable to determine = 0. These additional items were included as they were considered fundamental in determining precision of the effects of an intervention and associated statistical rigor. Individual studies were assigned a rating based on the percentage of items scored positively with the following criteria used: "high" (80% +); "moderate" (60 – 79%); "low" (40 – 59%); or "very low" (0 – 39%). For each of the primary meta-analysis outcomes an overall quality rating was assigned based on the mode rating of individual studies contributing data.

2.6 Statistical analysis

A Bayesian framework was chosen over frequentist methods to provide a more flexible modelling approach and enable results to be interpreted intuitively through reporting of subjective probabilities [31]. The effects of SIT on included outcomes were quantified by calculating effect sizes in the form of standardized mean differences (SMDs). Magnitude-based SMDs obtained by dividing the mean difference by the pre-intervention standard deviation are the most popular form of effect size used in meta-analyses in sport and exercise science and are informative when considering the change an individual can be expected to make relative to a population pre- to post-intervention [32]. Most studies did not include a no-exercise control and so intervention group only effect sizes were used for primary analyses. Sensitivity analyses were conducted where possible with effect sizes incorporating data from no-exercise controls [33]. Within-study variance of effect sizes were calculated according to standard distributions with bias correction for small samples applied to both the effect size estimate and its variance [32]. SMD effect sizes are equal to Dz effect sizes calculated using a pre-post correlation of 0.5. Dz effect sizes account for the pre-post correlation, and generally result in larger effect sizes

than SMD effect sizes, since the pre-post correlations are typically larger than 0.5. Dz effect sizes can be calculated using the SD of the difference scores or mathematically accounting for the pre-post correlation, if the correlation is reported. However, such distributions are influenced by pre-post correlations that are generally not reported [34]. Therefore, within study variances were calculated and inputted using a standard value of 0.7 [35], with an additional error term included to enable individual study values to vary. An informative Gaussian prior was placed on the error term such that the overall distribution of values matched the within-study variance distribution obtained from correlation values ranging from approximately 0.5 to 0.9 [35]. Three-level random-effects Bayesian hierarchical models were used to pool effect sizes and model average effects, variance between studies, and covariance of multiple outcomes reported in the same study (e.g. reporting of a single outcome across multiple time points and/or reporting values from multiple outcomes). The overall analysis approach was determined a priori and included an initial pooling of all effect sizes, followed by investigation of average effects by outcome category and training status. Meta-regressions were then performed to investigate associations between effect sizes and intervention duration, training intensity, training volume and training work to rest ratios. Meta-regressions were only performed where there were sufficient data including a minimum of four data points per category level, or 10 data points for continuous variables [36].

Non-informative priors were used for all model parameters other than the within study variance correlations. Inferences from all analyses were performed on posterior samples generated using the Hamiltonian Markov Chain Monte Carlo method with four chains for 20 000 iterations with a burn-in period of 10 000. Interpretations were based on the median value ($ES_{0.5}$: 0.5-quantile), the range within credible intervals (CrIs) and calculation of probabilities that the magnitude of the average effect size exceeded commonly used qualitative thresholds (e.g. small: 0.2,

medium: 0.5, and large: 0.8) [37]. Bayesian CrIs can be interpreted probabilistically, such that with a 95% CrI there is a 95% probability that the true (unknown) estimate would lie within the interval given the priors implemented and the evidence provided by the observed data. Additionally, the $ES_{0.5}$ represents the centre of the posterior such that values close to this point are generally more probable. Analyses were performed using the R wrapper package brms (example code presented in Electronic Supplementary Material Appendix S4) interfaced with Stan to perform sampling [38]. Convergence of parameter estimates was obtained for all models with Gelman-Rubin R-hat values below 1.1 [39]. All values presented in tables and figures include analyses conducted on data post removal of outliers, except for the association between controlled and no-exercise-controlled effect sizes presented in Figure 3 which include all data. Small-study effects (publication bias, etc.) were visually inspected with funnel plots and quantified with a multi-level extension of Egger's regression with effect sizes regressed on within-study variances and weights obtained from the reciprocal of the within- and between-study variances [40, 41].

3. RESULTS

3.1 Search results

Figure 1 illustrates the studies identified and selected included based on the search strategy and screening process. A total of 139 studies were screened at full-text and 84 excluded primarily due to sprint duration being greater than 30s, or sprints not completed at an 'all out' intensity. A total of 55 studies were included in the review [11-14, 25-27, 42-89].

3.2 Study characteristics

Details of the 55 studies included in this review are shown in Table 1, with 25 (45%) of the studies including a non-exercise control group. Thirty studies (55%) comprised all male participants, 2 studies (4%) comprised all female participants, and 23 studies (41%) comprised both males and females, with 3 of the studies reporting male and female data separately. In total, 589 participants were allocated to a SIT intervention (median group size = 9 [IQR: 8 to 11]), with 257 participants allocated to a non-exercise control group (median group size = 8 [IQR: 7 to 9]). Most studies (42 studies, 76%) recruited recreational participants, with 10 studies (18%) recruiting sedentary participants and 3 studies (6%) recruiting competitive athletes. In total, 617 outcomes were extracted demonstrating large variation in the number obtained from individual studies with the median equal to 7 [IQR: 3.5 to 15]. Fifty percent of the outcomes were categorised as aerobic, whereas 12% were categorised as anaerobic and 38% categorised as mixed.

3.3 Methodological quality

The overall quality ratings and ratings across the four domains evaluated are presented in Table 2. The mean (±sd) percentage quality rating score was 63% for comparator studies and 56% for non-comparator studies (Table 2). Quality ratings were highest for the reporting domain

with all studies clearly describing characteristics of participants and providing estimates of random variability in the data. Reporting of number of sessions attended and a minimum number of sessions for inclusion were identified as important requirements given the small number of sessions typically performed and the subsequent influence this could have on estimates of effectiveness. It was identified that less than half of studies (44 and 41%, respectively) reported this information.

Following reporting, the domain with the highest quality ratings was internal validity – confounding. Within this section, the highest scoring item (94%) was "were the participants in different intervention groups recruited from the same population", and the lowest scoring item (49%) was "were losses of participants to follow-up taken into account?". As part of the methodological evaluation, the present review also considered studies use of familiarization for both SIT sessions and outcome assessment methods, as these were identified as important sources of bias. Evaluation showed that 39% of studies included familiarization sessions for training sessions, and 53% of studies included familiarization sessions for outcome assessments. Finally, only nine studies demonstrated a priori sufficient power for their statistical analysis [46, 54, 59, 67, 68, 74, 82, 85, 90]. Additionally, only three of these studies adjusted power calculations to account for inclusion of multiple outcome variables [54, 82, 85].

3.4 Training intervention description

Most interventions were very short in duration, with 17 studies (31%) comprising interventions of two weeks, a total of 32 studies (58%) comprising interventions of 4 weeks or less, and the longest duration equal to twelve weeks. To describe the training interventions implemented, selected training data were extracted and summary statistics calculated to quantify frequency,

intensity, volume, energy system specificity and periodization. Training frequency was quantified by extracting the number of sessions performed per week. The most common training frequency employed across the studies was three training sessions per week (43 studies, 78%), with a range from two (6 studies, 11%) to seven (2 studies, 4%).

The intensity of the training stimulus was quantified by the external resistance applied during cycling and the average duration of sprints performed (shorter duration sprints characterised by higher intensities). Forty-seven studies (85%) reported applying external resistance as a percentage of body mass. Of these studies, 8 (17%) applied loads less than 7.5% of body mass (as low as 5% body mass), 37 (79%) applied a load equal to 7.5% of body mass, and 2 (4%) applied a load up to 9.5% of body mass. Similarly, a standard value was frequently applied to sprint duration, with 37 studies (67%) including average sprint durations of thirty seconds. The percentage of studies that included average sprint durations up to ten seconds, between ten and twenty seconds, and between twenty and thirty seconds was equal to 13, 16 and 4%, respectively.

The volume of training was quantified by the average number of sprints per session and total sprint time per session. Eighteen studies (33%) included interventions comprising on average between one and four sprints per session, approximately half (28 studies 51%) comprising five or six sprints per session, and nine studies (16%) comprising six or more with a maximum of 24. Total sprint time per session ranged from 17.5 to 210 s, with a median value of 150 (IQR: 75 to 150 s). Energy system specificity was quantified by calculating work to rest ratios, with values across studies ranging from 1/100 to 1/3, with a median ratio of 1/8 [IQR: 1/9 to 1/8]. Finally, the extent to which interventions employed periodization was quantified by examining

variation in training frequency, volume and intensity. Only 4 studies (7%) altered training frequency and only 5 studies (9%) altered intensity (as quantified by sprint duration). In contrast, most studies (41 studies, 75%) included variation in training volume, calculated by differences in the number of sprints performed each session. In those studies that included variation, the median absolute change in number of sprints was 2 [IQR: 2 to 3], with values ranging from 1 to 10. Periodisation models altering training volume tended to be simple and included linear increases in number of sprints performed per session. Several studies integrated a taper week through a decreased sprint number prior to post-intervention testing.

3.5 Meta-analysis

Of the 619 outcomes selected for extraction, 436 outcomes from 52 studies included sufficient before-and-after data from sprint intervention groups to be included in the meta-analysis. In contrast, only 114 outcomes from 24 studies included sufficient data from both sprint and a no-exercise control group to be included in sensitivity analyses. The primary meta-analysis conducted across all outcome types estimated a medium pooled effect demonstrating improved physical performance following SIT intervention ($ES_{0.5}$ = 0.52 [95%CrI: 0.42 to 0.62]; Figure 2). Relatively large between study variance was identified $\tau_{0.5}$ = 0.32 [75%CrI: 0.27 to 0.38] with central estimates indicating very low intraclass correlation $ICC_{0.5}$ = 0.02 [75%CrI: 0.00 to 0.09] of multiple outcomes reported within the same studies. When categorized by outcome type, the analysis provided some evidence of differences. The greatest effects were obtained for anaerobic outcomes ($ES_{0.5}$ = 0.61 [95%CrI: 0.48 to 0.75]), followed by mixed aerobic/anaerobic ($ES_{0.5}$ = 0.50 [95%CrI: 0.30 to 0.70]) and aerobic ($ES_{0.5}$ = 0.49 [95%CrI: 0.39 to 0.60]) outcomes. Sensitivity analyses of the main meta-analytic findings were conducted with effect sizes adjusted for no-exercise control group data. Initial assessment

comparing both non-controlled and no-exercise-controlled effect sizes demonstrated a close association (Figure 3) with a small positive bias identified for non-controlled effect sizes ($\beta_{0:0.5}$=0.09 [95%CrI: -0.04 to 0.23]; $\beta_{1:0.5}$=1.00 [95%CrI: 0.94 to 1.07]; Figure 3). Sensitivity analyses conducted for the pooled data and split by outcome category resulted in no substantive changes (Table 3).

Meta-regressions were performed to assess the effects of demographic factors and training related variables on pooled effect sizes. An initial meta-regression was performed across all outcome types to assess the effect of intervention duration with time in weeks included as a covariate. It was estimated that the pooled effect size increased by 0.03 per week (β_1: $ES_{0.5}$ = 0.03 [95%CrI: 0.00 to 0.06]), with the covariate added to all subsequent meta-regressions. Substantive variation was identified in the number of outcomes extracted across sedentary (23), recreationally active (350) and competitive (31) populations. No clear population differences were obtained for pooled effects sizes obtained in a meta-regression across all outcomes types, with large uncertainty in estimates identified ($\beta_{recreational:competitive}$: $ES_{0.5}$ = 0.21 [95%CrI: -0.20 to 0.61], $\beta_{recreational:sedentary}$: $ES_{0.5}$ = 0.13 [95%CrI: -0.16 to 0.38]).

The effects of training related variables were assessed pooling across all outcomes whilst controlling for intervention duration and outcome type (through inclusion of fixed effects), and were assessed for each outcome separately (Table 4). To assess the influence of training intensity, meta-regressions were performed separately with sprint duration and external load expressed as categorical variables. Sprint duration was categorised as short (5 to 10 s), medium (10 to 20 s), and long (+20 s). Pooled effects sizes obtained across all outcomes provided evidence of a reduced effect with short duration sprints ($\beta_{long:short}$: $ES_{0.5}$ = -0.15 [95%CrI: -0.42

to 0.08]), and no evidence of a difference between medium and long ($\beta_{long:mid}$: $ES_{0.5}$ = 0.04 [95%CrI: -0.12 to 0.19]) duration. External load was expressed as a binary variable and categorized as low (≤ 7% body mass) and high (+7% body mass). Results indicated a similar pooled effect size irrespective of the external load ($\beta_{high:low}$: $ES_{0.5}$ = -0.10 [95%CrI: -0.30 to 0.18]).

To assess the influence of training volume, meta-regressions were performed separately with number of sprints performed each session expressed as categorical variable and total sprint time per session expressed as a covariate. Number of sprints performed each session were categorised as low (1 to 4 sprints), medium (5 to 6 sprints), and high (+6 sprints). Pooled effects sizes obtained across all outcomes provided evidence of an increased effect with higher volume, reflected in both the high versus medium ($\beta_{high:medium}$: $ES_{0.5}$ = -0.14 [95%CrI: -0.42 to 0.12]) and high versus low ($\beta_{high:low}$: $ES_{0.5}$ = -0.20 [95%CrI: -0.51 to 0.13]) comparisons. Similarly, results demonstrated greater effects with increased total sprint time per session. The median estimate obtained using all outcome types indicated a 0.05 increase in pooled effect size for each standard deviation increase in total sprint time per session (β_1: $ES_{0.5}$ = 0.05 [95%CrI: 0.00 to 0.11]).

The final training variable assessed was work-to-rest ratio. The analysis conducted across all outcome variables identified no evidence of a change in pooled effect size when expressed in standard deviation units (β_1: $ES_{0.5}$ = -0.00 [95%CrI: -0.06 to 0.06]). However, when the analysis was conducted on individual outcome types, the results indicated that lower work-to-rest ratios were more effective for aerobic outcomes and increased work-to-rest ratios were more effective for anaerobic outcomes (Table 4). Meta-regressions performed for work-to-rest ratio were the

only analyses that demonstrated clear evidence of contrasting results across outcome types (Table 4).

3.6 Small study effects

Evidence of extensive small study effects were identified visually from funnel plot asymmetry of non-controlled effect sizes (Figure 4) and through the multi-level extension of Egger's regression (β_0: $ES_{0.5}$ = -0.77 [95%CrI: -0.90 to -0.64]). Results demonstrated that studies with small participant numbers ($n \leq 10$) were much more likely to report very large effect sizes (ES>1) but rarely reported small or negative effect sizes.

4. DISCUSSION

The aim of this review was to quantify the effects of SIT and potential moderators on a range of physical performance measures using aggregate data from published studies. The results demonstrated that healthy individuals engaging in SIT were most likely to experience moderate improvements across a range of physical performance outcomes. The largest pooled effect size was estimated for anaerobic outcomes; however, effect estimates were also similar for aerobic and mixed aerobic/anaerobic outcomes. Substantive variation in training protocols was identified with regards to primarily sprint duration (intensity) and number of sprints performed (volume). The results from meta-regressions identified that intervention protocols with longer sprint durations and more sprints resulted in greater improvements. Most interventions included were very short in duration, with 17 studies (31%) comprising interventions of two weeks and 32 (58%) studies comprising interventions of 4 weeks or less. Collectively, the findings indicate that SIT training can improve a range of performance outcomes dependent on both the aerobic and anaerobic energy systems over short intervention periods; indicating the training strategy may be effective for improving sport performance and provide multiple opportunities to include the training within broader training plans. However, it is noteworthy that only 6% of the data included in the analysis were obtained from competitive athletes which limits application of findings to this population. Additionally, analysis of methodological quality of studies and identification of extensive small study effects indicates limitations of the research base that likely overestimates the effectiveness of interventions and suggests areas for future development.

The finding that SIT interventions generate medium effects on physical performance outcomes is consistent with previous meta-analyses. Sloth et al. [21] and Gist et al. [22] reported pooled effects sizes of 0.69 and 0.63, respectively, for intervention only, and non-exercise-controlled comparisons. In the present review, Bayesian meta-analyses were conducted generating posterior distributions for pooled effect sizes that can be readily interpreted probabilistically. Across all outcomes the present review estimated a median pooled effect size of 0.52 with the probability the value was greater than small *(d* ≥0.2) almost equal to 1, and the probability the value was greater than medium (*d* ≥0.5) equal to 0.64. The quality rating of the included studies generating this overall outcome estimate was moderate. In agreement with previous reviews, the findings of the current meta-analysis identified the existence of potential moderators. Weston et al. [23] reported that participants initial training status was the most influential moderator with the largest pooled effects estimated for sedentary individuals. In the current review there was a large skew towards studies conducted with recreationally active participants (76%) compared with sedentary participants (18%) or competitive athletes (6%). No clear population differences were identified for the pooled effect size. In the current meta-analysis, there were overlaps in effect estimates between the three outcome domains, with central values indicating that the largest values were obtained for anaerobic outcomes (Table 3). The most common measures included in this category were related to anaerobic power (e.g. peak power) and capacity (e.g. mean power, total work). Improvements in anaerobic fitness following SIT can be attributed to improvements in both anaerobic and aerobic metabolism. Previous research has demonstrated a range of enzymatic adaptations to SIT including increased activity in creatine kinase and key glycolytic enzymes, such as phosphofructokinase, lactate dehydrogenase, glycogen phosphorylase and aldose [77, 91]. Additionally, research has established that adaptations to SIT can include greater muscular glycogen concentration

and enhanced muscle buffering capacity [50, 77]. Across sprint durations representative of SIT (i.e. 6 to 30 s), the contributions of phosphocreatine (PCr) and anaerobic glycolysis to ATP turnover are similar [92-94], leading to consistent increases in peak and mean power outputs. The ability to sustain a higher power output following SIT indicates greater fatigue resistance and enhanced exercise capacity [55]. However, the anaerobic ATP utilisation rate is reduced during the second half of a 20 s sprint when to compared to the first half [95]. Therefore, improvements in successive sprints are likely to be dependent on improvements in aerobic metabolism as demonstrated by a greater increase in aerobic ATP provision as multiple-sprints exercise progresses [96]. Therefore, while improvements in successive sprints may be dependent on improvements in aerobic metabolism as demonstrated by a greater increase in aerobic ATP provision as multiple-sprints exercise progresses [96], the extent of this is dependent on the programme variables utilised, which may explain the greater increases in anaerobic measures.

Few studies have investigated the relative importance of intervention duration, training volume and training frequency in mediating the magnitude and time course of physiological adaptations following SIT. The results of the current review identified a positive association between the pooled effect size and training volume (Table 4) quantified by the average number of sprints performed per session. This finding contradicts a previous meta-analysis conducted by Vollaard et al. [24] who did not find a clear relationship between number of sprints performed in each session and change in $\dot{V}O_{2max}$, but estimated that the relationship was most likely to be negative with improvements maximized by performing only two sprints per session. The dose-response relationship to SIT is likely to be determined by complex interactions between several factors with multiple ways to accumulate higher training volumes that could influence outcomes. Previous research by Stavrinou et al. [97]

identified that increasing training volume through increased frequency from two to three interval sessions per week resulted in greater increases in a range of outcome variables and altered the time-course over which positive improvements were obtained. At present there is limited research to summarize the relationship between improvements in SIT and training volume. Both the meta-regressions conducted in the present review and by Vollard et al. [24] were linear in nature. However, it is unlikely that the underlying relationship would be linear and consistent with other training modalities an initial positive relationship that plateaus and then reverses may be most likely.

