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Original Research Article

The Effect of Ischemic Preconditioning on Performance and Recovery during Repeated Supramaximal Cycling Bouts

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Abstract

Introduction: Ischemic preconditioning (IPC), a process of cyclically occluding and reperfusing blood to tissue, has been shown to preserve ATP, prolong vasodilation, and enhance exercise performance. **Purpose:** The aim of this study was to test the effects of IPC on repeated supramaximal cycling performance and recovery in 12 experienced cyclists. **Methods:** In a randomized, double-blind, placebo controlled, cross-over design, subjects received a 4 x 5 min bilateral leg IPC treatment then performed a supramaximal cycling trial, followed by a 20 min passive recovery, then repeated the identical trial and recovery again. Time to fatigue (TTF) for each trial was measured as well as blood lactate (La^-) and pH at minute 0, 5, 10, 15, and 20 during the passive recovery. **Results:** No significant effect was found for IPC on TTF for trial A ($p>.05$) and trial B ($p>.05$), however a great amount of individual variability was observed. No significant effect was found for IPC on the amount of La^- and pH recovery for trial A ($p>.05$) and B ($p>.05$). A significant effect was found earlier on the rate of La^- recovery in the IPC condition compared to placebo in both trial A ($p<.05$) and trial B ($p<.05$). **Conclusion:** These results suggest there is no effect of IPC on repeated supramaximal cycling performance, nor the amount of blood lactate or pH recovery, however, IPC does have an effect on the rate of blood lactate recovery.

Key Words: Cycling Performance, Ergogenic Aid, Lactate, Metabolic Acidosis, pH

Introduction

The ability to recovery quickly is critical if subsequent bouts of intense exercise are to be performed. In competitive cycling, these high-intensity exercise bouts come into play in critical phases such as closing gaps, short climbs at all-out speed, finish sprints, or time trials[1]. This high-intensity exercise is made possible by the non-oxidative conversion of carbohydrates into adenosine triphosphate (ATP), the body's energy molecule. This process is called fast glycolysis. An individual's capacity for anaerobic glycolysis can best be measured by an accumulated oxygen deficit (AOD) test[2]. Alongside the product of ATP, glycolysis also produces

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hydrogen ions (H^+), which are mostly removed from the cell during corresponding oxidative processes[3]. However, once the body's demand for ATP exceeds that of its H^+ removal capacity, the H^+ begin to concentrate, leading to decreases in blood and muscle pH, known as metabolic acidosis. This acidosis slows the enzymatic activity controlling the production rate of ATP which is thought to be a major player contributing to skeletal muscle fatigue[4]. A parallel glycolytic product to H^+ is pyruvate, which like H^+, is mostly consumed by the corresponding oxidative processes. Again, as the body's demand for ATP exceeds oxidative removal capacity, pyruvate is then converted to lactate and used elsewhere in the body. The presence of lactate found in the blood, as well as reduced blood pH, are indicators of high glycolytic flux[3]. The capability to sustain high-intensity exercise depends largely on the body's ability to minimize H^+ accumulation to maintain normal pH, [4]. There seems to be reasonable consensus that increases in muscle blood flow facilitate the elimination of H^+ and lactate and therefore improve recovery[5-8]. Exercise scientists exploring ways to enhance performance and recovery, have tested a procedure called ischemic preconditioning (IPC) as it has been shown to increase blood flow in ischemic tissue and preserve favorable pH[9-11].

IPC is the process of cyclically occluding and reperfusing blood to bodily tissue for brief periods of time[11]. It has been shown that IPC preserves cellular ATP, increases collateral blood flow, and enhances vasodilatory mechanisms during prolonged ischemia[10,12-14]. Although the mechanisms responsible for these actions are still under investigation, this procedure has captured the interest of exercise scientists as a novel intervention to enhance performance. Research exploring the effects of IPC on human performance have shown increases in maximal oxygen uptake (VO_{2max}), improvement in time-trial completion, increases in time to fatigue, increases in lactate removal, and increases in mean power output[15-19]. Conversely, studies have also shown no effect of IPC on repeated sprint and submaximal performance[20-23]. While the evidence is still being consolidated, the current results seem to rely on the oxidative energy pathways and a possible increase in central neural drive[24]. Meanwhile, no research has explored the effects of IPC on exercise recovery or blood pH kinetics during high intensity exercise. With the increases in H^+ and lactate removal as a result of enhanced muscular blood flow shown in previous research, one would question if the vascular functions resulting from IPC would have a positive effect on exercise recovery as well as H^+ and lactate removal.

In addition to cycling, exercise recovery is essential for other sports that require multiple bouts of high intensity output, such as ski mountaineering, soccer and hockey, to maintain performance. Understanding the recovery kinetics of blood pH and possible interventions to improve metabolic acidosis would benefit those looking for the

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competitive advantage. Therefore, the objective of this study was to examine the effect of IPC on time to fatigue and VO_2 during repeated supramaximal cycling bouts as well as observe blood pH and lactate change during subsequent passive recovery periods in experienced cyclists. Given the apparent ability of IPC to improve blood flow, it was hypothesized that it would improve cycling performance by reducing the time to fatigue and improve recovery by enhancing blood pH kinetics.

