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INVITED REVIEW

Ischemic preconditioning and exercise performance: shedding light through smallest worthwhile change

Moacir Marocolo[1] · Mario A. Moura Simim[2] · Anderson Bernardino[1] · Iury Reis Monteiro[1] · Stephen D. Patterson[3] · Gustavo R. da Mota[4]

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Abstract

Ischemic preconditioning (IPC) has been suggested as a potential ergogenic aid to improve exercise performance, although controversial findings exist. The controversies may be explained by several factors, including the mode of exercise, the ratio between the magnitude of improvement, or the error of measurement and physiological meaning. However, a relevant aspect has been lacking in the literature: the interpretation of the findings considering statistical tests and adequate effect size (ES) according to the fitness level of individuals. Thus, we performed a systematic review with meta-analysis to update the effects of IPC on exercise performance and physiological responses, using traditional statistics (*P* values), ES, and smallest worth change (SWC) approach contextualizing the IPC application to applied Sports and Exercise performance. Forty-five studies met the inclusion criteria. Overall, the results show that IPC has a minimal or nonsignificant effect on performance considering the fitness level of the individuals, using statistical approaches (i.e., tests with *P* value, ES, and SWC). Therefore, IPC procedures should be revised and refined in future studies to evaluate if IPC promotes positive effects on performance in a real-world scenario with more consistent interpretation.

Keywords Ischemia · Sports · Skeletal muscle · Statistical · Blood flow occlusion · Ergogenic

Abbreviations

CI	Confidence interval
ES	Effect size
I^2	Heterogeneity statistic
IPC	Ischemic preconditioning
PRISMA	Preferred reporting items for systematic reviews and meta-analysis
Q	Cochran test
RPE	Rating of perceived exertion
SWC	Smallest worthwhile change
VO_{2max}	Maximal oxygen consumption

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✉ Moacir Marocolo
isamjf@gmail.com

[1] Department of Physiology, Federal University of Juiz de Fora, Juiz de Fora, Minas Gerais, Brazil

[2] Institute of Physical Education and Sports, Federal University of Ceará, Fortaleza, Brazil

[3] Faculty of Sport, Health, and Applied Science, St. Mary's University, Twickenham, London, UK

[4] Department of Sport Sciences, Federal University of Triangulo Mineiro, Uberaba, Brazil

Introduction

Ischemic preconditioning (IPC) is a non-invasive technique conducting transient peripheral hypoxia and subsequently enhance tissue tolerance against ischemia–reperfusion injury (Paradis-Deschenes et al. 2016b). This technique promoted greater protection of heart tissue against infarct size (Murry et al. 1986), and has become widespread. Following numerous studies demonstrating tissue protection in clinical experiments (Eisen et al. 2004), the IPC technique has been suggested as a potential ergogenic aid to improve exercise performance (Marocolo et al. 2016a, 2017b; Incognito et al. 2016), focussing mainly on swimming (Marocolo et al. 2015), cycling (Crisafulli et al. 2011b), and running performance (Bailey et al. 2012b). Furthermore, studies have investigated IPC on resistance (Barbosa et al. 2015; Cochrane et al. 2013; Marocolo et al. 2016a), intermittent (Marocolo et al. 2017a), and fatiguing isometric (Tanaka et al. 2016) exercises. Despite numerous

investigations, the results are inconsistent, and an "ideal" IPC protocol has not yet been standardised (Marocolo et al. 2016a, 2017b, 2018; da Mota and Marocolo 2016; Incognito et al. 2016), making it difficult to elucidate the physiological mechanisms behind IPC. A few proposed mechanisms have been considered, first, the hyperemia experienced following the occlusion phase may play a role due to nitric oxide production (Singh et al. 2017). Furthermore, an increased phosphocreatine resynthesis, altered oxy-deoxyhaemoglobin kinetics (Bailey et al. 2012a), and increased oxygen consumption (Andreas et al. 2011) may play a role in improving exercise performance.

Investigation of the IPC effects on exercise performance should consider the analysis of a number of set parameters, including statistical tests, the ratio between the magnitude of the improvement, and the error of measurement. In addition, there should be consideration of the physiological meaning and the context of the fitness level and/or mode of exercise, and adequate effect size (ES) interpretations. For instance, improvements with small ES could be important when evaluating elite, but not amateur athletes (Marocolo et al. 2018). In sports sciences/medicine research, the *P* values from traditional statistics have been criticized (Buchheit 2016b, 2017). When *P* values are considered in isolation from other statistical indicators (e.g., confidence interval and ES), it may produce misleading conclusions, including misleading practical applications, wasted resources, and time. For example, one study may show a significant difference ($P < 0.05$) after an intervention, but with small ES in amateur athletes which has limited benefit when practically applied (Buchheit 2016b; Marocolo et al. 2018). Furthermore, the lack of magnitude of effects, which matters in the most cases (Cohen 1994), are motivating sports scientists to look for more realistic approaches instead of only *P* value analysis. In this context, the smallest worthwhile change (SWC) has been highly suggested for the analysis of exercise performance studies (Buchheit 2016a) due to its singular specificity for sports sciences area (e.g., small sample size, the practical relevance of the changes, and the typical error of measurements) (Marocolo et al. 2017b; Haugen and Buchheit 2016; Hopkins et al. 2009). In this context, the SWC calculated by 0.2 multiplied by standard deviation (SD) is more relevant for high fitness level participants, while the SWC calculated by 0.6 multiplied by SD is relevant for both high and low fitness level participants (Fig. 1).

Although IPC is an exciting tool to be used as an ergogenic aid to enhance performance, no research has determined the IPC effects considering the SWC approach in combination with the traditional statistical analyses, which could be relevant. Thus, this systematic review and meta-analysis aimed to update the IPC effects on exercise performance and physiological indicators using traditional statistics (*P* values), ES and SWC approach contextualizing the IPC application for performance.

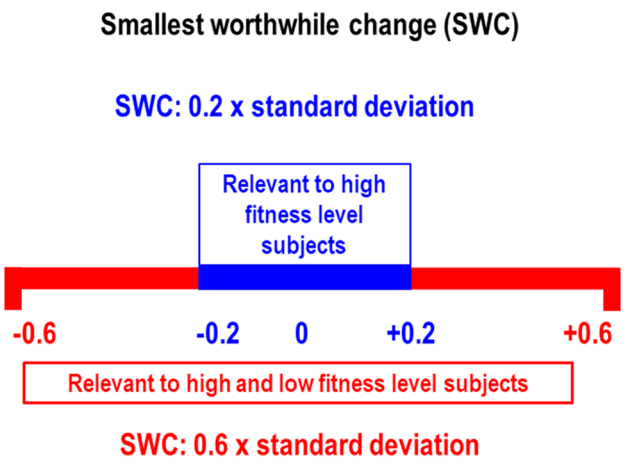


Fig. 1 Smallest worthwhile changes recommendation

Methods

Literature search

The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) recommendations were followed (Moher et al. 2009). This study identified IPC and exercise studies located primarily through the PubMed database with second-order internet search engines including Google Scholar (using [advanced search], [all fields]), and other online journals. The following crucial terms (1) "ischemic preconditioning"; (2) "blood flow" and "hyperemia"; and (3) "blood flow occlusion" were combined with "exercise performance", "athletes", "exercise", and "performance". Studies selected were limited to those written in the English language (Morrison et al. 2012; Juni et al. 2002) and included journal articles, ahead of print articles, and a master thesis.

Selection criteria

Studies were included based on strict criteria determined by 2 investigators including: (1) original study; (2) IPC performed prior to the exercise; (3) evaluation of healthy participants; (4) conduction of exercise or effort test; and (5) analysis of performance. Systematic review articles, meta-analyses, and studies with only animals or non-healthy participants were excluded from this review. The literature search included papers from 1st January 1900 to 23rd May 2018. The selected studies were read rigorously to determine if they met the inclusion/exclusion criteria. The search, selection, and inclusion process can be seen in Fig. 2. The

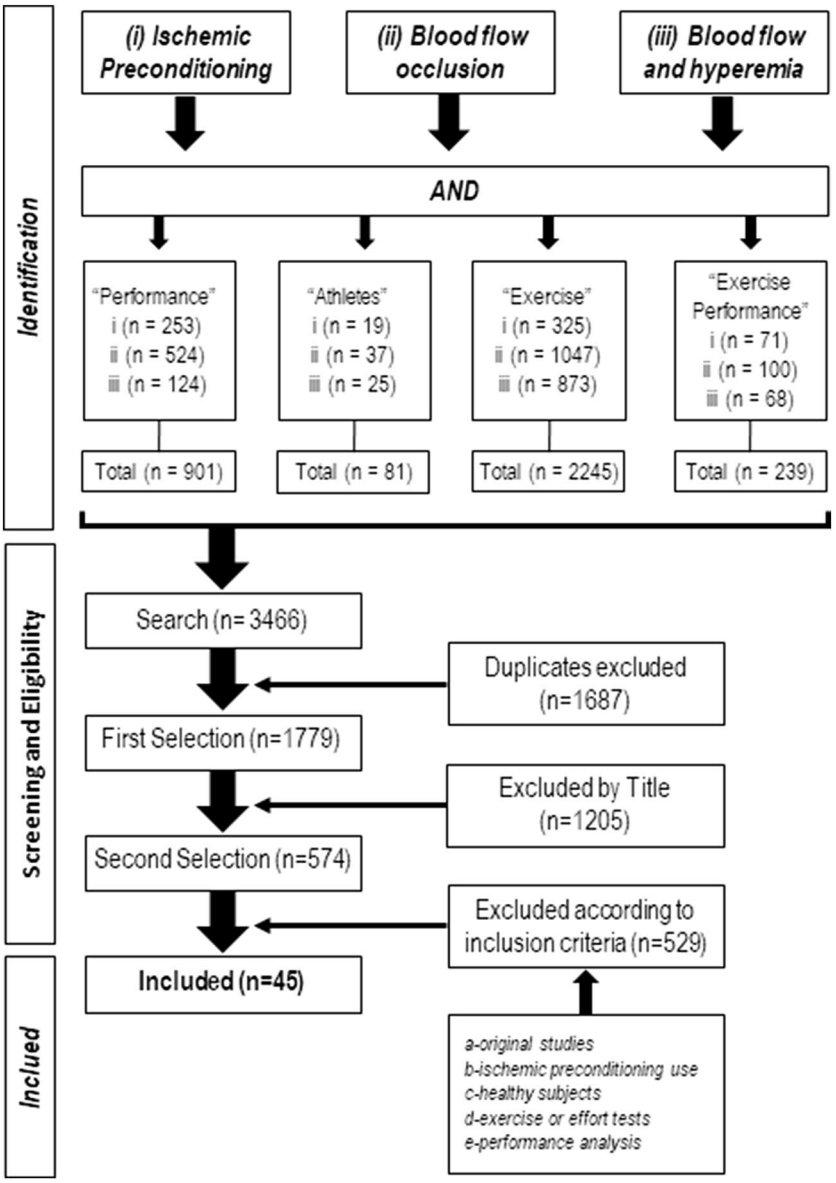


Fig. 2 Flow chart of search database

search displayed a total of 3466 papers, which were reduced to 1779 after exclusion of duplicate publications. Out of these papers, we excluded another 1205 by title, leaving 574 yet to be selected. Finally, after checking those papers for our defined inclusion criteria, 45 remained for further analysis.

Quality assessment and data extraction

The quality of all included papers was estimated according to a checklist based on and adapted from the studies by Downs and Black (1998) and van Velzen et al. (2006). At first, only one investigator analysed the methodological quality of the articles. There were 3 possible scores (Yes = 1 point, Unclear = 1/2 point, No = 0 points) for each item in the checklist (Table 1) with the maximum possible score = 15 points. In most questions, the expression "clearly" refers to the fact that information is explicitly presented in the paper. The general quality of each publication was achieved using the sum of the 15 criteria scores. After this initial screening, another author checked all selected papers according to the quality criteria and arrived at the conclusion, in concordance with the other author that the 17 candidate papers should be included in the meta-analysis.

