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Effect of Simultaneous Lower- and Upper-Body Ischemic Preconditioning on Lactate, Heart Rate, and Rowing Performance in Healthy Males and Females

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Abstract: The ergogenic effects of simultaneous lower- and upper-body ischemic preconditioning (IPC) are a factor that has not been investigated exhaustively. Therefore, this study aimed to investigate the effects of IPC on 500 m rowing performance (time, relative peak [RPP] and mean [MPP] power output, time to peak power [TPP], and blood lactate concentration [BLa]), as well as heart rate (HR) among forty-three physically active male (n = 24) and female (n = 19) subjects. In this cross-over randomized trial, either the IPC (220 mmHg) or SHAM (20 mmHg) protocol was applied to the upper and lower limbs simultaneously for 5 min. Then, after 5 min of reperfusion, the participants performed an all-out 500 m rowing trial. During rowing, HR was recorded, and after the completion of the rowing, the BLa concentration was determined. Wilcoxon's signed-rank test showed a significantly shorter TPP in the SHAM condition compared to under the IPC condition for females ($Z = 2.415$, $p = 0.017$), but not for males ($Z = 1.914$, $p = 0.056$). Moreover, a significant main effect of the group was reported for rowing time, BLa, RPP, and RMP ($p < 0.001$ for all dependent variables). No significant interactions nor a main effect of the condition were observed for rowing time, BLa, RPP, RMP, HR_{WP}, HR_{MEAN}, and HR_{MAX} ($p > 0.05$ for all dependent variables). Simultaneous lower- and upper-body IPC led to a significant decrease in the time to peak power during the 500 m ergometer rowing trial in females but not in males. Additionally, no significant effects on the time or other power output variables, HR, or BLa concentration were registered.

Keywords: blood flow restriction; occlusion; power output; sex-specific

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1. Introduction

Ischemic preconditioning (IPC) is considered a simple training intervention that may acutely improve subsequent athletic performance. IPC comprises inducing ischemia (or multiple cycles) prior to exercise by applying compression cuffs at the maximal proximal part of a limb. The supposed mechanisms underlying the enhancements in exercise capacity following IPC include greater metabolic efficiency [1,2], increased blood flow [3], and higher neural activation [4]. In the majority of studies examining ischemia [5–8], IPC is applied to either the upper or lower limbs (depending on which limbs are used predominantly in the subsequent exercise). Standard IPC protocols frequently consist of three to four 5 min cycles, necessitating a lengthy preconditioning period prior to exercise execution. To the best of the author's knowledge, only one study to date has examined the impact of a single IPC cycle on exercise performance [7]. A recent study by Salagas et al. [7] revealed that a single 5 min application of IPC to the upper limbs was sufficient to increase barbell velocity during a bench press exercise. Furthermore, probably no studies have investigated the effects of simultaneous IPC application to both the upper and lower limbs, despite there being research confirming the effects of IPC on exercises involving both the upper and lower limbs [9]. The simultaneous application of IPC to the upper and lower extremities could theoretically provide a strong stimulus in a brief period of time, thereby potentially shortening the duration of IPC procedures.

The influence of sex on the ergogenic effects of IPC is a factor that has not been investigated extensively. This is especially important considering that females may have a greater proportion of type I muscle fibers [10,11] and a greater capacity to utilize their aerobic metabolism than males [12]. In fact, a study by Paradis-Deschenes et al. [13] revealed that males experienced a larger increase in force production during maximal voluntary knee extensions than females. In accordance with this, a recent study by Teixeira et al. [14] found that IPC increased sympatholysis during handgrip exercise in males but not in females. This indicates that the ergogenic effects of IPC may be sex-specific. However, there are insufficient studies involving representative female groups on this topic to derive definitive conclusions. Therefore, more research, focusing on both male and female participants, is required to better comprehend any potential sex-related differences in the response to IPC and its overall ergogenic effect.