Methods

Participants

In a randomized, double-blind, crossover study, 12 healthy, recreational and elite cyclists (men and women, ages 20-48 yr) volunteered to participate (See Table 1). Subjects were naïve to the effect of IPC on exercise performance and were not informed about the rationale of the study. All subjects were acclimatized to 2350 meters, the location of the performance laboratory. They were fully informed of all procedures and associated risks before completing an informed consent, medical history questionnaire and physical activity readiness questionnaire (PAR-Q). Approval for the human research was granted by Western State Colorado University's Human Research Committee, which conforms to the Declaration of Helsinki.

Table 1. Participant anthropometric data: presented as mean ± (SD).

	Height (cm)	Weight (kg)	Age (yr)	VO_{2max} (mL·kg·min)
Male (n=7)	183 (6.0)	81.5 (7.3)	32.3 (13.0)	53.2 (5.0)
Female (n=5)	165 (7.8)	59.5 (6.2)	33.4 (9.5)	45.6 (2.4)

All subjects were acclimatized and tested to an altitude of 2350 meters. Centimeters (cm). Kilograms (kg). Years (yr). Milliliters per kilogram per minute (mL·kg·min).

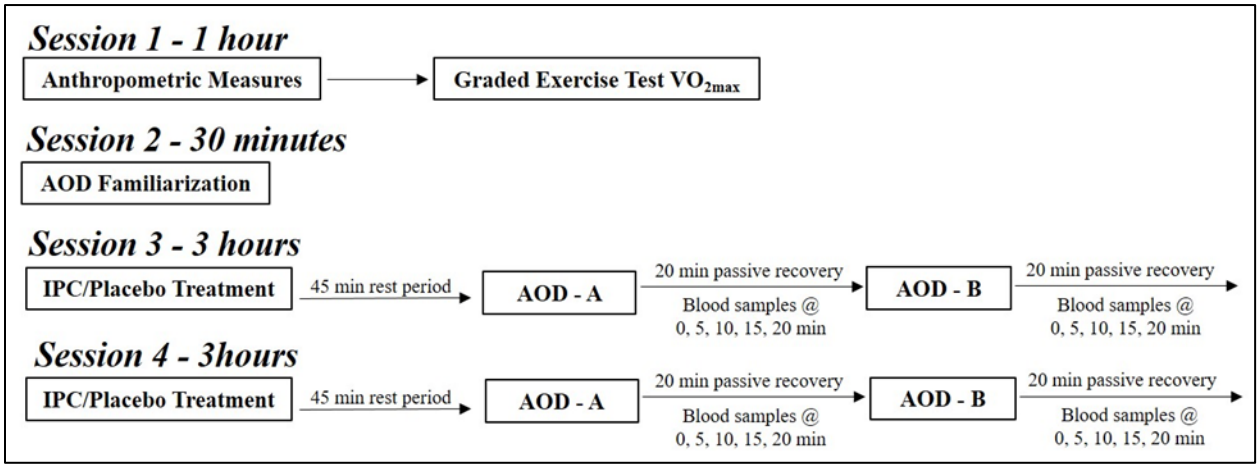

Figure 1. Experimental Flow Chart. Maximal oxygen uptake (VO_{2max}), accumulated oxygen deficit (AOD), ischemic preconditioning (IPC). Sessions 3 and 4 are 1-2 weeks apart for males and 4 weeks apart for females.

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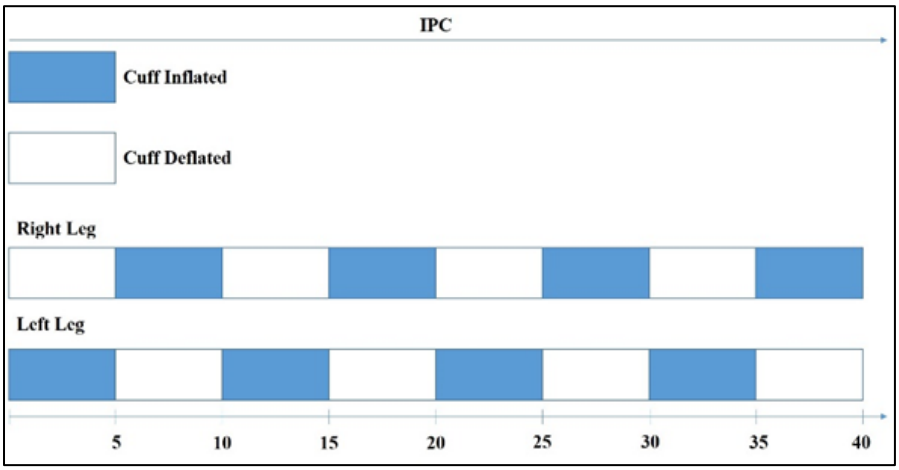

Figure 2. IPC treatment or placebo. Ischemic preconditioning (IPC). Shaded boxes represent 5 minutes of occlusion and unshaded boxes represent 5 minutes of reperfusion.