The variables were divided into categories, e.g., performance or physiological variables associated with performance and modalities, e.g., swimming, cycling, running, and resistance exercises. This classification aimed at a better description of the results, and most of the studies evaluated more than one variable.

Table 1 Quality criteria used to analyze the publications

	0	½	1
Reporting			
1. Is the hypothesis/aim/objective of the study clearly described?	No	Unclear	Yes
2. Are the main outcomes to be measured clearly described in the Introduction?	No	Unclear	Yes
3. Are the characteristics of the subjects included in the study clearly described?	No	Unclear	Yes
4. Are the interventions of interest clearly described?	No	Unclear	Yes
5. Are the main findings of the study clearly described?	No	Unclear	Yes
6. Does the study provide estimates of the random variability in the data for the main outcomes?	No	Unclear	Yes
7. Were the instruments of testing reliable?	No	Unclear	Yes
8. Was a follow-up duration sufficiently described and consistent within the study?	No	Unclear	Yes
9. Number of participants included in study findings	< 5	6–15	> 16
Analysis and presentation			
10. 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?	No	Unclear	Yes
11. Was there a statement adequately describing or referencing all statistical procedures used?	No	Unclear	Yes
12. Were the statistical analyses used appropriate?	No	Unclear	Yes
13. Was the presentation of results satisfactory?	No	Unclear	Yes
14. Were confidence intervals given for the main results?	No	Unclear	Yes
15. Was the conclusion drawn from the statistical analysis justified?	No	Unclear	Yes

Data analysis

The meta-analysis was performed separately for physiological and performance variables. No authors were asked to send the paper data and all calculations were performed with only the data presented in each study. The weight of the studies was calculated, confidence interval (95% CI) and standardized mean difference for each study individually; these values were then combined for the analysis of the studies. The analysis was performed with a random-effects model (Borenstein et al. 2009; Pigott 2012), and heterogeneity was assessed by the Q Cochran test (Cochran 1954), which was completed with I^2 (Higgins and Thompson 2002). The sample was homogeneous ($P \geq 0.05$) for the Q test and I^2 value ($\leq 25\%$). The general purpose of the analysis was tested using the Z test (Zaykin 2011). The criterion for statistical significance was $P < 0.05$ for 95% CI. These analyses were performed using the Review Manager Software (version 5.3, Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration 2014).

The Shapiro–Wilk test was applied to verify the normal distribution of the data. The Spearman test was used to examine the correlation between the percentage changes in the performance and physiological variables that showed statistical significance with "duration of exercise" (extracted from the information provided in each study), "total time of IPC maneuver", and "time prior to exercise". The ES was calculated to determine the meaningfulness of the difference (Cohen 1988) in performance and physiological variables of the studies. The magnitude of the ES was classified as trivial (< 0.2), small (> 0.2–0.6), moderate (> 0.6–1.2), large (> 1.2–2.0) and very large (> 2.0–4.0) based on the guidelines from Batterham and Hopkins (Batterham and Hopkins 2006). In addition, the SWC was estimated for all variables, whose studies provided enough data for this. SWC was considered as the standard deviation multiplied by 0.2 or 0.6, based on Cohen's ES principle (Buchheit 2016b; Buchheit et al. 2014). The significance level was 0.05, and GraphPad® (Prism 6.0, San Diego, CA, USA) was used for the analysis.

Results

Overall, the data suggest that a high-quality of studies have been selected. The effects of IPC on exercise performance, according to either traditional (P values) or alternative (SWC, ES) statistical tools, present a low magnitude. In addition, almost all studies lack real-world context (e.g., field tests or evaluations during competitions).

Quality of the papers

The quality scores of the analysed studies are shown in Table 2. All of the studies achieved the required standard to be considered a low risk of bias (mean quality score = 12.2 ± 1.4; 81%). Table 3 summarizes the characteristics of the studies examining IPC while, in the Table 4,

Table 2 Scores assigned to each of the studies (in chronological order) for each of the quality (*Q*) criteria

References	*Q*1	*Q*2	*Q*3	*Q*4	*Q*5	*Q*6	*Q*7	*Q*8	*Q*9	*Q*10	*Q*11	*Q*12	*Q*13	*Q*14	*Q*15	Score (% of max)
de Groot et al. (2010)	1	0.5	1	1	1	1	1	0.5	0.5	1	1	1	1	0	1	12.5 (83)
Barr (2011)	1	1	1	1	1	1	1	1	0.5	1	1	1	1	0	1	13.5 (90)
Crisafulli et al. (2011)	1	1	1	1	1	1	1	1	0.5	0	1	1	1	0	1	12.5 (83)
Foster et al. (2011)	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	14.0 (93)
Jean-St-Michel et al. (2011)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.0 (100)
Bailey et al. (2012b)	1	0.5	1	1	1	1	1	0.5	1	1	1	1	1	1	1	14.0 (93)
Beaven et al. (2012)	1	0.5	1	1	1	0.5	1	1	0.5	0	1	0.5	1	1	1	12.0 (80)
Clevidence et al. (2012)	1	1	1	1	1	1	1	0.5	0.5	0	1	1	1	0	1	12.0 (80)
Cochrane et al. (2013)	1	1	1	1	1	1	1	1	0.5	1	1	1	1	0	1	13.5 (90
Gibson et al. (2013)	1	1	1	1	1	1	1	1	0.5	0	1	1	0.5	0	1	12.0 (80)
Foster et al. (2011)	1	1	1	1	1	1	1	0.5	1	1	1	1	1	0	1	13.5 (90)
Kjeld et al. (2014)	0.5	1	1	1	1	1	1	0.5	1	0	1	1	1	0	1	12.0 (80)
Paixao et al. (2014)	1	1	1	1	1	1	1	0.5	1	0	1	1	0.5	0	1	12.0 (80)
Barbosa et al. (2015)	1	1	1	1	1	1	1	0.5	0.5	1	1	1	1	0	1	13.0 (87
Cruz et al. (2015)	1	1	1	1	1	1	1	1	0.5	1	1	1	1	0	1	13.5 (90)
Gibson et al. (2015)	1	1	1	1	1	1	1	0.5	0.5	0	1	1	1	0	1	12.0 (80)
Hittinger et al. (2015)	1	1	1	1	1	1	1	0.5	1	1	1	1	1	0	1	13.5 (90)
Lalonde and Curnier (2015)	1	1	1	1	1	0	1	0.5	1	1	1	1	1	0	1	12.5 (83)
Marocolo et al. (2015)	1	1	1	1	1	1	1	0.5	0.5	1	1	1	1	0	1	13.0 (87)
Martin et al. (2015)	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	14.5 (97)
Patterson et al. (2015)	1	1	1	1	1	1	1	0.5	0.5	0.5	1	1	1	1	1	13.5 (90)
Tocco et al. (2015)	1	1	1	1	1	1	1	1	0.5	0	1	1	1	0	1	12.5 (83)
Banks et al. (2016)	1	1	1	1	1	0.5	1	0.5	0.5	0.5	1	1	1	0	1	12.0 (80)
Cruz et al. (2016)	0.5	1	1	1	1	1	1	1	0.5	0.5	1	1	1	1	1	13.5 (90)
Ferreira et al. (2016)	1	0.5	1	1	1	0.5	1	1	1	1	1	1	1	0	1	13.0 (87)
James et al. (2016)	1	1	1	1	1	1	1	1	0.5	1	1	1	1	0	1	13.5 (90)
Kaur et al. (2017)	1	1	0.5	1	1	0	1	0.5	1	1	1	1	1	0	1	12.0 (80)
Marocolo et al. (2016a)	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	14.0 (93)
Marocolo et al. (2016b)	1	1	1	1	1	1	1	1	0.5	1	1	1	1	0	1	13.5 (90)
Northey et al. (2016)	0.5	1	1	1	1	1	1	1	1	1	1	1	1	0	1	13.5 (90)
Paradis-Deschenes et al. (2016a)	1	1	1	1	1	1	1	1	0.5	0	1	1	1	0	1	12.5 (83
Tanaka et al. (2016)	1	0.5	1	1	1	0.5	1	0.5	0.5	0.5	1	1	1	0	1	11.5 (77)
Sabino-Carvalho et al. (2017)	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	14.0 (93)
Seeger et al. (2017)	1	1	1	1	1	1	1	1	0.5	1	1	1	1	0	1	13.5 (93)
Cocking et al. (2018b)	0.5	0.5	1	1	1	1	1	0.5	1	1	1	0.5	0.5	0	0.5	11.0 (73)
Griffin et al. (2018)	1	0.5	1	1	1	0.5	1	1	0.5	1	1	1	1	0	1	12.5 (83)
Marocolo et al. (2017a)	1	1	1	1	1	1	1	1	0.5	1	1	1	1	0	1	13.5 (90)
Page et al. (2017)	1	1	0.5	1	1	1	1	1	1	0.5	1	1	1	0	1	13.0 (87)
Paradis-Deschenes et al. (2016b)	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14.5 (97)
Zinner et al. (2017)	1	1	0.5	1	1	1	1	0.5	0.5	1	1	1	1	1	1	13.5 (90)
Cocking et al. (2018a)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.0 (100)
Griffin et al. (2019)	1	0.5	1	1	1	0.5	1	1	0.5	1	1	1	1	0	1	12.5 (83)
Paradis-Deschenes et al. (2018)	1	1	1	1	1	0.5	1	1	0.5	1	1	1	1	1	1	14.0 (93)
Richard and Billaut (2018)	0.5	0.5	1	1	1	1	0.5	1	1	1	1	1	1	1	1	13.5 (90)
Williams et al. (2018)	1	1	1	1	1	1	1	0.5	1	1	1	1	1	0	1	13.5 (90)

Table 3 Characteristics of the studies examining IPC

References	Exercise protocol	Participants	*N*	IPC protocol Total IPC time	Group	Ischemia pressure (mmHg)/limb	Time to test	Test protocol	Variable analyzed
de Groot et al. (2010)	Cycling	Healthy	15	3×5 min/15 min	C/IPC	220/thigh	5 min	Maximal incremental	Max power VO_{2max}
Barr (2011)	Cycling	Active	24	3×5 min/15 min	C/IPC	220/thigh	20 min	Wingate	Peak power Mean power Fat. index
Crisafulli et al. (2011b)	Cycling	Healthy	17	3×5 min/15 min	C/IPC	50 > SAP/thigh	5 min	Maximal incremental	VO_{2max} Workload
Foster et al. (2011)	Cycling	Amateur cyclists	8	4×5 min/20 min	C/IPC	20 > SAP/one thigh	90 min	100 kJ normoxia 100 kJ hypoxia	Time trial
Jean-St-Michel et al. (2011)	Swimming	Elite swimmers	18	4×5 min/20 min	P/IPC	15 > SAP-10/arm	~45 min	100 m time trial	Time trial
Bailey et al. (2012b)	Running	Healthy	13	4×5 min/20 min	P/IPC	220–20/thigh	45 min	Incremental 5 km	VO_{2max} Time trial Heart rate Exhaust. time
Beaven et al. (2012)	Jump/sprints	Healthy	14	2×3 min/6 min	C/IPC	220–15/thigh	0–24 h	Squat jump CMJ	SJ (w) CMJ (w) 10 m sprint 40 m sprint
Clevidence et al. (2012)	Cycling	Cyclists	20	3×5 min/15 min	C/IPC	220–0/thigh	5 min	Incremental + 90% max	Avg. HR[a] Peak HR[b] Ex. toler.
Cochrane et al. (2013)	Strenuous eccentric exercise	Healthy and involved in physical activity	10	30 min–30 s alternating/15 min	C/IPC	10 > pulse pressure/leg	24–48–72 h	ECC exercise (3×100 rep)	CK VJPP VJ
Gibson et al. (2013)	Sprint	Team sport athletes	25	3×5 min/15 min	C/P/IPC	220–50/thigh	15 min	10 m sprint 20 m sprint 30 m sprint	Time
Foster et al. (2014)	Healthy	Running	12	5 days-4×5 min/20 min	P/IPC	~200–40/thigh	Prior	12.8 km	Time trial
Kjeld et al. (2014)	Rowing/apnea	Rowers/divers	11–6-14	4×5 min/20 min	C/IPC	40 > SAP/forearm	30 min	Dynamic apnea Static apnea Distance time	Time Time T. 1000 m
Paixao et al. (2014)	Cycling	Cyclists	15	4×5 min/20 min	P/IPC	250–20/thigh	12 min	3 Wingate/10 min break	Max Pw. 1 Mean Pw. 1 Mean Pw. 2
Barbosa et al. (2015)	Handgrip	Healthy	9/13	3×5 min/15 min	C/IPC	200–10/thigh	25 min	Rhythmic handgrip	T. fat