Overall, studies on IPC show performance enhancement in a variety of exercises. Bailey et al. [15], for example, demonstrated an improvement in a 5 km running time trial in healthy males after IPC. The authors also observed that IPC was associated with a decreased rise in blood lactate (BLa) concentration, indicating that IPC enables greater work rates and consequently improves time trial performance. Similarly, Bellini et al. [16] found increased time to exhaustion in arm-crank tests after IPC in recreationally active males compared to a control condition. In addition, there were no significant differences in heart rate (HR) or BLa concentration between the conditions. Consequently, it appears that the ergogenic effects of IPC are meaningful in both upper- and lower-body exercises. Under the protocols of these studies, IPC was applied to the extremities that were engaged in the subsequent exercise. It is important to note, however, that the influence of IPC on efficacy in whole-body exercises has received little attention. Turnes et al. [9] did not observe an enhancement in trained rowers' 2000 m rowing test time after IPC was applied to the thighs. On the other hand, Kjeld et al. [17] reported a slight 1000 m rowing performance improvement following upper-body IPC. The authors of those studies applied IPC solely to either the lower or upper extremities, although during rowing, the quadriceps, forearms, biceps, and lats are highly active. In such instances, a combined lower- and upper-body IPC approach may be required. Furthermore, this difference in results may suggest that the IPC effect is also dependent on the duration of the effort and more pronounced during shorter-duration efforts. Additionally, research is scarce on this topic regarding a distance of 500 m, representing a quarter of the distance in competitions; however, training sessions and testing at this distance are considerably more frequent [18]. To the best of the author's knowledge, however, there are no studies that examine the effects of simultaneous lower- and upper-body IPC on whole-body exercise performance, like rowing. To investigate the possible advantages of this method, additional research is required in this field.

Considering the insufficient knowledge on sex-specific responses to IPC and the lack of studies examining the effect of simultaneous lower and upper-limb IPC on athletic performance, the aim of this study was to determine the impact of simultaneous upper- and lower-body IPC on 500 m rowing ergometer test performance, as well as its effects on HR and BLa concentrations in recreationally active males and females. It was hypothesized that IPC would enhance rowing performance via decreased time and greater power output in both sexes, but with a greater magnitude in males than in females.

2. Materials and Methods

2.1. Experimental Approach to a Problem

The experiment was performed following a single-blind, randomized cross-over design where IPC and SHAM were used as preconditioning. This setup aimed to investigate the effects of a particular session on 500 m rowing performance (time, relative peak power—RPP, relative mean power—RMP, time to peak power—TPP, BLa, and HR) among physically active males and females.

After the standardized warm-up, either the IPC or SHAM protocol was applied to the upper and lower limbs simultaneously for 5 min with a pressure of 220 mmHg for the IPC condition or 20 mmHg for the SHAM condition. Then, after 5 min of reperfusion, participants performed an all-out 500 m rowing trial. During rowing, HR was recorded, and after the completion of the rowing, a blood sample from a finger stick was obtained to determine the BLa concentration (Figure 1).

Figure 1. Schematic representation of the experimental design. SHAM—sham condition; IPC—ischemia preconditioning condition; BLa—blood lactate.

2.2. Subjects

Forty-three healthy participants took part in this study (24 males: 20 ± 1 years, 182 ± 6 cm, 79.6 ± 8.4 kg; and 19 females: 20 ± 1 years, 166.7 ± 5.5 cm, 62.7 ± 8 kg). Participants were recreationally active (≥60 min of moderate-intensity exercise at least 3 times per week, self-reported) and experienced in ergometer rowing but not specifically trained. The experimental procedure was approved by the Bioethics Committee for Scientific Research according to the ethical standards of the latest version of the Declaration of Helsinki, 2013. All participants provided written informed consent for study participation. The sample size was calculated a priori based on a statistical power of 0.9, a repeated measures ANOVA, within–between interaction, an effect size $d = 0.58$, and a significance level of 0.05, taking rowing time as a reference variable [16]. A minimum sample size of 34 individuals was determined (G*Power [version 3.1.9.2], Dusseldorf, Germany). Considering a potential dropout rate of 20%, we aimed to recruit around 41 participants.