Experimental Design

Subjects reported to the laboratory for 4 sessions over the course of 8 weeks. Session 1 consisted of anthropometric measures and an incremental exercise test on an electro-dynamically braked cycle ergometer (Lode Excalibur Sport, Groningen, the Netherlands) to calculate peak oxygen uptake (VO_{2max}) and maximum power (MP). 48 hours or later, subjects returned for session 2 consisting of a familiarization with the AOD protocol and passive recovery. Session 3 consisted of the randomized IPC or placebo IPC treatment, 45 minutes of rest, and two AOD tests with subsequent 20-minute passive recovery periods. Time to fatigue (TTF) was recorded after each AOD test as well as blood samples were taken by fingerprick at minute 0, 5, 10, 15 and 20 throughout the recovery period and analyzed for blood pH (pH) and lactate (La^-) concentration. During all tests, subjects were verbally encouraged to give their best efforts and blinded to the elapsed time. Lead researcher and subjects were blinded to assignment of IPC or placebo IPC. Session 4 was a replication of session 3 in a counterbalanced manner of the IPC or placebo IPC treatment (See Figure 1).

Cycling Test Procedures

All cycling tests were performed on an electro-dynamically braked cycle ergometer (Lode Excalibur Sport, Groningen, the Netherlands) and commenced at the same time of the same day of the week. Settings for the bicycle were replicated for each test. The graded exercise VO_{2max} test consisted of a 5-minute warm-up at 50 watts (W) followed by an increase in power by 20W per minute for females 30W per minute for males, until cadence fell below 40rpm. For the assessment of metabolic parameters, breath-by-breath VO_2 (Oxycon Mobile metabolic system, CareFusion Respiratory Care, Yorba Linda, CA) and heart rate (Polar F1 heart rate monitor, Polar USA, Warminster, PA) were continuously registered

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during the VO_{2max} tests. The AOD protocol began with a warm up of 50W for eight minutes, then two minutes of unloaded pedaling at 0W. Immediately thereafter, 110% of MP was applied and subjects pedaled until they could no longer maintain a cadence of 40rpm. TTF was recorded at the point the subject reached 40rpm.

Ischemic Preconditioning

IPC was performed in the supine position. The occlusion cuffs were placed proximally around the upper thigh and inflated to 220mmHg for five minutes. The cuff was then removed for a five minute period of reperfusion and placed on the other thigh and inflated to 220mmHg. This procedure was repeated four times totaling 40 minutes (See figure 2). During the placebo IPC condition, subjects followed the same protocol, but instead the cuff was inflated to 40mmHg. Subjects rested passively at end of this procedure for 45 minutes before the exercise tests. Subjects could read or do computer work during this passive rest period.

Recovery and blood sampling

Following the IPC/placebo IPC treatment and 45-minute passive rest, subjects performed AOD 1. Immediately after, subjects passively recovered in a chair directly next to the cycle ergometer for 20 minutes. Fingerprick blood samples were taken from a hyperemic fingertip at minute 0, 5, 10, 15, and 20. Blood samples were collected in a capillary tube and immediately analyzed for pH (Radiometer, ABL80 Co-Ox, La Brea, CA) and La^- concentration (Lactate Plus, www.lactate.com). Once the recovery period was finished, subjects performed AOD 2 replicating the exact protocol as the first one. Upon cessation, the identical 20-minute passive recovery protocol, pH and La^- measures were taken. Men performed session 3 and 4 with counterbalanced treatments one or two weeks apart. Women performed them four weeks apart to ensure identical menstrual cycle phases for each test.

Statistical analyses

Measurements were analyzed using the Statistical Package for the Social Sciences, Version 23.0 (IBM Corporation, Armonk, NY). All variables were initially checked for normality using the Kolmogorov-Smirnov test. Measures of centrality and spread are presented as frequency and mean ± standard deviation (SD) and 95% confidence intervals (CI). A within subject coefficient of variability (CV) criterion was used to calculate test-to-test variability (±15.8%)[25]. Delta values (Δ) were calculated (IPC value minus placebo value divided by placebo value) for percent change in time to fatigue and participants were categorized as responders (%Δ > 15.8%), non-responders (%Δ within ± 15.8%), or adverse responders (%Δ > -15.8%) to the IPC treatment. Differences in La^- and pH over recovery time, were assessed using one-way repeated measures ANOVA. Differences in TTF, La^- and pH between the intervention and control over recovery time were analyzed using two-way repeated measures ANOVA. When a significant f-value was observed in the ANOVA, post-hoc tests with Bonferroni's correction were used to identify differences. Effect sizes (ES) were also

calculated using means and pooled SD. The alpha level of statistical significance was set at $p < 0.05$ for all analyses.