Table 3 (continued)

References	Exercise protocol	Participants	*N*	IPC protocol Total IPC time	Group	Ischemia pressure (mmHg)/limb	Time to test	Test protocol	Variable analyzed
Cruz et al. (2015)	Cycling	Recreationally trained cyclists	12	4×5 min /20 min	C/IPC	220/thighs (IPC) 20/thighs (C)	90 min	Incremental	Time to exhaustion VO_{2max} Blood [La]
Gibson et al. (2015)	Sprint	Trained population	16	3×5 min/15 min	C/P/IPC	220–50/thigh	5 min	Sprint 5×6 s	Lactate Peak power Total power
Hittinger et al. (2015)	Cycling	High trained cyclists and triathletes	28	4×5 min/20 min	C/IPC	10–20 > SAP/thigh	45 min	Incremental/sea level Incremental high alt	Ex. capacity Ex. capacity
Lalonde and Curnier (2015)	Cycling	Healthy	17	4×5 min/20 min	P/IPC	50 > SAP-10/right arm	–	Progressive 6×6 s Wingate	Peak power Mean power Peak power Mean power
Marocolo et al. (2015)	Swimming	Recreational athletes	15	4×5 min/20 min	C/P/IPC	220–5/arm	15 min	100 m time trial	Time trial
Martin et al. (2015)	Anaerobic cycling	College hockey players	10	30 min (sic)/30 min	P/EPC	5 chambers of 70 mmHg	5 min	Wingate Anaerobic Test	Heart rate [La] Overall fatigue index
Patterson et al. (2015)	Cycling	Recreational active in sprint sports	14	3×5 min/15 min	P/IPC	220–20/thigh	30 min	12×6 s sprints	Peak power VO_2 (l min^{-1})
Tocco et al. (2015)	Running	Skilled runners	11	3×5 min/15 min	C/P/IPC	50 > SAP-10 < DAP/thigh	5 min	5 km	Speed (m s^{-1}) mVO_2 (l min^{-1}) Time to 5 km
Banks et al. (2016)	Cycling	Sedentary young adults	10	4×5 min/9 days (180 min)	IPC	200 mmHg/leg	24 h	Prog Ramp Bicycle	Cardiac PCr/ATP ratio Blood pressure PESM PCr recovery
Cruz et al. (2016)	Cycling	Recreational cyclists	15	4×5 min /20 min	C/IPC	220/thighs (IPC) 20/thighs (C)	33 min	Incremental	Mean power output VO_{2Peak} Blood [La] peak Quadriceps EMG

Table 3 (continued)

References	Exercise protocol	Participants	*N*	IPC protocol Total IPC time	Group	Ischemia pressure (mmHg)/limb	Time to test	Test protocol	Variable analyzed
Ferreira et al. (2016)	Swimming	Short distance college swimmers	23	3×5 min/30 min	P/C/IPC	220 (IPC) 50 (C) 10 (P)	30 min	Repeated sprint swimming	sprint time (best) Sprint time (worst) Sprint time (total) Sprint time (decr.)
James et al. (2016)	Running	Recreational club runners	11	4×5 min/20 min	C/IPC	220 (IPC) 50 (C)	20 min	Graded Exercise Test	Heart rate Speed [La]: 2/4 mmol Running economy $\dot{V}O_2$ Total run time v$\dot{V}O_{2Max}$ Heart rate$^{(GTX2)}$
Kaur et al. (2017)	Running	Healthy	18	3×5/15 min	P/IPC	220 (IPC) 20 (P)	15 min	Incremental	Blood [La] Running economy Caloric cost unit
Marocolo et al. (2016b)	Resistance exercise	Healthy	21	4×5 min/20 min	P/IPC	220 (IPC) 20 (P)	8 min	12-RM Test	Blood [La] RPE Number of repetitions
Marocolo et al. (2016a)	Resistance exercise	Healthy	13	4×5 min/40 min	C/P/IPC	220/20 0 mmHg	8 min	12-RM Test	Blood [La] Fatigue index Number of repetitions
Northey et al. (2016) (Post)	Resistance exercise	Strength-trained	12	2×3 min/12 min (alternating thighs)	C/OCC	220 mmHg/thighs	24 h (time after the test)	Fatiguing back squart test (10 sets of 10 repetitions)	Peak torque Mean SJ height Mean CMJ height Perceived Recovery Status Scale Perceived Soreness Scale

Table 3 (continued)

References	Exercise protocol	Participants	*N*	IPC protocol Total IPC time	Group	Ischemia pressure (mmHg)/limb	Time to test	Test protocol	Variable analyzed
Paradis-Deschenes et al. (2016a)	Isokinetic exercise	Strength-trained men	10	3×5 min/15 min	P/IPC	200 (IPC) 20 (P)	18 ± 2 min	Max. voluntary knee extension	Peak knee ext. force Tot. knee ext. force Avg. knee ext. force Muscle Hb avg. conc Muscle Hb peak conc
Tanaka et al. (2016)	Fatiguing isometric exercise	Healthy	12	3×5 min/15 min	C/IPC	> 300 mmHg (IPC) No cuff inflation (C)	5 min	MVC	Time to fatigue Muscle oxygenation
Sabino-Carvalho et al. (2017)	Running	Runners	18	4×5 min/20 min	C/P/IPC	220 (IPC) Therap ultras (P)	10 min	Incremental/ supramaximal	VO_{2max} (incremental test) Heart rate (IT) RER (IT) Blood [La] (IT) Borg (IT) VO_{2max} (Supramaximal test) HR (ST) RER (ST) Blood [La] (ST)
Seeger et al. (2017)	Running	Healthy	12	4×5 min/20 min	P/IPC	220 (IPC) 20 (P)	60 min	5 km	Time trial RPE/BORG Blood [La] Time trial 24 h
Cocking et al. 2017)	Cycling	Trained cyclists	12	4×5 min/20 min	P/IPC	220 mmHg (IPC) 20 mmHg (P)	35 min	Time trial	Blood [La] VO_2 Power (avg)
Griffin et al. (2018)	Cycling	Recreationally active males	12	4×5 min/40 min	P/IPC	220 mmHg (IPC) 20 mmHg (P)	3 min	Ramp Cycle Ergometer Test	Critical power Total O_2 consumed Total work done Blood [La]
Marocolo et al. (2017a)	YOYO intermittent	Amateur soccer players	13	4×5 min/20 min	C/P/IPC	220 mmHg (IPC) 20 mmHg (P)	6 min	Distance	Heart rate RPE Blood [La] Distance

Table 3 (continued)

References	Exercise protocol	Participants	*N*	IPC protocol Total IPC time	Group	Ischemia pressure (mmHg)/limb	Time to test	Test protocol	Variable analyzed
Page et al. (2017)	Drop-jumps	Recreationally-active males	16	3×5 min	P/OCC	220 mmHg (IPC) 20 mmHg (P)	24 h (time after the test)	Drop-jumps (5 sets of 20 repetitions)	MIVC CMJ DOMS CK
Paradis-Deschenes et al. (2016b)	Leg extension	Strength-trained	17	3×5 min	P/IPC	200/right thigh (IPC) 20/right thigh (P)	18.5 ± 0.1 min	5 sets of 5 max. voluntary knee extension	Average force Δ [THb] Δ [HHb]
Zinner et al. (2017)	Sprint	Team sport athletes	13	3×5 min/15 min	P/IPC	240/thighs (IPC) 180–190/arms (RIPC) 20/thighs (P)	45 min	Sprint 16×30 m	Mean time Oxygen uptake Respiratory exchange ratio Ventilation Heart rate SmO_2 during recovery SmO_2 during sprint
Cocking et al. (2018a)	Handgrip	Recreationally trained	18	4×5 min/20 min	P/IPC	220/arms (IPC) 220/legs (RIPC) 20/arms (P)	20 min	25% of MVC 30 min (30 contract/relax cycles/min)	Peak diameter response Blood velocity 30 s force Peak force
Griffin et al. (2019)	Sprint	Recreationally trained	20	4×5 min/20 min	P/IPC	220/arm and leg (IPC) 20/thighs na leg (P)	15 min	Sprint 3× (6×15 + 15 m)	Total sprint time Mean muscle oxy Mean blood [La] Mean RPE^{ge}

Table 3 (continued)

References	Exercise protocol	Participants	*N*	IPC protocol Total IPC time	Group	Ischemia pressure (mmHg)/limb	Time to test	Test protocol	Variable analyzed
Paradis-Deschenes et al. (2018)	Cycling	Road cyclists Mountain bikers Triathletes	13	3×5 min/15 min	P/IPC	220/thighs (IPC) 20/thighs (P)	25.6 ± 0.7 min	Time trial 5 km	Mean HR LA Mean SV LA Mean *Q* LA Δ [HHb] LA Δ [THb] LA RPE LA SpO_2 (%) LA 5 km TT LA Power output LA TSI (%) LA Mean HR MA Mean SV MA Mean *Q* MA Δ [HHb] MA Δ [THb] MA RPE MA SpO_2 (%) MA 5 km TT MA Power output MA TSI (%) MA
Richard and Billaut (2018)	Ice race	Speed skaters	9	3×5 min/15 min	P/IPC	Arms: 30 > SAP (IPC) 10 mmHg (P)	60 min	On-ice 1000 m race	Mean TSI (%) Total Hb Avg deoxyHb

Table 3 (continued)

References	Exercise protocol	Participants	*N*	IPC protocol Total IPC time	Group	Ischemia pressure (mmHg)/limb	Time to test	Test protocol	Variable analyzed
Williams et al. (2018)	Swimming	Swimmers	20	4×5 min/20 min	P/IPC	160–228 thighs (IPC) 15 thighs (P)	2 h or 24 h	100 m 200 m	Time 100 m (s) Time 200 m (s) Stroke count 50 m Stroke rate 50 m Stroke count 100 m Stroke rate 100 m Blood lactate TCO_2 HCO_3 SO_2 (%)