2.3. Experimental Session

Participants were required to attend the laboratory for two sessions over a two-week period, and tests were interspersed with a week of recovery. Each participant was tested at the same time of day to minimize the effect of diurnal variation (±2 h) in a temperature-controlled environment (approximately ~21 °C). After the same warm-up, participants took part in IPC and SHAM conditions in a random order. Sessions were separated by a week of recovery. During both conditions, nylon, non-elastic cuffs (FitCuffs®, Odder, Denmark) were simultaneously applied to the most proximal parts of the lower (cuff width 10.5 cm) and upper limbs (cuff width 7.5 cm) for 5 min, but they differed in pressure: 220 mmHg for the IPC condition or 20 mmHg for the SHAM condition. After a 5 min rest interval following the IPC/SHAM application, the 500 m rowing test started. Both tests were performed on a commercially available air-braked indoor rowing ergometer (Concept 2E, Morrisville, VT, USA). The time to complete the test, TPP, RPP, and RMP were recorded using the manufacturer's application (ErgData, V1.4.4® app; Concept2, Morrisville, VT, USA) downloaded from an account created at https://log.concept2.com/, accessed on

17 July 2023. The foot position on the ergometer was individually adjusted for comfort, and these settings were replicated for subsequent visits. Once the participant was ready, the test started. Participants were instructed to perform the test in an all-out manner and were verbally encouraged but were blinded to all performance feedback.

2.3.1. Heart Rate Measurement

Moreover, HR (i.e., average after warm-up, average, and maximum during rowing) during the rowing was measured by using a Polar H10 heart rate monitor (Polar, Finland). Before being attached to the participants, the electrodes on the back of the Polar H10 chest strap were moistened with room-temperature water. The HR sensor was then positioned on the xiphoid process of the sternum, and the chest strap was then adjusted to the participant's chest, just below the chest muscles.

2.3.2. Blood Lactate Measurement

To determine BLa concentration, capillary blood samples obtained from a finger stick were analyzed using a reliable [19] Lactate Scout 4 Analyzer (EKF Diagnostics, Barleben, Germany) approximately 2 min after the completion of the test. The measurements were carried out by the same experienced researcher.

2.4. Statistical Analysis

All data were analyzed using IBM SPSS Statistics for Macintosh, Version 25.0 (IBM Corp., Armonk, NY, USA) and shown as means with standard deviations (±SD) with their 95% confidence intervals (CIs). Statistical significance was set at $p < 0.05$. The normality of the data distribution, the assumption of variance homogeneity, and the assumption of variance sphericity were verified using Shapiro–Wilk, Levene's, and Mauchly's tests, respectively. Repeated measures ANOVAs (2 groups [males; females] × 2 conditions [SHAM; IPC]) were used to investigate the influence of IPC on the following dependent variables: rowing performance, BLa concentrations, and HR. When a significant interaction or main effect was found, post hoc tests with the Bonferroni correction were used to analyze the pairwise comparisons. Furthermore, because the data distribution in TPP was not normal, the Wilcoxon signed-rank test was employed to assess the impact of sex. The magnitude of mean differences was expressed as a standardized effect size. The thresholds for the qualitative descriptors of Cohen's d were interpreted as <0.20—"trivial", 0.2–0.49—"small", 0.5–0.79—"moderate", and >0.8—"large".

