THE EFFECT OF HIGH-INTENSITY INTERVAL TRAINING ON POST-EXERCISE OXYGEN CONSUMPTION: A META-ANALYSIS

SYSTEMATIC REVIEW
REVISÃO SISTEMÁTICA
REVISIÓN SISTEMÁTICA

EFEITO DO TREINAMENTO INTERVALADO DE ALTA INTENSIDADE SOBRE O CONSUMO DE OXIGÊNIO DEPOIS DO EXERCÍCIO: METANÁLISE

EFECTO DEL ENTRENAMIENTO DE INTERVALOS DE ALTA INTENSIDAD SOBRE EL CONSUMO DE OXÍGENO DESPUÉS DELEJERCICIO: METAANÁLISIS

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ABSTRACT

Introduction: The objective of this study was to present a systematic review and meta-analysis to compare total excess post-exercise oxygen consumption (EPOC) for two training intervention models in healthy individuals, and the secondary objective was to understand whether oxygen consumption after exercise could really promote a meaningful help. Design: To design a meta-analysis review to compare two training intervention models (experimental: high-intensity interval training; and control: continuous moderate-intensity) and their effects on total EPOC in healthy individuals. Participants: Seventeen studies were considered to be of good methodological quality and with a low risk of bias. Methods: Literature searches were performed using the electronic databases with no restriction on year of publication. The keywords used were obtained by consulting Mesh Terms (PubMed) and DeCS (BIREME Health Science Descriptors). Results: The present study findings showed a tendency (random-effects model: 0.87, 95%-CI [0.35,1.38], I2=73%, p<0.01) to increase EPOC when measured following high-intensity interval training. Conclusions: Our study focused on the analysis of high- and moderate-intensity oxygen uptake results following exercise. Despite the growing popularity of high-intensity interval training, we found that the acute and chronic benefits remain limited. We understand that the lack of a standard protocol and standard training variables provides limited consensus to determine the magnitude of the EPOC. We suggest that longitudinal experimental studies may provide more robust conclusions. Another confounding factor in the studies investigated was the magnitude (time in minutes) of VO2 measurements when assessing EPOC. Measurement times ranged from 60 min to 720 min. Longitudinal studies and controlled experimental designs would facilitate more precise measurements and correct subject numbers would provide accurate effect sizes. ***Systematic reviewb of Level II studies.***

Keywords: Oxygen consumption; Exercise; HYPERLINK "about:blank" Physical conditioning, human; High-intensity interval training.

RESUMO

Introdução: O objetivo deste estudo foi apresentar uma revisão sistemática e metanálise para comparar os efeitos de dois modelos de intervenção de treinamento sobre o consumo excessivo de oxigênio pós-exercício (EPOC) em indivíduos saudáveis em treinamento, e o objetivo secundário foi entender se o consumo de oxigênio depois de exercício realmente pode proporcionar ajuda substancial. Objetivo: Elaborar uma revisão de metanálise para comparar um modelo de treinamento de duas intervenções (experimental: treinamento intervalado de alta intensidade, e controle: contínuo de intensidade moderada) e o efeito sobre o EPOC total em indivíduos saudáveis. Participantes: Os 17 estudos foram considerados de boa qualidade metodológica e baixo risco de viés. Métodos: As buscas bibliográficas foram realizadas nos bancos de dados eletrônicos sem restrição de ano de publicação. Os descritores usados foram obtidos em MeSH (PubMed) e DeCS (Descritores em Ciências da Saúde da BIREME). Resultados: Os achados do presente estudo mostraram uma tendência (modelo de efeitos aleatórios: 0,87, IC 95% [0,35;1,38], $I^2 = 73\%$, $p < 0,01$) de aumento do EPOC quando as medidas foram realizadas depois de treinamento intervalado de alta intensidade. Conclusões: Nosso estudo concentrou-se na análise dos resultados de alta e moderada intensidade no consumo de oxigênio depois do exercício. Apesar da crescente popularidade do treinamento intervalado de alta intensidade, descobrimos que os benefícios agudos e crônicos permanecem limitados. Entendemos que a falta de um protocolo e variáveis padronizadas de treinamento fornecem consenso limitado para determinar a magnitude do EPOC. Sugerimos que estudos experimentais longitudinais podem fornecer conclusões mais robustas. Outro fator de confusão nos estudos investigados foi a magnitude (tempo em minutos) das medidas do VO_2 na avaliação do EPOC. Os tempos de medição variaram de 60 a 720 min. Estudos longitudinais e projetos experimentais controlados facilitariam medições mais precisas e números corretos de indivíduos forneceriam tamanhos de efeito precisos. ***Nível de evidência II; Revisão sistemática[b] de Estudos.***

Descritores: *Consumo de oxigênio; Exercício; Condicionamento físico humano; Treinamento intervalado de alta intensidade.*