The meta-regressions conduced in the current review also demonstrated increased effectiveness with long duration sprints (>20 s) compared with short duration sprints (<10 s) across all outcome categories (Table 4). Most outcomes (72%) included in the meta-analysis were extracted from 30 s sprints reflecting seminal research conducted on Wingate-based protocols [92, 98, 99]. However, based on criticisms that repeated 30 s sprints may not be time efficient overall [60, 100], there has been an increasing number studies investigating shorter duration sprints. The finding that increased effect sizes may be obtained with longer duration sprints is consistent with previous research demonstrating greater oxidative contributions to ATP turnover due to PCr depletion and glycolytic inhibition [92], resulting in increased mitochondrial biogenesis, mitochondrial enzyme activity, and skeletal muscle capillarisation [48]. Additionally, during longer duration sprints the number of muscular contraction cycles (i.e. cross-bridge attachments and detachments) are increased leading to greater disturbances in metabolic environments, potentially augmenting the response. While this mechanism is yet to be fully explored, increased cross-bridge cycling will promote greater movement of Calcium ions (Ca^{2+}), increased levels of adenosine monophosphate (AMP) and AMP-activated protein kinase activation, and

subsequent rate of peroxisome proliferator-activated receptor gamma co-activator 1-alpha (PGC-1α) expression [101-105]. Following repeated 30 s sprints, PGC-1α expression has been shown to increase seven-fold [105] compared to only 2-fold following 4 s sprints [103], with associations demonstrated between PGC-1α expression and mitochondrial adaptations and improvements in physical performance [101, 102, 104]. However, it is important to note that the aforementioned measures were taken 4 and 3 hours respectively following sprints, with measures taken from mRNA and not protein changes [103, 105]. Further research is required to identify the influence of sprint duration on adaptations to SIT interventions and the underling mechanisms that may be responsible.

The only meta-regressions to exhibit clearer difference in moderating effect across outcome types were obtained with work to rest ratios (Table 4). When analysed across all outcomes the meta-regression identified no evidence of an effect. However, when split by outcome type the results identified that work to rest ratios with shorter rest periods were more effective for aerobic outcomes, whereas ratios with longer rest periods were more effective for anaerobic outcomes. These findings are consistent with those reported by Kavaliauskas et al. [14] who investigated the effects of a SIT intervention comprising 10 s sprints interspersed with either a 30, 80, or 120 s recovery. The aerobic performance measures demonstrating greater improvements with shorter rest periods included $\dot{V}O_{2peak}$, incremental time to exhaustion, and 3km time trial, whereas the anaerobic performance measures demonstrating greater improvements with longer rest periods included peak and mean power output [14]. These adaptations were suggested to occur due to reduced rest periods eliciting a greater aerobic challenge from a lack of PCr replenishment and glycolytic inhibition; and longer rest periods enabling greater PCr resynthesis and increased power output to stimulate anaerobic adaptations [14]. This hypothesis is supported by a

recent acute comparison study demonstrating a stronger cardiorespiratory response with higher VE_{peak}, $\dot{V}O_{2peak}$ and HR_{peak} values in participants performing 10 s sprints interspersed with 30 s versus 4 min recovery periods [106]. In contrast, no significant differences were reported by Lloyd Jones et al. [13] for groups performing 6 s sprints interspersed with 48, 60, or 72 s recovery periods for either aerobic (10km time trial) or anaerobic (peak power output, mean power output) performance measures. Similarly, Olek et al. [107] reported no significant differences in aerobic, anaerobic, or skeletal muscle enzyme activity following two weeks of 10 s SIT matched for total sprint time but with two different recovery times (1 vs. 4 min). Contrasting results between studies may be due to a range of factors including the length of interventions, different work-to-rest ranges investigated across groups and the interrelation between factors such as sprint duration and the nature of the recovery (active vs passive). The results from this meta-analysis and the subsequent increased statistical power obtained support the hypothesis that work to rest ratios can be altered to more effectively target aerobic or anaerobic based outcomes. However, the modifying effects reported must be treated with caution as aggregate analyses made over studies may not hold at the individual level. In addition to statistical heterogeneity due to compounding intervention differences (e.g. types of participants, training stimulus, and setting), methodological differences (e.g. control over bias) can also act to confound moderator analyses.

Consistent with the findings reported by Vollard et al. [24], the current meta-analysis identified no moderating effects of sprint resistance. Clustering of loads may have influenced results with most studies (79%) applying resistance as a percentage of body mass and selecting a load of 7.5%. Given the consistent use of 7.5% body mass as a resistance, only two authors in the included studies that selected an alternative value

provided justification. Broatch et al. [47] stated that the selection of an increased resistance was made to reduce power output to 20 W/s, whereas Kavaliauskas et al. [65] selected a reduced resistance for female participants due to lower expected muscle mass compared with males. Whilst scaling resistance to body mass is less challenging practically, scaling to muscle mass may represent a more standardized stimulus for training prescription and represents an area for future research.

In the current review methodological quality of studies was assessed using a modified version of the Downs and Black checklist. Most studies were classified as moderate (51%) or low (42%) in methodological quality. The average score obtained was 62% with the highest scoring study achieving 88% [46, 47] and the lowest 37% [58] which was the only study to be classified as very low. The most notable methodological limitations identified in the present review included failure to blind outcome assessors, a lack of statistical power and limited reporting of familiarisation sessions. Similar findings have been reported by Sultana et al. [108] who also used a modified Downs and Black checklist and Rosenblat et al. [5] who used the PEDro scale. Previous authors identified similar limitations and noted the substantive risk of bias in comparison studies where outcome assessors were not blinded to allocation. The methodological limitations identified in the present review may also have contributed to the finding of extensive funnel plot asymmetry. Often wrongly attributed solely to publication bias, funnel plot asymmetry can be caused by a range of phenomenon collectively referred to as small study effects [109]. Statistical heterogeneity and methodological differences can be causes of small study effects if they induce correlations between sampling error and intervention effects. However, sample size across the included studies was consistent with the interquartile range restricted to between 8 and 11 participants such that statistical heterogeneity may not be the most influential factor

explaining the asymmetry. Previous meta-analyses investigating SIT interventions have not identified any small study effects. Funnel plots and associated null hypothesis tests were presented by Gist et al. [22], Vollaard et al. [24] and Rosenblat et al. [5] with authors reporting non-significant results and no clear asymmetry in the visual plots. Across these reviews the number of data points investigated was low ranging from 9 to 38 reflecting the narrow focus of the reviews to either $\dot{V}O_{2max}$ or $\dot{V}O_{2peak}$. In contrast, in the present meta-analysis a total of 411 outcomes were included in the primary meta-analysis across an extensive range of variables reflecting many different physical outcomes relevant to sporting performance. The included studies all featured interventions conducted on cycle ergometers popular within exercise science laboratories. Software packages connected to cycle ergometers automatically calculate numerous variables that can be analysed and presented as absolute or relative values. Additionally, researchers often compare these variables across multiple repetitions and time points thereby increasing the reported number of outcomes. Across the included studies in the present review, the median number of outcomes extracted was 7, with 15 or more outcomes extracted from over 25% of the studies. Based on the performance focus of this review, additional variables such as metabolic markers and muscle fibre measures which are also frequently reported in SIT intervention studies were not included in this summary such that the actual number of variables analysed by authors was even higher. The potential for researchers to retrospectively select amongst an extensive pool of variables and publish multiple outcomes is a common problem in sport and exercise science which leads to overestimation of effects [110] and may be a primary factor creating the small study effects identified in the present review. With many variables and small participant numbers, by chance, effects for many variables will be overestimated and in a relatively small number of cases overestimations will be extremely large.

An additional source of bias that has the potential to overestimate effects reported in this current review is a lack of familiarisation with testing procedures. Approximately half (53%) of the included studies integrated familiarisation with testing protocols. Where this was included, it was mainly limited to just one familiarisation session or minimal information was provided regarding the procedures adopted. Connected to the issue of familiarisation, the present review identified that only 20% of the included studies reported the reliability of main outcome measures further limiting the confidence that can be placed on accuracy. To assess the effects of potential sources of bias, a comparison between effects sized calculated with and without non-exercise controls was included. The results identified a small positive bias with non-controlled effect sizes, however, some data points demonstrated very large positive errors (Figure 4). Additionally, it may be expected that studies that include a control group are generally of a higher overall quality and are less likely to exhibit large systematic biases. Collectively, instances of very large differences between non-controlled and controlled effect sizes, and the presence of many very large effect sizes (41 effects > 2) despite interventions generally lasting between 2 to 4 weeks, demonstrate that the small study effects identified present a challenge for accurately estimating the benefits of SIT interventions and the most important moderators to generate optimum protocols.

RECOMMENDATIONS FOR FUTURE RESEARCH

The findings from the present review suggest several important areas for future research. Firstly, the review highlights that a large array of both performance outcomes and SIT protocols have been investigated, with the results generally demonstrating moderate improvements. Reflecting the moderator analyses conducted here, future research should

continue to tease out combinations of protocols that maximise specific, predetermined adaptations. However, greater emphasis is required on establishing effective methods to progress SIT training and obtain greater improvements over longer time periods. Most studies investigating SIT interventions are extremely short in duration and often feature no variation or progression in the training stimulus. Where progression has been included, it has generally been restricted to small increases in the number of sprints performed per session. However, given the complexity and interrelated nature of SIT training variables, progression could be achieved through many different options. It is recommended that future studies focus on longer duration interventions guided by periodisation structures and research designs investigated with other training modalities such as resistance training. Secondly, the review highlights limitations of the evidence base that are consistent with other areas in sports science. Most notably, the review identified extensive small study effects that are suggested to be caused primarily by a posteriori selection of outcome variables and data reduction procedures. It is recommended that where possible, future research should be hypothesis-driven with clear and defined outcome measures that best match the aims and hypothesis of the research. It is also recommended that studies select a priori a smaller number outcomes that demonstrate appropriate validity, reliability (only 20% of studies reported reliability of outcome measures) and practical relevance. To address issues of statistical power and precision of effect size estimates, it is suggested that more collaborative work featuring multicentre data collection be considered. Given the ability to standardise training protocols on cycle ergometers and the consistency of equipment used, SIT research may provide an effective model for prospective multicentre collaboration. With regards to improvement of overall methodological quality, prospective reference tools such as the Downs and Black checklist, the Consolidated Standards of Reporting Trials (CONSORT) and Consensus on Exercise Reporting Template (CERT)

can assist with study design and address common limitations including use of small sample sizes, omission of control groups and insufficient use of familiarisation sessions [111-113].

PRACTICAL APPLICATIONS

- Short-term SIT interventions can be used to create medium improvements across a range of physical performance outcomes in healthy individuals.
- Training protocols comprising longer sprint durations and more sprints, result in greater improvements in performance outcomes. These outcomes can be affected by the work to rest ratio, with shorter rest periods more effective for aerobic outcomes, whereas longer rest periods were more effective for anaerobic outcomes.
- Future SIT interventions studies should be designed and conducted in accordance with the proposed methodological guidelines identified within this review. It is recommended that prior to data collection researchers select a limited number of outcomes that match the research hypothesis and select data reduction procedures that are appropriate and adequately statistical powered accounting for multiplicity issues. Use of research evaluation tools (Downs and Black, CONSORT & CERT) should be used to inform study design.

Declarations

Funding: Not Applicable.

Conflicts of Interest/Competing Interest: The authors declare there are no conflicts of interest or competing interests.

Availability of Data and Material: Summaries of data generated within the present study will be included within the published article and supplementary files. Further data requests should be made through reasonable contact with the corresponding author.

Ethics Approval and Consent to Participate: Not applicable.

Consent for Publication: Not applicable.

Authors' Contributions: The protocol was designed by AH, PS and TC. AH, PS and TC independently undertook the searches and selected studies. AH and TC screened all titles and abstracts of sources, and independently completed data extraction. Where discrepancies or disagreements occurred, with these were resolved through collective agreements with PS, MK and RA. Methodological quality and risk of bias were evaluated by TC, RA and MK. PS undertook all statistical analyses, with the resultant manuscript written by AH, PS, RA, MK and JB. All authors have read and approved the final manuscript.

Acknowledgements: Not applicable.

Authors' Information: Not applicable.

References

1. Ramos JS, Dalleck LC, Tjonna AE, Beetham KS, Coombes JS. The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: A systematic review and meta-analysis. Sports medicine. 2015;45(5):679-92.

2. Gibala MJ, Little JP, Macdonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. J Physiol (Lond). 2012 03;590(5):1077-84.

3. Milanović Z, Sporiš G, Weston M. Effectiveness of high-intensity interval training (HIT) and continuous endurance training for VO improvements: A systematic review and meta-analysis of controlled trials. Sports Medicine. 2015 10;45(10):1469-81.

4. Billat LV. Interval training for performance: A scientific and empirical practice. Sports medicine. 2001;31(1):13-31.

5. Rosenblat MA, Perrotta AS, Thomas SG. Effect of high-intensity interval training versus sprint interval training on time-trial performance: A systematic review and meta-analysis. Sports Medicine. 2020:1-17.

6. Viana AA, Fernandes B, Alvarez C, Guimarães GV, Ciolac EG. Prescribing high-intensity interval exercise by RPE in individuals with type 2 diabetes: Metabolic and hemodynamic responses. Applied Physiology, Nutrition, and Metabolism. 2019;44(4):348-56.

7. Esfarjani F, Laursen PB. Manipulating high-intensity interval training: Effects on V˙ O2max, the lactate threshold and 3000 m running performance in moderately trained males. Journal of science and medicine in sport. 2007;10(1):27-35.

8. Stepto NK, Hawley JA, Dennis SC, Hopkins WG. Effects of different interval-training programs on cycling time-trial performance. Med Sci Sports Exerc. 1999;31:736-41.

9. Akca F, Aras D. Comparison of rowing performance improvements following various high-intensity interval trainings. The Journal of Strength & Conditioning Research. 2015;29(8):2249-54.

10. Sousa AC, Fernandes RJ, Boas JPV, Figueiredo P. High-intensity interval training in different exercise modes: Lessons from time to exhaustion. Int J Sports Med. 2018 Sep;39(9):668-73.

11. Astorino TA, Allen R, Roberson D, Jurancich M, Lewis R, McCarthy K, et al. Adaptations to high-intensity training are independent of gender. Eur J Appl Physiol. 2011 07;111(7):1279-86.

12. Yamagishi T, Babraj J. Effects of reduced-volume of sprint interval training and the time course of physiological and performance adaptations. Scand J Med Sci Sports. 2017;27(12):1662-72.

13. Lloyd Jones MC, Morris MG, Jakeman JR. Effect of work: Rest ratio on cycling performance following sprint interval training: A randomized control trial. J Strength Cond Res. 2019;33(12):3263-8.

14. Kavaliauskas M, Aspe RR, Babraj J. High-intensity cycling training: The effect of work-to-rest intervals on running performance measures. Journal of Strength and Conditioning Research. 2015;29(8):2229-36.

15. Mitchell BL, Lock MJ, Davison K, Parfitt G, Buckley JP, Eston RG. What is the effect of aerobic exercise intensity on cardiorespiratory fitness in those undergoing cardiac rehabilitation? A systematic review with meta-analysis. Br J Sports Med. 2019;53(21):1341-51.

16. Etxebarria N, Anson JM, Pyne DB, Ferguson RA. High-intensity cycle interval training improves cycling and running performance in triathletes. European Journal of Sport Science EJSS : Official Journal of the European College of Sport Science. 2014;14(6):521-9.

17. Naimo MA, de Souza EO, Wilson JM, Carpenter AL, Gilchrist P, Lowery RP, et al. High-intensity interval training has positive effects on performance in ice hockey players. Int J Sports Med. 2015 Jan;36(1):61-6.

18. Naves JPA, Viana RB, Rebelo ACS, de Lira, Claudio Andre B, Pimentel GD, Lobo PCB, et al. Effects of high-intensity interval training vs. sprint interval training on anthropometric measures and cardiorespiratory fitness in healthy young women. Frontiers in physiology. 2018;9:1738.

19. Viana RB, de Lira C,Andre Barbosa, Naves JPA, Coswig VS, Del Vecchio FB, Ramirez-Campillo R, et al. Can we draw general conclusions from interval training studies? Sports Medicine. 2018 09;48(9):2001-9.

20. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle. Sports medicine. 2013;43(10):927-54.

21. Sloth M, Sloth D, Overgaard K, Dalgas U. Effects of sprint interval training on VO2max and aerobic exercise performance: A systematic review and meta-analysis. Scand J Med Sci Sports. 2013 12;23(6):e341-52.

22. Gist NH, Fedewa MV, Dishman RK, Cureton KJ. Sprint interval training effects on aerobic capacity: A systematic review and meta-analysis. Sports Medicine. 2014 Feb;44(2):269-79.

23. Weston KS, Wisloff U, Coombes JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: A systematic review and meta-analysis. Br J Sports Med. 2014 Aug;48(16):1227-34.

24. Vollaard NBJ, Metcalfe RS, Williams S. Effect of number of sprints in an SIT session on change in VO2max: a meta-analysis. Med Sci Sports Exerc. 2017 Jun;49(6):1147-56.

25. Zelt JGE, Hankinson PB, Foster WS, Williams CB, Reynolds J, Garneys E, et al. Reducing the volume of sprint interval training does not diminish maximal and submaximal performance gains in healthy men. Eur J Appl Physiol. 2014;114(11):2427-36.

26. Creer AR, Ricard MD, Conlee RK, Hoyt GL, Parcell AC. Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. Int J Sports Med. 2004;25(2):92-8.

27. Vera-Ibanez A, Colomer-Poveda D, Romero-Arenas S, Vinuela-Garcia M, Marquez G. Neural adaptations after short-term wingate-based high-intensity interval training. Journal of Musculoskeletal Neuronal Interactions. 2017 Dec 01;17(4):275-82.

28. Moher D, Liberati A, Tetzlaff J, Altman DG, Prisma Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS med. 2009;6(7):e1000097.

29. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: An emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008 Apr 26;336(7650):924-6.

30. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. Journal of Epidemiology & Community Health. 1998;52(6):377-84.

31. Kruschke JK, Liddell TM. The bayesian new statistics: Hypothesis testing, estimation, meta-analysis, and power analysis from a bayesian perspective. Psychon Bull Rev. 2018;25(1):178-206.

32. Caldwell A, Vigotsky AD. A case against default effect sizes in sport and exercise science. PeerJ. 2020;8:e10314.

33. Morris SB. Estimating effect sizes from pretest-posttest-control group designs. Organ Res Methods. 2008;11(2):364-86.