VJPP vertical jump peak power, *C* control, *P* placebo, *IPC* ischemic preconditioning, *Exhaust. time* time to exhaustion, *Exer. toler.* exercise tolerance, *Fat. index* fatigue index, *T.Fat.* time to fatigue, *T. 1000 m* time to 1000 m; *Max. Pw.* maximal power in Wingate, *mean Pw1* mean power Wingate 1, *Mean Pw. 2* mean power Wingate 2, *Ex. capacity* exercise capacity, mVO_2 (l min^{-1}) mean VO_2, *VJPP* vertical jump peak power, *VJ* vertical jump, *C* control group without cuff administration, *P* placebo group with a sham intervention, *IPC* ischemic preconditioning, *CMJ* countermovement jumps, *SJ* squat jump, *CK* creatine kinase; *B [La]* blood lactate concentration, *Cardiac PCr/ATP ratio* cardiac phosphocreatinine-to-adenosine-triphosphate ratio, *PESM PCr* recovery post-exercise skeletal muscle phosphocreatine recovery, *Blood [La] peak* peak blood lactate concentration, *Quadriceps EMG* electromyography of quadriceps muscle, *GXT 1* graded exercise test 1, *GXT 2* graded exercise test 2; *RPE* rating of perceived exertion, *Perc. Rec.Stat. Scale* perceived recovery status scale, *Perc. Soreness Scale* perceived muscle soreness scale; *Ext.* extension; *Avg* average; *conc* concentration, *Muscle Hb avg. conc.* muscle hemoglobin average concentration, *Muscle Hb peak conc.* muscle hemoglobin peak concentration, *MIVC* maximal isometric voluntary contraction, *DOMS* muscle soreness, *Δ [THb]* changes in concentration of deoxy-hemoglobin, *Δ [HHb]* changes in concentration of total hemoglobin, *Resp. E. ratio* respiratory exchange ratio, SmO_2 percentage of hemoglobin containing O_2, *Ω* the study did not provide enough data to calculate effect size (ES), *α* the study did not provide *P* value

[a]Average heart rate (bpm) 30% VO_{2max}

[b]Peak heart rate (bpm) 30% VO_{2max}

Table 4 All papers data with statistical results: calculated values of SWC (SD×0.2 and SD×0.6), *P* values and effect sizes

References	Variable analyzed	Change (%)	*P*	ES	SWC (SD × 0.2)	SWC (SD × 0.6)	Mean difference between IPC and control intervention	Achievement	
								SWC 0.2	SWC 0.6
de Groot et al. (2010)	Max power	1.6	0.05	0.10	12.4	37.2	6	Yes	No
	VO_{2max}	2.8	0.003	0.25	1.4	4.1	1.6	No	No
Barr (2011)	Peak power	−0.7	0.48	−0.03	49.7	149.1	−7.56	No	No
	Mean power	0.6	0.40	0.04	23.8	71.4	4.79	No	No
	Fat. index	−1.1	0.67	−0.06	2.2	6.5	−0.55	No	No
Crisafulli et al. (2011b)	VO_{2max}	3.6	NS	0.32	51.3	154.0	105.2	Yes	No
	Workload	3.7	< 0.05	0.22	8.8	26.4	10.3	Yes	No
Foster et al. (2011)	Time trial	−0.3	NS	0.01	24.8	74.4	1.0	No	No
		2.6	NS	−0.07	43.2	129.6	−14	No	No
Jean-St-Michel et al. (2011)	Time trial	1.1	0.03	−0.11	1.2	3.7	−0.67	No	No
Bailey et al. (2012b)	VO_{2max}	1.2	NS	0.13	0.9	2.6	0.6	No	No
	Time trial	2.5	NS	−0.26	29.2	87.6	−34	No	No
	Heart rate	0.0	NS	0	0.8	2.4	0	No	No
	Exhaust. time	1.0	NS	0.09	0.4	1.3	0.2	No	No
Beaven et al. (2012)	SJ (w)	4.1	NS	0.5	2.3	6.7	Ω	Ω	Ω
	CMJ (w)	− 1.0	NS	1.3	2.8	8.4	Ω	Ω	Ω
	10 m sprint	0.7	NS	−0.26	2.4	7.2	0.3	No	No
	40 m sprint	9	NS	−0.20	1.8	5.4	2.0	No	No
Clevidence et al. (2012)	Avg. HR[a]	−5.1	< 0.05	0.54	2.2	6.7	6	Yes	No
	Peak HR[b]	−4.4	< 0.05	0.42	2.3	6.9	5	Yes	No
	Ex. toler.	0.0	NS	0	12.9	38.8	0	No	No
Cochrane et al. (2013)	CK	0.0	NS	0.00	0.1	0.2	0.0	No	No
	VJPP	1.6	NS	0.11	55.8	167.2	38.6	No	No
	VJ	0.9	NS	0.06	1.0	3.1	0.3	No	No
Gibson et al. (2013)	Time	1.1	NS	0.2	0	0.1	−0.03	No	No
		−0.3	NS	0.16	0	0.1	−0.03	Yes	No
		0.0	NS	0.18	0.1	0.2	−0.05	No	No
Foster et al. (2014)	Time trial	7.0	0.03	0.32	6.8	0.0	−9.7	No	No
Kjeld et al. (2014)	Time	8.2	< 0.05	0.60	3.2	9.6	9	Yes	No
	Time	− 17.2	< 0.05	0.86	14.4	43.2	48	Yes	Yes
	T. 1000 m	0.4	< 0.05	0.22	0.7	2.2	−0.8	No	No
Paixao et al. (2014)	Max Pw. 1	−2.2	< 0.05	0.93	4.4	13.2	−20	No	No
	Mean Pw. 1	−2.8	< 0.01	1.35	3.2	9.6	−21	No	No
	Mean Pw. 2	−2.9	< 0.01	1.35	3.0	9.0	−21	No	No
Barbosa et al. (2015)	T. Fat	10.6	< 0.05	0.28	13.2	39.6	19	Yes	No

Table 4 (continued)

References	Variable analyzed	Change (%)	*P*	ES	SWC (SD × 0.2)	SWC (SD × 0.6)	Mean difference between IPC and control intervention	Achievement	
								SWC 0.2	SWC 0.6
Cruz et al. (2015)	Time to exhaustion	8	0.01	Ω	Ω	Ω	Ω	Ω	Ω
	VO_{2max}	2.9	0.04	0.1	0.2	0.7	0.11	No	No
	Blood [La]	7.5	0.07	0.5	0.2	0.7	0.6	Yes	No
Gibson et al. (2015)	Blood [La]	−11.8	NS	−0.33	0.5	1.3	−0.8	No	No
	Peak power	−0.4	NS	−0.08	92.3	221.2	−34.3	No	No
	Total power	−1.2	NS	−0.11	342.4	848.2	−173.4	No	No
Hittinger et al. (2015)	Ex. capacity	1.5	NS	0.15	5.4	16.2	5	No	No
	Ex. capacity	3.8	NS	0.29	7.8	23.4	10	Yes	No
Lalonde and Curnier (2015)	Peak power	1.1	NS	Ω	Ω	Ω	Ω	Ω	Ω
	Mean power	0.0	NS	Ω	Ω	Ω	Ω	Ω	Ω
	Peak power	2.3	NS	Ω	Ω	Ω	Ω	Ω	Ω
	Mean power	1.8	NS	Ω	Ω	Ω	Ω	Ω	Ω
Marocolo et al. (2015)	Time trial	1.4	<0.05	0.15					
Martin et al. (2015)	Heart rate	3.125	0.567	0.17	2.4	7.2	2	No	No
	Blood [La]	17.6	0.529	0.35	0.2	0.5	0.3	Yes	No
	Overall fatigue index	0.9	0.862	0.06	1.9	5.6	0.5	No	No
Patterson et al. (2015)	Peak power	2.3	A	0.18	41.6	124.8	36	No	No
	VO_2 (l min^{-1})	3.8	A	0.29	0.1	0.2	0.1	No	No
Tocco et al. (2015)	Speed (m s^{-1})	−0.6	NS	0.07	0.1	0.2	−0.02	No	No
	mVO_2 (l min^{-1})	−3.3	NS	0.12	0.2	0.5	−0.12	Yes	No
	Time to 5 km	−0.7	NS	0.07	14.4	43.1	4.5	No	No
Banks et al. (2016)	Aerobic capacity	0	NS	0	2	6	0	No	No
	Cardiac PCr/ATP ratio	9.5	NS	0.44	0.1	0.3	0.2	Yes	No
	Blood pressure	0	0.77	0	1.4	4.2	0	No	No
	PESM PCr recovery	−8.8	NS	−0.27	2.2	6.6	−3	No	No
Cruz et al. (2016)	Mean power output	2	0.001	0.26	8.6	25.7	11	Yes	No
	VO_2 peak	0	0.937	0	0.1	0.2	0	No	No
	Blood [La] peak	3.8	0.111	0.26	0.4	1.2	0.5	Yes	No
	Quadriceps EMG	9.7	0.017	–	–	–	–	No	No
Ferreira et al. (2016)	Sprint time (best)	−0.5	0.36	−0.19	0.2	0.5	−0.15	No	No
	Sprint time (worst)	−1.9	0.04	−0.97	0.1	0.4	−0.68	No	No
	Sprint time (total)	−1.2	0.02	−0.52	0.9	2.7	−2.4	No	No
	Sprint time (decr.)	−10.1	0.31	−1.02	0.2	0.6	−0.84	No	No

Table 4 (continued)

References	Variable analyzed	Change (%)	*P*	ES	SWC (SD × 0.2)	SWC (SD × 0.6)	Mean difference between IPC and control intervention	Achievement	
								SWC 0.2	SWC 0.6
James et al. (2016)	Heart rate$^{(GXT1)}$	−6.7	0.01	−0.4	2	6	−4	No	No
	Running speed: 4 mmol	−0.73	–	−0.09	0.2	0.6	−0.1	No	No
	B [La]: 2 mmol	0.86	–	0.08	0.2	0.7	0.1	No	No
	Running economy	−1.52	0.125	−0.2	3.6	10.8	−3.4	No	No
	VO_2	0.9	0.436	0.16	0.7	2.2	0.5	No	No
	Total run time	9.2	0.166	0.58	8.4	25.2	32	Yes	Yes
	vVO_{2max}	2.67	0.021	0.33	0.2	0.7	0.4	Yes	No
Kaur et al. (2017)	Heart rate$^{(GXT2)}$	0	0.74	0	2	6	0	No	No
	Running economy	−0.44	0.67	−0.06	3.2	9.7	−0.9	No	No
	Caloric cost unit	1	0.21	0.11	0	0	0.01	No	No
Marocolo et al. (2016b)	Blood [La]	11.3	0.32	0.36	0.3	0.9	0.6	Yes	No
	RPE	2.3	0.78	0.17	0.22	0.7	0.2	No	No
	Number of repetitions	4.3	0.9	0.26	0.4	1.3	0.6	Yes	No
Marocolo et al. (2016a)	Blood [La]	−4.6	0.098	−0.14	0.4	1.1	−0.3	No	No
	Fatigue index	−20.2	0.46	−0.32	2.8	8.3	−6.4	No	No
	Number of repetitions	−0.53	0.015	0.05	0.2	0.5	−0.07	No	No
IPC-post exercise (Northey et al. 2016)	Peak torque	4.8	0.003	−0.31	7.2	21.6	−13	No	No
	SJ mean jump height	−2.7	≤0.05	−0.15	1.2	3.6	−1	No	No
	Mean CMJ height	0.0	≤0.05	0.00	1.4	4.2	0	No	No
	Perc. Rec. Stat. Scale	13.7	0.40	0.42	0.4	1.1	0.7	Yes	No
	Perc. Soreness Scale	−29.5	0.27	−0.62	0.5	1.4	−1.3	No	No
Paradis-Deschenes et al. (2016b)	Peak knee ext. force	8.5	A	0.91	8.6	25.7	45	Yes	Yes
	Tot. knee ext. force	12.9	A	0.54	76	228	230	Yes	Yes
	Avg. knee ext. force	13.3	A	1.12	7.6	22.8	47	Yes	Yes
	Muscle Hb avg. conc	10.6	A	0.43	3.2	9.5	6.8	Yes	No
	Muscle Hb peak conc	8.5	A	1.38	0.9	2.7	6.4	Yes	Yes
Tanaka et al. (2016)	Time to fatigue	17.7	0.001	1.12	6.2	18.7	35	Yes	Yes
	Muscle oxygenation	29.2	0.01	0.65	2.4	7.1	7.9	Yes	Yes