Associate Editor responsible for the review process: Paulo Sergio Martino Zogaib

RESUMEN

Introducción: El objetivo de este estudio fue presentar una revisión sistemática y un metaanálisis para comparar los efectos de dos modelos de intervención de entrenamiento sobre el exceso de consumo de oxígeno post-ejercicio (EPOC) en individuos sanos en entrenamiento, y el objetivo secundario fue comprender si el consumo de oxígeno después del ejercicio realmente puede proporcionar una ayuda sustancial. Objetivo: Preparar una revisión de metaanálisis para comparar un modelo de entrenamiento de dos intervenciones (experimental: entrenamiento en intervalos de alta intensidad; y control: continuo de intensidad moderada) y los efectos sobre el EPOC total en individuos sanos. Participantes: Los 17 estudios se consideraron de buena calidad metodológica y de bajo riesgo de sesgo. Métodos: Se realizaron búsquedas bibliográficas en bases de datos electrónicas sin restricción de año de publicación. Los descriptores utilizados se obtuvieron de la consulta a Mesh (PubMed) y DeCS (Descriptores en Ciencias de la Salud de BIREME). Resultados: Los hallazgos del presente estudio mostraron una tendencia (modelo de efectos aleatorios: 0,87, IC 95% [0,35; 1,38], I2 = 73%, p < 0,01) de aumento del EPOC cuando las medidas se realizaron después de un entrenamiento en intervalos de alta intensidad. Conclusiones: Nuestro estudio se centró en el análisis de resultados del consumo de oxígeno post-ejercicio de alta y moderada intensidad.. A pesar de la creciente popularidad del entrenamiento en intervalos de alta intensidad, hemos comprobado que los beneficios agudos y crónicos siguen siendo limitados. Entendemos que la falta de un protocolo y variables de entrenamiento estandarizadas proporcionan un consenso limitado para determinar la magnitud del EPOC. Sugerimos que los estudios experimentales longitudinales pueden proporcionar conclusiones más sólidas. Otro factor de confusión en los estudios investigados fue la magnitud (tiempo en minutos) de las mediciones del VO2 al evaluar el EPOC. Los tiempos de medición oscilaron entre 60 y 720 minutos. Los estudios longitudinales y los diseños experimentales controlados facilitarían mediciones más precisas y el número correcto de sujetos proporcionaría tamaños de efecto precisos. ***Nivel de evidencia II; Revisión sistemáticab de Estudios.***

Descriptores: *Consumo de oxigeno; Ejercicio; Acondicionamiento físico humano; Entrenamiento de intervalos de alta intensidad.*

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INTRODUCTION

Due to the increase of obesity in recent years, there has been an increase in the search for strategies to help reduce fat mass. One non--pharmacological strategy is exercise. Several training designs, models of exercise, and different intensities and durations have been used to increase energy expenditure during and after exercise. Energy expenditure post exercise is normally quantified by measuring excess post exercise oxygen consumption (EPOC).[1-5] However, finding the exercise mode that increases energy expenditure after exercise is difficult. In addition, an intensity that can be used to control, maintain and decrease body weight and control diseases associated with obesity is also desirable. Energy expenditure during and post-exercise is measured by oxygen uptake (VO_2) using a gas analyzer.[6,7] During exercise, there is an increase in VO_2 to support increased energy needs. Post exercise, VO_2 does not return to resting levels immediately and may remain elevated for some time. Exercise intensity is an important factor in the determination of excess post-exercise oxygen consumption (EPOC).[3]

There are several models of training (resistance training, high-intensity training, and continuous training) that can increase EPOC between 1 to 48 hours above resting levels.[1,3,8-13]. In this context, it has been suggested that there is a curvilinear relationship between EPOC magnitude (total O_2 consumed during recovery) and exercise intensity.

High-intensity interval training (HIIT) has been recommended because of the relatively rapid, increased amount of energy expenditure during and after exercise when compared to continuous aerobic training. However, aerobic training has been reported as an effective method to control or lose weight.[14] On the other hand, resistance training (RT) has been described as intermittent in nature and might induce a prolonged EPOC during recovery.[2] Tucker et al.[15] have suggested that it is unlikely that the greater fat loss observed after interval exercise training reported in some studies is due to greater EPOC after interval exercise. In this context, Binzen et al.[2] investigated the acute effects of 45 min of RT on EPOC and substrate oxidation 120 min following exercise in moderately trained women. The overall 2h EPOC was 6.2 L (RT: 33.4 ± 5.1 L *vs*. control: 27.2 ± 0.3 L), corresponding to an 18.6% elevation over the measurement period.

The literature seems inconclusive about the magnitude effect of EPOC and the relationship with the intensity of exercise during training. Nowadays, professionals have been recommending high-intensity interval training models related to the relative and absolute increases in energy expenditure following exercise. However, high-intensity interval training models may not be effective for all individuals, especially sedentary, elderly and overweight/obese individuals.[16-18]

Objectives

Therefore, the aim of this study was to present a systematic review and meta-analysis to compare two training intervention models (experimental: high-intensity interval training; and control: continuous moderate-intensity) in total oxygen consumption during recovery (EPOC) in healthy individuals in training, and the secondary objective was to understand whether oxygen consumption after exercise really could promoter meaningfully help.

METHODS

The meta-analysis review was carried out in accordance with the recommendations of Khan et al.[19] considering: 1) framing of the questions for a literature review; 2) identification of the relevant research; 3) evaluation of the quality of the studies; 4) summary of the evidence; 5) and interpretation of the results. In addition, we adhered to the 27 items by checklists of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). To ensure transparency and complete communication this systematic review and meta-analysis complied with suggestions outlined previously.[20] The research questions were defined by the PICOS model in accordance with PRISMA guidelines, as follows:

1. Population: males and females with experience in training.
2. Intervention: an acute session which incorporated a high-intensity training design.
3. Comparator: oxygen uptake compared to other interventions (moderate-intensity training).
4. Outcomes: amount of oxygen uptake after exercise.
5. Study design: randomized controlled designs, counterbalanced crossover or repeated measure designs that investigated the acute oxygen uptake responses from high-intensity training.

The review was approved and registered at National Institute for Health Research - International prospective register of systematic reviews (PROSPERO) CRD42020170195 last 04/28/2020.

Criteria for considering studies for this review

Type of Studies

We included randomized clinical trials (with parallel-group design, within-person design, cluster design, or the first phase of cross-over trials) evaluating the mindfulness strategies and programs on the resistance training systems, compared to each resistance training system. We excluded non-randomized clinical trials, such as cohorts, case-control, and case reports studies. We did not impose language, publication date, or status restrictions for potentially retrieved records.

Types of participants

We included studies of adult both genre (aged 18 years or over) adults with or without experience in resistance training, without diagnostic diseases.

Type of interventions

We included studies that assessed the effects of training using high-intensity compared to low- or moderate-intensity exercise.