34. Saunders B, Elliott-Sale K, Artioli GG, Swinton PA, Dolan E, Roschel H, et al. Beta-alanine supplementation to improve exercise capacity and performance: A systematic review and meta-analysis. Br J Sports Med. 2017 Apr;51(8):658-69.

35. Estrada E, Ferrer E, Pardo A. Statistics for evaluating pre-post change: Relation between change in the distribution center and change in the individual scores. Frontiers in psychology. 2019;9:2696.

36. Fu R, Gartlehner G, Grant M, Shamliyan T, Sedrakyan A, Wilt TJ, et al. Conducting quantitative synthesis when comparing medical interventions: AHRQ and the effective health care program. J Clin Epidemiol. 2011;64(11):1187-97.

37. Cohen J. Statistical power analysis for the behavioral sciences. Academic press; 2013.

38. Bürkner P. An R package for bayesian multilevel models using stan. J Statist Software.

39. Gelman A, Carlin JB, Stern HS, Dunson DB, Vehtari A, Rubin DB. Bayesian data analysis. CRC press; 2013.

40. Moreno SG, Sutton AJ, Ades A, Stanley TD, Abrams KR, Peters JL, et al. Assessment of regression-based methods to adjust for publication bias through a comprehensive simulation study. BMC medical research methodology. 2009;9(1):2.

41. Fernández-Castilla B, Declercq L, Jamshidi L, Beretvas SN, Onghena P, Van den Noortgate W. Detecting selection bias in meta-analyses with multiple outcomes: A simulation study. The Journal of Experimental Education. 2019:1-20.

42. Babraj JA, Vollaard NBJ, Keast C, Guppy FM, Cottrell G, Timmons JA. Extremely short duration high intensity interval training substantially improves insulin action in young healthy males. BMC Endocrine Disorders. 2009;9:3-.

43. Bailey SJ, Wilkerson DP, DiMenna FJ, Jones AM. Influence of repeated sprint training on pulmonary O2 uptake and muscle deoxygenation kinetics in humans. J Appl Physiol. 2009;106(6):1875-87.

44. Barnett C, Carey M, Proietto J, Cerin E, Febbraio M, Jenkins D. Muscle metabolism during sprint exercise in man: Influence of sprint training. Journal of science and medicine in sport. 2004;7(3):314-22.

45. Bayati M, Farzad B, Gharakhanlou R, Agha-Alinejad H. A practical model of low-volume high-intensity interval training induces performance and metabolic adaptations that resemble 'all-out' sprint interval training. Journal of Sports Science and Medicine. 2011;10(3):571-6.

46. Benítez-Flores S, Medeiros AR, Voltarelli FA, Iglesias-Soler E, Doma K, Simões HG, et al. Combined effects of very short “all out” efforts during sprint and resistance training on physical and physiological adaptations after 2 weeks of training. Eur J Appl Physiol. 2019;119(6):1337-51.

47. Broatch JR, Petersen A, Bishop DJ. Cold-water immersion following sprint interval training does not alter endurance signaling pathways or training adaptations in human skeletal muscle. American Journal of Physiology - Regulatory Integrative & Comparative Physiology. 2017 Oct 01;313(4):R372-84.

48. Burgomaster KA, Hughes SC, Heigenhauser GJF, Bradwell SN, Gibala MJ. Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. Journal of Applied Physiology (Bethesda, Md.: 1985). 2005;98(6):1985-90.

49. Burgomaster Ka, Heigenhauser GJF, Gibala MJ. Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance. Journal of applied physiology (Bethesda, Md.: 1985). 2006;100(6):2041-7.

50. Burgomaster KA, Cermak NM, Phillips SM, Benton CR, Bonen A, Gibala MJ. Divergent response of metabolite transport proteins in human skeletal muscle after sprint interval training and detraining. American Journal of Physiology.Regulatory, Integrative and Comparative Physiology. 2007;292(5):R1970-6.

51. Burgomaster KA, Howarth KR, Phillips SM, Rakobowchuk M, Macdonald MJ, McGee SL, et al. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. J Physiol (Lond). 2008;586(1):151-60.

52. Camacho-Cardenosa M, Camacho-Cardenosa A, Martinez Guardado I, Marcos-Serrano M, Timon R, Olcina G. A new dose of maximal-intensity interval training in hypoxia to improve body composition and hemoglobin and hematocrit levels: A pilot study. Journal of Sports Medicine & Physical Fitness. 2017 Jan-Feb;57(1-2):60-9.

53. Cochran AJR, Percival ME, Thompson S, Gillen JB, MacInnis MJ, Potter MA, et al. Beta-alanine supplementation does not augment the skeletal muscle adaptive response to 6 weeks of sprint interval training. International Journal of Sport Nutrition & Exercise Metabolism. 2015 Dec;25(6):541-9.

54. Cocks M, Shaw CS, Shepherd SO, Fisher JP, Ranasinghe AM, Barker TA, et al. Sprint interval and endurance training are equally effective in increasing muscle microvascular density and eNOS content in sedentary males. J Physiol (Lond). 2013;591(3):641-56.

55. Forbes SC, Slade JM, Meyer RA. Short-term high-intensity interval training improves phosphocreatine recovery kinetics following moderate-intensity exercise in humans. Applied Physiology, Nutrition, and Metabolism. 2008;33(6):1124-31.

56. Gibala MJ, Little JP, van Essen M, Wilkin GP, Burgomaster Ka, Safdar A, et al. Short-term sprint interval versus traditional endurance training: Similar initial adaptations in human skeletal muscle and exercise performance. J Physiol (Lond). 2006;575:901-11.

57. Gillen JB, Martin BJ, MacInnis MJ, Skelly LE, Tarnopolsky MA, Gibala MJ. Twelve weeks of sprint interval training improves indices of cardiometabolic health similar to traditional endurance training despite a five-fold lower exercise volume and time commitment. PLoS ONE [Electronic Resource]. 2016;11(4):e0154075.

58. Harmer AR, McKenna MJ, Sutton JR, Snow RJ, Ruell Pa, Booth J, et al. Skeletal muscle metabolic and ionic adaptations during intense exercise following sprint training in humans. Journal of Applied Physiology (Bethesda, Md.: 1985). 2000;89(5):1793-803.

59. Harris E, Rakobowchuk M, Birch KM. Sprint interval and sprint continuous training increases circulating CD34 cells and cardio-respiratory fitness in young healthy women. PLoS ONE. 2014;9(9):e108720.

60. Hazell TJ, MacPherson REK, Gravelle BMR, Lemon PWR. 10 or 30-s sprint interval training bouts enhance both aerobic and anaerobic performance. Eur J Appl Physiol. 2010;110(1):153-60.

61. Hommel J, Öhmichen S, Rudolph UM, Hauser T, Schulz H. Effects of six-week sprint interval or endurance training on calculated power in maximal lactate steady state. Biology of Sport. 2019 01;36(1):47-54.

62. Ijichi T, Hasegawa Y, Morishima T, Kurihara T, Hamaoka T, Goto K. Effect of sprint training: Training once daily versus twice every second day. European journal of sport science. 2015;15(2):143-50.

63. Ikutomo A, Kasai N, Goto K. Impact of inserted long rest periods during repeated sprint exercise on performance adaptation. European Journal of Sport Science EJSS : Official Journal of the European College of Sport Science. 2018 Feb;18(1):47-53.

64. Jakeman J, Adamson S, Babraj J. Extremely short duration high-intensity training substantially improves endurance performance in triathletes. Applied Physiology, Nutrition, and Metabolism. 2012;37(5):976-81.

65. Kavaliauskas M, Steer T, Babraj J. Cardiorespiratory fitness and aerobic performance adaptations to a 4-week sprint interval training in young healthy untrained females. Sport Sciences for Health. 2017 04;13(1):17-23.

66. Larsen RG, Maynard L, Kent JA. High-intensity interval training alters ATP pathway flux during maximal muscle contractions in humans. Acta Physiologica. 2014 05;211(1):147-60.

67. Lewis EJH, Stucky F, Radonic PW, Metherel AH, Wolever TMS, Wells GD. Neuromuscular adaptations to sprint interval training and the effect of mammalian omega-3 fatty acid supplementation. Eur J Appl Physiol. 2017 Mar;117(3):469-82.

68. Little JP, Langley J, Lee M, Myette-Côté E, Jackson G, Durrer C, et al. Sprint exercise snacks: A novel approach to increase aerobic fitness. Eur J Appl Physiol. 2019;119(5):1203-12.

69. McGarr GW, Hartley GL, Cheung SS. Neither short-term sprint nor endurance training enhances thermal response to exercise in a hot environment. Journal of occupational and environmental hygiene. 2014;11(1):47-53.

70. Metcalfe RS, Babraj JA, Fawkner SG, Vollaard NBJ. Towards the minimal amount of exercise for improving metabolic health: Beneficial effects of reduced-exertion high-intensity interval training. Eur J Appl Physiol. 2012;112(7):2767-75.

71. Metcalfe RS, Tardif N, Thompson D, Vollaard NB. Changes in aerobic capacity and glycaemic control in response to reduced-exertion high-intensity interval training (REHIT) are not different between sedentary men and women. Applied Physiology, Nutrition, and Metabolism. 2016;41(11):1117-23.

72. Muggeridge DJ, Sculthorpe N, James PE, Easton C. The effects of dietary nitrate supplementation on the adaptations to sprint interval training in previously untrained males. Journal of Science & Medicine in Sport. 2017 Jan;20(1):92-7.

73. Nalçakan GR. The effects of sprint interval vs. continuous endurance training on physiological and metabolic adaptations in young healthy adults. Journal of Human Kinetics. 2014;44(1):97-109.

74. Nalçakan GR, Songsorn P, Fitzpatrick BL, Yüzbasioglu Y, Brick NE, Metcalfe RS, et al. Decreasing sprint duration from 20 to 10 s during reduced-exertion high-intensity interval training (REHIT) attenuates the increase in maximal aerobic capacity but has no effect on affective and perceptual responses. Applied Physiology, Nutrition & Metabolism. 2018 04;43(4):338-44.

75. O'Driscoll JM, Wright SM, Taylor KA, Coleman DA, Sharma R, Wiles JD. Cardiac autonomic and left ventricular mechanics following high intensity interval training: A randomized crossover controlled study. J Appl Physiol. 2018 10;125(4):1030-40.

76. Ørtenblad N, Lunde PK, Levin K, Andersen JL, Pedersen PK. Enhanced sarcoplasmic reticulum ca(2+) release following intermittent sprint training. American Journal of Physiology. Regulatory, Integrative and Comparative Physiology. 2000;279(1):R152-60.

77. Parra J, Cadefau JA, Rodas G, Amigo N, Cusso R. The distribution of rest periods affects performance and adaptations of energy metabolism induced by high-intensity training in human muscle. Acta Physiol Scand. 2000;169(2):157-65.

78. Rakobowchuk M, Tanguay S, Burgomaster KA, Howarth KR, Gibala MJ, MacDonald MJ. Sprint interval and traditional endurance training induce similar improvements in peripheral arterial stiffness and flow-mediated dilation in healthy humans. AJP: Regulatory, Integrative and Comparative Physiology. 2008;295(1):R236-42.

79. Richardson A, Gibson O. Simulated hypoxia does not further improve aerobic capacity during sprint interval training. J Sports Med Phys Fitness. 2015;55(10):1099-106.

80. Rodas G, Ventura JL, Cadefau JA, Cusso R, Parra J. A short training programme for the rapid improvement of both aerobic and anaerobic metabolism. Eur J Appl Physiol. 2000;82(5-6):480-6.

81. Scalzo RL, Peltonen GL, Binns SE, Shankaran M, Giordano GR, Hartley DA, et al. Greater muscle protein synthesis and mitochondrial biogenesis in males compared with females during sprint interval training. The FASEB Journal. 2014;28(6):2705-14.

82. Schlittler M, Neyroud D, Tanga C, Zanou N, Kamandulis S, Skurvydas A, et al. Three weeks of sprint interval training improved high-intensity cycling performance and limited ryanodine receptor modifications in recreationally active human subjects. Eur J Appl Physiol. 2019;119(9):1951-8.

83. Shenouda N, Gillen JB, Gibala MJ, MacDonald MJ. Changes in brachial artery endothelial function and resting diameter with moderate-intensity continuous but not sprint interval training in sedentary men. J Appl Physiol. 2017 Oct 01;123(4):773-80.

84. Shepherd SO, Cocks M, Tipton K, Ranasinghe AM, Barker TA, Burniston JG, et al. Sprint interval and traditional endurance training increase net intramuscular triglyceride breakdown and expression of perilipin 2 and 5. J Physiol (Lond). 2013;591(3):657-75.

85. Songsorn P, Lambeth-Mansell A, Mair JL, Haggett M, Fitzpatrick BL, Ruffino J, et al. Exercise training comprising of single 20-s cycle sprints does not provide a sufficient stimulus for improving maximal aerobic capacity in sedentary individuals. Eur J Appl Physiol. 2016 Aug;116(8):1511-7.

86. Terada T, Toghi Eshghi SR, Liubaoerjijin Y, Kennedy M, Myette-Côté E, Fletcher K, et al. Overnight fasting compromises exercise intensity and volume during sprint interval training but improves high-intensity aerobic endurance. J Sports Med Phys Fitness. 2019;59:357-65.

87. Thompson C, Wylie LJ, Blackwell JR, Fulford J, Black MI, Kelly J, et al. Influence of dietary nitrate supplementation on physiological and muscle metabolic adaptations to sprint interval training. J Appl Physiol. 2017 Mar 01;122(3):642-52.

88. Thompson C, Vanhatalo A, Kadach S, Wylie LJ, Fulford J, Ferguson SK, et al. Discrete physiological effects of beetroot juice and potassium nitrate supplementation following 4-wk sprint interval training. J Appl Physiol. 2018;124(6):1519-28.

89. Yamagishi T, Babraj J. Active recovery induces greater endurance adaptations when performing sprint interval training. J Strength Cond Res. 2019 Apr;33(4):922-30.

90. Metcalfe R, Fawkner S, Vollaard N. No acute effect of reduced-exertion high-intensity interval training (REHIT) on insulin sensitivity. Int J Sports Med. 2016 05;37(5):354-8.

91. Linossier MT, Dormois D, Perier C, Frey J, Geyssant A, Denis C. Enzyme adaptations of human skeletal muscle during bicycle short-sprint training and detraining. Acta Physiol Scand. 1997;161(4):439-45.

92. Gaitanos GC, Williams C, Boobis LH, Brooks S. Human muscle metabolism during intermittent maximal exercise. J Appl Physiol. 1993;75(2):712-9.

93. Bogdanis GC, Nevill ME, Boobis LH, Lakomy HK. Contribution of phosphocreatine and aerobic metabolism to energy supply during repeated sprint exercise. Journal of Applied Physiology (Bethesda, Md.: 1985). 1996;80(3):876-84.

94. Sousa FAB, Vasque RE, Gobatto CA. Anaerobic metabolism during short all-out efforts in tethered running: Comparison of energy expenditure and mechanical parameters between different sprint durations for testing. PloS one. 2017;12(6):e0179378.

95. Bogdanis GC, Nevill ME, Lakomy HKA, Boobis LH. Power output and muscle metabolism during and following recovery from 10 and 20 s of maximal sprint exercise in humans. Acta Physiol Scand. 1998;163(3):261-72.

96. Fiorenza M, Hostrup M, Gunnarsson TP, Shirai Y, Schena F, Iaia FM, et al. Neuromuscular fatigue and metabolism during high-intensity intermittent exercise. Med Sci Sports Exerc. 2019 Aug;51(8):1642-52.

97. Stavrinou PS, Bogdanis GC, Giannaki CD, Terzis G, Hadjicharalambous M. High-intensity interval training frequency: Cardiometabolic effects and quality of life. Int J Sports Med. 2018;39(03):210-7.

98. Bogdanis GC, Nevill ME, Boobis LH, Lakomy H, Nevill AM. Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. J Physiol (Lond). 1995;482(2):467-80.

99. MacDougall JD, Hicks AL, MacDonald JR, McKelvie RS, Green HJ, Smith KM. Muscle performance and enzymatic adaptations to sprint interval training. Journal of Applied Physiology (Bethesda, Md.: 1985). 1998;84(6):2138-42.

100. Lloyd Jones MC, Morris MG, Jakeman JR. Impact of time and work:rest ratio matched sprint interval training programmes on performance: A randomised controlled trial. Journal of Science and Medicine in Sport. 2017 (1034-1038).

101. Gibala MJ, McGee SL, Garnham AP, Howlett KF, Snow RJ, Hargreaves M. Brief intense interval exercise activates AMPK and p38 MAPK signaling and increases the expression of PGC-1α in human skeletal muscle. J Appl Physiol. 2009;106(3):929-34.

102. Little JP, Safdar A, Bishop D, Tarnopolsky MA, Gibala MJ. An acute bout of high-intensity interval training increases the nuclear abundance of PGC-1α and activates mitochondrial biogenesis in human skeletal muscle. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology. 2011;300(6):R1303-10.

103. Serpiello FR, McKenna MJ, Bishop DJ, Aughey RJ, Caldow MK, Cameron-Smith D, et al. Repeated sprints alter signaling related to mitochondrial biogenesis in humans. Med Sci Sports Exerc. 2012 May;44(5):827-34.

104. Edgett BA, Bonafiglia JT, Baechler BL, Quadrilatero J, Gurd BJ. The effect of acute and chronic sprint-interval training on LRP130, SIRT3, and PGC-1alpha expression in human skeletal muscle. Physiological Reports. 2016;4(17):09.

105. Taylor CW, Ingham SA, Hunt JE, Martin NR, Pringle JS, Ferguson RA. Exercise duration-matched interval and continuous sprint cycling induce similar increases in AMPK phosphorylation, PGC-1α and VEGF mRNA expression in trained individuals. Eur J Appl Physiol. 2016;116(8):1445-54.

106. Danek N, Smolarek M, Michalik K, Zatoń M. Comparison of acute responses to two different cycling sprint interval exercise protocols with different recovery durations. International Journal of Environmental Research and Public Health. 2020;17(3):1026.

107. Olek RA, Kujach S, Ziemann E, Ziolkowski W, Waz P, Laskowski R. Adaptive changes after 2 weeks of 10-s sprint interval training with various recovery times. Frontiers in physiology. 2018;9:392.

108. Sultana RN, Sabag A, Keating SE, Johnson NA. The effect of low-volume high-intensity interval training on body composition and cardiorespiratory fitness: A systematic review and meta-analysis. Sports Medicine. 2019:1-35.

109. Sterne JA, Sutton AJ, Ioannidis JP, Terrin N, Jones DR, Lau J, et al. Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. BMJ. 2011 Jul 22;343:d4002.

110. Buttner F, Toomey E, McClean S, Roe M, Delahunt E. Are questionable research practices facilitating new discoveries in sport and exercise medicine? the proportion of supported hypotheses is implausibly high. Br J Sports Med. 2020 Jul 22.

111. Bishop D. An applied research model for the sport sciences. Sports Medicine. 2008;38(3):253-63.

112. Dwan K, Li T, Altman DG, Elbourne D. CONSORT 2010 statement: Extension to randomised crossover trials. BMJ. 2019 Jul 31;366:l4378.