Results

Time to Fatigue

Treatment and testing was well tolerated among all subjects with a total of 11 out of 12 subjects completing the entire experiment, due to 1 schedule conflict. No significant main effect of trial on TTF ($p > .05$) and treatment on TTF ($p > .05$) was found nor an interaction of trial and treatment on TTF ($p > .05$). Performance was similar across trial A with and without the IPC treatment (See Table 2). A greater reduction in performance was observed in trial B after IPC treatment than without, but no statistical significance was found ($p > .05$). Mean and individual responses for TTF for each trial between IPC treatment and placebo are represented in Figure 3. Individual performance responses to IPC varied greatly and the categorization of responsiveness is displayed in Figure 3 and 4.

Table 2. Time to fatigue (TTF) performance in seconds (sec).

	Trial A	Trial B	Change A to B
TTF Placebo (n=11)	128.8 (27.8)	126.3 (26.9)	-2.5 (15.2)
TTF IPC (n=11)	129.9 (18.6)	116.6 (20.2)	-13.3 (18.4)

Data are reported as mean (SD). Ischemic preconditioning (IPC).

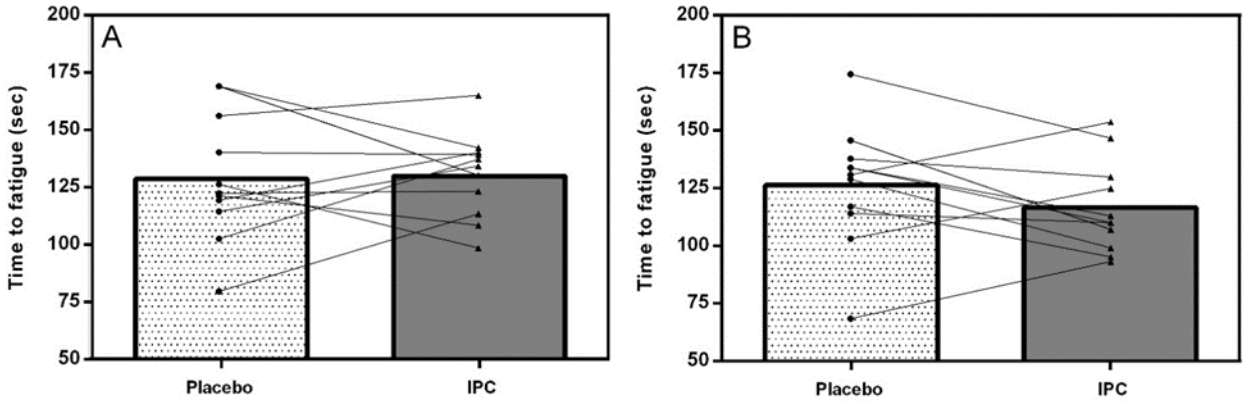

Figure 3. Time to fatigue (TTF) mean responses for placebo and ischemic preconditioning (IPC) treatments for each trial are represented by solid bars. TTF individual responses for placebo in both trials are indicated by circles and IPC treatment TTF responses are indicated by triangles. Mean responses show no significant change in performance with IPC treatment, although individual responses vary greatly.

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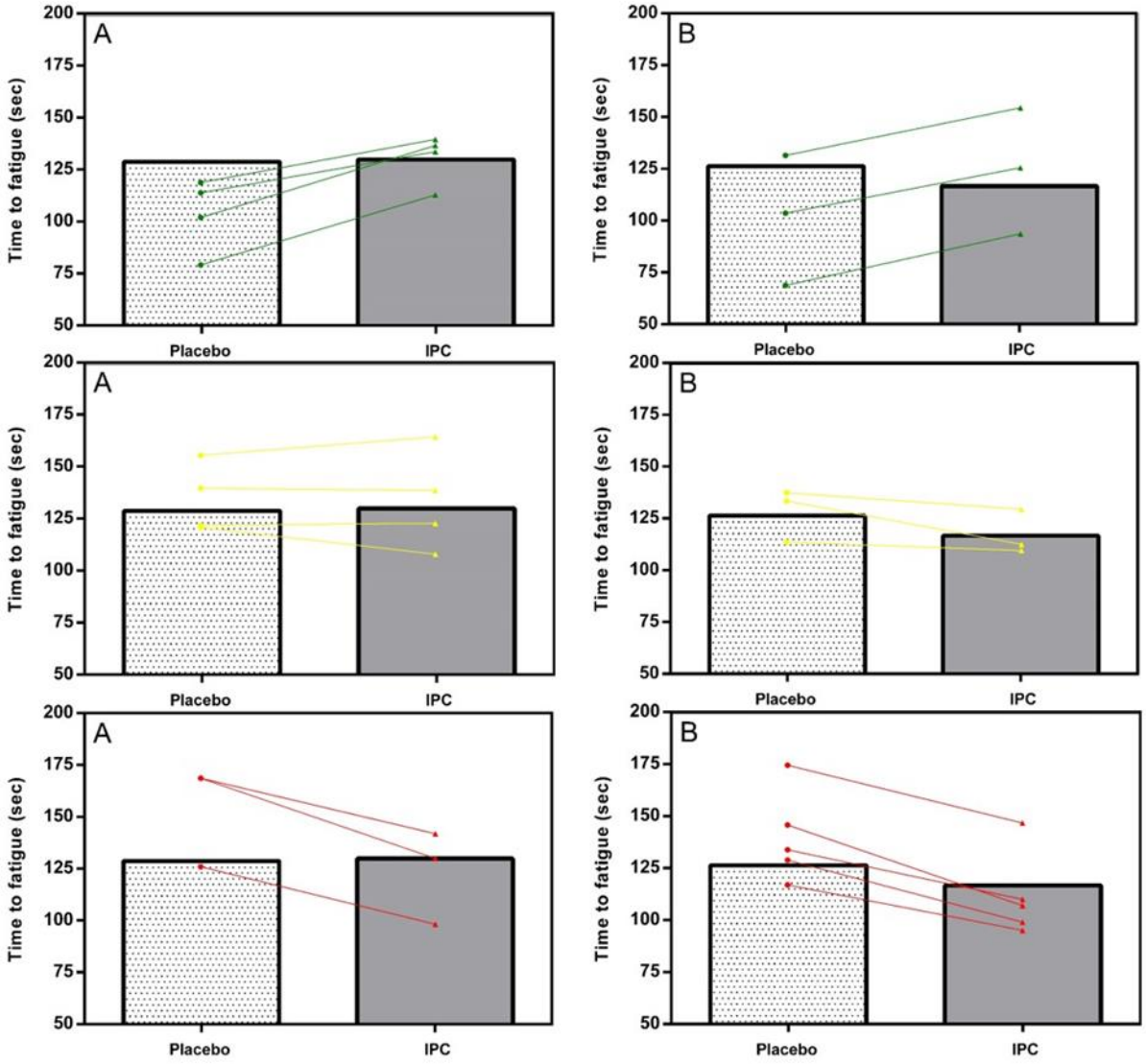