Type of outcome measures

Primary outcomes

1. Oxygen consumption (liter) and calorie (kcal)
2. Adverse effects (e. g., worsening of the parameters mentioned above after treatment)

Secondary outcomes

1. Metabolic changes
2. Change in level of cardiorespiratory fitness
3. Effect of exercise on heart rate

Search methods for identification of studies

Literature search

For this review, literature searches were performed using the (Virtual Library for Health - BVS, PubMed, Embase, Ebsco SPORTDiscus and Science Direct) electronic databases without any year restriction. Manual reference searching was performed to identify other relevant studies. The keywords used were obtained through consultation of Mesh Terms (PubMed) and DeCS (keywords of subjects in BIREME health science). The combination of excess post-exercise oxygen consumption (epoc; oxygen consumption; oxygen; metabolic equivalent) and high intensity interval training (High-Intensity; Sprint Interval Training; High-Intensity Intermittent; exercise) with "AND" and "OR" combination: epoc and exercise (pubmed) ((epoc[All Fields] AND ("exercise"[MeSH Terms] OR "exercise"[All Fields])) AND Search((epoc[Title/Abstract]) AND (("Oxygen Consumption"[Mesh] OR "Consumption, Oxygen" OR "Consumptions, Oxygen" OR "Oxygen Consumption" OR "Metabolic Equivalent"))) AND (("High-Intensity Interval Training"[Mesh]High Intensity Interval Training OR "High-Intensity Interval Trainings" OR " Interval Training, High-Intensity" OR "Interval Trainings, High-Intensity" OR "Training, High-Intensity Interval" OR "Trainings, High-Intensity Interval" OR "High-Intensity Intermittent Exercise" OR "Exercise, High-Intensity Intermittent" OR "Exercises, High-Intensity Intermittent" OR "High-Intensity Intermittent Exercises" OR "Sprint Interval Training" OR "Sprint Interval Trainings")). After the removal of duplicates, the title and abstract of each article were initially screened for suitability. Full-text articles were retrieved in order to determine inclusion or exclusion. Two authors (BCL and EFR) performed the search independently. In the case of any selection bias, a third assessor (GAJ) was included. The search was conducted throughout January 2018 and updated in December of 2019.

Searching other resources

Additionally, we checked the reference list and citations of eligible studies, grey literature (Open Grey, www.opengrey.eu), and related systematic reviews. Where required, we attempted to contact the authors of the original reports for clarification or to request missing data.

Inclusion and exclusion criteria

Studies were included in this review if they met the following criteria: (a) implemented high-intensity in comparison to moderate-intensity; (b) results reported in oxygen consumption (liter) and calorie (kcal); (c) the study had an acute design or part thereof; and (d) was published in an English-language peer-reviewed journal.

Selection of studies and reviewing process

To increase reliability, two researchers **(**GAJ and DR**)** performed the analyses independently during all stages of the study, and in the case of a discrepancy, a third assessor (GAJ) was used as a moderator. For all included articles, the following data were extracted: (1) study characteristics (author, year, sample size and study design); (2) participant demographics (age, sex and training experience); (3) protocols of the training (high-intensity, and moderate-intensity structure [i.e. rest period, number of sets and repetitions, duration the session, exercise selection and intensity according to the previous studies]);[21,22] and (4) outcome measures (VO_2 [L], and showed calorie value [kcal]) post-intervention and reported an average change and standard deviation using a validated measure. The reference lists of articles retrieved were then screened for any additional articles that had relevance to the topic, according to previous publications[23] (Figure 1).

Data extraction and management

Data extraction forms were used to extract data from each study. Data extracted included the size and characteristics of the sample (i.e., age, gender, body weight, height, mass fat, free-fat mass, experience of resistance training), characteristics of the interventions (study design, number of sessions, duration of each session of treatment, intensity of training, a model of training), instruments used to evaluate the outcomes (oxygen consumption), and results of the included studies. Two independent reviewers performed the data extraction. Any disagreements were resolved by a third reviewer. When data were not available in the manuscripts or in the case of uncertainty, the authors were contacted where possible for clarification.

Risk of bias and quality assessment

The risk of bias in the studies was assessed by three authors (GAJ, DR and AF) the according to The Joanna Briggs Institute (JBI) Critical Appraisal tools for use in JBI Systematic Reviews.[24] The JBI critical appraisal checklist for analytical cross-sectional studies for analyzing by the risk of bias was assessed by considering the following questions: were the criteria for inclusion in the sample clearly defined? were the study subjects and the setting described in detail? was the exposure measured in a valid and reliable way? were objective, standard criteria used for the measurement of the conditions? were confounding factors identified? were strategies to deal with confounding factors stated? were the outcomes measured in a valid and reliable way? was appropriate statistical analysis used?