113. Slade SC, Dionne CE, Underwood M, Buchbinder R. Consensus on exercise reporting template (CERT): Explanation and elaboration statement. Br J Sports Med. 2016 Dec;50(23):1428-37.

Figure Legends

Figure 1: PRISMA flow diagram detailing the results of each search and screening stage. A final number of 55 studies were included in the review.

Figure 2 (above plot): Bayesian Forest plot of multilevel meta-analysis conducted on non-controlled effect sizes.

Figure 2 (below plot)

Results from individual studies represent shrunken estimates based on the random effects model fitting and borrowing of information across studies to reduce uncertainty. Circles represent the pooled estimate from individual studies and across studies (average), generated with Bayesian inference along with the 95% credible intervals (95%CrI). Positive values describe improvements in outcomes based on SIT intervention.

Figure 3 (above plot): Comparison of non-controlled and no-exercise-controlled effect sizes

Figure 3 (below plot): Solid line is the unity line and dashed line is the best fit line illustrating positive bias of non-controlled effect sizes.

Figure 4 (above plot): Funnel plot of non-controlled effect sizes and their standard errors.

Figure 4 (below plot): Highlighted blue region illustrates pooled effect size estimate and 95% credible interval. Red line illustrates a null effect.

Table 1: Overview of studies included in systematic review and meta-analysis

Author	Aim	SIT Intervention Population	Study Design	Intervention Variables	Extracted Outcomes	Summary of findings	Quality Rating
Astorino et al [11]	To compare differences in adaptations to short-term high intensity training in active men and women matched for age and VO_{2max}.	Recreational males (n = 11) and females (n = 9)	Non-exercise control	2 weeks (6 sessions), 4-6 x 30s sprints, 300s recovery, 7.5%BM resistance	Peak Power (W.kg), Mean Power (W.kg) and Minimum Power (W.kg), from a Wingate Test; VO_{2max} (L.min; ml.kg.min), VCO_2 (L.min), V_E (L.min), O2 Pulse at VO_{2max} (ml.beat) and RER from an incremental exercise test to exhaustion on a cycle ergometer	Similar improvements in power output and oxygen kinetics occurred between sexes matched for VO_{2max} and physical activity.	18/24 75% Moderate
Babraj et al [42]	To determine if low volume high intensity interval exercise involving ~250kcal work improves glycaemic control in sedentary young adults.	Sedentary males (n = 16)	Non-exercise control	2 weeks (6 sessions), 4-6 x 30s sprints, 240s recovery, 7.5%BM resistance	250kJ Cycle Time Trial (s)	Low volume high intensity interval exercise increases glycaemic control and 250kJ cycle time trial performance increased	12/24 50% Low
Bailey et al [43]	To determine the effect of work-matched repeated sprint training and endurance training on the kinetics of VO2, HR and muscle deoxygenation during moderate and severe intensity exercise and	Recreational males (n = 5) and females (n = 3)	Exercise comparator (Endurance Training), and Non-exercise control	2 weeks (6 sessions), 4-7 x 30s sprints, 240s recovery, 7.5%BM resistance	Total Work Done (kJ) within each training session; VO_{2peak} (L.min; ml.kg.min), VO_2 (L.min) and work rate (W) at gas exchange threshold, and peak work rate (W) from an incremental	Repeated sprint training accelerated VO_2 kinetics during transitions to moderate and severe intensity exercise and enhanced exercise tolerance	17/24 70.8% Moderate

	tolerance in recreationally active subjects				exercise test to exhaustion on a cycle ergometer; VO_{2peak} (L.min) and time to exhaustion (s) during a moderate and severe cycle step test	compared to endurance training	
Barnett et al [44]	To compare enzymatic and histochemical adaptations to sprint training with sprint performance and exercise-induced changes in high energy phosphagens, muscle glycogen and lactate	Recreational (n = 8)	Non-exercise control	8 weeks (24 sessions), 3-6 x 30s sprints, 180s recovery, 8.87 flywheel revolutions per pedal crank revolution gear ratio resistance	VO_{2peak} (L.min) from an incremental exercise test to exhaustion on a cycle ergometer; Peak Power (W) and Mean Power (W) during 10s sprint	Sprint training improved sprint and VO_{2peak} performance, and lowered net ATP degradation during sprint exercise	10/24 41.7% Low
Bayati et al [45]	To compare the established SIT protocol versus a modified type of high intensity training on both aerobic and anaerobic performance measures	Recreational males (n = 8)	Exercise comparator (Sprint training at 125% power at VO_{2max}) and Non-exercise control	4 weeks (12 sessions), 3-5 x 30s sprints, 240s recovery, 7.5%BM resistance	VO_{2max} (ml.kg.min) from an incremental exercise test to exhaustion on a cycle ergometer; Power at VO_{2max} (W), Total Work (kJ), and time to exhaustion at power at VO_{2max} (s) from a time to exhaustion at power at VO_{2max} test; Peak Power (W), Mean Power (W) and Total Work (kJ) from a Wingate Test	Aerobic and anaerobic performance similarly improved across both protocols, except for mean power output which only improved within the SIT protocol	13/24 54.2% Low
Benítez-Flores et al [46]	To determine the combined effects of resistance and sprint	Recreational males (n = 4) and females (n = 4)	Exercise comparator	2 weeks (6 sessions), 6-12 x 5s	VO_{2max} (ml.kg.min), Power at VO_{2max} (W), and RER_{max} from an	Concurrent training promotes improvements in	21/24

	training, with very short efforts (5s), on aerobic and anaerobic performances and cardio-metabolic health-related parameters in young healthy adults		(Undulating periodised resistance training), and (Concurrent resistance training and SIT), and Non-exercise control	sprints, 24s recovery, 0.7Nm resistance	incremental exercise test to exhaustion on a cycle ergometer; Peak Power (W), Total Work (kJ) and Maximum Pedalling Rate (rpm) from 2x5s sprints; CMJ height (cm); Mean Velocity ($m.s^{-1}$), Mean Power (W), Mean Force (N) from an Isoinertial Squat Test	lower body strength and aerobic capacity similar to resistance training and SIT interventions.	87.5% High
Broatch et al [47]	To determine the effects of regular post-exercise cold water immersion on key markers of mitochondrial biogenesis following 6 weeks of SIT	Recreational males (n = 8)	Exercise comparator (Cold water immersion)	6 weeks (18 sessions), 4-6 x 30s sprints, 240s recovery, 7.5-9.5%BM resistance	2km Cycle Time Trial (s) and Mean Power (W); 20km Cycle Time Trial (s), Lactate Threshold and Peak Aerobic Power (W) from an intermittent graded exercise test; VO_{2peak} (ml.kg.min) from a steady state cycle to fatigue at supramaximal power output.	Cold water immersion administered following 6 weeks of SIT had limited effects on endurance performance, mitochondrial biogenesis, or changes in mitochondrial content and function	19/24 79.2% Moderate
Burgomaster et al [48]	To determine the effects of six sessions of SIT on muscle oxidative potential, VO_{2peak}, and endurance time to fatigue during cycling at an intensity equivalent to 80% VO_{2peak}.	Recreational males (n = 6) and females (n = 2)	Non-exercise control	2 weeks (6 sessions), 4-7 x 30s sprints, 240s recovery, 7.5%BM resistance	O_2 uptake (L.min), Expired Ventilation (L.min), RER, VO_{2peak} (ml.kg.min), and time to fatigue (min) from an incremental exercise test to exhaustion on a cycle ergometer;	SIT increased citrate synthase maximal activity and doubled endurance capacity during cycling exercise at 80% VO_{2peak} in recreationally active subjects	12/24 50% Low

					Peak Power (W) and Mean Power (W) across four consecutive Wingate Tests		
Burgomaster et al [49]	To determine the effects of 2 weeks of SIT on carbohydrate metabolism during submaximal exercise	Recreational males (n = 8)	Non-exercise control	2 weeks (6 sessions), 4-6 x 30s sprints, 240s recovery, 7.5%BM resistance	Peak Power (W) and Mean Power (W) from a Wingate Test; 250kJ Time Trial (s) and Mean Power (W); VO_2 (L.min) at 60% VO_{2peak} and 90% VO_{2peak} during a two stage cycling test.	SIT decreased net muscle glycogenolysis and lactate accumulation, increased pyruvate oxidation capacity, and decreased 250kJ Time Trial time.	15/24 62.5% Moderate
Burgomaster et al [50]	To determine the time course for adaptations in metabolite transport proteins following SIT	Recreational males (n = 8)	Non-exercise control	6 weeks (18 sessions), 4-6 x 30s sprints, 240s recovery, 7.5%BM resistance	250kJ Cycle Time Trial (min) and Mean Power (W)	Muscle oxidative potential and proteins associated with glucose and lactate/H^+ transport, GLUT4 and MCT4, increased following 1 week of SIT, and MCT1 increased following 6 weeks of SIT	12/24 50% Low
Burgomaster et al [51]	To compare the effects of endurance training and SIT on adaptations of metabolic markers	Recreational males (n = 5) and females (n = 5)	Exercise comparator (Endurance training)	2 weeks (6 sessions), 4-6 x 30s sprints, 270s recovery, ~500W resistance	VO_{2peak} (ml.kg.min; L.min) from an incremental exercise test to exhaustion on a cycle ergometer, and VO_2 (L.min), RER and Ventilation (L.min) at 65%VO_{2max}	SIT elicits comparable adaptations in markers of skeletal muscle carbohydrate and lipid metabolism, and metabolic control, as endurance training despite a lower training duration	12/24 50% Low

Camacho-Cardenosa et al [52]	To determine the effects of maximal-intensity interval training in hypoxia in active adults	Recreational participants (n = 8)	Exercise comparator (Hypoxia), and Non-exercise control	4 weeks (8 sessions), 2 sets of 5 x 10s sprints, 20-600s recovery, no resistance stated	VO_{2max} (ml.kg.min), Peak Power (W), Mean Power (W), Mean Cadence (rpm), Maximum Torque (Nm) from a 3-minute all out test	Eight sessions of maximal-intensity interval training in hypoxia is enough to decrease the percentage of fat mass, improve HCT and Hb parameters, and mean muscle power in healthy and active adults	15/24 62.5% Moderate
Cochran et al [53]	To determine if β-ALA supplementation or a placebo would improve physiological and performance adaptations following SIT	Recreational males (n = 12)	Exercise comparator (β-ALA supplement & SIT)	6 weeks (18 sessions), 4-6 x 30s sprints, 240s recovery, 7.5%BM resistance	VO_{2peak} (ml.kg.min) and Peak Power (W) from an incremental exercise test to exhaustion on a cycle ergometer; 250kJ Time trial Mean Power (W) and time (s); Mean Power (W) from a repeated Wingate test	SIT with β-ALA supplementation did not augment performance measures, training workload, or improvements in skeletal muscle oxidative capacity in comparison with a SIT with placebo intervention	19/24 79.2% Moderate
Cocks et al [54]	To determine the effects of 6 weeks of traditional endurance training and SIT on skeletal muscle microvascular density and microvascular enzyme content (eNOS and NOX2) in previously sedentary men.	Sedentary males (n = 8)	Exercise comparator (Endurance Training)	6 weeks (18 sessions), 4-6 x 30s sprints, 270s recovery, 7.5%BM resistance	VO_{2peak} (ml.kg.min), and Peak Aerobic Power Output (W) from an incremental exercise test to exhaustion on a cycle ergometer	Muscle microvascular density and eNOS protein content increased following endurance training and sprint interval training in sedentary males	15/24 62.5% Moderate

Creer et al [26]	To determine the effects of short term, high intensity sprint training on the root mean squared and median frequency derived from EMG, peak power, mean power, total work, and plasma lactate levels during a series of 30-s maximal sprints compared to endurance training alone in trained cyclists.	Competitive males (n = 10)	Non-exercise control	4 weeks (8 sessions), 4-10 x 30s sprints, 240s recovery, no resistance stated	VO_{2max} (L.min) from an incremental exercise test to exhaustion on a cycle ergometer; Peak Power (W), Mean Power (W) and Total Work (kJ) from a Wingate Test	SIT increased motor unit recruitment and total work compared to endurance training alone.	12/24 50% Low
Forbes et al [55]	To determine whether a short-term high-intensity interval cycling training program increases the rate of PCr recovery following moderate-intensity exercise in which pH changes are minimal.	Recreational males (n = 4) and females (n = 3)	Non-exercise control	2 weeks (6 sessions), 4-6 x 30s sprints, 240s recovery, 6.5-7.5%BM resistance	Leg extension peak force (N); Mean Power (W) and Mean Peak Power (W) in training sessions 1 and 6	Short term SIT increases PCr recovery following moderate intensity exercise, indicating an improvement in oxidative capacity.	16/24 66.7% Moderate
Gibala et al [56]	To compare changes in exercise capacity, and molecular and cellular adaptations in skeletal muscle after low volume SIT and high volume endurance training.	Recreational males (n = 8)	Exercise comparator (Endurance Training)	2 weeks (6 sessions), 4-6 x 30s sprints, 240s recovery, 7.5%BM resistance	750kJ Cycle Time Trial (s) and Mean Power (W); 50kJ Cycle Time Trial (s) and Mean Power (W)	Low volume SIT or traditional high volume endurance training induced similar improvements in muscle oxidative capacity,	14/24 58.3% Low

						muscle buffering capacity and exercise performance	
Gillen et al [57]	To determine whether SIT was a time-efficient exercise strategy to improve insulin sensitivity and other indices of cardiometabolic health to the same extent as traditional moderate-intensity continuous training.	Sedentary males (n = 9)	Exercise comparator (Moderate Intensity Continuous Training) and a Non-exercise control	12 weeks (31 sessions), 3 x 20s sprints, 120s recovery, 5%BM resistance	VO_{2peak} (ml.kg.min; L.min) and maximum workload (W) from an incremental exercise test to exhaustion on a cycle ergometer	SIT improved insulin sensitivity, cardiorespiratory fitness, and skeletal muscle mitochondrial content to the same extent as Moderate Intensity Continuous Training, despite a five-fold lower exercise volume and training time commitment	18/24 75% Moderate
Harmer et al [58]	To determine the effects of sprint training on respiratory, metabolic, and ionic perturbations during intense exercise conducted at an identical power output in two separate tests: one test matched for duration in pre- and post training trials and the other continued until exhaustion.	Recreational males (n = 7)	No control	7 weeks (21 sessions), 4-10 x 30s sprints, 180-240s recovery, 7.5%BM resistance	Peak, Mean and Relative Expired Ventilation (L.min), Peak, Mean and Relative O_2 uptake (L.min), Peak, Mean and Relative CO_2 output (L.min), Peak RER, Accumulated VO_2 (mmol.kg), Total Work (kJ) and Time to exhaustion (s) from a test to exhaustion at 130% VO_{2peak}; VO_{2peak} (L.min), Power Output (W) and Time to exhaustion (s) from an incremental exercise test to exhaustion on a cycle ergometer; Peak Power (W) and Total work (kJ) from a 30s all out sprint	Sprint training reduces metabolic and ionic perturbations within tissue during intense exercise matched for power output and work production, although indexes of anaerobic metabolism were not augmented during exhaustive exercise after training, despite the increased exercise duration, suggesting the importance of aerobic adaptations to	7/19 36.8% Very Low

						performance after sprint training	
Harris et al [59]	To determine and compare the effects of work matched SIT with a less time committing sprint continuous protocol on brachial artery endothelial function, arterial stiffness, cardiorespiratory fitness and circulating angiogenic cell number and function.	Recreational females (n = 6)	Exercise comparator (Sprint Continuous Training)	4 weeks (12 sessions), 4 x 30s sprints, 270s recovery, 7.5%BM resistance	VO_{2max} (ml.kg.min; L.min), Lactate Threshold (ml.min.kg), Peak work rate (W) and time (min) from an incremental step exercise test on a cycle ergometer	Sprint continuous training improved cardio-respiratory fitness to a similar extent as SIT, with a trend for brachial artery FMD increase following SIT but not sprint continuous training	18/24 75% Moderate
Hazell et al [60]	To determine whether 10s or 30s SIT bouts with 2 or 4 min recovery periods can improve aerobic and anaerobic performance.	Recreational males (n = 6) and females (n = 6) in each of the 3 SIT groups	Non-exercise control	2 weeks (6 sessions), 4-6 x 30s sprints, 240s recovery, 100g.kg.BM resistance 2 weeks (6 sessions), 4-6 x 10s sprints, 240s recovery, 100g.kg.BM resistance	VO_{2max} (ml.kg.min) from an incremental exercise test to exhaustion on a cycle ergometer; 5km time trial (s); Peak power (W/kg) and Mean power (W/kg) from a 30s Wingate test	The 10s SIT protocols produced similar improvements in VO_{2max} and 5-km time trial performance compared to the established 30s SIT protocol	14/24 58.3% Low