Table 4 (continued)

References	Variable analyzed	Change (%)	*P*	ES	SWC (SD × 0.2)	SWC (SD × 0.6)	Mean difference between IPC and control intervention	Achievement	
								SWC 0.2	SWC 0.6
Sabino-Carvalho et al. (2017)	VO_{2max} (incremental test)	0.3	0.92	0.11	0.4	1.1	0.2	Yes	No
	Heart rate (incremental test)	−0.5	0.1	−0.33	0.6	1.8	−1	Yes	No
	RER (incremental test)	−0.9	0.42	−1	0	0	−0.01	No	No
	Blood [La] (Icremental Test)	0	0.82	0	0.1	0.2	0	Yes	No
	Borg (incremental test)	−4.3	0.26	−1	0.1	0.2	−0.4	No	No
	VO_{2max} (supramaximal test)	0.3	0.17	0.12	0.4	1.1	0.2	Yes	Yes
	HR (supramaximal test)	0	0.71	0	0.6	1.8	0	No	No
	RER (supramaximal test)	0	0.8	0	0	0	0	No	No
	Blood [La] (supramaximal test)	4.5	0.37	0.73	0.1	0.3	0.4	No	No
Seeger et al. (2017)	Time Trial	1.3	0.3	−0.18	22.4	67.2	−19	No	No
	RPE	0	0.6	0	0.4	1.2	0	No	No
	Blood [La]	28.2	0.24	0.55	0.6	1.9	1.6	Yes	No
	Time trial 24 h	1	0.3	−0.13	22.4	67.2	−15	No	No
Cocking et al. (2017)	Blood [La]	3.5	0.69	0.11	0.9	2.6	0.4	No	No
	VO_2	−1.3	0.1	−0.15	0.9	2.6	−0.7	No	No
	Power (avg)	1.05	0.99	0.08	7	21	3	No	No
Griffin et al. (2018)	Critical power	3	0.111	0.1	13.4	40.2	7	No	No
	Total O_2 consumed	1.1	0.719	−0.06	0.4	1.3	−0.12	No	No
	Total work done	−0.5	0.83	−0.02	2.5	7.6	−0.3	No	No
	Blood [La]	6.7	0.212	0.47	0.3	0.8	0.8	Yes	Yes
Marocolo et al. (2017a)	Heart Rate	0	0.17	0	1.0	3.0	0	No	No
	RPE	3.4	0.69	0.25	0.3	0.8	0.3	Yes	No
	Blood [La]	−2.6	0.19	−0.1	0.6	1.8	−0.3	No	No
	Distance	−0.7	0.1	−0.03	42.4	127.2	−6	No	No
Page et al. (2017) (Post)	MIVC	10.9	NS	1	1.3	4	8.9	Yes	Yes
	CMJ	5.6	NS	0.8	1.3	3.9	4.5	Yes	Yes
	DOMS	−46.3	<0.05	−1.8	6	18.1	−49.1	No	No
	CK	−47.2	0.78	−1.5	60	180.1	−300.6	No	No
Paradis-Deschenes et al. (2016b)	Average force	4.8	NI	0.67	5.8	17.3	19.92	Yes	Yes
	Δ [THb]	14.1	NI	0.92	0.2	6.0	0.74	Yes	No
	Δ [HHb]	−18.1	NI	−1.3	1.3	4.0	−12.54	No	No

Table 4 (continued)

References	Variable analyzed	Change (%)	*P*	ES	SWC (SD × 0.2)	SWC (SD × 0.6)	Mean difference between IPC and control intervention	Achievement	
								SWC 0.2	SWC 0.6
Paradis-Deschenes et al. (2016b)	Average force	8.9	NI	1.3	6.8	20.4	49.64	Yes	Yes
	Δ [THb]	12.7	NI	0.7	0.2	0.6	0.78	Yes	Yes
	Δ [HHb]	6.2	NI	0.94	1.2	3.7	4.84	Yes	Yes
Zinner et al. (2017)	Mean time	0	0.5	0	0.3	0.9	0	No	No
	Oxygen uptake	−2.6	0.99	−0.1	0.1	0.4	−0.08	No	No
	Resp. E. ratio	0	0.92	0	0	0.1	0	No	No
	Ventilation	−2.7	0.99	−0.1	6.2	18.5	−3	No	No
	Heart rate	−0.8	0.86	−0.1	2.2	6.6	−1.4	No	No
	SmO_2 during recovery	5.6	> 0.05	0.2	3.4	10.3	3.4	Yes	No
	SmO_2 during sprint	−10.1	> 0.05	−0.26	4.1	12.4	−5.1	No	No
Zinner et al. (2017)	Mean time	1.1	0.5	0.1	0.3	0.9	0.18	No	No
	Oxygen uptake	−1.9	0.99	−0.08	0.1	0.4	−0.06	No	No
	Resp. E. ratio	0	0.92	0	0	0.1	0	No	No
	Ventilation	−2.7	0.99	−0.1	6.2	18.5	−3	No	No
	Heart rate	0.3	0.86	0.05	2.2	6.6	0.6	No	No
	SmO_2 during recovery	7.8	> 0.05	0.26	3.4	10.3	4.75	Yes	No
	SmO_2 during sprint	−5.9	> 0.05	−0.16	4.1	12.4	−3	No	No
Cocking et al. (2018a)	Peak diameter resp.	4.2	0.91	0.4	0	0.0	0.02	No	No
	Blood velocity	16.1	< 0.005	0.2	1.3	4.0	1.28	No	No
	30 s force	−2.8	0.4	−0.1	1.0	2.9	−0.6	No	No
	Peak force	−1.2	0.91	−0.05	1.1	3.4	−0.3	No	No
Cocking et al. (2018a)	Peak diameter resp.	2.1	0.09	0.2	0	0.0	0.01	No	No
	Blood velocity	4.4	< 0.005	0.06	1.3	4.0	0.35	No	No
	30 s force	2.8	0.4	0.1	1.0	2.9	0.6	No	No
	Peak force	0	0.91	0	1.1	3.4	0	No	No
Griffin et al. (2018)	Total sprint time	0	0.538	0	1.5	4.5	0	No	No
	Mean muscle oxy	−2.8	0.261	0.07	1.5	4.5	0.5	No	No
	Mean blood [La]	−1.6	0.7	−0.08	0.6	1.7	−0.2	No	No
	Mean RPE^{ge}	−3	0.693	−0.28	0.3	1.0	−0.5	No	No
Griffin et al. (2018)	Total sprint time	−0.5	0.538	−0.08	1.6	4.7	−0.6	No	No
	Mean muscle oxy	−5.8	0.261	0.1	1.5	4.4	0.9	No	No
	Mean blood [La]	0.8	0.7	0.03	0.7	2.0	0.1	No	No
	Mean RPE^{ge}	0	0.693	0	0.4	1.1	0	No	No

Table 4 (continued)

References	Variable analyzed	Change (%)	*P*	ES	SWC (SD × 0.2)	SWC (SD × 0.6)	Mean difference between IPC and control intervention	Achievement	
								SWC 0.2	SWC 0.6
Paradis-Deschenes et al. (2018)	Mean HR (LA)	3.4	NI	1.75	0.8	2.4	5.7	Yes	Yes
	Mean SV (LA)	2.3	NI	0.39	1.9	5.8	3.6	Yes	No
	Mean *Q* (LA)	4.9	NI	0.84	0.3	1.0	1.3	Yes	Yes
	Δ [HHb] (LA)	0.1	NI	0.01	1.4	4.3	0.1	No	No
	Δ [THb] (LA)	1.9	NI	0.06	0.3	1.0	0.1	No	No
	RPE (LA)	0	NS	0	0.1	0.2	0	No	No
	SpO_2 (%) (LA)	−0.1	NS	Ω	Ω	Ω	−0.1	Ω	Ω
	5 km TT (LA)	−1.1	0.01	−0.22	Ω	Ω	−5.2	Ω	Ω
	Power output (LA)	2.4	0.51	0.75	2.2	6.7	7.5	Yes	Yes
	TSI (%) (LA)	−2.3	NS	Ω	Ω	Ω	−0.9	Ω	Ω
	Mean HR (MA)	−2	NI	−0.98	0.7	2.0	−3.4	No	No
	Mean SV (MA)	4.2	NI	0.54	2.7	8.2	7.05	Yes	No
	Mean *Q* (MA)	2.4	NI	0.3	0.5	1.5	0.69	Yes	No
	Δ [HHb] (MA)	−3	NI	−0.24	2.4	7.2	−2.8	No	No
	Δ [THb] (MA)	−25	NI	−1.1	0.3	1.0	−1.8	No	No
	RPE (MA)	−4	NI	−0.86	0.1	0.2	−0.3	No	No
	SpO_2 (%) (MA)	1.1	NI	Ω	Ω	Ω	0.9	Ω	Ω
	5 km TT (MA)	−1.5	NI	−0.38	Ω	Ω	−7.3	Ω	Ω
	Power output (MA)	2.3	NI	0.34	2.5	7.6	6.7	Yes	No
	TSI (%) (MA)	−5.5	NI	Ω	Ω	Ω	−2	Ω	Ω
Richard and Billaut (2018)	Mean TSI (%)	−1.5	NI	−0.09	1.5	4.4	−0.72	No	No
	Total Hb	1.9	NI	0.06	5.3	16.0	1.6	No	No
	Avg.[THb]	0.8	NI	0.02	3.5	10.4	0.4	No	No
	On-ice 1000 m TT	0.1	NI	0.01	1.1	3.3	0.08	No	No

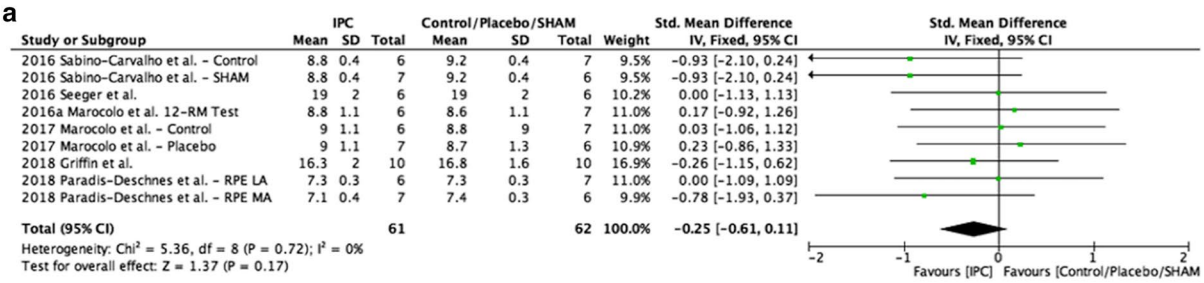
Table 4 (continued)