3. Results

No significant interactions (groups × conditions) were observed for rowing time ($F = 2.583$; $p = 0.116$), BLa ($F = 1.172$; $p = 0.285$), RPP ($F = 0.503$; $p = 0.482$), RMP ($F = 0.509$; $p = 0.48$), HR_{WP} ($F = 0.295$; $p = 0.59$), HR_{MEAN} ($F = 0.313$; $p = 0.579$), or HR_{MAX} ($F = 0.16$; $p = 0.691$) (Figures 2 and 3).

Similarly, no significant main effect of the condition was found for rowing time ($F = 3.482$; $p = 0.069$), BLa ($F = 1.152$; $p = 0.289$), RPP ($F = 1.383$; $p = 0.246$), RMP ($F = 2.378$; $p = 0.131$), HR_{WP} ($F = 0.047$; $p = 0.829$), HR_{MEAN} ($F = 0.012$; $p = 0.912$), or HR_{MAX} ($F = 0.105$; $p = 0.748$).

However, the group main effect showed a significant difference in rowing time ($F = 146.72$; $p < 0.001$), with shorter times observed among males compared to females. Additionally, males exhibited higher levels of BLa ($F = 27.013$; $p < 0.001$), RPP ($F = 70.701$; $p < 0.001$), and RMP ($F = 97.49$; $p < 0.001$) compared to females (Table 1). No significant main effects were revealed for HR_{WP} ($F = 0.295$; $p = 0.59$), HR_{MEAN} ($F = 0.681$; $p = 0.414$), or HR_{MAX} ($F = 4.012$; $p = 0.052$).

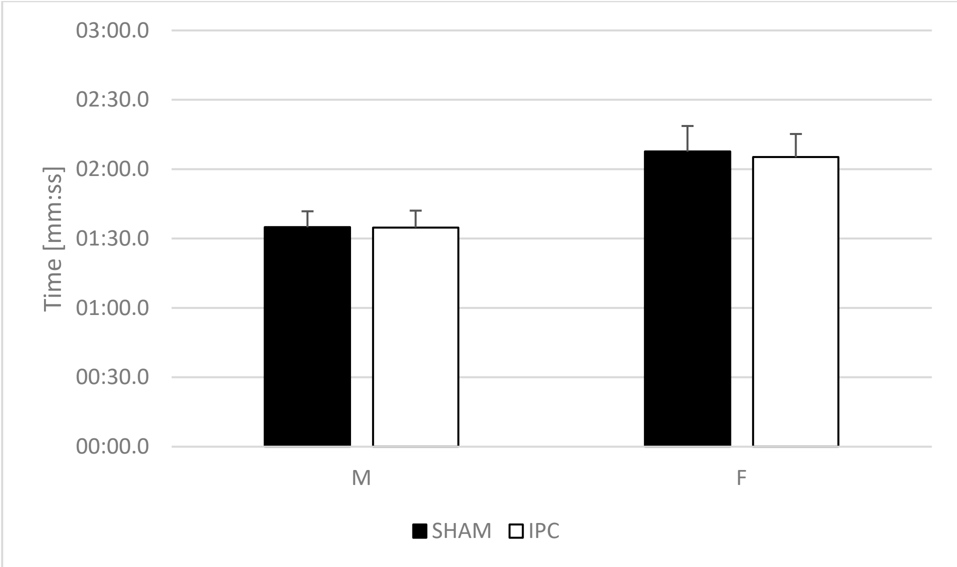

Figure 2. Comparison of 500 m rowing time in sham and ischemia preconditioning conditions. SHAM—sham condition; IPC—ischemia preconditioning condition; M—males; F—females.