				2 weeks (6 sessions), 4-6 x 10s sprints, 120s recovery, 100g.kg.BM resistance			
Hommel et al [61]	To determine and compare the influence of SIT and endurance training on calculated power in maximal lactate steady state and maximal oxygen uptake.	Recreational males (n = 10)	Exercise comparator (Endurance Training), and Non-exercise control	6 weeks (18 sessions), 4-6 x 30s sprints, 270s recovery, 7.5%BM resistance	VO_{2max} (ml.min.kg) from an incremental exercise test to exhaustion on a cycle ergometer; Power in Lactate Steady State (W); Peak Anaerobic Power (W) from a modified sprint test.	SIT and endurance training improve calculated power in maximal lactate steady state through differently influencing maximal lactate production rate and VO_{2max}.	15/24 62.5% Moderate
Ijichi et al [62]	To compare the effects of sprint training on exercise performance between sprint training twice every second day and sprint training once daily, with the same total number of training sessions.	Recreational males (n = 20) SIT once every day (n = 10) SIT twice every second day (n = 10)	No control	SIT daily: 5 days per week x4 weeks (20 sessions), 3 x 30s sprints, 10 min recovery, 5%BM resistance SIT twice: 2-3 sessions per week x 4 weeks (20 sessions total), 3 x 30s sprints, 10 min	VO_{2max} (ml.min.kg; L/min), Peak aerobic power (W) and onset of blood lactate accumulation (W) from an incremental exercise test to exhaustion on a cycle ergometer; Time to fatigue (s) from a submaximal cycling test at 90% VO_{2max}; Peak power (W) and Mean power (W) from 2 x 30s maximal sprint tests	Similar improvements in peak and mean power output during 30s sprint tests and anaerobic endurance capacity occurred between groups, although SIT every second day improved the onset of blood lactate accumulation to a greater extent in physically active males.	12/24 50% Low

				recovery, 5%BM resistance			
Ikutomo et al [63]	To determine the influence of inserted long rest periods during repeated sprint training on performance adaptations in competitive athletes.	Competitive male (n = 17) and female (n = 4) sprinters Short recovery (n = 10) Long recovery group (n = 11)	No control	Short recovery: 3 weeks (9 sessions), 2 sets of 12 x 6s sprints, 24s recovery, 20 mins between sets, 7.5%BM resistance Long recovery: 3 weeks (9 sessions), 2 sets of 12 x 6s sprints, 24s recovery – with an additional 7 mins recovery every third sprint, 20 mins between sets, 7.5%BM resistance	VO_{2max} (ml.min.kg) from an incremental exercise test to exhaustion on a cycle ergometer; Time to exhaustion (s) at 80% VO_{2max}; Peak Power (W/kg) per sprint, 10 min, and 30 min following a repeated sprint test	Repeated sprint training with longer rest periods is an efficient strategy for improving power output compared to shorter rest periods alone	10/24 41.7% Low
Jakeman et al [64]	To determine whether shorter duration high intensity training involving 6 s sprints and totalling 60 s of exercise per session could elicit improvements in performance	Recreational males (n = 6)	Non-exercise control	2 weeks (6 sessions), 10 x 6s sprints, 60s recovery, 7.5%BM resistance	Time to Exhaustion (s) and the Onset of blood lactate accumulation (s) from an incremental exercise test to exhaustion on a cycle ergometer; 10km Time Trial (s); Peak power	Shorter duration SIT repeated over 2 weeks improves aerobic performance and produces an attenuation of blood lactate accumulation normally seen with longer	11/24 45.8% Low

					output (W) for each training session	duration sprints or longer training interventions	
Kavaliauskas et al [14]	To determine the effectiveness of cycling based high intensity training with different work-to-rest ratios for long-distance running.	Competitive males (n = 14) and females (n = 18) 1:3 group: males (n = 3) and females (n = 5) 1:8 group: males (n = 3) and females (n = 5) 1:12 group: males (n = 4) and females (n = 4)	Non-exercise control	1:3 group: 2 weeks (6 sessions), 6 x 10s sprints, 30s recovery, 7.5%BM resistance 1:8 group: 2 weeks (6 sessions), 6 x 10s sprints, 80s recovery, 7.5%BM resistance 1:12 group: 2 weeks (6 sessions), 6 x 10s sprints, 120s recovery, 7.5%BM resistance	3km running time trial (s); VO_{2peak} (ml.min.kg) and Time to exhaustion (s) from an incremental exercise test to exhaustion on a cycle ergometer; Peak Power (W.kg) and Mean Power (W.kg) from a Wingate Test	SIT with a lower work-to-rest ratio provides a sufficient training stimulus for improving running performance, with non-specific training contributing to running performance in runners who regularly undergo endurance training.	12/24 50% Low
Kavaliauskas et al [65]	To determine the effects of SIT on cardiorespiratory fitness and aerobic performance measures in young females.	Recreational females (n = 8)	Non-exercise control (Participants	4 weeks (8 sessions), 4 x 30s sprints, 240s	VO_{2peak} (ml.min.kg) and Time to exhaustion (s) from an incremental exercise test to exhaustion on a cycle ergometer;	SIT performed twice per week improves aerobic performance measures in young, untrained females	12/19 63.2% Moderate

			acted as own controls)	recovery, 7%BM resistance	10km time trial (s); 3-min critical power (W/kg); Peak Power (W), Mean Power (W), Sum of Peak Power (W) and Sum of Mean Power (W) during training sessions		
Larsen et al [66]	To determine the acute and short term effects of high intensity training on human skeletal muscle energetics in vivo using phosphorus magnetic resonance spectroscopy	Recreational males (n = 8)	No control	2 weeks (6 sessions), 4-6 x 30s sprints, 240s recovery, 7.5%BM resistance	VO_{2peak} (ml.min.kg), Time to exhaustion (s) and peak workload (W) from an incremental exercise test to exhaustion on a cycle ergometer; Knee extension maximal force (N); Peak Power (W) and Mean Power (W) during training sessions	6 sessions of high intensity training alter in vivo muscle energetics likely contributing to increased exercise capacity	14/19 73.7% Moderate
Lewis et al [67]	To determine the neuromuscular adaptations to SIT	Recreational males (n = 7)	No control	2 weeks (6 sessions), 4-7 x 30s sprints, 240s recovery, 7.5%BM resistance	10km Time trial (s); Peak Power (W) and Mean Power (W) during training sessions; Quadriceps maximal voluntary contraction (N) pre and post sprints	SIT improved performance measures without measureable neuromuscular adaptations	18/24 75% Moderate
Little et al [68]	To determine if sprint snacks increased VO_{2peak} and aerobic exercise performance in healthy individuals	Recreational males (n = 14) and females (n = 14)	No control	Sprint Snacks: 6 weeks (18 sessions), 3 x 20s sprints, 1-4hr	VO_{2peak} (ml.min.kg; L/min), Peak Power W), and Time to exhaustion (min) from an incremental exercise	Sprint Snacks improved VO_{2peak}, peak aerobic power, and 150 kJ time trial	19/24 79.2% Moderate

		Sprint Snacks: males (n = 5) and females (n = 7) Traditional SIT: males (n = 9) and females (n = 7)		recovery, 0.21 N m/kg resistance Traditional SIT: 6 weeks (18 sessions), 3 x 20s sprints, 180s recovery, 0.21 N m/kg resistance	test to exhaustion on a cycle ergometer; 150kJ Time trial (min); Peak Power (W), Mean Power (W) and Total Work (kJ) across each training session	performance to the same extent as traditional SIT	
Lloyd Jones et al [13]	To determine whether repeated 6s sprint bouts with differing work to rest ratios resulted in different training adaptations.	Recreational males (n = 18) and females (n = 9) 1:8 group: males (n = 6) and females (n = 3) 1:10 group: males (n = 6) and females (n = 3) 1:12 group: males (n = 6) and females (n = 3)	Non-exercise control	1:8 group: 2 weeks (6 sessions), 10 x 6s sprints, 48s recovery, 7.5%BM resistance 1:10 group: 2 weeks (6 sessions), 10 x 6s sprints, 60s recovery, 7.5%BM resistance 1:12 group: 2 weeks (6 sessions), 10 x 6s sprints, 72s	10km Time Trial (s); Peak Power (W), Mean Power (W) and Session Work (kJ) across each training session	All SIT conditions resulted in significant improvements in performance with no significant differences in improvement across any of the groups	12/24 50% Low

				recovery, 7.5%BM resistance			
McGarr et al [69]	To determine and compare any improvements in heat adaptation from short term endurance training and SIT in moderately fit individuals.	Recreational males (n = 6) and females (n = 2)	Exercise comparator (Endurance training)	2 weeks (8 sessions), 4-5 x 30s sprints, 240s recovery between each sprint, 7.5%BM resistance	VO_{2peak} (ml.kg.min) from an incremental exercise test to exhaustion on a cycle ergometer	Short term endurance and SIT improved aerobic fitness and attenuated cardiovascular strain during exercise in a hot environment, although neither training modality increased heat loss responses nor in minimised thermal strain	17/24 70.8% Moderate
Metcalfe et al [70]	To determine the effects of a reduced exertion high intensity training exercise intervention on insulin sensitivity and aerobic capacity.	Sedentary males (n = 7) and females (n = 8)	Non-exercise control	6 weeks (18 sessions), 2 x 10-20s sprints, 200-220s recovery, 7.5%BM resistance	VO_{2peak} (L.min; ml.min.kg) from an incremental exercise test to exhaustion on a cycle ergometer	SIT is associated with improved insulin sensitivity in sedentary young men, and improved aerobic capacity in men and women.	16/24 66.7% Moderate
Metcalfe et al [71]	To determine whether there is a true sex difference in response to reduced exertion high intensity interval training, of if these findings can be explained by the large inter-individual variability	Sedentary males (n = 17) and females (n = 18)	No control	6 weeks (18 sessions), 1-2 x 10-20s sprints, 200-220s recovery, 5%BM resistance	VO_{2peak} (ml.min.kg) and VO_{2max} (L.min; ml.min.kg) from an incremental exercise test to exhaustion on a cycle ergometer	Reduced exertion high intensity interval training presented substantial inter-individual variability for all	18/24 75% Moderate

	response inherent to all exercise training.					parameters with no sex differences evidenced	
Muggeridge et al [72]	To determine the effects of dietary nitrate on the response to 3 weeks of SIT	Recreational males (n = 10)	Exercise Comparator (SIT with nitrate) and a non-exercise control	3 weeks (9 sessions), 4-6 x 15s sprints, 240s recovery, 7%BM/5-10 Air Brake resistance	VO_{2max} (ml.min.kg), ventilatory threshold (W), and maximal workrate (W) from an incremental exercise test to exhaustion on a cycle ergometer; Peak Power (W) and Mean Power (W) from each sprint within training session 1 and 9	SIT improved performance parameters, although no additional benefit was gained from the administration of dietary nitrate supplementation.	18/24 75% Moderate
Nalçakan [73]	To determine and compare the effects of SIT and continuous endurance training on anthropometric, aerobic and anaerobic performance indices, mechanical gross efficiency, blood lipids, inflammation, skeletal muscle damage, and myocardial cell injury in healthy young males.	Recreational males (n = 8)	Exercise comparator (Endurance Training)	7 weeks (21 sessions), 4-6 x 30s sprints, 270s recovery, 7.5%BM resistance	Peak Power (W), Mean Power (W), Time to Peak Power (s), and Power Drop (%) from a Wingate Test; Mechanical Gross Efficiency from a submaximal cycle test at 60% VO_{2max}	SIT improved body composition and performance measures to the same extent as continuous endurance training, although no changes occurred in lipid profile, serum levels of inflammatory markers, myocardinal cell injury markers, or skeletal muscle damage markers following training.	15/24 62.5% Moderate
Nalçakan et al. [74]	To determine whether reducing the sprint duration in the reduced exertion high intensity training protocol from 20s to 10s per	Recreational males (n = 19) and females (n = 17)	No control group	20s group: 6 weeks (18 sessions), 2 x 10-20s sprint, 220-	VO_{2max} (L.min) from an incremental exercise test to exhaustion on a cycle ergometer	SIT involving 20s sprints reported greater	16/19 84.2%

	sprint influences acute affective responses and the change in VO_{2max} following training.	20s sprint group: males (n = 8) and females (n = 10) 10s sprint group: males (n = 11) and females (n = 7)		240s recovery, 7.5%BM resistance 10s group: 6 weeks (18 sessions), 2 x 5-10s sprint, 220-230s recovery, 7.5%BM resistance		improvements in VO_{2max} compared to 10s sprints	High
O'Driscoll et al [75]	To determine the combined adaptations of the cardiac autonomic nervous system and myocardial functional and mechanical parameters to high intensity interval training.	Sedentary males (n = 40)	Non-exercise control (Participants acted as own controls)	2 weeks (6 sessions), 3 x 30s sprints, 120s recovery, 7.5%BM resistance	VO_{2peak} (ml.min.kg; ml/min) and ventilatory equivalent (ml.min) from an incremental exercise test to exhaustion on a cycle ergometer	SIT improves cardiac autonomic modulation, myocardial function, and myocardial mechanics.	20/24 83.3% High
Ørtenblad et al [76]	To determine the effects of 5 weeks of sprint training on intermittent exercise performance, SR Ca^{2+} sequestration, and release function and SR ryanodine binding.	Recreational males (n = 9)	Non-exercise control	5 weeks (15 sessions), 20 x 10s sprints, 50s recovery, 8.25%BM resistance	VO_{2peak} (ml.min.kg) from an incremental exercise test to exhaustion on a cycle ergometer; Total work (kJ) and Mean power (W/kg) from a 10 x 8s sprint test; Mean power (W/kg) across each training session sprint and each second of each sprint	High intensity intermittent training increases the peak rate of $AgNO_3$-stimulated SR Ca^{2+} release	12/24 50% Low

Parra et al [77]	To determine the effect of two different SIT protocols on muscle metabolic response and performance	Recreational males (n = 10) No recovery programme (n = 5) Two days recovery programme (n = 5)	SIT groups only	2 weeks (14 sessions), 4-14 x 15-30s sprints, 45s - 12 min recovery between sprints, 7.5%BM resistance (no recovery days between sessions) 6 weeks (14 sessions), 4-14 x 15-30s sprints, 45s - 12 min recovery between sprints, 7.5%BM resistance (two days recovery between sessions)	Peak Power (W) and Mean Power (W) from a Wingate Test	During high-intensity training shorter rest periods between sessions induced greater biochemical adaptations in human muscle compared to longer rest periods	11/24 45.8% Low
Rakobowchuk et al [78]	To determine whether 6 weeks of high-intensity, low-volume, SIT improves central (carotid) artery distensibility, peripheral (popliteal) artery distensibility and endothelial function in the trained legs to the same extent as high-volume, moderate-intensity endurance training.	Sedentary males (n = 5) and females (n = 5)	Exercise comparator (Endurance Training)	6 weeks (18 sessions), 4-6 x 30s sprints, 270s recovery, 7.5%BM resistance	VO_{2peak} (ml.min.kg) from an incremental exercise test to exhaustion on a cycle ergometer, Peak Power Output (W) from a Wingate Test	SIT elicits similar improvements in peripheral vascular structure and function to endurance training, although central artery distensibility may require a longer training stimuli or greater initial vascular stiffness.	14/19 73.7% Moderate

Richardson and Gibson [79]	To determine the effects of hypoxic SIT on aerobic capacity.	Recreational males (n = 6) and females (n = 3)	Non-exercise control	2 weeks (6 sessions), 4-7 x 30s sprints, 240s recovery, 7.5%BM resistance	VO_{2peak} (L.min) from an incremental exercise test to exhaustion on a cycle ergometer, Time to Exhaustion (min) from an incremental exercise test to exhaustion on a cycle ergometer at 80% VO_{2peak} power output, and Mean Power Output (W.kg) across the first 4 sprints in sessions 1 and 6.	VO_{2peak} and time to exhaustion improved following hypoxic and normoxic SIT compared to a control, although hypoxia did not provide any additional improvements in endurance performance.	13/24 54.2% Low
Rodas et al [80]	To determine the changes in aerobic and anaerobic metabolism produced by a new incremental training programme of 'all-out' loads, repeated daily for 2 weeks, and with long recovery periods.	Recreational males (n = 5)	No control	2 weeks (14 sessions), 4-14 x 15-30s sprints, 45-720s recovery, 7.5%BM resistance	VO_2 (ml.kg.min) and Power Output (W) from an incremental exercise test to exhaustion on a cycle ergometer, VO_2 (ml.kg.min) and Peak and Mean Power Output (W) from a Wingate Test, and Pedalling Rate (rpm) across each training session	Enzymatic activities of energetic pathways improve in a short time following short duration, high load and long recovery period 'all out' sprints.	9/19 47.4% Low
Scalzo et al [81]	To determine changes in endurance exercise performance after SIT and to measure the integrated muscle protein synthesis response, mitochondrial biogenesis, and proteome kinetics in males and females over the course of 3 weeks of SIT.	Recreational males (n = 11) and females (n = 10)	No control	3 weeks (9 sessions), 4-8 x 30s sprints, 240s recovery, 7.5%BM resistance	VO_{2max} (ml.kg.min) from an incremental exercise test to exhaustion on a cycle ergometer, 40km Time Trial (s) and Mean Power Output (W; W.kg fat free mass) across each sprint for sessions 1 and 9.	Greater synthesis rates of muscle protein synthesis and mitochondrial biogenesis were observed in males than females during SIT, although there were no differences in VO_{2max}, time	12/19 63.2% Moderate

						trial or power output when normalised to fat free mass.	
Schlittler et al [82]	To determine the effects of three weeks of SIT on high-intensity cycling performance, ryanodine receptor modifications, and the recovery of isometric force in recreationally active human subjects.	Recreational males (n = 8)	No control	3 weeks (9 sessions), 4-6 x 30s sprints, 240s recovery, 0.7Nm.kg BM resistance	Maximal power (W) from an incremental exercise test to exhaustion on a cycle ergometer; Total work (kJ) and Peak power (W/kg) across six Wingate cycles; Isometric knee extension maximal voluntary contraction (N) pre and post training session	SIT did not accelerate the recovery of isometric force, although did provide incomplete protection against RyR1 alteration.	10/19 52.6% Low
Shenouda et al [83]	To determine the effects of 6 and 12 weeks of moderate intensity continuous training and low volume SIT on brachial and popliteal artery endothelial function and diameter, and central and lower limb arterial stiffness in sedentary, healthy men compared with non-training controls.	Sedentary males (n = 9)	Exercise comparator (Moderate intensity continuous training), and a Non-exercise control	12 weeks (31 sessions), 3 x 20s sprints, 120s recovery, 5%BM resistance	VO_{2peak} (ml.kg.min) from an incremental exercise test to exhaustion on a cycle ergometer	Brachial artery responses to SIT may follow a different time course not captured by a 6- and 12-wk intervention although these are observed with moderate intensity continuous training	17/24 70.8% Moderate
Shepherd et al [84]	To determine whether SIT induces improvements in insulin sensitivity and net IMTG breakdown, and to investigate the underlying mechanisms.	Sedentary males (n = 8)	Exercise comparator (Endurance Training)	6 weeks (18 sessions), 4-6 x 30s sprints, 270s recovery, 7.5%BM resistance	VO_{2peak} (L.min; L.kg.min) and Peak Workload (W) from an incremental exercise test to exhaustion on a cycle ergometer, and VO_2 (L.min), VCO_2 (L.min)	6 weeks of SIT and endurance training improve insulin sensitivity through mechanisms involved with increased PLIN2, PLIN5	17/19 89.5% High

					and RER from a 60 minute cycle at 65% VO_{2peak}	and IMTG utilisation during exercise.	
Songsorn et al [85]	To determine whether a single 20-s cycle sprint per training session can provide a sufficient stimulus for improving VO_{2max}.	Recreational males (n = 5) and females (n = 10)	Non-exercise control	4 weeks (12 sessions), 1 x 20s sprints, 7.5%BM resistance	VO_{2max} (L.min) and Peak Power Output (W) from an incremental exercise test to exhaustion on a cycle ergometer	A single 20-s cycle sprint per training session is not a sufficient stimulus for improving VO_{2max}.	20/24 83.3% High
Terada et al [86]	To determine the effects of SIT with exogenous carbohydrate supplementation and SIT following overnight fast on aerobic capacity and high-intensity aerobic endurance.	Recreational males (n = 11)	Exercise Comparator (SIT with exogenous carbohydrate)	4 weeks (12 sessions), 4-7 x 30s sprints, 240s recovery, 7.5%BM resistance	VO_{2peak} (ml.O_2.kg.min) from an incremental exercise test to exhaustion on a cycle ergometer, Cycling Time to Exhaustion (s) at 85%VO_{2peak}, and Mechanical Work (Joules.kg) and Peak Power Output (W.kg) across each training week.	Fasted SIT compromises exercise intensity and volume, but can increase the ability to sustain high intensity aerobic endurance exercise compared to SIT with exogenous carbohydrate supplementation	19/19 100% High
Thompson et al [87]	To determine the independent and combined performance and physiological effects of SIT and NO_3^- supplementation during a 4 week intervention.	Recreational males (n = 6) and females (n = 6)	Non-exercise control (with concurrent NO_3^- beetroot juice) and Exercise Comparator (SIT with concurrent NO_3^- beetroot juice)	4 weeks (14 sessions), 4-5 x 30s sprints, 240s recovery, 7.5%BM resistance	VO_{2peak} (L.min) and Peak Work Rate (W) from an incremental exercise test to exhaustion on a cycle ergometer, and VO_{2peak} (L.min) and Work Rate (W) at Gas Exchange Threshold	NO_3^- supplementation reduced the O_2 cost of submaximal exercise, resulting in a greater improvement in incremental exercise performance and muscle metabolic adaptations to training compared to a placebo.	18/19 94.7% High