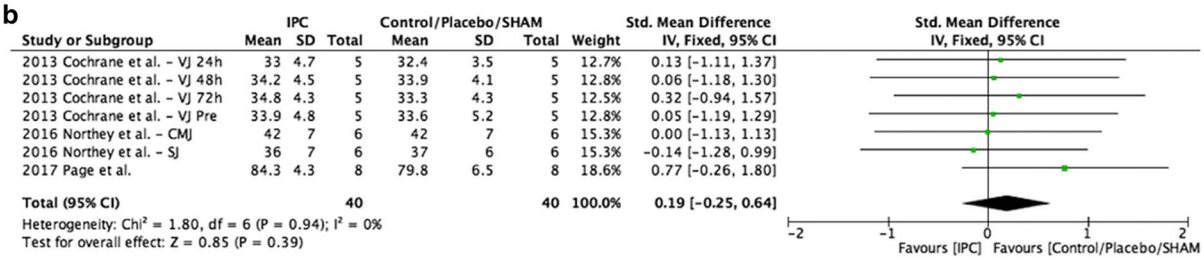
References	Variable analyzed	Change (%)	*P*	ES	SWC (SD × 0.2)	SWC (SD × 0.6)	Mean difference between IPC and control intervention	Achievement	
								SWC 0.2	SWC 0.6
Williams et al. (2018) (2 h)	Time 100 m (s)	0	0.995	0	1.6	4.9	0	No	No
	Time 200 m (s)	−1.9	0.405	−0.24	2.1	6.2	−2.5	No	No
	Stroke count 50 m	−2.6	0.56	−0.2	0.5	1.4	−0.5	No	No
	Stroke rate 50 m	−3.1	0.72	−0.17	1.6	4.8	−1.4	No	No
	Stroke count 100 m	−4	0.57	−0.28	0.6	1.9	−0.9	No	No
	Stroke rate 100 m	−0.5	0.99	−0.03	1.4	4.3	−0.2	No	No
	Blood [La]	3.7	< 0.001	0.12	0.8	2.4	0.46	No	No
	TCO_2	11.7	< 0.001	−0.23	1.5	4.6	−1.35	No	No
	HCO_3	0.3	< 0.001	−0.01	1.1	3.4	−0.04	No	No
	SO_2 (%)	−180	< 0.001	−0.19	0.4	1.2	−0.36	No	No
Williams et al. (2018) (24 h)	Time 100 m (s)	−0.4	0.995	−0.03	1.6	4.9	−0.27	No	No
	Time 200 m (s)	−0.7	0.405	−0.08	2.1	6.2	−0.94	No	No
	Stroke count 50 m	−4.7	0.56	−0.36	0.5	1.4	−0.9	No	No
	Stroke rate 50 m	−4.2	0.72	−0.04	1.6	4.8	−1.9	No	No
	Stroke count 100 m	−4.9	0.57	−0.32	0.6	1.9	−1.1	No	No
	Stroke rate 100 m	−0.9	0.99	−0.01	1.4	4.3	−0.4	No	No
	Blood [La]	0	< 0.001	0	0.8	2.4	0	No	No
	TCO_2	−185.7	< 0.001	2.68	1.5	4.6	21.45	Yes	Yes
	HCO_3	−27.1	< 0.001	0.43	1.1	3.4	3.15	Yes	No
	SO_2 (%)	135	< 0.001	0.13	0.4	1.2	0.27	No	No

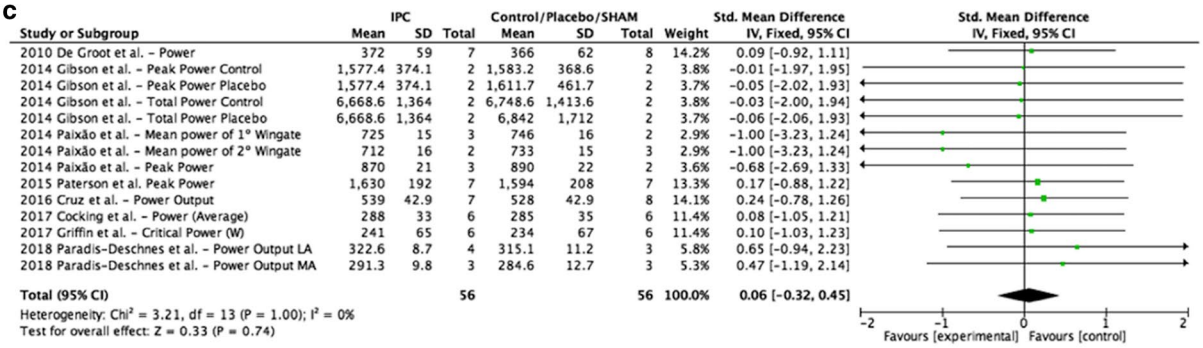
VJPP vertical jump peak power, *C* control, *P* placebo, *IPC* ischemic preconditioning, *Exhaust. time* time to exhaustion, *Exer. toler.* exercise tolerance, *Fat. index* fatigue index, *T.Fat.* time to fatigue, *T. 1000 m* time to 1000 m, *Max. Pw.* maximal power in Wingate, *Mean Pw1* mean power Wingate 1, *Mean Pw. 2* mean power Wingate 2, *Ex. capacity* exercise capacity, mVO_2 (l min^{-1}) mean VO_2, *VJPP* vertical jump peak power, *VJ* vertical jump, *C* control group without cuff administration, *P* placebo group with a sham intervention, *IPC* ischemic preconditioning, *CMJ* countermovement jumps, *SJ* squat jump, *CK* creatine kinase, *B [La]* blood lactate concentration, *Cardiac PCr/ATP ratio* cardiac phosphocreatinine-to-adenosine-triphosphate ratio, *PESM PCr recovery* post-exercise skeletal muscle phosphocreatine recovery, *Blood [La] peak* peak blood lactate concentration, *Quadriceps EMG* electromyography of quadriceps muscle, *GXT 1* graded exercise test 1, *GXT 2* graded exercise test 2, *RPE* rating of perceived exertion, *Perc. Rec. Stat. Scale* perceived recovery status scale, *Perc. Soreness Scale* perceived muscle soreness scale, *Ext.* extension; *Avg* average, *Conc* concentration, *Muscle Hb avg. Conc.* muscle hemoglobin average concentration, *Muscle Hb peak conc.* muscle hemoglobin peak concentration, *MIVC* maximal isometric voluntary contraction; *DOMS* muscle soreness; *Δ [THb]* changes in concentration of deoxy-hemoglobin, *Δ [HHb]* changes in concentration of total hemoglobin, *Resp. E. ratio* respiratory exchange ratio, SmO_2 percentage of hemoglobin containing O_2, *Ω* the study did not provide enough data to calculate effect size (ES), *α* the study did not provide *P* value

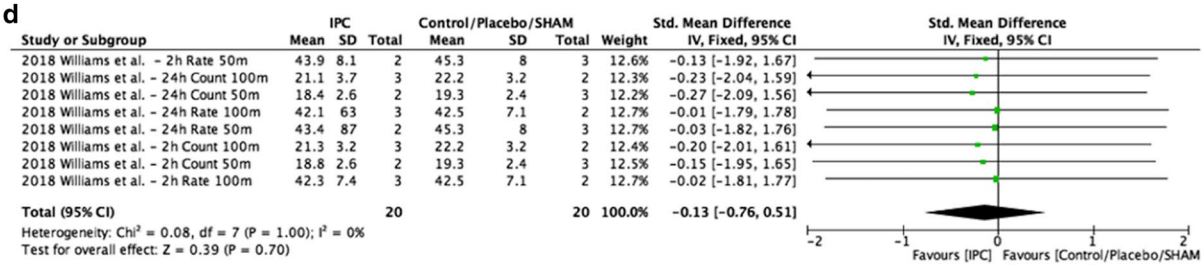
[a]Average heart rate (bpm) 30% VO_{2max}

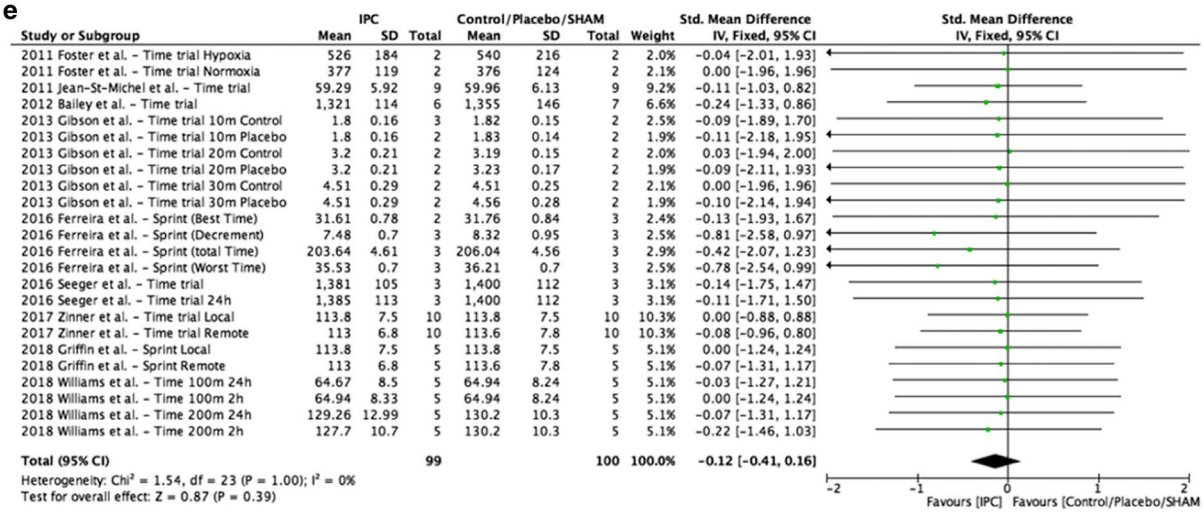
[b]Peak heart rate (bpm) 30% VO_{2max}


a
IPC
Control/Placebo/SHAM
Std. Mean Difference
Std. Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Fixed, 95% CI
IV, Fixed, 95% CI
2016 Sabino-Carvalho et al. - Control 8.8 0.4 6 9.2 0.4 7 9.5% -0.93 [-2.10, 0.24]
2016 Sabino-Carvalho et al. - SHAM 8.8 0.4 7 9.2 0.4 6 9.5% -0.93 [-2.10, 0.24]
2016 Seeger et al. 19 2 6 19 2 6 10.2% 0.00 [-1.13, 1.13]
2016a Marocolo et al. 12-RM Test 8.8 1.1 6 8.6 1.1 7 11.0% 0.17 [-0.92, 1.26]
2017 Marocolo et al. - Control 9 1.1 6 8.8 9 7 11.0% 0.03 [-1.06, 1.12]
2017 Marocolo et al. - Placebo 9 1.1 7 8.7 1.3 6 10.9% 0.23 [-0.86, 1.33]
2018 Griffin et al. 16.3 2 10 16.8 1.6 10 16.9% -0.26 [-1.15, 0.62]
2018 Paradis-Deschnes et al. - RPE LA 7.3 0.3 6 7.3 0.3 7 11.0% 0.00 [-1.09, 1.09]
2018 Paradis-Deschnes et al. - RPE MA 7.1 0.4 7 7.4 0.3 6 9.9% -0.78 [-1.93, 0.37]
Total (95% CI) 61 62 100.0% -0.25 [-0.61, 0.11]
Heterogeneity: Chi² = 5.36, df = 8 (P = 0.72); I² = 0%
Test for overall effect: Z = 1.37 (P = 0.17)
-2 -1 0 1 2
Favours [IPC] Favours [Control/Placebo/SHAM]


b
IPC
Control/Placebo/SHAM
Std. Mean Difference
Std. Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Fixed, 95% CI
IV, Fixed, 95% CI
2013 Cochrane et al. - VJ 24h 33 4.7 5 32.4 3.5 5 12.7% 0.13 [-1.11, 1.37]
2013 Cochrane et al. - VJ 48h 34.2 4.5 5 33.9 4.1 5 12.8% 0.06 [-1.18, 1.30]
2013 Cochrane et al. - VJ 72h 34.8 4.3 5 33.3 4.3 5 12.5% 0.32 [-0.94, 1.57]
2013 Cochrane et al. - VJ Pre 33.9 4.8 5 33.6 5.2 5 12.8% 0.05 [-1.19, 1.29]
2016 Northey et al. - CMJ 42 7 6 42 7 6 15.3% 0.00 [-1.13, 1.13]
2016 Northey et al. - SJ 36 7 6 37 6 6 15.3% -0.14 [-1.28, 0.99]
2017 Page et al. 84.3 4.3 8 79.8 6.5 8 18.6% 0.77 [-0.26, 1.80]
Total (95% CI) 40 40 100.0% 0.19 [-0.25, 0.64]
Heterogeneity: Chi² = 1.80, df = 6 (P = 0.94); I² = 0%
Test for overall effect: Z = 0.85 (P = 0.39)
-2 -1 0 1 2
Favours [IPC] Favours [Control/Placebo/SHAM]