Figure 4. Time to fatigue (TTF) individual responses to ischemic preconditioning (IPC) split into responders (top), non-responders (middle), and adverse responders (bottom) for trial A and B. Mean responses for placebo and IPC treatments for each trial are represented by solid bars. Mean responses show no significant change in performance with IPC treatment, although individual responses vary greatly.

Blood Lactate Recovery

No main effect was found for treatment on the amount of La^- recovery for both trials ($p > .05$) nor interaction of treatment and time point on the amount of La^- recovery for both trials ($p > .05$) (See Table 3). Significant main effects of time point during recovery on La^- were found for placebo trials A and B ($p < .05$, ES .88, .90) as well as IPC trials A and B ($p < .05$, ES .86, .86). La^- was significantly reduced earlier during recovery with IPC than without in both trials (See Figure 5). Results from post-hoc pairwise comparisons are illustrated on Figure 5.

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Table 3. Passive recovery blood lactate means (±SD) for each time point for both trial A and B following placebo and ischemic preconditioning (IPC) treatment.

	0 min	5 min	10 min	15 min	20 min
Placebo Trial A (n=12)	10.8 (2.1)	9.8 (2.1)	8.1 (2.0)	6.8 (1.8)	5.6 (1.4)
Placebo Trial B (n=12)	10.3 (2.5)	9.7 (2.7)	7.8 (2.5)	6.4 (2.1)	5.4 (1.8)
IPC Trial A (n=11)	10.3 (2.2)	9.1 (1.8)	8.2 (2.1)	6.9 (2.1)	5.9 (2.1)
IPC Trial B (n=11)	10.0 (2.1)	8.7 (2.4)	7.5 (2.3)	6.0 (2.3)	4.8 (2.0)

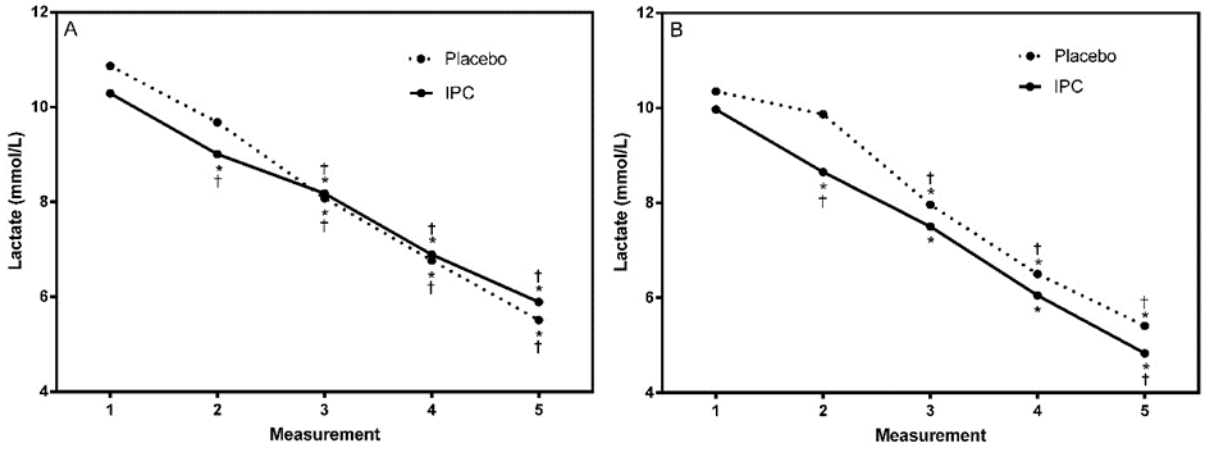

Figure 5. Mean blood lactate values following placebo or ischemic preconditioning (IPC) treatment over trial A and B. Measurement 1 is obtained immediately post-exercise and then taken every 5 minutes during a 20-minute passive recovery. Lactate decreased in a similar pattern for both trials with and without IPC treatment. * Significant change from time point to immediately post-exercise. † Significant change from time point to previous time point.