Thompson et al [88]	To compare the physiological and exercise performance adaptations to 4 weeks of SIT accompanied by concurrent supplementation with NO_3^- beetroot juice, or potassium NO_3^- or SIT undertaken without dietary NO_3^-.	Recreational males (n = 6) and females (n = 6)	Exercise Comparators (SIT with concurrent NO_3^- beetroot juice) and (SIT with concurrent potassium NO_3^-)	4 weeks (14 sessions), 4-5 x 30s sprints, 240s recovery, 7.5%BM resistance	VO_{2peak} (L.min) and Peak Work Rate (W) from an incremental exercise test to exhaustion on a cycle ergometer, VO_{2peak} (L.min) and Time to Task Failure (s) during a moderate and severe cycle step test	4 weeks of sprint interval training with concurrent NO_3^- beetroot juice supplementation results in greater exercise capacity adaptations compared to sprint interval training alone or sprint interval training with concurrent potassium NO_3^- supplementation.	19/19 100% High
Vera-Ibanez et al [27]	To determine the neural adaptations associated with a low volume Wingate based high intensity interval training.	Recreational males (n = 7)	Non-exercise control	4 weeks (12 sessions), 3-6 x 30s sprints, 240s recovery, 7.5%BM resistance	Peak Power (W; W.kg) from a Wingate Test, Plantar Flexor MVC (N) on a soleus isolation machine	Wingate based training increased peak power and higher spinal excitability, with no changes in volitional wave or MVC.	14/24 58.3% Low
Yamagishi et al [12]	To determine the time course of training adaptations to two different SIT programmes with the same sprint: rest ratio (1:8) but different sprint duration.	Recreational males (n = 13) and females (n = 5) 15s sprint group (n = 9) males (n = 7) and females (n = 2) 30s sprints group (n = 8) males (n = 5) and females (n = 3)	Non-exercise control	9 weeks (18 sessions), 4-6 x 15s sprints, 120s recovery, 7%BM resistance 9 weeks (18 sessions), 4-6 x 30s sprints, 240s recovery, 7%BM resistance	VO_{2peak} (ml.min.kg; L.min), O2 Pulse (ml/beat/kg) and Time to Exhaustion (s) from an incremental exercise test to exhaustion on a cycle ergometer, 10km Time Trial (s), Critical Power (W) from a 3-minute critical power test, Peak Power Output (W.kg) and Total Work (kJ) across training sessions 6, 12 and 18.	A 50% reduction in sprint duration does not diminish overall training adaptations over 9 weeks, although cardiorespiratory function plateaus within several weeks of sprint interval training with endurance capacity more sensitive to training over a longer timeframe.	13/24 54.2% Low

Yamagishi et al [89]	To determine the effects of recovery intensity on endurance adaptations during SIT.	Recreational males (n = 9) and females (n = 5) 30s sprints group (n=7) males (n = 4) and females (n = 3) Recreational males (n = 5) and females (n = 2)	No control	2 weeks (6 sessions), 4-6 x 30s sprints, 240s active recovery at 40%VO_{2peak}, 7.5%BM resistance 2 weeks (6 sessions), 4-6 x 30s sprints, 240s passive recovery, 7.5%BM resistance	VO_{2peak} (ml.min.kg; L.min) and Peak Power (W) from an incremental exercise test to exhaustion on a cycle ergometer; 10km Cycle Time Trial (s); Critical Power (W) from a 3-minute critical power test; Total Work (kJ), Peak VO_{2peak} (L.min) and Mean VO_{2peak} (L.min) for total test and across every 30s from a 3-minute critical power test; Total Work (kJ), Peak Power (W.kg), Peak and Mean Power Reproducibility (%) across every training session; Mean VO_2 (L.min) over 4 sprints, and 4 rest periods within sessions 1 and 6	Greater endurance adaptations occurred with active recovery when performing SIT over a short time frame, without increasing total training commitment time.	10/24 41.7% Low
Zelt et al [25]	To determine the effect of reducing SIT work interval duration on increases in maximal and submaximal performance.	Recreational males (n = 23) 30s sprint group (n = 11)	Exercise comparator (Endurance Training)	4 weeks (12 sessions), 4-6 x 30s sprints, 270s recovery, 7.5%BM resistance	VO_{2peak} (ml.min), Lactate Threshold (mmol.L), Relative Lactate Threshold (%VO_{2peak}) and Peak O_2 Pulse (mlO_2/beat), from an incremental exercise test to exhaustion on a cycle ergometer, Peak Power (W) and Mean Power	Reducing SIT work interval from 30 to 15s does not impact training induced increases in either aerobic or anaerobic power, absolute lactate threshold or critical power	15/19 78.9% Moderate

	15s sprint group (n = 12)	4 weeks (12 sessions), 4-6 x 15s sprints, 285s recovery, 7.5%BM resistance	(W) from a Wingate Test, Critical Power (W) from a 3-minute critical power test.

Table 2: Overall and domain specific methodological quality ratings

Research Design	Reporting	Internal Validity Bias	Internal Validity Confounding	Statistical Power	Overall Rating
Comparator	80%	43%	67%	10%	High: 6% Moderate: 51% Low: 43%
Non-comparator	78%	43%	49%	11%	Moderate: 50% Low: 33% Very Low: 17%
Both comparator and non-comparator	79%	43%	63%	11%	High: 6% Moderate: 50% Low: 42% V. Low: 2%

Table 3. Results from primary analyses conducted on non-controlled effect sizes and sensitivity analyses conducted on controlled effect sizes from studies including non-exercise control groups. Effect sizes are magnitude-based standardized mean differences.

Analysis	Analysis Details	Effect Size / Probability of Medium Effect	Sensitivity Analysis	Sensitivity Analysis Details	Effect Size / Probability of Medium Effect
Non-controlled effect sizes: All outcomes	432 effect sizes from 52 studies (mode quality = Moderate: 50%)	0.52 [95%CrI: 0.42 to 0.62; d ≥ 0.5: Pr=64%]	Controlled effect sizes: All outcomes	111 effect sizes from 24 studies (mode quality = Low: 58%)	0.51 [95%CrI: 0.27 to 0.76; d ≥ 0.5: Pr = 55%]
Non-controlled effect sizes: Aerobic outcomes	259 effect sizes from 49 studies (mode quality = Moderate: 51%)	0.49 [95%CrI: 0.39 to 0.60; d ≥ 0.5: Pr = 41%]	Controlled effect sizes: Aerobic outcomes	76 effect sizes from 22 studies (mode quality = Low: 50%)	0.45 [95%CrI: 0.32 to 0.70; d ≥ 0.5: Pr = 39%]
Non-controlled effect sizes: Anaerobic outcomes	59 effect sizes from 20 studies (mode quality = Low: 50%)	0.61 [95%CrI: 0.48 to 0.75; d ≥ 0.5: Pr = 93%]	Controlled effect sizes: Anaerobic outcomes	23 effect sizes from 8 studies (mode quality = Low: 63%)	0.59 [95%CrI: 0.21 to 0.91; d ≥ 0.5: Pr = 73%]
Non-controlled effect sizes: Mixed aerobic/anaerobic outcomes	114 effect sizes from 18 studies (mode quality = Moderate: 53%)	0.50 [95%CrI: 0.30 to 0.70; d ≥ 0.5: Pr = 50%]	Controlled effect sizes: Mixed aerobic/anaerobic outcomes	12 effect sizes from 2 studies (mode quality = Moderate: 50%)	0.40 [95%CrI: =0.12 to 0.726; d ≥ 0.5: Pr = 32%]

Results are from multilevel random effects models with median parameter estimates and 95% credible intervals (95%CrI). Pr expresses the proportion of the pooled effect size posterior sample that is greater or equal to a moderate effect (d ≥ 0.5).

Table 4: Results from meta-regressions conducted on training variables across all outcomes and individual outcome categories. Effect sizes are magnitude-based standardized mean differences.

	All Outcomes $ES_{0.5}$ [95%CrI]	**Aerobic $ES_{0.5}$ [95%CrI]**	**Mixed $ES_{0.5}$ [95%CrI]**	**Anaerobic $ES_{0.5}$ [95%CrI]**
Training Intensity				
Sprint Duration				
Long (+20s): Short (5 to 10s)	-0.15 [-0.42 to 0.08] Number of effects: (302/75)	-0.24 [-0.51 to -0.01] Number of effects: sizes: (195/25)	-0.02 [-0.44 to 0.66] Number of effects: (58/42)	-0.26 [-0.96 to 0.44] Number of effects: (49/8)
Long (+20s): Medium (10 to 20s)	0.04 [-0.12 to 0.19] Number of effects: (302/55)	-0.03 [-0.21 to 0.15] Number of effects: (195/39)	0.22 [-0.19 to 0.64] Number of effects: (58/14)	Analysis not completed due to sample size
External Load				
High (>7% BM): Low (≤7% BM)	-0.10 [-0.30 to 0.18] Number of effects: (311/79)	-0.10 [-0.44 to 0.22] Number of effects: (186/47)	-0.10 [-0.82 to 0.68] Number of effects: (78/32)	Analysis not completed due to sample size
Training Volume				
Number of sprints per session				
High (+6 sprints): Medium (5 to 6 sprints)	-0.14 [-0.42 to 0.12] Number of effects: (97/280)	-0.06 [-0.40 to 0.27] Number of effects: (41/174)	-0.22 [-0.61 to 0.10] Number of effects: (42/64)	-0.19 [-0.52 to 0.15] Number of effects: (14/42)
High (+6 sprints): low (1 to 4 sprints)	-0.20 [-0.51 to 0.13] Number of effects: (97/55)	-0.16 [-0.47 to 0.14] Number of effects: (41/44)	-0.39 [-0.71 to 0.15] Number of effects: (42/8)	Analysis not completed due to sample size
Total sprint time per session (standardised)	0.05 [0.00 to 0.11] Number of effects: 432	0.05 [-0.05 to 0.11] Number of effects: 259	0.07 [-0.21 to 0.34] Number of effects: 114	-0.04 [-0.29 to 0.20] Number of effects: 59
Work to Rest Ratio				
Work to rest ratio (standardised)	-0.00 [-0.06 to 0.06] Number of effects: 432	0.06 [-0.01 to 0.12] Number of effects: 259	-0.03 [-0.35 to 0.29] Number of effects: 114	-0.08 [-0.19 to 0.04] Number of effects: 59

Results are from multilevel random effects models with median parameter estimates and 95% credible intervals [95%CrI]. BM = body mass.

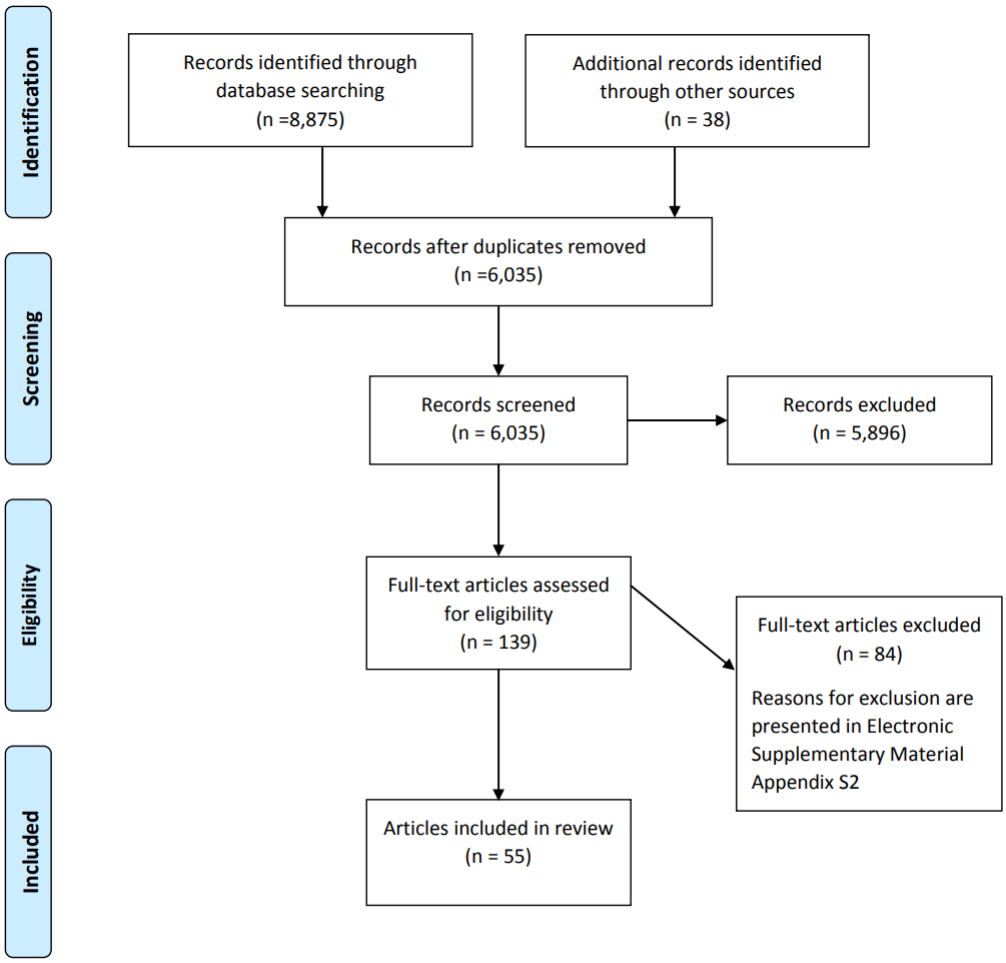
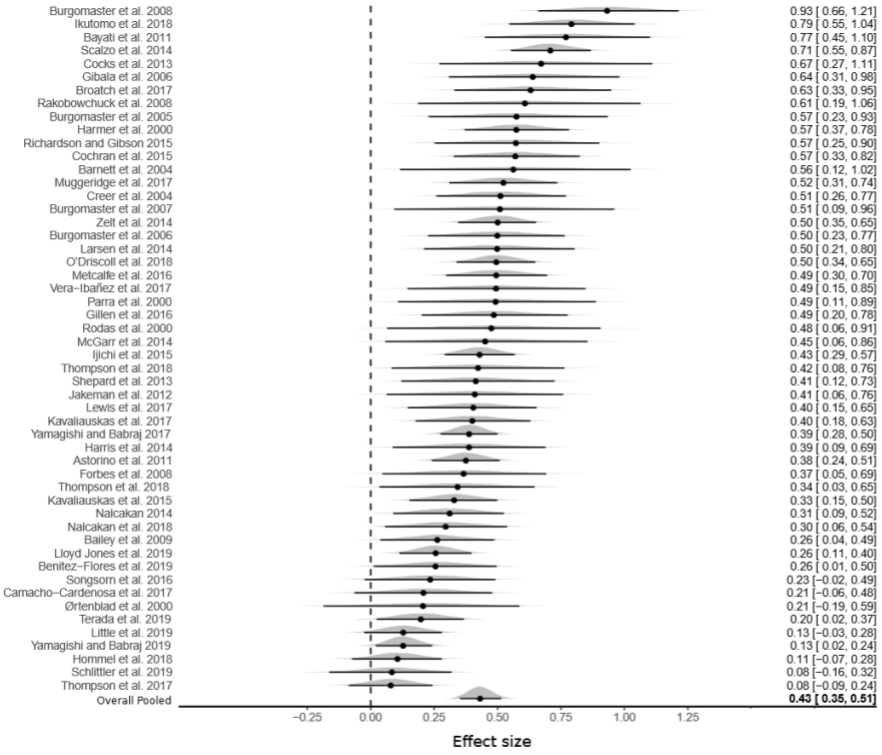


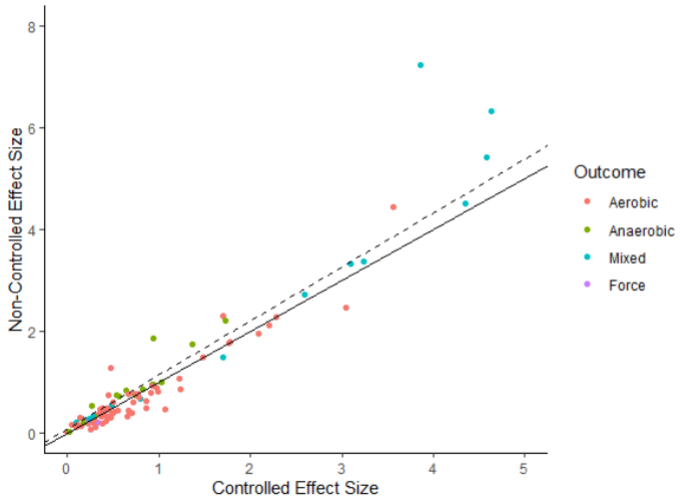
Figure 1: PRISMA flow diagram detailing the results of each search and screening stage. A final number of 55 studies were included in the review.

Figure 2: Bayesian Forest plot of multilevel meta-analysis conducted on non-controlled effect sizes.



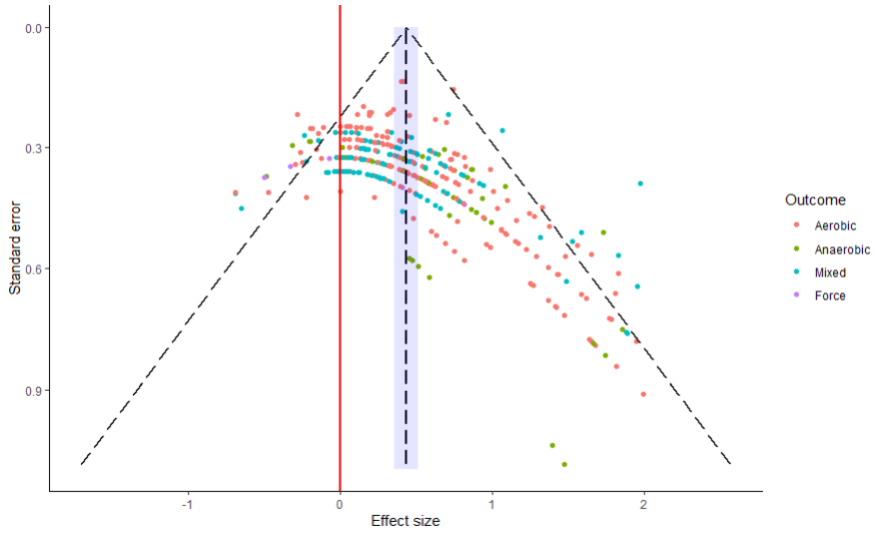
Positive effect sizes describe improvements in outcomes based on SIT intervention. The study specific intervals represent individual effect size estimates and sampling error. The circle represents the pooled estimate generated with Bayesian inference along with the 95% credible interval (95% CrI)

Figure 3: Comparison of non-controlled and non-exercise-controlled effect sizes



Solid line is the unity line and dashed line is the best fit line illustrating positive bias of non-controlled effect sizes.