c
IPC
Control/Placebo/SHAM
Std. Mean Difference
Std. Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Fixed, 95% CI
IV, Fixed, 95% CI
2010 De Groot et al. - Power 372 59 7 366 62 8 14.2% 0.09 [-0.92, 1.11]
2014 Gibson et al. - Peak Power Control 1,577.4 374.1 2 1,583.2 368.6 2 3.8% -0.01 [-1.97, 1.95]
2014 Gibson et al. - Peak Power Placebo 1,577.4 374.1 2 1,611.7 461.7 2 3.7% -0.05 [-2.02, 1.93]
2014 Gibson et al. - Total Power Control 6,668.6 1,364 2 6,748.6 1,413.6 2 3.8% -0.03 [-2.00, 1.94]
2014 Gibson et al. - Total Power Placebo 6,668.6 1,364 2 6,842 1,712 2 3.7% -0.06 [-2.06, 1.93]
2014 Paixão et al. - Mean power of 1° Wingate 725 15 3 746 16 2 2.9% -1.00 [-3.23, 1.24]
2014 Paixão et al. - Mean power of 2° Wingate 712 16 2 733 15 3 2.9% -1.00 [-3.23, 1.24]
2014 Paixão et al. - Peak Power 870 21 3 890 22 2 3.6% -0.68 [-2.69, 1.33]
2015 Paterson et al. Peak Power 1,630 192 7 1,594 208 7 13.3% 0.17 [-0.88, 1.22]
2016 Cruz et al. - Power Output 539 42.9 7 528 42.9 8 14.1% 0.24 [-0.78, 1.26]
2017 Cocking et al. - Power (Average) 288 33 6 285 35 6 11.4% 0.08 [-1.05, 1.21]
2017 Griffin et al. - Critical Power (W) 241 65 6 234 67 6 11.4% 0.10 [-1.03, 1.23]
2018 Paradis-Deschnes et al. - Power Output LA 322.6 8.7 4 315.1 11.2 3 5.8% 0.65 [-0.94, 2.23]
2018 Paradis-Deschnes et al. - Power Output MA 291.3 9.8 3 284.6 12.7 3 5.3% 0.47 [-1.19, 2.14]
Total (95% CI) 56 56 100.0% 0.06 [-0.32, 0.45]
Heterogeneity: Chi² = 3.21, df = 13 (P = 1.00); I² = 0%
Test for overall effect: Z = 0.33 (P = 0.74)
-2 -1 0 1 2
Favours [experimental] Favours [control]


d
IPC
Control/Placebo/SHAM
Std. Mean Difference
Std. Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Fixed, 95% CI
IV, Fixed, 95% CI
2018 Williams et al. - 2h Rate 50m 43.9 8.1 2 45.3 8 3 12.6% -0.13 [-1.92, 1.67]
2018 Williams et al. - 24h Count 100m 21.1 3.7 3 22.2 3.2 2 12.3% -0.23 [-2.04, 1.59]
2018 Williams et al. - 24h Count 50m 18.4 2.6 2 19.3 2.4 3 12.2% -0.27 [-2.09, 1.56]
2018 Williams et al. - 24h Rate 100m 42.1 63 3 42.5 7.1 2 12.7% -0.01 [-1.79, 1.78]
2018 Williams et al. - 24h Rate 50m 43.4 87 2 45.3 8 3 12.7% -0.03 [-1.82, 1.76]
2018 Williams et al. - 2h Count 100m 21.3 3.2 3 22.2 3.2 2 12.4% -0.20 [-2.01, 1.61]
2018 Williams et al. - 2h Count 50m 18.8 2.6 2 19.3 2.4 3 12.5% -0.15 [-1.95, 1.65]
2018 Williams et al. - 2h Rate 100m 42.3 7.4 3 42.5 7.1 2 12.7% -0.02 [-1.81, 1.77]
Total (95% CI) 20 20 100.0% -0.13 [-0.76, 0.51]
Heterogeneity: Chi² = 0.08, df = 7 (P = 1.00); I² = 0%
Test for overall effect: Z = 0.39 (P = 0.70)
-2 -1 0 1 2
Favours [IPC] Favours [Control/Placebo/SHAM]


e
IPC
Control/Placebo/SHAM
Std. Mean Difference
Std. Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Fixed, 95% CI
IV, Fixed, 95% CI
2011 Foster et al. - Time trial Hypoxia 526 184 2 540 216 2 2.0% -0.04 [-2.01, 1.93]
2011 Foster et al. - Time trial Normoxia 377 119 2 376 124 2 2.1% 0.00 [-1.96, 1.96]
2011 Jean-St-Michel et al. - Time trial 59.29 5.92 9 59.96 6.13 9 9.2% -0.11 [-1.03, 0.82]
2012 Bailey et al. - Time trial 1,321 114 6 1,355 146 7 6.6% -0.24 [-1.33, 0.86]
2013 Gibson et al. - Time trial 10m Control 1.8 0.16 3 1.82 0.15 2 2.5% -0.09 [-1.89, 1.70]
2013 Gibson et al. - Time trial 10m Placebo 1.8 0.16 2 1.83 0.14 2 1.9% -0.11 [-2.18, 1.95]
2013 Gibson et al. - Time trial 20m Control 3.2 0.21 2 3.19 0.15 2 2.0% 0.03 [-1.94, 2.00]
2013 Gibson et al. - Time trial 20m Placebo 3.2 0.21 2 3.23 0.17 2 1.9% -0.09 [-2.11, 1.93]
2013 Gibson et al. - Time trial 30m Control 4.51 0.29 2 4.51 0.25 2 2.1% 0.00 [-1.96, 1.96]
2013 Gibson et al. - Time trial 30m Placebo 4.51 0.29 2 4.56 0.28 2 1.9% -0.10 [-2.14, 1.94]
2016 Ferreira et al. - Sprint (Best Time) 31.61 0.78 2 31.76 0.84 3 2.4% -0.13 [-1.93, 1.67]
2016 Ferreira et al. - Sprint (Decrement) 7.48 0.7 3 8.32 0.95 3 2.5% -0.81 [-2.58, 0.97]
2016 Ferreira et al. - Sprint (total Time) 203.64 4.61 3 206.04 4.56 3 2.9% -0.42 [-2.07, 1.23]
2016 Ferreira et al. - Sprint (Worst Time) 35.53 0.7 3 36.21 0.7 3 2.5% -0.78 [-2.54, 0.99]
2016 Seeger et al. - Time trial 1,381 105 3 1,400 112 3 3.1% -0.14 [-1.75, 1.47]
2016 Seeger et al. - Time trial 24h 1,385 113 3 1,400 112 3 3.1% -0.11 [-1.71, 1.50]
2017 Zinner et al. - Time trial Local 113.8 7.5 10 113.8 7.5 10 10.3% 0.00 [-0.88, 0.88]
2017 Zinner et al. - Time trial Remote 113 6.8 10 113.6 7.8 10 10.3% -0.08 [-0.96, 0.80]
2018 Griffin et al. - Sprint Local 113.8 7.5 5 113.8 7.5 5 5.1% 0.00 [-1.24, 1.24]
2018 Griffin et al. - Sprint Remote 113 6.8 5 113.6 7.8 5 5.1% -0.07 [-1.31, 1.17]
2018 Williams et al. - Time 100m 24h 64.67 8.5 5 64.94 8.24 5 5.1% -0.03 [-1.27, 1.21]
2018 Williams et al. - Time 100m 2h 64.94 8.33 5 64.94 8.24 5 5.1% 0.00 [-1.24, 1.24]
2018 Williams et al. - Time 200m 24h 129.26 12.99 5 130.2 10.3 5 5.1% -0.07 [-1.31, 1.17]
2018 Williams et al. - Time 200m 2h 127.7 10.7 5 130.2 10.3 5 5.1% -0.22 [-1.46, 1.03]
Total (95% CI) 99 100 100.0% -0.12 [-0.41, 0.16]
Heterogeneity: Chi² = 1.54, df = 23 (P = 1.00); I² = 0%
Test for overall effect: Z = 0.87 (P = 0.39)
-2 -1 0 1 2
Favours [IPC] Favours [Control/Placebo/SHAM]

◂**Fig. 3** Forest plot of perceptual (rating of perceived exertion—RPE) and performance variables. **a** RPE; **b** jump; **c** power; **d** stroke rate; **e** time trial and sprint. Values shown are effect sizes with 95% confidence intervals. *SD* standard deviation, *IV* inverse variance, *Std.* standard, *CI* confidence interval, *df* degrees of freedom. Note: it is possible to have a single study repeated multiple times if such study presented numerous comparisons (e.g., IPC vs., SHAM; IPC vs., control; time-course of comparisons)

it could be noted the statistical parameters related to IPC effects (i.e., *P* value, ES and SWC).

Forty-five studies were included in this meta-analysis. Across all included studies, the results indicate low heterogeneity ($I^2 = 0\%$; $Z = 0.33$–1.37; $P > 0.05$; Figs. 3, 4).

Discussion

The aim of this review was to interpret the application of IPC on exercise performance using both traditional statistics (*P* value and ES) and SWC approach in healthy individuals. The main finding was that IPC promotes a small magnitude of beneficial effects, alternated with null or detrimental effects. The selected studies presented high quality; however, most of them did not describe statistical significance in the measured performance or physiological variables. Seven studies reported significant beneficial and one detrimental effects of IPC. Among these studies, only one included a placebo/sham group in their experimental design to control a potential placebo/nocebo effect from the experiments, and this flaw could have generated biased results. Therefore, considering the SWC analysis, the current data showed trivial or non-positive effect from the IPC intervention.

Quality of the papers

The general mean score for quality was 81%. Most part of the assessed studies showed some limitations: Only 11 studies included the CI for the main results (criterion 14). This is particularly important, because the CI is influenced by the sample size, the homogeneity of the data sample, and the confidence level selected by the researcher. The CI is based on the fact that there is a sampling error, which depends on how well the statistics represent the target population. Therefore, a report of the CI values provides a range, not a single point, which likely includes the estimate of the average of the population. Nine further studies lacked information about quality criterion, which referred to reports of the actual probability values. Reporting the exact *P* value provides more information about the strength of the evidence against the null hypothesis and allows each reader to reject it. Finally, there were deficiencies with regard to quality criterion in eight studies. Specifically, 18 studies did not report any follow-up analysis of the participants in the studies (e.g., no information about a potential interruption of the IPC protocol, due to discomfort). However, all experimental designs were cross-sectional, which may explain this lack of information. In addition, all of these studies failed to reference at least one of the relevant issues for experimental studies, such as the study design (randomized, double-blind study), a description of the study dropouts or relocation of the participants.