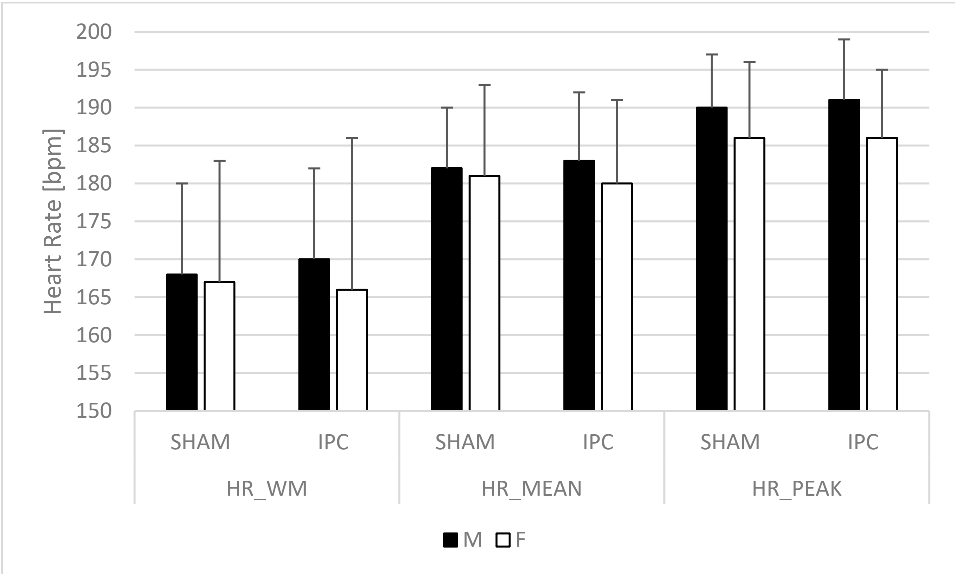

Figure 3. Comparison of heart rate values in sham and ischemia preconditioning conditions. SHAM—sham condition; IPC—ischemia preconditioning condition; HR_WM—heart rate after warm-up; HR_MEAN—mean heart rate recorded during 500 m rowing; HR_PEAK—maximum heart rate recorded during 500 m rowing; M—males; F—females.

Table 1. Comparison of blood lactate concentration, relative power output values, and time to achieve peak power output in sham and ischemia preconditioning conditions.

	M (95%CI)	**F (95%CI)**
	Blood Lactate Concentration [mmol/L]	
SHAM	19.4 ± 2.7 (18.3 to 20.6)	15.7 ± 4.2 (13.7 to 17.7)
IPC	19.5 ± 1.9 (18.6 to 20.3)	14.7 ± 3.3 (13.1 to 16.3)

Table 1. *Cont.*

	M (95%CI)	F (95%CI)
d	0.04	0.26
Relative Peak Power Output [W/kg]		
SHAM	6.5 ± 1.4 (6.0 to 7.1)	3.8 ± 1.1 (3.3 to 4.3)
IPC	6.8 ± 1.1 (6.3 to 7.2)	3.8 ± 1 (3.4 to 4.3)
d	0.16	0
Relative Mean Power Output [W/kg]		
SHAM	5.3 ± 0.8 (4.9 to 5.6)	2.8 ± 0.7 (2.5 to 3.2)
IPC	5.3 ± 0.9 (4.9 to 5.7)	3.0 ± 0.7 (2.6 to 3.3)
d	0	0.29
Time to Peak Power Output [s] (Median; IQR)		
SHAM	23.9 ± 25.3 (13.2 to 34.6; [12.4; 16])	25.3 ± 27.8 (13.2 to 34.6; [16; 15])
IPC	17.3 ± 24.6 (6.9 to 27.7; [9.9; 20.8])	11.2 ± 29.7 * (−3.1 to 25.5; [1; 1.5])
d	0.26	0.49

M—males; F—females; CI—confidence interval; SHAM—sham condition; IPC—ischemia preconditioning condition; *d*—Cohen effect size; IQR—interquartile range. * significant difference between conditions.

Wilcoxon's signed-rank test showed a significantly shorter TPP in the SHAM compared to the IPC condition for females (Z = 2.415, $p = 0.017$), but not for males (Z = 1.914, $p = 0.056$).