Figure 4: Funnel plot of non-controlled effect sizes and their standard errors.



Highlighted blue region illustrates pooled effect size estimate and 95% credible interval.

Title: The Effects of Sprint Interval Training on Physical Performance: A Systematic Review and Meta-Analysis

Supplementary Material

Andy, J. Hall[1]. Rodrigo, R. Aspe[1]. Thomas P. Craig[1]. Mykolas Kavaliauskas[2]. John Babraj[3]. Paul, A. Swinton[1]

[1] School of Health Sciences, Robert Gordon University, Aberdeen, United Kingdom

[2] School of Applied Sciences, Edinburgh Napier University, United Kingdom

[3] Division of Sport and Exercise Science, Abertay University, United Kingdom

Correspondence:

Dr Paul, A. Swinton

School of Health Sciences,

Robert Gordon University,

Garthdee Road, Aberdeen, United Kingdom.

E-mail: p.swinton@rgu.ac.uk

Phone: +44 1224 263361

Electronic Supplementary Material Appendix S1: Database search results

Source	Search	Hits
MEDLINE	1. ("sprint interval training" or "high intensity interval training" or "high intensity intermittent training" or "HIIT" or "interval exercise" or "high intensity training" or "high intensity exercise" or "high intensity aerobic interval training" or "aerobic interval training").mp.	1. 6,118
	2. Limit 1 to (english language and humans and yr="2000 - 2020")	2. 3,545
Web of Science	1. ("sprint interval training" or "high intensity interval training" or "high intensity intermittent training" or "HIIT" or "interval exercise" or "high intensity training" or "high intensity exercise" or "high intensity aerobic interval training" or "aerobic interval training").mp.	1. 7,218
	2. Limit 1 to (english language and Sport Science and yr="2000 - 2020")	2. 3,135
SportDiscuss	1. ("sprint interval training" or "high intensity interval training" or "high intensity intermittent training" or "HIIT" or "interval exercise" or "high intensity training" or "high intensity exercise" or "high intensity aerobic interval training" or "aerobic interval training").mp.	1. 3,282
	2. Limit 1 to (english language and Academic Journals and yr="2000 - 2020")	2. 2,195

Electronic Supplementary Material Appendix 2 Studies excluded at full-text screening and reasons for exclusion

0: Reason for exclusion; 1: Meets the inclusion criteria.

	Population Based			Intervention Based				
Reference	**Non-Diseased**	**Non-overweight / obese recruitment**	**Mean age 18-45**	**'All out' cycling, ≤30s duration**	**≥2 Week Duration**	**Pre-Post Outcome Measures**	**Non-Supplementation Training Group**	**Total Score**
Androulakis-Korakakis P, Langdown L, Lewis A, Fisher JP, Gentil P, Paoli A, et al. Effects of Exercise Modality During Additional "High-Intensity Interval Training" on Aerobic Fitness and Strength in Powerlifting and Strongman Athletes. Journal of Strength & Conditioning Research. 2018; 32(2):450-457.	1	1	1	0	1	1	1	6
Astorino TA, Edmunds RM, Clark A, King L, Gallant RA, Namm S, et al. High-intensity interval training increases cardiac output and VO2max. Med Sci Sports Exerc. 2017;49(2):265-73.	1	1	1	0	1	1	1	6
Astorino TA, Vella CA. Predictors of change in affect in response to high intensity interval exercise (HIIE) and sprint interval exercise (SIE). Physiol Behav. 2018;196:211-7.	1	1	1	0	0	0	1	4
Astorino TA, Edmunds RM, Clark A, Gallant R, King L, Ordille GM, et al. Change in maximal fat oxidation in response to different regimes of periodized high-intensity interval training (HIIT). Eur J Appl Physiol. 2017 Apr;117(4):745-55.	1	1	1	0	1	1	1	6
Astorino TA, deRevere J, Anderson T, Kellogg E, Holstrom P, Ring S, et al. Change in VO 2max and time trial performance in response to high-intensity interval training prescribed using ventilatory threshold. Eur J Appl Physiol. 2018;118(9):1811-20.	1	1	1	0	1	1	1	6
Bentley RF, Jones JH, Hirai DM, Zelt JT, Giles MD, Raleigh JP, et al. Submaximal exercise cardiac output is increased by 4 weeks of sprint interval training in young healthy males with low initial Q-V O2: Importance of cardiac response phenotype. Plos one. 2019;14(1):e0195458.	1	1	1	0	1	1	1	6
Boer P. Sprint interval training vs. high intensity interval training in untrained university students. South African Journal for Research in Sport, Physical Education and Recreation. 2019;41(3):17-30.	1	1	1	0	1	1	1	6

Bogdanis GC, Stavrinou P, Fatouros IG, Philippou A, Chatzinikolaou A, Draganidis D, et al. Short-term high-intensity interval exercise training attenuates oxidative stress responses and improves antioxidant status in healthy humans. Food & Chemical Toxicology. 2013; 61:171-177.	1	1	1	0	1	1	1	6
Bonafiglia JT, Edgett BA, Baechler BL, Nelms MW, Simpson CA, Quadrilatero J, et al. Acute upregulation of PGC-1α mRNA correlates with training-induced increases in SDH activity in human skeletal muscle. Applied Physiology, Nutrition & Metabolism. 2017 06;42(6):656-66.	1	1	1	0	1	1	1	6
Burn N, Niven A. Why do they do (h) it? using self-determination theory to understand why people start and continue to do high-intensity interval training group exercise classes. International Journal of Sport and Exercise Psychology. 2019;17(5):537-51.	1	1	1	0	0	0	1	4
Byrd BR, Keith J, Keeling SM, Weatherwax RM, Nolan PB, Ramos JS, et al. Personalized moderate-intensity exercise training combined with high-intensity interval training enhances training responsiveness. International journal of environmental research and public health. 2019;16(12):2088.	1	1	1	0	1	1	1	6
Capostagno B, Lambert MI, Lamberts RP. Standardized versus customized high-intensity training: effects on cycling performance. International journal of sports physiology & performance. 2014; 9(2):292-301.	1	1	1	0	0	1	1	5
Cavar M, Marsic T, Corluka M, Culjak Z, Zovko IC, Müller A, et al. Effects of 6 weeks of different high-intensity interval and moderate continuous training on aerobic and anaerobic performance. The Journal of Strength & Conditioning Research. 2019;33(1):44-56.	1	1	1	0	1	1	1	6
Clark B, Costa VP, O'Brien BJ, Guglielmo LG, Paton CD. Effects of a seven day overload-period of high-intensity training on performance and physiology of competitive cyclists. PLoS ONE [Electronic Resource]. 2014; 9(12):e115308.	1	1	1	1	0	1	1	6
Cochran AJR, Percival ME, Tricarico S, Little JP, Cermak N, Gillen JB, et al. Intermittent and continuous high-intensity exercise training induce similar acute but different chronic muscle adaptations. Experimental physiology. 2014; 99(5):782-791.	1	1	1	0	1	0	1	5
Connolly LJ, Bailey SJ, Krustrup P, Fulford J, Smietanka C, Jones AM. Effects of self-paced interval and continuous training on health markers in	1	1	1	0	1	1	1	6

women. European journal of applied physiology. 2017; 117(11):2281-2293.								
Da Silva CR, Santana PV, Mendes PC, Saraiva B, Da SL, Leite RD, et al. Metabolic and cardiorespiratory acute responses to fasting versus feeding during high-intensity interval training. Sport Sciences for Health. 2018; 14(2):347-355.	1	1	1	1	0	0	1	5
Da Silva Machado, Daniel G, Costa EC, Ray H, Beale L, Chatzisarantis NL, de Farias-Junior LF, et al. Short-term psychological and physiological effects of varying the volume of high-intensity interval training in healthy men. Percept Mot Skills. 2019;126(1):119-42.	1	1	1	0	1	1	1	6
Denham J, Gray A, Scott-Hamilton J, Hagstrom AD. Sprint Interval Training Decreases Circulating MicroRNAs Important for Muscle Development. International Journal of Sports Medicine. 2018; 39(1):67-72.	1	1	1	1	1	0	1	6
Edge J, Bishop D, Hill-Haas S, Dawson B, Goodman C. Comparison of muscle buffer capacity and repeated-sprint ability of untrained, endurance-trained and team-sport athletes. European journal of applied physiology. 2006; 96(3):225-234.	1	1	1	1	0	1	1	6
Edge J, Eynon N, McKenna MJ, Goodman CA, Harris RC, Bishop DJ. Altering the rest interval during high-intensity interval training does not affect muscle or performance adaptations. Experimental physiology. 2013; 98(2):481-490.	1	1	1	0	1	1	1	6
Edgett BA, Bonafiglia JT, Baechler BL, Quadrilatero J, Gurd BJ. The effect of acute and chronic sprint-interval training on LRP130, SIRT3, and PGC-1alpha expression in human skeletal muscle. Physiological Reports. 2016; 4(17):09.	1	1	1	0	1	1	1	6
Eskelinen J, Heinonen I, Löyttyniemi E, Saunavaara V, Kirjavainen A, Virtanen KA, et al. Muscle-specific glucose and free fatty acid uptake after sprint interval and moderate-intensity training in healthy middle-aged men. Journal of applied physiology. 2015; 118(9):1172-1180.	1	0	0	1	1	1	1	5
Etxebarria N, Anson JM, Pyne DB, Ferguson RA. High-intensity cycle interval training improves cycling and running performance in triathletes. European Journal of Sport Science EJSS : Official Journal of the European College of Sport Science. 2014; 14(6):521-529.	1	1	1	0	1	1	1	6
Forbes SC, Sletten N, Durrer C, Myette-Côté É, Candow D, Little JP. Creatine Monohydrate Supplementation Does Not Augment Fitness,	1	1	1	1	1	1	0	6

Performance, or Body Composition Adaptations in Response to Four Weeks of High-Intensity Interval Training in Young Females. International Journal of Sport Nutrition & Exercise Metabolism. 2017; 27(3):185-192.								
Vinuela Garcia M, Vera Ibanez A, Colomer Poveda D, Marquez Sanchez G, Romero Arenas S. Effect of 12 sessions of high-intensity interval training on body composition in young adults. NUTRICION HOSPITALARIA. 2016;33(3):637-43.	0	0	0	0	0	0	0	0
Gatterer H, Menz V, Salazar-Martinez E, Sumbalova Z, Garcia-Souza L, Velika B, et al. Exercise Performance, Muscle Oxygen Extraction and Blood Cell Mitochondrial Respiration after Repeated-Sprint and Sprint Interval Training in Hypoxia: A Pilot Study. Journal of Sports Science & Medicine. 2018; 17(3):339-347.	1	1	1	0	1	1	1	6
Gibala MJ, McGee SL, Garnham AP, Howlett KF, Snow RJ, Hargreaves M. Brief intense interval exercise activates AMPK and p38 MAPK signaling and increases the expression of PGC-1α in human skeletal muscle. Journal of Applied Physiology. 2009; 106(3):929-934.	1	1	1	1	0	0	1	5
Gibala MJ, Bostad W, McCarthy DG. Physiological adaptations to interval training to promote endurance. Current Opinion in Physiology. 2019;10:180-4.	0	0	0	0	0	0	0	0
Gray SR, Aird TP, Farquharson AJ, Horgan GW, Fisher E, Wilson J, et al. Inter-individual responses to sprint interval training, a pilot study investigating interactions with the sirtuin system. Applied Physiology, Nutrition, & Metabolism = Physiologie Appliquee, Nutrition et Metabolisme. 2018; 43(1):84-93.	1	1	1	1	1	0	1	6
Gunnarsson TP, Brandt N, Fiorenza M, Hostrup M, Pilegaard H, Bangsbo J. Inclusion of sprints in moderate intensity continuous training leads to muscle oxidative adaptations in trained individuals. Physiological reports. 2019;7(4):e13976.	1	1	1	0	1	1	1	6
Gurd BJ, Giles MD, Bonafiglia JT, Raleigh JP, Boyd JC, Ma JK, et al. Incidence of nonresponse and individual patterns of response following sprint interval training. Applied Physiology, Nutrition, & Metabolism = Physiologie Appliquee, Nutrition et Metabolisme. 2016; 41(3):229-234.	1	1	1	0	1	0	1	5
Hajizadeh Maleki B, Tartibian B, Chehrazi M. The effects of three different exercise modalities on markers of male reproduction in healthy subjects: a	1	1	1	0	1	1	1	6

randomized controlled trial. Reproduction. 2017; 153(2):157-174.								
Hatle H, Stobakk PK, Molmen HE, Bronstad E, Tjonna AE, Steinshamn S, et al. Effect of 24 sessions of high-intensity aerobic interval training carried out at either high or moderate frequency, a randomized trial. PLoS ONE [Electronic Resource]. 2014; 9(2):e88375.	1	1	1	0	1	1	1	6
Hebisz P, Hebisz R, Murawska-Ciałowicz E, Zatoń M. Changes in exercise capacity and serum BDNF following long-term sprint interval training in well-trained cyclists. Applied Physiology, Nutrition, and Metabolism. 2019;44(5):499-506.	1	1	1	0	1	1	1	6
Heiskanen MA, Leskinen T, Heinonen IHA, Loyttyniemi E, Eskelinen J, Virtanen K, et al. Right ventricular metabolic adaptations to high-intensity interval and moderate-intensity continuous training in healthy middle-aged men. American Journal of Physiology - Heart & Circulatory Physiology. 2016; 311(3):H667-75.	1	1	0	1	1	1	1	6
Hill MW, Higgins MF, Price MJ. The effect of high-intensity cycling training on postural sway during standing under rested and fatigued conditions in healthy young adults. European journal of applied physiology. 2016; 116(10):1965-1974.	1	1	1	0	1	1	1	6
Hostrup M, Gunnarsson TP, Fiorenza M, Mørch K, Onslev J, Pedersen KM, et al. In-season adaptations to intense intermittent training and sprint interval training in sub-elite football players. Scand J Med Sci Sports. 2019;29(5):669-77.	1	1	1	0	1	1	1	6
Huffman LS, Wadsworth DD, McDonald JR, Foote SJ, Hyatt H, Pascoe DD. Effects of a Sprint Interval and Resistance Concurrent Exercise Training Program on Aerobic Capacity of Inactive Adult Women. The Journal of Strength & Conditioning Research. 2019; 33(6):1640-1647.	1	1	1	0	1	1	1	6
Inoue A, Impellizzeri FM, Pires FO, Pompeu FAMS, Deslandes AC, Santos TM. Effects of Sprint versus High-Intensity Aerobic Interval Training on Cross-Country Mountain Biking Performance: A Randomized Controlled Trial. PLoS ONE [Electronic Resource]. 2016; 11(1):e0145298.	1	1	1	0	1	1	1	6
Islam H, Townsend LK, Hazell TJ. Modified sprint interval training protocols. Part I. Physiological responses. Applied Physiology, Nutrition, & Metabolism = Physiologie Appliquee, Nutrition et Metabolisme. 2017; 42(4):339-346.	1	1	1	0	0	0	1	4

Jabbour G, Iancu H, Mauriege P, Joanisse DR, Martin LJ. High-intensity interval training improves performance in young and older individuals by increasing mechanical efficiency. Physiological Reports. 2017; 5(7).	1	0	1	1	1	1	1	6
Kellogg E, Cantacessi C, McNamer O, Holmes H, von Bargen R, Ramirez R, et al. Comparison of Psychological and Physiological Responses to Imposed vs. Self-selected High-Intensity Interval Training. Journal of strength and conditioning research. 2019; 33(11):2945-2952.	1	1	1	0	1	1	1	6
Kim J, Lee N, Trilk J, Kim E, Kim S, Lee M, et al. Effects of sprint interval training on elite Judoists. International Journal of Sports Medicine. 2011; 32(12):929-934.	1	1	1	0	1	1	1	6
Kiviniemi AM, Tulppo MP, Eskelinen JJ, Savolainen AM, Kapanen J, Heinonen IHA, et al. Cardiac autonomic function and high-intensity interval training in middle-age men. Medicine & Science in Sports & Exercise. 2014; 46(10):1960-1967.	1	1	0	1	1	1	1	6
Kiviniemi AM, Tulppo MP, Eskelinen JJ, Savolainen AM, Kapanen J, Heinonen IHA, et al. Autonomic Function Predicts Fitness Response to Short-Term High-Intensity Interval Training. International Journal of Sports Medicine. 2015; 36(11):915-921.	1	1	0	1	1	1	1	6
Kliszczewicz B, McKenzie M, Nickerson B. Physiological adaptation following four-weeks of high-intensity functional training. Vojnosanitetski pregled. 2019; 76(3):272-277.	1	1	1	0	1	1	1	6
Kristoffersen M, Sandbakk Ø, Rønnestad BR, Gundersen H. Comparison of short-sprint and heavy strength training on cycling performance. Frontiers in physiology. 2019; 10:1132.	1	1	1	0	1	1	1	6
Lamberts RP, Swart J, Noakes TD, Lambert MI. Changes in heart rate recovery after high-intensity training in well-trained cyclists. European journal of applied physiology. 2009; 105(5):705-713.	1	1	1	0	1	1	1	6
Lira F, Antunes B, Figueiredo C, Campos E, Panissa V, St-Pierre D, et al. Impact of 5-week high-intensity interval training on indices of cardio metabolic health in men. Diabetes & Metabolic Syndrome: Clinical Research & Reviews. 2019; 13(2):1359-1364.	1	1	1	0	1	1	1	6
Lopes WA, Hortmann K, de Oliveira GH, Okawa RTP. Does 6 weeks of HIIT alter structural and functional cardiac and arterial stiffness in young adults? Eur J Appl Physiol. 2019;119(4):1041-2.	0	0	0	0	0	0	1	1
Ma JK, Scribbans TD, Edgett BA, Boyd JC, Simpson CA, Little JP, et al. Extremely low-volume, high-	1	1	1	0	1	1	1	6