Time between IPC and exercise or test and general characteristics of IPC protocols

The first attempts to evaluate the IPC effects on exercise performance applied the tests immediately after the maneuver, probably to take advantage of the period of reactive hyperemia (Nukada 1955; Muller 1958; Collier and Percival 1959; de Groot et al. 2010). However, more recent studies have used an interval time of up to 45 min (Bailey et al. 2012b; Hittinger et al. 2015; Jean-St-Michel et al. 2011; Zinner et al. 2017), 60 min (Seeger et al. 2017; Richard and Billaut 2018), 90 min (Higgins and Thompson 2002; Barr 2011) or up to 24 h (Beaven et al. 2012; Cochrane et al. 2013; Banks et al. 2016; Northey et al. 2016; Page et al. 2017) in some studies. Short intervals (i.e., less than 10 min) between IPC and exercise promoted beneficial (Bailey et al. 2012b; Singh et al. 2017; James et al. 2016) and detrimental effects (Paixao et al. 2014; Tocco et al. 2015), as well as long intervals (i.e., more than 30 min) when faster swimming time or higher cycling power (Jean-St-Michel et al. 2011; Patterson et al. 2015) and less peak torque (Northey et al. 2016) were found. Interestingly, intervals of more than 45 min promoted less detrimental effects compared to shorter ones, which could speculate that IPC effects requires a minimal time window.

The most common IPC applied protocol is three (17 studies) of four (20 studies) cycles of 5 min ischemia followed by 5 min reperfusion. Other protocols, such as 2 cycles of 3 min ischemia and 30 s alternating were also found in two studies. Interestingly, beneficial IPC effect with statistical difference ($P < 0.05$) occurred in six studies that applied the 3×5 min protocol, while only in one study that used 4×5 min protocol. It seems that at least three cycles of ischemia, with no more than five minutes promotes the best beneficial effects on exercise performance.

Exercise and test modalities

Sixteen experiments performed cycling tests, with 10 of these involving incremental or time-trial efforts and six anaerobic cycling sprints (6–30 s duration). Time-trial running was used in six studies, while five evaluated sprints and one a YOYO intermittent test. Swimming of 100 m

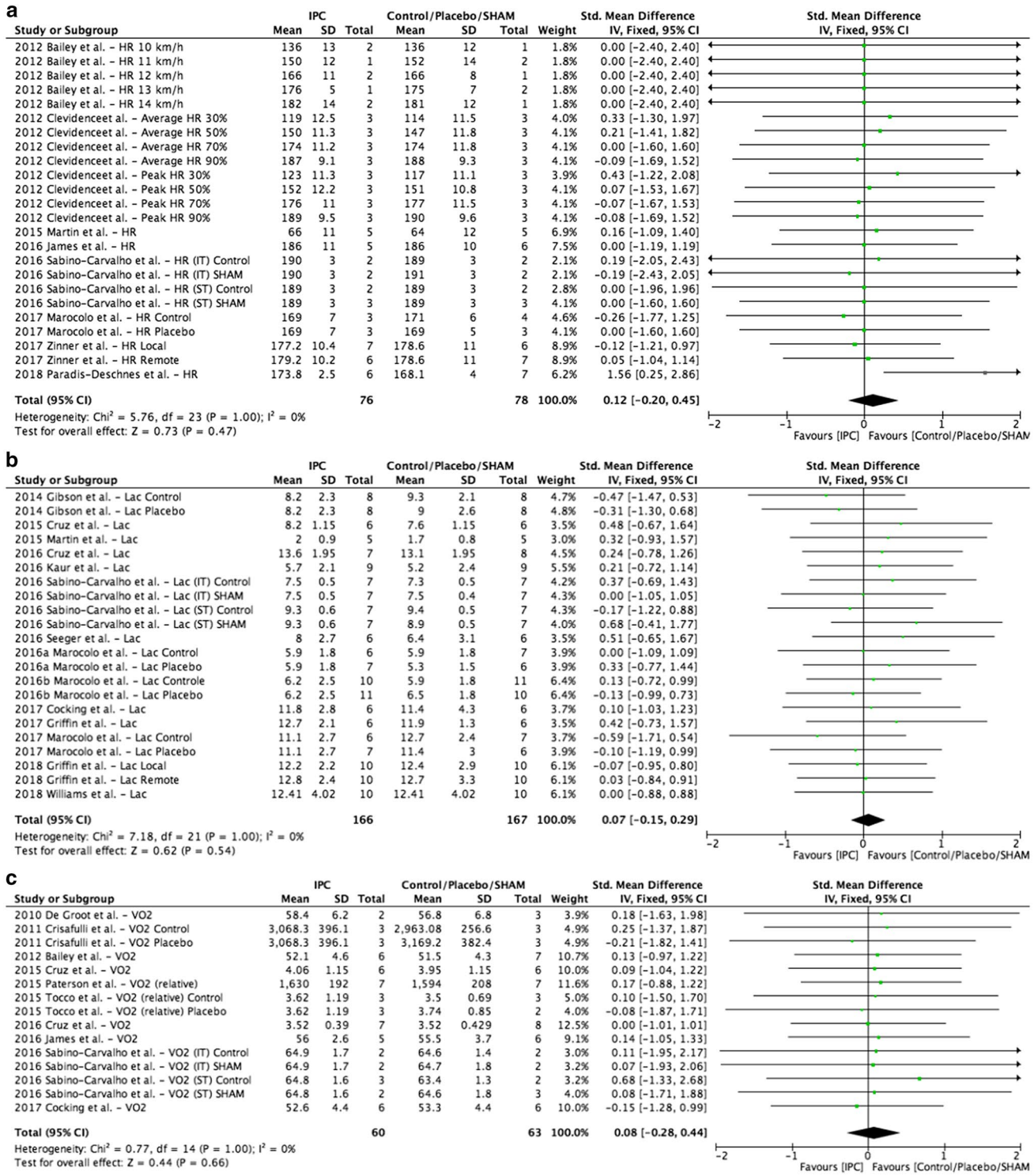


Fig. 4 Forest plot of physiological variables. **a** Heart rate (HR); **b** lactate (Lac); **c** oxygen uptake (VO_2). Values shown are effect sizes with 95% confidence intervals. *SD* standard deviation, *IV* inverse variance, *Std.* standard, *CI* confidence interval, *df* degrees of freedom. Note: it is possible to have a single study repeated multiple times if such study presented numerous comparisons (e.g., IPC vs., SHAM; IPC vs., control; time-course of comparisons)

and 200 m time trial were found in three studies and also dynamic and static apnea were tested. The most significant results of IPC are found in cycling modalities, maybe due to specificity of test or sensitivity of measured parameters, while only two studies reported significant beneficial effects using a real-world exercise, one running and skating. Most of the experiments carried out a laboratory test, which could interfere on the results, minimizing the real IPC effects. In this context, it is relevant to highlight that what happens during real training or competition is quite different from the artificial setting of a laboratory (Buchheit 2016b, 2017). Therefore, the current results could not be easily transferred to real-world settings of athletes/competitions even if positive and meaningful findings were confirmed (Marocolo et al. 2018).

Fitness level of participants

It is largely known that training level of participants is directly related to results analysis. Just two studies selected for this review presented high fitness level participants (based on physiological and performance parameters, e.g., VO_{2max}, time-trial): Richard and Billaut (2018) tested elite speed skaters, while Paradis–Deschenes analysed cyclists (Paradis-Deschenes et al. 2018). All other studies included amateur or recreational participants, even when the title or some part of the text mentioned "highly trained". The lack of studies including elite athletes is understandable, because the natural limitations to do that. However, the reader should be aware of a minor SWC could be relevant for an elite athlete but not for a recreational one.

IPC effects in view of SWC and ES

Thirteen studies (~ 29%) reported results achieving 0.2 SWC for performance parameters, while five (~ 11%) achieved 0.6 SWC. Based on statistical proposals, for amateur or recreational fitness level of participants, the 0.6 SWC should be considered. In this hand, only two studies (Paradis-Deschenes et al. 2018; Richard and Billaut 2018) have evaluated elite athletes and did not achieve either 0.2 or 0.6 SWC for performance parameters, although one of them reported significance statistical values ($P < 0.05$). At first glance, this analysis could suggest that IPC promote effects of low magnitude in most part of the studies and, when the magnitude of effect is higher the fitness level of participants is lower. Although IPC results showed more magnitude of effects in lower trained participants, futures studies should test if IPC response-interventions are related to fitness level.

This fact is supported by the analysis of forest plot (Fig. 3), showing that performance variables are in most cases near to null mean difference the line and, if a favor IPC/Placebo effect is noted, a large range follow and small representative power of the experiment is also presented. Figure 4 shows in part a similar null IPC effect or in most part of studies, a favor effect to placebo/sham/control is depicted. Therefore, although IPC has shown some beneficial effects on exercise performance, under the view of SWC, our data do not support IPC as an effective ergogenic aid. On the other hand, perhaps, the optimal IPC protocol per si (e.g., number of cycles of ischemia–reperfusion and time to start the exercise) has not been found yet, and future studies should explore it.

We have excluded 86 non-English language studies from the current review, being 17 of these classified as reviews. From the 69 remaining papers, we have excluded 67 by title or abstract. Therefore, two papers could have some interesting content about IPC and exercise performance, but no abstract information could be found for both manuscripts. The first one was written in German (year date 1969; it was not possible to identify the exact author due the similarity of surnames) and another written in Slovak (year date 1986; we have sent an email to correspondent author requesting that paper but we had no answer). While there are reports in the scientific literature, showing that this exclusion does not impact the final findings of systematic reviews (Morrison et al. 2012; Juni et al. 2002), we acknowledge it might be a limitation.

IPC-induced mechanisms on exercise performance

Although the current study is a meta-analysis, the selected papers overall lack investigating the physiological mechanisms. The physiological mechanisms underlying a potential ergogenic effect from IPC on exercise performance are unclear and we have discussed some insights from the literature briefly.

A lower perception of fatigue could explain the better endurance performance found in some studies. IPC could desensitize group III and IV nerve endings to metabolite accumulation, since type III and IV nerve endings would influence cardiovascular function during exercise (Amann et al. 2011), contributing to improvements in performance. Type III and IV nerves modulate the sympathetic tone on the active muscle, stimulating type III mainly as mechano- and IV as metabo-receptors (Nobrega et al. 2014), resulting in increases in sympathetic tone, regulating, for instance, cardiac contractility (Marongiu et al. 2013; Crisafulli et al. 2011a).

IPC-induced mechanisms are also related to local vasodilation at moderate-intensity exercise (Horiuchi et al. 2015), which may contribute to blood supply and consequently optimize the delivery of nutrients and oxygen to the peripheral tissue, and muscle deoxygenation kinetics during exercise (Kido et al. 2015). Then, increasing in blood flow and muscle oxygenation (Barbosa et al. 2015; Paradis-Deschenes

et al. 2016a) resulted in improved oxygen consumption (Tapuria et al. 2008; Beaven et al. 2012). In addition, a bidirectional brain-body integration mechanism may promote physiological responses through mechanical-sensory receptors (Taylor et al. 2010; Cromwell and Panksepp 2011; de Souza et al. 2019) increasing resistance exercise performance (de Souza et al. 2019).

A few studies have confirmed such IPC effect evidence according to this review. In this review, considering 'only' the SWC (not *P* values), four studies showed improvements in performance associated with any physiological parameters. Among such four studies, the primary physiological indicators which could explain the IPC-induced ergogenic effects were:

- Increased muscle perfusion and oxygen uptake or a higher peripheral oxygen extraction, collaborating with an increase in average (Paradis-Deschenes et al. 2016b) or peak knee extension force (Paradis-Deschenes et al. 2016a).
- Rises in blood lactate with a higher mean power output (Cruz et al. 2016).
- Higher heart rate, systolic volume, and cardiac output during time-trial exercise at moderate altitude, raising the power output (Paradis-Deschenes et al. 2018).

Conclusion

Most of the selected studies evaluated participants with low fitness level. Although few studies had been reported significant positive IPC, most of them did not use a sham procedure to control a potential placebo effect from the experiments, occasioning biased results.

Both traditional (test with *P* value) and SWC statistics were not significantly in most part of the analysed studies. Considering the real-world effects from IPC (SWC and ES analysis), the current data showed that most part of the results did not achieve the minimum threshold.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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