Blood pH Recovery

Main effects of time point during recovery on pH was found for placebo B ($p < .05$, ES .53). Means and standard deviations for all measures are represented in Table 4. See Figure 6 for the results of post-hoc pairwise comparisons. Although no main effect was found for treatment on pH in both trials ($p > .05$) nor interaction of treatment and time point on pH for both trials ($p > .05$), pH was lower at all time points during recovery with IPC treatment compared to placebo (See Figure 6).

Table 4. Passive recovery blood pH means (±SD) for each time point for both trial A and B following placebo and ischemic preconditioning (IPC) treatment.

	0 min	5 min	10 min	15 min	20 min
Placebo Trial A (n=12)	7.47 (.1)	7.44 (.1)	7.47 (.1)	7.53 (.1)	7.54 (.1)
Placebo Trial B (n=12)	7.48 (.1)	7.47 (.1)	7.52 (.1)	7.54 (.1)	7.60 (.1)
IPC Trial A (n=10)	7.41 (.2)	7.40 (.2)	7.43 (.1)	7.47 (.1)	7.47 (.1)
IPC Trial B (n=10)	7.40 (.2)	7.42 (.2)	7.41 (.1)	7.47 (.1)	7.50 (.1)

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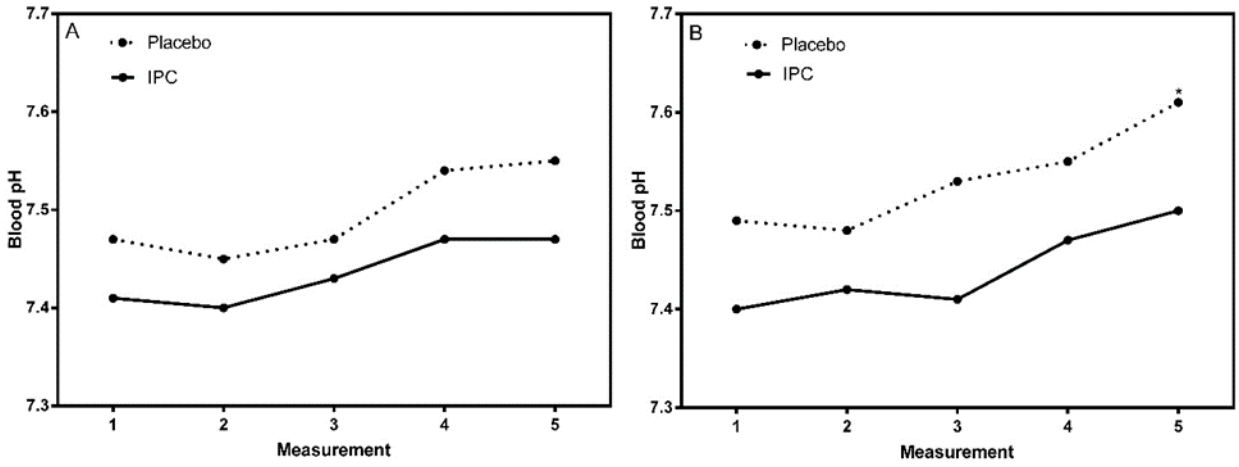

Figure 6. Mean blood pH values following placebo or ischemic preconditioning (IPC) treatment over trial A and B. Measurement 1 is obtained immediately post-exercise and then taken every 5 minutes during 20-minute passive recovery. * Significant change from time point to immediately post-exercise.

Discussion

The main findings of this study are 1) the mean response for TTF was not significantly different following placebo or IPC for trial A or B, and individual performances varied greatly, 2) the amount of La^- recovery was not significantly different for trial A or B with or without IPC treatment, but the rate of La^- recovery was increased for IPC in both trial A and B, 3) and blood pH was lower with IPC treatment but recovered in a similar pattern for both trials with or without IPC treatment. No main effect of IPC treatment was found on time to fatigue and therefore, the hypothesis that IPC would improve performance was rejected. A main effect was found for IPC on the rate of La^- recovery but not on the amount of La^- recovery nor on pH recovery, therefore, the hypothesis that IPC would improve recovery remains equivocal.