intensity interval training improves exercise capacity and increases mitochondrial protein content in human skeletal muscle. Open Journal of Molecular and Integrative Physiology. 2013; 3(04):202.								
Mallol M, Bentley DJ, Norton L, Norton K, Mejuto G, Yanci J. Comparison of Reduced-Volume High-Intensity Interval Training and High-Volume Training on Endurance Performance in Triathletes. International Journal of Sports Physiology & Performance. 2019; 14(2):239-245.	1	1	1	0	1	1	1	6
Marles A, Legrand R, Blondel N, Mucci P, Betbeder D, Prieur F. Effect of high-intensity interval training and detraining on extra VO2 and on the VO2 slow component. European journal of applied physiology. 2007; 99(6):633-640.	1	1	1	0	1	1	1	6
Martin LJ, Anderson SH, Schmale MS, Hallworth JR, Hazell TJ. A group-enhanced sprint interval training program for amateur athletes. Applied Physiology, Nutrition & Metabolism. 2016; 41(8):809-815.	1	1	1	0	1	1	1	6
May RW, Seibert GS, Sanchez-Gonzalez MA, Fincham FD. Self-regulatory biofeedback training: An intervention to reduce school burnout and improve cardiac functioning in college students. Stress. 2019;22(1):1-8.	1	1	1	0	1	1	1	6
McGinley C, Bishop DJ. Rest interval duration does not influence adaptations in acid/base transport proteins following 10 wk of sprint-interval training in active women. American Journal of Physiology - Regulatory Integrative & Comparative Physiology. 2017; 312(5):R702-R717.	1	1	1	0	1	1	1	6
McKie GL, Islam H, Townsend LK, Robertson-Wilson J, Eys M, Hazell TJ. Modified sprint interval training protocols: physiological and psychological responses to 4 weeks of training. Applied Physiology, Nutrition & Metabolism. 2018; 43(6):595-601.	1	1	1	0	1	1	1	6
Naves JPA, Viana RB, Rebelo ACS, de Lira, Claudio Andre B, Pimentel GD, Lobo PCB, et al. Effects of high-intensity interval training vs. sprint interval training on anthropometric measures and cardiorespiratory fitness in healthy young women. Frontiers in physiology. 2018; 9:1738.	1	1	1	0	1	1	1	6
O'Connor D, Malone JK. The Dose Response for Sprint Interval Training Interventions May Affect the Time Course of Aerobic Training Adaptations. Sports. 2019; 7(4):85.	1	1	1	0	1	1	1	6
Olney N, Wertz T, LaPorta Z, Mora A, Serbas J, Astorino TA. Comparison of acute physiological and psychological responses between moderate-intensity	1	1	1	1	0	0	1	5

continuous exercise and three regimes of high-intensity interval training. Journal of Strength & Conditioning Research. 2018; 32(8):2130-2138.								
Puype J, Van Proeyen K, Raymackers J, Deldicque L, Hespel P. Sprint Interval Training in Hypoxia Stimulates Glycolytic Enzyme Activity. Medicine & Science in Sports & Exercise. 2013; 45(11):2166-2174.	1	1	1	0	1	1	1	6
Raleigh JP, Giles MD, Scribbans TD, Edgett BA, Sawula LJ, Bonafiglia JT, et al. The impact of work-matched interval training on VO2peak and VO2 kinetics: diminishing returns with increasing intensity. Applied Physiology, Nutrition, & Metabolism = Physiologie Appliquee, Nutrition et Metabolisme. 2016; 41(7):706-713.	1	1	1	0	1	1	1	6
Raleigh JP, Giles MD, Islam H, Nelms M, Bentley RF, Jones JH, et al. Contribution of central and peripheral adaptations to changes in maximal oxygen uptake following 4 weeks of sprint interval training. Applied Physiology, Nutrition & Metabolism. 2018; 43(10):1059-1068.	1	1	1	0	1	1	1	6
Richards JC, Johnson TK, Kuzma JN, Lonac MC, Schweder MM, Voyles WF, et al. Short-term sprint interval training increases insulin sensitivity in healthy adults but does not affect the thermogenic response to beta-adrenergic stimulation. Journal of Physiology. 2010; 588(Pt 15):2961-2972.	1	1	1	1	1	0	1	6
Riffe JJ, Stout JR, Fukuda DH, Robinson EH, Miramonti AA, Beyer KS, et al. The Dmax method is a valid procedure to estimate physical working capacity at fatigue threshold. Muscle & nerve. 2017; 55(3):344-349.	1	1	1	0	1	1	1	6
Saanijoki T, Nummenmaa L, Eskelinen J, Savolainen AM, Vahlberg T, Kalliokoski KK, et al. Affective Responses to Repeated Sessions of High-Intensity Interval Training. Medicine & Science in Sports & Exercise. 2015; 47(12):2604-2611.	1	0	0	1	1	1	1	5
Sandvei M, Jeppesen PB, Støen L, Litleskare S, Johansen E, Stensrud T, et al. Sprint interval running increases insulin sensitivity in young healthy subjects. Archives of Physiology and Biochemistry. 2012; 118(3):139-147.	1	1	1	0	1	1	1	6
Schaer CE, Wuthrich TU, Beltrami FG, Spengler CM. Effects of Sprint-Interval and Endurance Respiratory Muscle Training Regimens. Medicine and science in sports and exercise. 2019; 51(2):361-371.	1	1	1	0	1	1	1	6

Schaun GZ, Vecchio FBD. High-Intensity Interval Exercises' Acute Impact on Heart Rate Variability: Comparison between Whole-Body and Cycle Ergometer Protocols. Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins). 2018; 32(1):223-229.	1	1	1	0	0	1	0	4
Schaun GZ, Pinto SS, Brasil B, Nunes GN, Alberton CL. Neuromuscular adaptations to sixteen weeks of whole-body high-intensity interval training compared to ergometer-based interval and continuous training. Journal of sports sciences. 2019; 37(14):1561-1569.	1	1	1	0	1	1	1	6
Scribbans TD, Ma JK, Edgett BA, Vorobej KA, Mitchell AS, Zelt JGE, et al. Resveratrol supplementation does not augment performance adaptations or fibre-type-specific responses to high-intensity interval training in humans. Applied Physiology, Nutrition & Metabolism. 2014; 39(11):1305-1313.	1	1	1	0	1	1	0	5
Siahkouhian M, Khodadadi D, Shahmoradi K. Effects of high-intensity interval training on aerobic and anaerobic indices: comparison of physically active and inactive men. Science & Sports. 2013; 28(5):e119-e125.	1	1	1	0	1	1	1	6
Silva JR. Concurrent aerobic and strength training for performance in soccer. In: Concurrent Aerobic and Strength Training. Springer; 2019. p. 397-416.	0	0	0	0	0	0	0	0
Stork MJ, Martin Ginis K,A., Gibala MJ. Psychological and Behavioral Responses to Interval and Continuous Exercise. Medicine & Science in Sports & Exercise. 2018; 50(10):2110-2121.	1	1	1	1	0	0	1	5
Suzuki Y, Ito O, Takahashi H, Takamatsu K. The effect of sprint training on skeletal muscle carnosine in humans. International Journal of Sport and Health Science. 2004; 2:105-110.	1	1	1	1	1	1	0	6
Thom G, Kavaliauskas M, Babraj J. Changes in lactate kinetics underpin soccer performance adaptations to cycling-based sprint interval training. European journal of sport science. 2020;20(4):486-94.	1	1	0	1	1	1	1	6
Tsuchiya Y, Ijichi T, Goto K. Effect of sprint training on resting serum irisin concentration - Sprint training once daily vs. twice every other day. Metabolism: Clinical & Experimental. 2016; 65(4):492-495.	1	1	1	1	1	0	1	6
Turnes T, de Aguiar RA, de Oliveira Cruz RS, Lisboa FD, Pereira KL, Caputo F. Short-term interval training at both lower and higher intensities in the severe exercise domain result in improvements in	1	1	1	0	1	1	1	6

VO2 on-kinetics. European journal of applied physiology. 2016; 116(10):1975-1984								
Viana RB, de Lira C,Andre Barbosa, Naves JPA, Coswig VS, Del Vecchio FB, Ramirez-Campillo R, et al. Can We Draw General Conclusions from Interval Training Studies? Sports Medicine. 2018; 48(9):2001-2009.	1	1	1	0	1	1	1	6
Wang R, Fukuda DH, Hoffman JR, La Monica MB, Starling TM, Stout JR, et al. Distinct effects of repeated-sprint training in normobaric hypoxia and β-alanine supplementation. J Am Coll Nutr. 2019;38(2):149-61.	1	1	1	0	1	1	1	6
Weber CL, Schneider DA. Increases in maximal accumulated oxygen deficit after high-intensity interval training are not gender dependent. Journal of applied physiology. 2002; 92(5):1795-1801.	1	1	1	0	1	1	1	6
Wood KM, Olive B, LaValle K, Thompson H, Greer K, Astorino TA. Dissimilar Physiological and Perceptual Responses Between Sprint Interval Training and High-Intensity Interval Training. Journal of Strength & Conditioning Research. 2016; 30(1):244-250.	1	1	1	0	0	0	1	4
Zinner C, Sperlich B, Born D, Michels G. Effects of combined high intensity arm and leg training on performance and cardio-respiratory measures. Journal of Sports Medicine & Physical Fitness. 2017; 57(7-8):969-975.	1	1	1	0	1	1	1	6

Electronic Supplementary Material Appendix S3: Modified Downs and Black checklists

Control trials checklist:

1. Is the hypothesis/aim/objective of the study clearly described?

YES	1
NO	0

2. Are the main outcomes to be measured clearly described in the Introduction or Methods section?
    a. If the main outcomes are first mentioned in the Results section, the question should be answered no.

YES	1
NO	0

3. Are the characteristics of the participants included in the study clearly described?
    a. In cohort studies and trials, inclusion and/or exclusion criteria should be given. In case-control studies, a case-definition and the source for controls should be given.

YES	1
NO	0

4. Are the interventions of interest clearly described?
    a. Treatments and placebo (where relevant) that are to be compared should be clearly described.

YES	1
NO	0

5. Are the distributions of principal confounders in each group of participants to be compared clearly described?
    a. A list of principal confounders is provided.

YES	2
PARTIALLY	1
NO	0

6. Are the main findings of the study clearly described?
    a. Simple outcome data (including denominators and numerators) should be reported for all major findings so that the reader can check the major analyses and conclusions. (This question does not cover statistical tests which are considered below).

YES	1
NO	0

7. Does the study provide estimates of the random variability in the data for the main outcomes?
    a. In non-normally distributed data the inter-quartile range of results should be reported. In normally distributed data the standard error, standard deviation or confidence intervals should be reported. If the distribution of the data is not described, it must be assumed that the estimates used were appropriate and the question should be answered yes.

YES	1
NO	0

8. Have the characteristics of participants lost to follow-up been described?
    a. This should be answered yes where there were no losses to follow-up or where losses to follow-up were so small that findings would be unaffected by their inclusion. This should be answered no, where a study does not report the number of participant lost to follow-up.

YES	1
NO	0

9. Have actual probability values been reported (e.g.0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?

YES	1
NO	0

10. Was an attempt made to blind those measuring the main outcomes of the intervention?

YES	1
NO	0
UNABLE TO DETERMINE	0

11. Were the statistical tests used to assess the main outcomes appropriate?
    a. The statistical techniques used must be appropriate to the data. For example nonparametric methods should be used for small sample sizes. Where little statistical analysis has been undertaken but where there is no evidence of bias, the question should be answered yes. If the distribution of the data (normal or not) is not described it must be assumed that the estimates used were appropriate and the question should be answered yes.

YES	1
NO	0
UNABLE TO DETERMINE	0

12. Was compliance with the intervention/s reliable?
    a. Where there was noncompliance with the allocated treatment or where there was contamination of one group, the question should be answered no. For studies where the effect of any misclassification was likely to bias any association to the null, the question should be answered yes.

YES	1
NO	0
UNABLE TO DETERMINE	0

13. Were the main outcome measures used accurate (valid and reliable)?
    a. For studies where the outcome measures are clearly described, the question should be answered yes. For studies which refer to other work or that demonstrates the outcome measures are accurate, the question should be answered as yes.

YES	1
NO	0
UNABLE TO DETERMINE	0

14. Were the participants in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?
    a. For example, participants for all comparison groups should be selected from the same hospital. The question should be answered unable to determine for cohort and case control studies where there is no information concerning the source of participants included in the study.

YES	1
NO	0
UNABLE TO DETERMINE	0

15. Were study subjects randomised to intervention groups?
    a. Studies which state that subjects were randomised should be answered yes except where method of randomisation would not ensure random allocation. For example alternate allocation would score no because it is predictable.

YES	1
NO	0
UNABLE TO DETERMINE	0

16. Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?
    a. This question should be answered no for trials if: the main conclusions of the study were based on analyses of treatment rather than intention to treat; the distribution of known confounders in the different treatment groups was not described; or the distribution of known confounders differed between the treatment groups but was not taken into account in the analyses. In nonrandomised studies if the effect of the main confounders was not investigated or confounding was demonstrated but no adjustment was made in the final analyses the question should be answered as no.

YES	1
N/A Reported no base line differences and therefore no requirement	1
NO – was a difference and didn't adjust	0
UNABLE TO DETERMINE any baseline differences	0

17. Were losses of participants to follow-up taken into account?
    a. If the numbers of participants lost to follow-up are not reported, the question should be answered as unable to determine. If the proportion lost to follow-up was too small to affect the main findings, the question should be answered yes.

YES	1
N/A if there was a statement that all recruited made it to post	1
NO	0
UNABLE TO DETERMINE	0

18. Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%? (WAS THE POWER CALCULATION DONE)
    a. Sample sizes have been calculated to detect a difference of x% and y%.

YES	1
NO	0

19. If a power calculation was done, was this adjusted to take into account multiple outcome variables (if multiple variables were collected)? ADD TO POWER DOMAIN

YES (N/A only 1 variable)	1
NO	0

20. Were familiarisation sessions of training completed? ADDED TO INTERNAL VALIDITY - BIAS

YES	1
NO	0

21. Were familiarisation sessions of testing completed? ADDED TO INTERNAL VALIDITY - BIAS

YES	1
NO	0

22. Was number of sessions attended reported? ADDED TO REPORTING DOMAIN

YES	1
NO	0

23. Was a minimum number of sessions for inclusion reported? ADDED TO REPORTING DOMAIN

YES	1
NO	0

Non-Control trials checklist:

1. Is the hypothesis/aim/objective of the study clearly described?

YES	1
NO	0

2. Are the main outcomes to be measured clearly described in the Introduction or Methods section?
    a. If the main outcomes are first mentioned in the Results section, the question should be answered no.

YES	1
NO	0

3. Are the characteristics of the participants included in the study clearly described?
    a. In cohort studies and trials, inclusion and/or exclusion criteria should be given. In case-control studies, a case-definition and the source for controls should be given.

YES	1
NO	0

4. Are the interventions of interest clearly described?
    a. Treatments and placebo (where relevant) that are to be compared should be clearly described.

YES	1
NO	0

5. Are the main findings of the study clearly described?
    a. Simple outcome data (including denominators and numerators) should be reported for all major findings so that the reader can check the major analyses and conclusions. (This question does not cover statistical tests which are considered below).

YES	1
NO	0

6. Does the study provide estimates of the random variability in the data for the main outcomes?
    a. In non-normally distributed data the inter-quartile range of results should be reported. In normally distributed data the standard error, standard deviation or confidence intervals should be reported. If the distribution of the data is not described, it must be assumed that the estimates used were appropriate and the question should be answered yes.

YES	1
NO	0

7. Have the characteristics of participants lost to follow-up been described?
    a. This should be answered yes where there were no losses to follow-up or where losses to follow-up were so small that findings would be unaffected by their inclusion. This should be answered no, where a study does not report the number of participant lost to follow-up.

YES	1
NO	0

8. Have actual probability values been reported (e.g.0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?

YES	1
NO	0

9. Was an attempt made to blind those measuring the main outcomes of the intervention?

YES	1
NO	0
UNABLE TO DETERMINE	0

10. Were the statistical tests used to assess the main outcomes appropriate?
    a. The statistical techniques used must be appropriate to the data. For example nonparametric methods should be used for small sample sizes. Where little statistical analysis has been undertaken but where there is no evidence of bias, the question should be answered yes. If the distribution of the data (normal or not) is not described it must be assumed that the estimates used were appropriate and the question should be answered yes.

YES	1
NO	0
UNABLE TO DETERMINE	0

11. Was compliance with the intervention/s reliable?
    a. Where there was noncompliance with the allocated treatment or where there was contamination of one group, the question should be answered no. For studies where the effect of any misclassification was likely to bias any association to the null, the question should be answered yes.

YES	1
NO	0
UNABLE TO DETERMINE	0

12. Were the main outcome measures used accurate (valid and reliable)?
    a. For studies where the outcome measures are clearly described, the question should be answered yes. For studies which refer to other work or that demonstrates the outcome measures are accurate, the question should be answered as yes.

YES	1
NO	0
UNABLE TO DETERMINE	0

13. Were losses of participants to follow-up taken into account?
    a. If the numbers of participants lost to follow-up are not reported, the question should be answered as unable to determine. If the proportion lost to follow-up was too small to affect the main findings, the question should be answered yes.

YES	1
N/A if there was a statement that all recruited made it to post	1
NO	0
UNABLE TO DETERMINE	0

14. Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%? (WAS THE POWER CALCULATION DONE)
    a. Sample sizes have been calculated to detect a difference of x% and y%.

YES	1
NO	0

15. If a power calculation was done, was this adjusted to take into account multiple outcome variables (if multiple variables were collected)? ADD TO POWER DOMAIN

YES (N/A only 1 variable)	1
NO	0

16. Were familiarisation sessions of training completed? ADDED TO INTERNAL VALIDITY - BIAS

YES	1
NO	0

17. Were familiarisation sessions of testing completed? ADDED TO INTERNAL VALIDITY - BIAS

YES	1
NO	0

18. Was number of sessions attended reported? ADDED TO REPORTING DOMAIN

YES	1
NO	0

19. Was a minimum number of sessions for inclusion reported? ADDED TO REPORTING DOMAIN

YES	1
NO	0

Electronic Supplementary Material Appendix S4: Example brms code

Variables:

1) Standardised mean difference effect sizes: SprintES
2) Within study effect size variance calculated form 0.7 correlation : SprintSE0.7
3) Study identifier: StudyId
4) Outcome identifier: OucomeId
5) Regression variable: Var1

Example basic model:

```
mod1.prior = get_prior(SprintES | se(SprintSE,sigma=TRUE) ~ 1 + (1| StudyId/OucomeId), family = gaussian(), data=Data)

mod1.prior$prior[7] = "student_t(3, 0, 1.5)"

set.seed(123)

mod1 = brm(SprintES | se(SprintSE,sigma=TRUE) ~ 1 + (1| StudyId/OucomeId), family = gaussian(),

    data = Data, prior = mod1.prior, chains = 4, iter = 20000, warmup = 10000)

mod1Posterior = posterior_samples(mod1)

# Pooled Effect Size

quantile(mod1Posterior[,1],c(0.025,0.5,0.975))

# Between study variation

quantile(mod1Posterior[,2],c(0.125,0.5,0.875))
```

Example regression model:

```
mod2.prior = get_prior(SprintES | se(SprintSE,sigma=TRUE) ~ Var1 + (1| StudyId/OucomeId), family = gaussian(), data=Data)

mod2.prior$prior[9] = "student_t(3, 0, 1.5)"

set.seed(123)

mod2 = brm(SprintES | se(SprintSE,sigma=TRUE) ~ Var1 + (1| StudyId/OucomeId), family = gaussian(),

    data = Data, prior = mod2.prior, chains = 4, iter = 20000, warmup = 10000)

mod2Posterior = posterior_samples(mod2)

# Intercept effect size

quantile(mod2Posterior[,1],c(0.025,0.5,0.975))

# Comparison of intercept to level 2 of Var1

quantile(mod2Posterior[,2],c(0.025,0.5,0.975))

# Between study variation

quantile(mod2Posterior[,3],c(0.125,0.5,0.875))
```