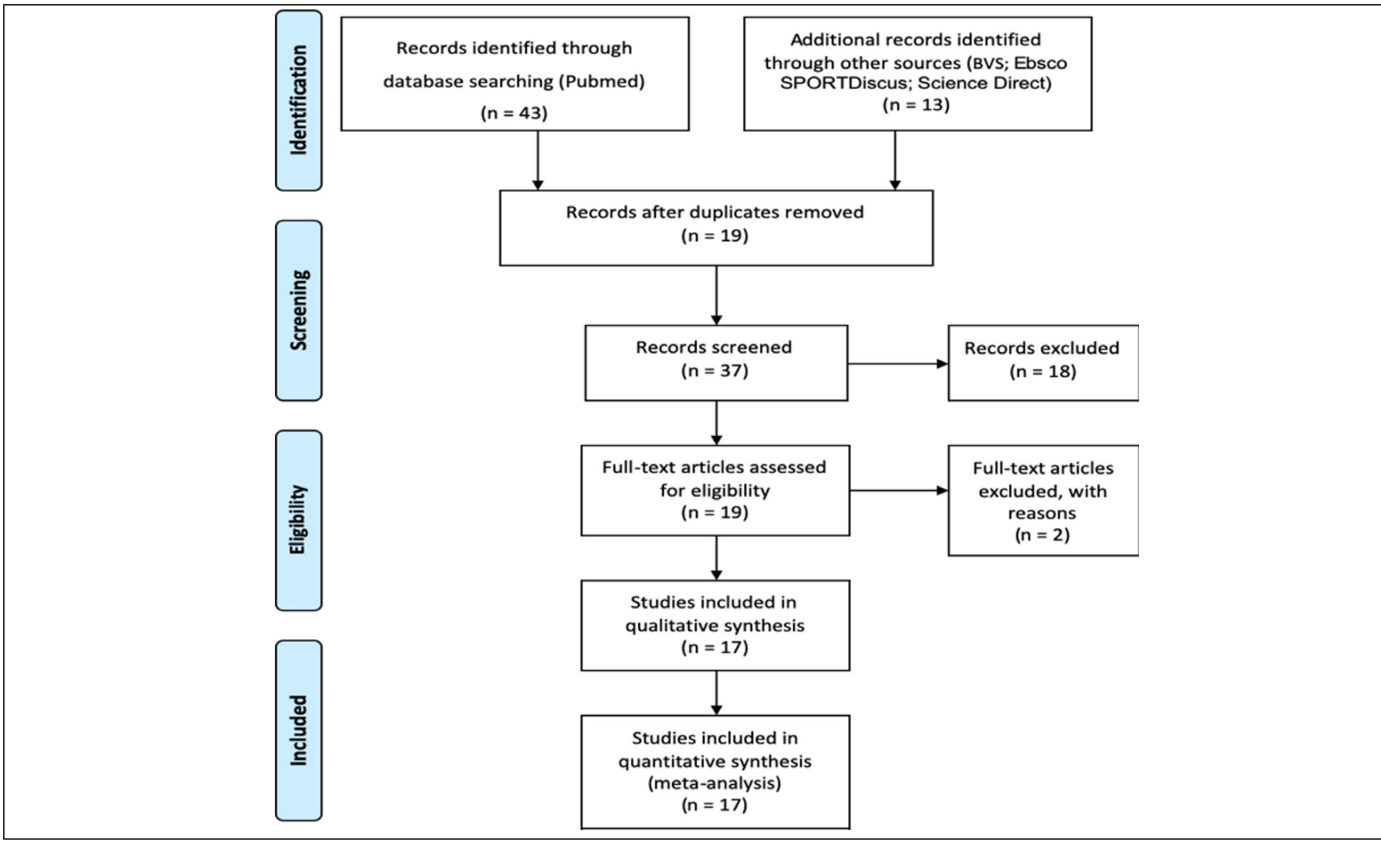

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flowchart of the literature search strategy.[20]

These systematic reviews incorporated a process of critique and appraisal of the research evidence. Therefore, the purpose of this appraisal was to assess the methodological quality of a study and to determine the extent to which a study has addressed the possibility of bias in its design. Conduct, and analysis according to previous models were employed in this meta-analysis[25,26] (Figures 2 and 3).

Statistical Meta-analysis

Measure of treatment effect

The random-effects meta-analysis was conducted for the performance variable oxygen consumption. The performance variable outcome was presented as standardized mean differences SMD ± standard deviation (SD), and 95% confidence interval (CI) values. For each study, SMD was computed such that positive values indicate that the intervention group (i.e. high-intensity training) was superior to the control group (i.e. moderate-intensity training).[27]

Dealing with missing data

Missing data was dealt with as outlined in Chapter 10 of the Cochrane Handbook of Systematic Reviews; hence, where possible, we performed intention-to-treat analysis for primary and secondary outcomes (randomized studies). Irrespective of the study design, we tried to contact the trial investigators or sponsors to obtain missing outcome data. Where these data remain unavailable, we rated the relevant domains of the Cochrane tool for assessing the risk of bias accordingly.

Assessment of heterogeneity

We assessed statistical heterogeneity employing the Cochran Q test to determine the strength of evidence that any heterogeneity was genuine. We considered a threshold of P-value < 0.1 as an indicator of whether heterogeneity (genuine variation in effect sizes) is present. In addition, we examined and interpreted the I^2 statistic as follows: < 25% (no heterogeneity); 25% to 49% (low heterogeneity); 50% to 74% (moderate heterogeneity); ≥ 75% (high heterogeneity).[28]

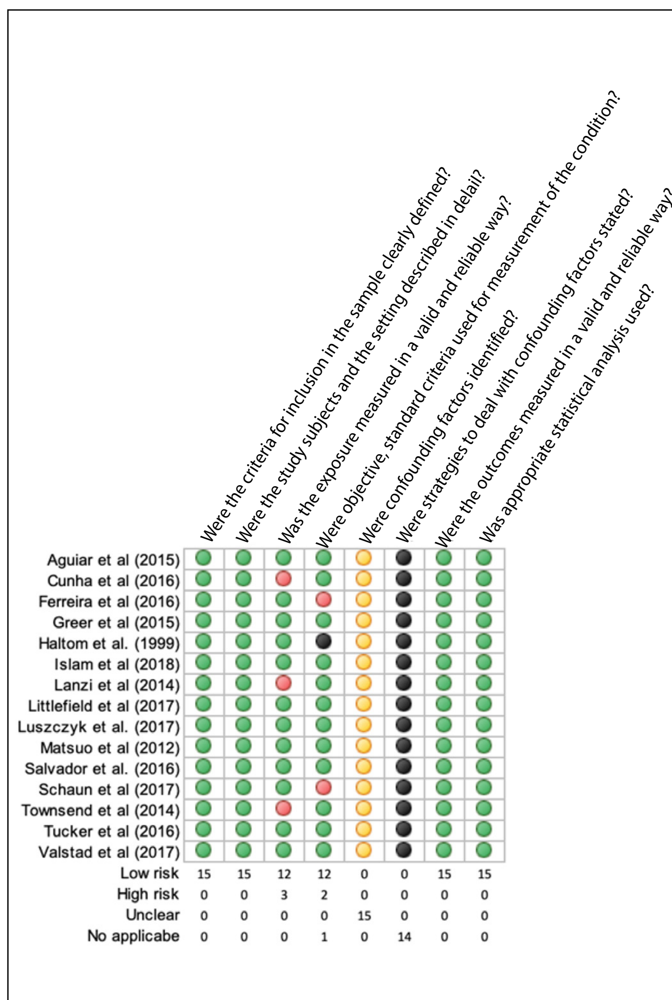

Figure 2. Risk of bias of selected studies.