4. Discussion

The objective of this study was to investigate whether IPC acutely enhances 500 m rowing performance while having no effect on HR and BLa levels, with a potentially larger improvement in females compared to males. The main finding of this study was that the combined IPC intervention had no significant effect on 500 m rowing performance (time, peak and mean power output). Furthermore, the IPC protocol applied did not have a significant impact on BLa concentration and HR in the studied groups. Across all the measured variables, IPC significantly shortened the TPP in the females' group but not in the males.

Recent studies suggest that the ergogenic effects of IPC may be sex-specific and related to differences in female and male metabolism during exercise [20–23]. Green et al. [20], Maher et al. [21], and Hunter [22] revealed sex differences in total muscle fiber mass and type, as well as skeletal muscle energy metabolism. However, to the best of the author's knowledge, this is one of the few studies that have investigated the sex-specific effects of IPC [13,14,24]. From all the studied variables in the current study related to 500 m rowing performance, IPC solely led to a reduction in TPP exclusively in the female group. This finding partially contradicts recent reports indicating either no effects of IPC on the subsequent performance of female participants [24] or, if present, greater benefits in males than in females [13]. Paradis-Deschenes et al. [13] showed that during five sets of five maximal voluntary knee extensions, males demonstrated greater increases in the overall generated force than females. Moreover, Gibson et al. [24] reported no effects of IPC on repeated sprint cycling (5 × 6 s) in female as well as male team sport athletes.

The reason for this discrepancy may lie in the differences in the applied protocols across studies, particularly in the number of IPC cycles, reperfusion time, and muscle groups targeted by IPC. Paradis-Deschênes et al. [13] employed three cycles of 5 min with

18.5 min of reperfusion before the subsequent task, while Gibson et al. [24] used a similar protocol but with 11 min of reperfusion. In contrast, in this study, a single 5 min cycle with 5 min of reperfusion was applied. Such brief IPC has been revealed to be effective in a recent study conducted by Salagas et al. [7]. The authors showed that a single 5 min application of IPC to the upper limbs was sufficient to increase barbell velocity during 12 s of bench presses followed by 5 min of reperfusion in males. Moreover, it has to be mentioned that in this study, IPC was applied to both the upper and lower limbs, whereas in the aforementioned studies, it was exclusively applied to the limbs involved in the task. This could suggest that, for females, a brief IPC stimulus with short reperfusion should be used to enhance short-duration, high-intensity exercise. Additionally, in this study, the TPP also decreased in the male participants after IPC; however, this difference did not reach statistical significance (small effect size $d = 0.26$). Therefore, the simultaneous application of IPC to both the upper and lower limbs could potentially be a time-efficient method of reaping the benefits of ischemia, but its effectiveness may be limited to short-duration efforts, with a greater effect observed in females. Nevertheless, the 500 m rowing time, which would be the most relevant metric for individuals aiming to enhance their athletic performance, did not change.