Time to Fatigue

The TTF performance results are in contrast with two studies[18,26] of comparable exercise intensity and duration. Cruz et al.[18], using a similar placebo controlled cross-over design, tested 15 recreational cyclists after 4 x 5min bilateral leg IPC. Subjects performed a 60sec maximal pedal at an intensity of 7.5% of the individual's body weight, 33 minutes after the IPC. The researchers found that IPC improved maximal power output by 2.1%, increased the anaerobic contribution, and increased the rate of lactate recovery. Jean-St-Michel et al.[26], also using a similar placebo controlled cross-over design, tested 23 elite swimmers on time to completion of a maximal competitive 100m swim, following 4 x 5min bilateral arm IPC. The researchers found that IPC was associated with a significant improvement in competitive swim time by an average of .7sec. The exercise bout of the current study, as well as Cruz et al.[18] and Jean-St-Michel et al.[26], relied greatly on

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glycolysis for ATP regeneration, yet results were conflicting. The amount of individual variability in the current study could be the explanation of the differences in mean responses.

Kido et al.[27], measuring IPC's effects on TTF with a cycle-ergometer, also found conflicting results when compared to the present study. Kido et al.[27] performed bilateral leg 3 x 5min IPC, inflated to 300mmHg, as well as no IPC in a counterbalanced manner. Following each treatment, subjects performed a 3-step incremental cycling test, consisting of a low-intensity stage, a moderate-intensity stage, and a severe-intensity stage that continued until exhaustion. Researchers measured VO_2, TTF for the final stage and muscle deoxygenation. They found that IPC significantly improved the subjects TTF[27]. Although the final stage of the cycling test was similar intensity to the present study, the amount of cuff inflation as well as the exercise design was different. The methodology, as well as the aforementioned individual variability in the present study, could be a factor in the dissimilar findings.

Crisafulli et al.[17] demonstrated similar results to the current study, after an all-out cycling test of equivalent duration. Following a 3 x 5min bilateral leg IPC treatment or no IPC, subjects performed a supramaximal cycling bout pushing 130% of their established max workload until exhaustion. No significant difference was found for their TTF between treatments. The present results are also partly in line with the observations from Patterson et al.[23]. Subjects received 4 x 5 min bilateral leg IPC, as well as a placebo in a cross-over design, thirty minutes prior to 12 x 6sec cycling sprints against a resistance calculated from their body weight, with 30 seconds of passive recovery in between each sprint. They demonstrated that IPC improved the peak and mean power output for the first three cycling sprints but no improvement was found in the following 9 sprints. In the current study, TTF after IPC was increased by~1 second in trial A, followed by a greater decrease in trial B. This similar pattern of initial performance gains after IPC with a subsequent drop off during maximal and supramaximal exercise could be explained by the central governor theory[17-18,27]. The concept of the central governor that recruits motor units in response to metabolic feedback, may be the neural drive allowing the subjects to reach a higher workload at the onset of exercise[7]. It is proposed that IPC activates opioid receptors in the brain that decrease the excitability of peripheral nerve terminals to receive feedback from muscle contraction, thus reducing the inhibitory influences they exert over motor control[28]. If this is the case, subjects could have surpassed their protective metabolic and neural thresholds to a deleterious point and therefore prevented adequate recovery for the subsequent exercise.

Gibson et al.[22], performing 3 x 5min unilateral leg IPC or placebo, tested 5 x 6sec maximal cycling sprints, with 24sec of recovery in between. They also observed similar results to the current investigation where no effect of IPC was found on the repeated sprint performance. The intensity and modality of this bout were

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comparable to the present study, however, the duration of exercise was much shorter, relying greatly on the phosphagen system for ATP production. The duration of the exercise in the present study was between 1.5 to 2.5 minutes, recruiting more ATP production from glycolysis. However, the phosphagen system had a large energy supply role at the beginning of both trials. If IPC does not increase the capacity of the phosphagen system, as shown in Gibson et al.[22] and Patterson et al.[23], this could be an explanation for the similar results in the current study.

Although the identification of who is a responder, non-responder, and adverse responder to IPC is undefined, it is clear from the current results, as well as one other study, that individual responsiveness variation exists[21]. Results are commonly presented as group means ± standard deviation and therefore may fail to identify individual confounders to IPC's effectiveness. Recently, it has been proposed that technical error (TE), the combination of day-to-day biological variability and measurement error, should be applied to categorize response rate[29-30]. TE was used in the current study to categorize the individual performance into responders (>TE), non-responders (within ±TE), and adverse responders (<TE). Presenting individual response data, along with group comparisons will provide further insight into the effectiveness of IPC and why variation occurs.

Research into factors that influence responsiveness to IPC is in its infancy, however, profound results have already been discovered. It has been shown in rabbits that hypercholesterolemia prevents responsiveness to IPC[31], as well as Type II Diabetes in rats[32]. In humans it has been shown that younger males respond to IPC greater than older males, suggesting that ageing may attenuate the protective effects[33]. These preliminary results indicate the possibility that poor vascular endothelial function may prevent positive responsiveness to IPC. Other factors that could affect endothelial function such as exercise over-training, other cardiometabolic risk factors, and genetics should be investigated as influences on IPC responsiveness. In the current study, endothelial function was not measured prior to IPC treatment, and could have provided the answer to why such individual variation occurred.