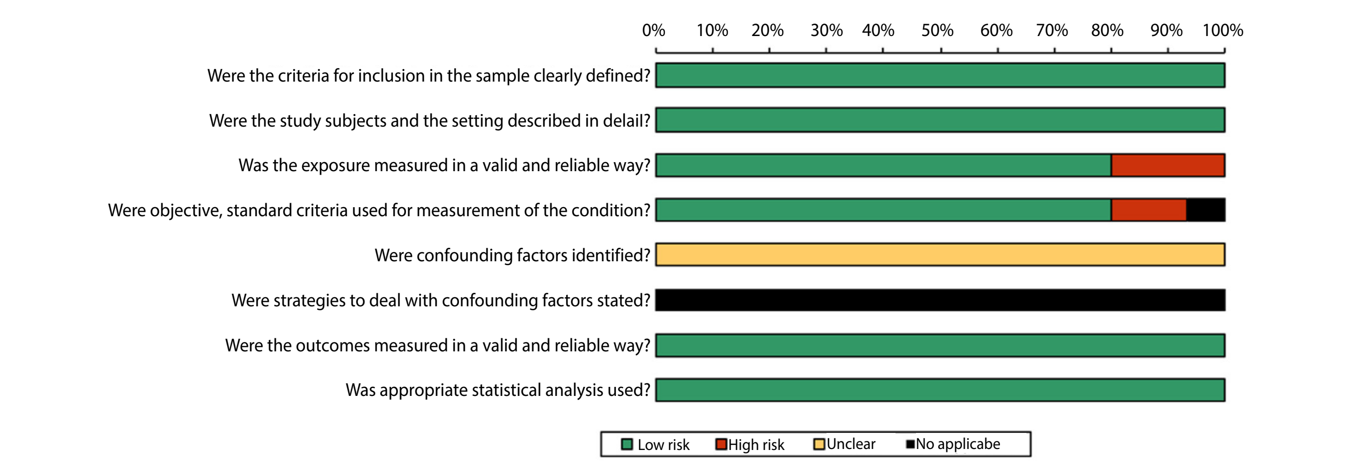

Figure 3. Summary of risk of bias of selected studies by Joanna Briggs Institute (JBI) Critical Appraisal tools for use in JBI Systematic Reviews for risk bias analysis.

Therefore, the effect of training type was determined by standardized SMD values post-intervention after calculating the inverse of the variance.[29,30] The amount of heterogeneity was estimated (with the DerSimonian-Laird estimator) and incorporated into the standard error of the estimated average effect and the corresponding confidence interval.

Assessment of reporting biases

Funnel plots and Trim and fill were used to assess publication bias using Egger's regression tests where non-significant asymmetry indicated no bias.[31]

Data synthesis

The meta-analyses

We used the metafor package version 1.2-1 and rmeta version 3.0 implemented in R-3.6.2 software for Mac to perform and synthesize the direct and indirect evidence of the oxygen consumption post exercise effect. Therefore, all analyses were performed using package meta in R version 1.0.4.4 – © 2009-2016 RStudio, Inc (The R Foundation for Statistical Computing, Vienna, Austria). An α level of $p < 0.05$ was used to determine statistical significance.

Subgroup analysis and investigation of heterogeneity

We performed subgroup analysis in case of heterogeneity considering the following variables: VO_2 or kcal post-exercise: RT = studies that included only resistance exercise, and used instrument equipment, free-weights; RU = studies that included only running training and used a treadmill; and CY = studies that included only cycling training, and used a cycle-ergometer).

Sensitivity analysis

We performed a sensitivity analysis that included: Effects of risk of bias by excluding trials with high or unclear risk of bias; Influence of unpublished studies excluding trials with abstracts only; and Influence of sponsorship by excluding industry-funded studies.

RESULTS

Characteristics of included trials and participants

The 17 studies were judged to be of good methodological quality and at low risk of bias. Full details of the risk of bias are presented in (supplementary material). The presented high-intensity interval training n = 152 experimental group and moderate-intensity training n = 150 control groups (total of 302 adults from both genders were included and randomized respectively). The mean age ranged from 26.17 ± 6.55 years (body mass: 77.26 ± 11.82 kg, stature: 175.17 ± 4.18 cm, body mass index: 25.31 ± 4.48 kg.m^2). (Table 1 (part I and part II))

Main analysis

Data pooled from 17 studies showed a large effect significant in favor of the experimental group (high-intensity interval training) (SMD: 1.24; 95%-CI [0.78; 1.71]; z: 5.25, Q: 1.08; $p < 0.01$). However, there was large heterogeneity tau^2: 0.6150; H: 1.74 [1.35; 2.24]; $I^2 = 67\%$ [44.9%; 80.1%].

The intervention characteristics are outlined in Table 2. Interventions were conducted to compare high-intensity interval training and continuous moderate-intensity in all studies. Ten studies[1,4,5,32-38] reported by VO_2 in liters; three studies[2,39,40] reported outcomes only in energy expenditure in calories (kcal); and five studies[15,41-44] reported outcomes in both (VO_2 and kcal) respectively.