This study found that IPC had no significant effect on HR or BLa concentration. The lack of effect on HR following IPC is consistent with the majority of previous reports [6]. Cruz et al. [4] found no effect of IPC on peak HR during maximal constant load cycling, comparable to Griffin et al. [25] and Mota et al. [26] during 3 min sprint cycling and 3 min sprint arm cycling, respectively. Therefore, it appears that IPC has no effect on HR, and there is no evidence that the ergogenic effect of IPC is related to its effect on the cardiovascular response. Similarly, the absence of a substantial impact on BLa concentration observed in this investigation is consistent with a recent literature review by O'Brien and Jacobs [6]. The authors indicated that the overwhelming majority of studies (34 out of 43 included in their review) found no significant changes in BLa concentration following IPC. Specifically, Ferreira et al. [27] found no difference in BLa concentrations between IPC and SHAM conditions after a repetitive sprint swimming protocol. In contrast, Gibson et al. [24] demonstrated a reduction in BLa concentration following IPC relative to placebo and control conditions, but only in female participants and not in males. In addition, Kraus et al. [28] revealed that IPC had no effect on BLa concentrations compared to the SHAM condition; however, they investigated remote IPC (upper body, prior to a Wingate cycling test). Despite the results of this study showing no effect of IPC on the concentration of BLa, a consistent trend in its reduction could be seen in females ($d = 0.26$). Consequently, it appears that additional studies are necessary to comprehend the impact of IPC in modulating BLa concentration responses during exercise, particularly in female participants. Females have a greater capacity for oxidative metabolism utilization than males [12,23,29], which could potentially challenge the ergogenic effect of IPC; however, sex-specific responses have been found only in the TPP within this study. This suggests that IPC might shift metabolism towards anaerobic pathways, resulting in a shorter time being needed to obtain peak power output in females. Existing findings indicate that IPC enhances exercises utilizing distinct energy pathways [30,31]; however, direct comparisons of the effects of IPC on various types of exercises (phosphagen vs. glycolytic vs. oxidative) in male and female populations are lacking. The available evidence suggests that sex-specific responses to IPC may exist, and additional research with larger and well-controlled female cohorts is required to completely elucidate the potential effects of IPC on the performance and metabolic responses of female participants.

Several limitations of this study should be considered. The procedure of this study tested only one IPC protocol, i.e., 5 min at 220 mmHg, applied simultaneously to the lower and upper limbs, while the vast majority of studies used upper- or lower-body-only IPC, often employing multiple cycles. Moreover, although we tested both physically active males and females, these were not highly trained participants; therefore, we cannot extrapolate our findings to elite athletes. Additionally, our evaluation solely focused on

500 m rowing performance, leaving the impact of simultaneous upper- and lower-limb IPC on other exercise types unexplored. This underscores the need for further investigations specifically targeting female cohorts, scrutinizing diverse IPC protocols and their effects on various performance dimensions.

Building upon the foregoing, future research should pivot towards discerning the impact of IPC under varied ischemic conditions (different exposure times and cuff pressures) and intervals between exposure and the onset of exercise or testing. The efficacy of a singular exposure versus repeated IPC remains ambiguous. Also, subsequent studies should be conducted among elite athletes, as they stand to potentially benefit from this methodology.

5. Practical Implications

The findings of the current study suggest that the simultaneous application of upper- and lower-body IPC resulted in a significant reduction in time to peak power output among females, while no such effect was observed in males. Additionally, no significant differences were noted in time or the peak and mean power output between the SHAM and IPC conditions across the sexes. Therefore, coaches and practitioners may consider utilizing a single simultaneous upper- and lower-body 5 min cycle of IPC at 220 mmHg before all-out efforts to shorten the time to peak power output, specifically in females. This may prove beneficial, particularly in training phases aimed at improving power production. Despite the lack of performance enhancement in 500 m rowing, it is worth noting that IPC may still induce additional training stimuli, potentially enhancing physiological responses. Nevertheless, more studies that include thorough physiological evaluations are necessary to properly comprehend the effects of IPC conditions on athletic performance.

6. Conclusions

To the best of the author's knowledge, this is the first study to investigate the simultaneous application of upper- and lower-body IPC on rowing performance. The results of this study suggest limited potential for the applied IPC protocol to enhance short-term endurance capacity. Specifically, simultaneous lower- and upper-body IPC (5 min at 220 mmHg) led to a significant decrease in the time to peak power during 500 m ergometer rowing in females but not in males. Moreover, there were no significant effects on time, relative peak and mean power output, HR, or BLa concentration for both physically active males and females.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

SHAM	sham condition
IPC	ischemia preconditioning condition
RPP	relative peak power output
MPP	relative mean power output

TPP	time to peak power
BLa	blood lactate
HR_{WP}	heart rate after warm-up
HR_{MEAN}	mean heart rate recorded during 500 m rowing
HR_{MAX}	maximum heart rate recorded during 500 m rowing
M	males
F	females

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