The cycle ergometer was the most common modality of exercise (eight studies),[4,5,15,34,36,37,41,43] followed by the Treadmill (seven studies),[4,32,33,35,37,38,44] and resistance exercise was the least common modality of exercise (two studies).[1,42]

Table 2 shows a large effect in favor of high-intensity training for VO_2 post-exercise using a cycle ergometer or treadmill. There were different significances in favor of high-intensity exercise for energy expenditure (calorie) when the intervention was resistance exercise.

Thus, there is evidence that the results of the meta-analysis were influenced by a publication bias. After analysis the asymmetry in funnel ($t = 1.09$; = -0.61 (13), p-value = 0.30), we used the Trim and Fill method for the adjusted effect size.

The adjusting for publication bias showed studies used of high-intensity training seems a positive influence in increasing energy expenditure and/or uptake oxygen post-exercise. The full details are summarized in Figure 4.

DISCUSSION

Our study focused specifically on evaluating high-intensity interval training and moderate-intensity results for oxygen uptake following exercise. We observed that the studies are not conclusive in relation to EPOC. Our study demonstrated a tendency (random-effects model: 0.87, 95%-IC [0.35; 1.38], $I^2 = 73\%$, $p < 0.01$) to increase EPOC when the exercise performed was high-intensity interval training (Figure 4).

Several studies[1,5,15,37,40,41,43,45] have shown that high-intensity interval training does not elevate oxygen consumption. However, other studies[4,32,34,35,38,39,42,44] have shown positive results when the intervention used comprises of high-intensity interval training. Therefore, EPOC results are conflicting when we consider previous studies.

After adjusting for publication bias, studies that used high-intensity interval training seemed to positively influence the increase in energy expenditure and/or oxygen uptake after exercise. However, there was a large heterogeneity observed ($I^2 = 73\%$) between the studies (Figure 4).

Table 1. Outlines Characteristics of Included Trials and Participants and Program of Characteristics Interventions (part I).

Study	Sample size	Gender		Age (years)	Weight (kg)	Height (cm)
Abboud et al. (2013)	8	healthy men	both (untrained and trained)	22 ± 3	88.0 ± 8.7	176.0 ± 5.0
Aguiar et al. (2015)	22	healthy men	trained	29 ± 4	70.2 ± 8.6	181.0 ± 8.0
Cunha et al. (2016)	10	healthy men	trained	28 ± 4	NR	NR
Ferreira et al. (2016)	5	healthy men	trained	31 ± 7.7	77.0 ± 7.7	180.2 ± 4.3
Greer et al. (2015)	10	healthy men	physically active	22 ± 2	77.1 ± 16.4	173.0 ±11.6
Haltom et al. (1999)	7	healthy men	trained	27 ± 1	85.4 ± 3	180.4 ± 2.8
Islam et al. (2018)	8	active young men	trained	23 ± 3	78.7 ± 8.1	178.2 ± 2.7
Littlefield et al. (2017)	7	healthy men	untrained	43 ± 10	100.6 ± 17.7	177.0 ± 0.06
Luszczyk et al. (2017)	6	healthy men	recreationally active	23 ± 1	NR	NR
Matsuo et al. (2012)	10	healthy men	trained	24 ± 3.3	61.9 ± 5.7	170.8 ± 5.0
Salvador et al. (2016)	13	healthy men	futsal players trained	23 ± 6	76.0 ±10.2	178.7 ± 6.6
Schaun et al .(2017)	26	healthy men	physically active	CONT: 23 ± 3; HIIT: 23 ± 3	CONT: 79.9 ± 12.6; HIIT: 73.8±12.6	CONT: 179.0 ±5: HIIT 175.0 ± 4.8
Schleppenbach et al. (2017)	26	healthy men and women	physically active	21 ± 3	75.16±16.37	172.54 ± 9.24
Thornton et al. (2002)	14	healthy female	trained women	27 ± 5	63.1±4.2	164.5± 7.3
Townsend et al (2014)	16	healthy men and women	healthy recreationally active	male 24 ± 4 / female 22 ± 1	male 83.6 ± 10.1 / female 65.4 ± 9.2	male 180.8 ± 6.7 / female 168.9 ± 6.2
Tucker et al (2016)	10	healthy men	recreationally active males and nonsmoking	24 ± 4	73.1 ± 8.2	171.6 ± 5.1
Valstad et al (2017)	12	healthy men and women	healthy college students	22 ± 2	70.0 ± 7.7	176 ± 0.09
Haddock et al. (2006)	15	healthy women	resistance trained	24 ± 1	63.5 ± 2.4	± 1.5

- NR: not reported; CONT: continuous aerobic training; HIIT: high-intensity interval training; SIT: sprint/speed interval training

Table 1. Outlines Characteristics of Included Trials and Participants and Program of Characteristics Interventions (part II).

Study	Exercise modality	Intervention	Exercise intensity (% max); (interval:rest)		Frequency (days/week)	Exercise time (min)	Attendance rate, dropouts and adverse events	Instrument
			High-intensity (HIIT)	Moderate-intensity (CONT)				
Abboud et al. (2013)	RT	investigate the effect of load-volume on EPOC; total load-volume 20,000 kg *vs*. total load-volume 10,000 kg	total load-volume 20,000 kg; 4 exercises; 6 - 8 reps; 85% 1RM	total load-volume 10,000 kg; 4 exercises; 6 - 8 reps; 85% 1RM	1 day	10,000 kg = 90 min; 20,000 kg = 43.6 min	-	ParvoMedics
Aguiar et al. (2015)	Running	training status and blood lactate concentration (BLC) responses on the EPOC	HIIT: 1-min (all-out test by 100 m - sprint) in sprinters individuals	CONT: 1-min (all-out test by 100 m - sprint) in endurance individuals.	5 to 6 days of the week	1 min	-	$K4b^2$
Cunha et al. (2016)	Running and Cycling	investigate (EPOC) of continuous and intermittent running and cycling (isocaloric) exercises	HIIT: (2 x 200) running and cycling 75% VO_2	CONT: (400 kcal) running and cycling 75% VO_2	3 times per week	CONT running: 32min; HIIT running: 38min; CONT cycling: 37min; HIIT cycling: 43min	-	VO2000
Ferreira et al. (2016)	Cycling	determine the effects of a diet High CHO in EPOC after a set exhaustive exercise	115% of peak oxygen uptake (VO_2 peak) until exhaustion with low (10% CHO)	115% of peak oxygen uptake (VO_2 peak) until exhaustion with low or high pre-exercise (80% CHO)	1 day with 7-day interval for each test	6 min	-	$K4b^2$
Greer et al. (2015)	Cycling / RT	compare the effect of exercise and EPOC intensity controlling energy expenditure and duration	Cycling HIIT: 90% VO_2 peak 30-sec; IR:120-180s; CT: 4 exercise, 60% of the 1RM for one set until fatigue with 1min of rest between exercises	CONT: 39% VO_2 peak	1 time every 7 days, totaling 3 times	Cycling (HIIT or CONT): 43 min; CT 46 min	-	ParvoMedics
Islam et al. (2018)	Running	examined EPOC and fat utilization following acute at CONT and SIT	repeated "all-out" sprinting	65% VO_{2max}	1 day	CONT = 30 min; SIT= 14 min	-	Gas collection system (MAX II)
Littlefield et al. (2017)	Running	to evaluate the effects of low and high intensity exercise on postprandial lipemia; and to determine the contribution of EPOC	70 to 80% do VO_2 reserve	40 to 50% VO_2 reserve	-	HIIT: 74min CONT: 47 min	-	ParvoMedics & VO2000

Matsuo et al. (2012)	Cycling	verify the association between the level of cardiorespiratory fitness and EPOC using three protocols with different intensities, that is, SIT; HIIT; CONT	SIT = 7 sets of 30 seconds, 120% $VO_{2max;}$ HIIT = 3 sets of 3 min; 80-90% $VO_{2max.}$	60 to 65% $VO_{2max.}$	3 days	30 min all protocols	-	AE-310S
Schaun et al. (2017)	Running	compare the energy expenditure during and after two treadmill protocols, HIIT and CONT	8 bouts (20-sec at 130% of the velocity associated with the VO_{2max};10-sec of RI;	submaximal velocity equivalent to 90-95% HR.	1 day	HIIT: 27 min; CONT: 30min	-	VO 2000
Schleppenbach et al. (2017)	Running / RT	check the impact of high- and moderate-intensity (SIT *vs*. CT), without recovery oxygen consumption in exercise	Running SIT: consisted of ten 30-sec running bouts on a self-propelled treadmill, with 30-sec RI;	CT (2 sets; star jumps; high-knees; burpees; line jumps; wall-taps; 30-sec exercise:30-sec RI)	-	All protocol was similar: 10 min	The original sample size, before dropouts occurred were 16 subjects for each group	$K4b^2$
Townsend et al. (2014)	Running / Cycling	determine the acute effects of 1 session of SIT run at EPOC and there are gender differences	running: "all-out" efforts as fast as possible; 4min RI	cycling: 4 rep, 30-sec "all-out", 75% body mass; 4min RI	-	28 min all protocols	-	SensorMedics Corporation
Tucker et al. (2016)	Cycling	Compared EPOC after HIIT; and CONT	"all out", six 30-second Wingate sprints, separated by 4 min RI	30 minutes at 80% of HRpeak	12 days	HIIT - 23 min CONT - 30 min	-	Oxycon Mobile™
Valstad et al. (2017)	Running	compared the effects of long and short intervals of exercise bouts on running performance (EPOC)	short intervals (4 × 8 × 20-sec, 90-95% of HRpeak	long (4 × 4 min), 80% of HRpeak	2 days	-	-	OxyconPro;
Haltom et al. (1999)	RT	energy expenditure during and after CT determine the effect of rest-interval duration upon the magnitude of 1 h of excess post-exercise oxygen consumption (EPOC)	20 RI; 20 reps; 75% 1-RM	60 RI; 20 reps; 75% 1-RM	1 day	HIIT: 13 min; CONT: 23 min	-	Automated metabolic analysis system

-RT: resistance training; NR: not reported; RI: rest interval; Reps: repetitions; VO_2: consumption oxygen; HR: heart rate; HRpeak: peak heart rate; 1RM: one maximum repetition; RMs: maximum repetitions; CT: circuit weight training; CONT: continuous aerobic training; HIIT: high-intensity interval training;; SIT: sprint/speed interval training.

Table 2. Subgroup meta-analysis in all studies.

Parameters	Studies	Number of participants	Meta-analysis				Trim and Fill effect size (CI-95%) [adjusted studies]
			SMD	CI-95%	P-value	I^2	
VO_2 (L)	17						
High-intensity		152					
Moderate-intensity		150	1.24	0.78 to 1.71	< 0.01	67%	0.86 (0.40 to 1.32)
Resistance training	2						
High-intensity		15					
Moderate-intensity		15	2.63	-2.83 to 8.09	> 0.05	93%	
EXERCISE MODALITY							
Running	7						
High-intensity		72					
Moderate-intensity		70	1.32	0.65 to 1.99	< 0.01	67%	
Cycling	8						
High-intensity		65					
Moderate-intensity		65	1.13	0.57 to 1.69	< 0.01	49%	
CALORIE (kcal)	8						
High-intensity		86					
Moderate-intensity		84	1.89	1.08 to 2.71	< 0.01	77%	
EXERCISE MODALITY							
Resistance Training	5						
High-intensity		56					
Moderate-intensity		56	2.51	1.25 to 3.77	< 0.01	82%	
Cycling	2						
High-intensity		16					
Moderate-intensity		16	0.85	-0.23 to 1.94	> 0.05	47%	

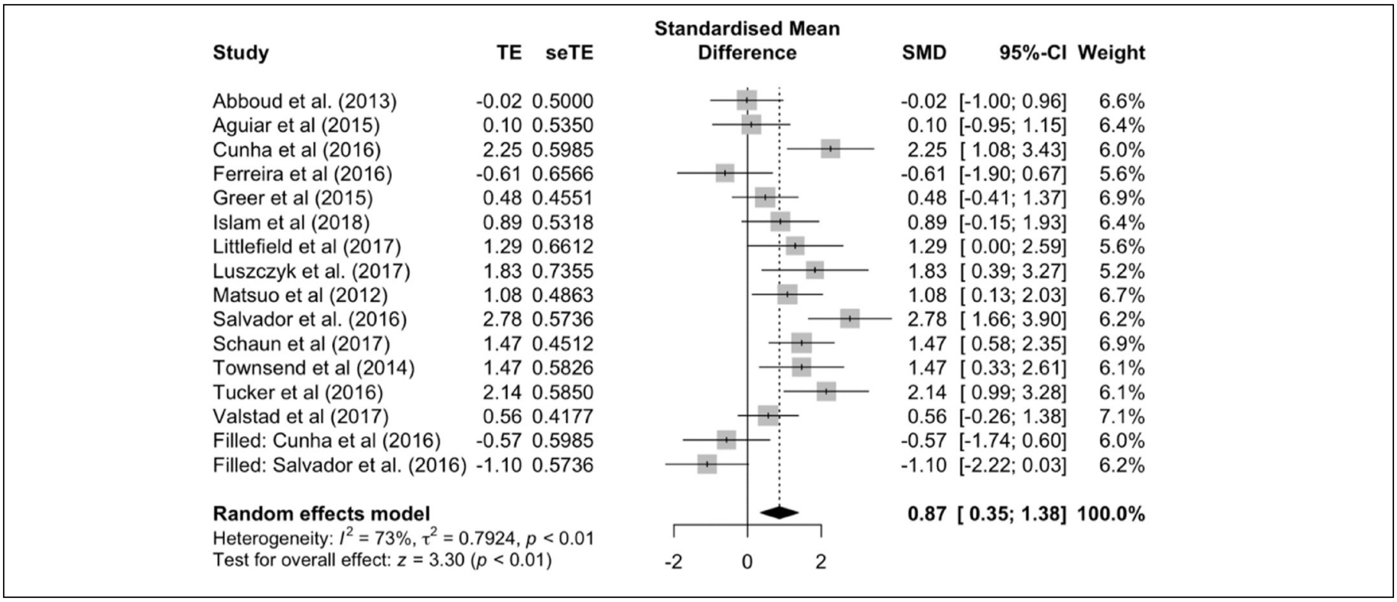

Figure 4. Adjusting bias risk by Trim and Fill method. There were observed between outcomes Experimental group (high-intensity training) and Control group (continuous moderate-intensity training)

The heterogeneity among the studies can be explained by examination of different variables including, age, sex, physical condition, oxygen collection instrument, type of protocol, VO_2 intensity, effort strength time, modality mode, weekly frequency, and the magnitude (time-min) of the analysis of oxygen consumption after exercise. In particular, the EPOC magnitude effect presented ranges from 10 to 90 minutes. [4,5,15,32,34,38,39,43,44] Other studies were analyzed for over 90 min.[1,2,35-37,41]

Despite the limitations by heterogeneity, our data demonstrate that the intensity of effort can be considered as a determining factor for increasing EPOC during exercises using both treadmills and bicycles. As for caloric parameters, we observed significant changes only in RT (Table 2).

Although our results point to a significant trend towards high intensity exercise, studies are inconclusive when analyzed individually.

For example, studies by Turker et al.[15] compared EPOC after high--intensity interval exercise (HIE), and sprint interval exercise (SIE), and steady-state exercise (SSE). Ten recreationally active males participated in a randomized crossover trial. Although 3h EPOC and total net EE after exercise were higher (p=0.01) for SIE (22.0 ± 9.3 L; 110 ± 47 kcal) compared to SSE (12.8 ± 8.5 L; 64 ± 43 kcal), total (exercise + post exercise) net O_2 consumed and net EE were greater (p=0.03) for SSE (69.5 ± 18.4 L; 348 ± 92 kcal) than for SIE (54.2 ± 12.0 L; 271 ± 60 kcal). On the other hand, Schaun et al.[44] compared the energy expenditure during and after two treadmill protocols, high-intensity interval training (HIIT) and moderate continuous training (CONT), in young adult men. The protocols HIIT (8 bouts, 20s at 130% of the velocity associated with the $VO_{2\,max.}$ on a treadmill with 10s of RI) versus CONT (30min on a treadmill at a submaximal velocity equivalent to 90–95% of HR associated with the anaerobic threshold). No difference was found between the groups for VO_2, EE and EPOC post-exercise and were higher than HIIT (69.31 ± 10.88; 26.27 ± 2.28 kcal, respectively).

CONCLUSIONS

Our study focused on the analysis of high and moderate-intensity exercise results and effects on oxygen uptake following exercise. Despite the growing popularity of high-intensity interval training, we found that acute and chronic benefits remain limited. We understand that lack a of similar protocols and the control of the variables that influence training outcomes, will affect the measures that are used to determine EPOC magnitude. We also suggest that controlled longitudinal studies would reveal additional perspectives in relation to the measurement of EPOC. A further confounding factor is the magnitude (time in minutes) of VO_2 measurement during EPOC assessment as it ranged from 60 min to 720 min. Longitudinal studies and controlled experimental design would permit a higher combination of effect size which would be a desirable outcome. The findings of the present study showed a tendency (random-effects model: 0.87, 95%-IC [0.35; 1.38], I^2 = 73%, *p < 0.01*) for increases in EPOC post exercise when the exercise performed prior to EPOC measurement was high-intensity interval training.

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