Blood Lactate and pH

The amount of blood La^- recovery was similar for IPC treatment and placebo for both trial A and B. Immediately post-exercise La^- was lower following IPC but was found not significantly different from placebo. What was found significant was the rate of La^- recovery. La^- was removed from the blood earlier during the recovery period following the IPC treatment. The La^- results of Cruz et al.[18] demonstrated the same rate of recovery pattern. However, immediately post-exercise, Cruz et al.[18] found significantly greater peak La^- in the IPC treatment. This is in contrast to the current study. What both studies suggest, is that IPC may enhance the capacity to clear La^- from the blood. The La^- transporters, also known as

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monocarboxylate transporter 1 (MCT1) and monocarboxylate transporter 4 (MCT4), are responsible for the influx and efflux of La^- during and after high-intensity exercise[34]. The MCT1 is found on type I muscle fibers, the heart, the brain, and the erythrocytes, and favors the influx of La^- to be used as a fuel source for ATP production. The MCT4 is found primarily on type II muscle fibers and favors the efflux of La^- into the blood. Research by Juel et al.[34] found that oxygen deprivation increased the expression and content of MCT1 on the membrane of erythrocytes. IPC, which induces an ischemic, also hypoxic, stress to the cells, could be enough to elicit this MCT1 adaptation. This increased MCT1 expression on the erythrocytes may explain why the rate of La^- clearance was increased following IPC in both studies. No other studies are known where La^- was measured over multiple time points during passive recovery following IPC treatment and anaerobic exercise.

Blood pH kinetics were also similar for IPC treatment and placebo for both trial A and B. However, pH was lower at all time points during recovery following IPC treatment. This was the first study to measure IPC's effect on post-exercise blood pH. The change in pH during the passive recovery in the present study is comparable to the change in pH during passive recovery in research investigating different recovery modes[35]. It was expected that the enhancement of blood flow elicited by IPC would increase the removal of H^+, therefore buffer acidosis, and improve subsequent exercise performance. Siegler et al.[35] hypothesized that active and passive recovery modes would buffer acidosis differently as well and demonstrate differences in subsequent exercise performance. Findings in the current study and Siegler et al.[35] were alike in that the state of blood acidosis prior to subsequent exercise did not benefit exercise performance.

Tissue hypoxia occurs when the supply of oxygen from the bloodstream does not meet the demand from the cells in the tissue. This supply-demand mismatch is created during physiological situations and high-altitude exposure. Hypoxia-inducible transcription factor-1 (HIF-1) is triggered during chronic hypoxia and mediates adaptations to this stressful situation[36-37]. The process of IPC elicits the same hermetic response and therefore activates HIF-1[38-39]. Juel et al.[34] found increased Na^+/H^+ transporter density in the skeletal muscle of individuals exposed to hypoxic stress. HIF-1 could be partially responsible for this adaptation, as it is known to alter other proteins within the cell[40-41].

During and post high-intensity exercise, La^- and H^+ are transported out of the cell and into the blood in a 1:1 ratio through the MCT4[6]. This provides the picture in the blood of the correlation between increased La^- and decreased pH post high-intensity exercise. However, as shown in Figure 6 of the current study, blood pH levels were more acidic at every time point during recovery following the IPC treatment compared to placebo, yet the typical inverse relationship of increased La^- was not demonstrated. This could be explained by

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an additional release of H^+ through the Na^+/H^+ transporters that were possibly overexpressed after the ischemic stress of IPC[34,38]. This would result in a greater presence of H^+, therefore lower pH, that did not directly correlate to the amount of La^- in the blood.

It was hypothesized that IPC would elicit a greater increase in pH during the recovery period more than placebo. However, this was not the case. Blood pH remained low for each time point during recovery following IPC treatment, compared to placebo. During recovery from exercise, phosphocreatine (PCr), the substrate used in the phosphagen energy system, is resynthesized via oxidative ATP production in the mitochondria[3]. This was assumed to happen during each recovery period following trial A and trial B in the current study. However, it has been shown that PCr recovery is slower in the presence of acidosis, or low pH[42]. It is possible that the IPC induced acidity, demonstrated during the recovery period following trial A, could have prevented adequate PCr replenishment, and therefore negatively affected the performance for trial B. This could be the explanation for the increased decrement in performance for trial B following IPC.

Limitations

Little is presently known concerning the individual variability of responsiveness to IPC. This has been suggested by other authors as a limitation and a much needed area of future research[21]. Indeed, differences in individual response are commonly demonstrated in other training and ergogenic aid performance studies[43-44]. Exploring why this variability occurs in responsiveness to IPC, would provide greater insight into the diverse results found in exercise performance research.

CONCLUSION

In conclusion, IPC has shown performance enhancements in several modalities and exercise designs[18-19,26-27]. However, due to the variability in TTF performance, no significant effect of IPC was found on repeated supramaximal cycling performance at an altitude of 2350 meters in acclimatized, experienced cyclists. The rate of blood lactate recovery was shown to be increased by IPC in both trials. IPC also lowered blood pH at all time points during all recovery periods but no significant effect was found for the recovery amount. Further research is warranted into the contributing factors of increased La^- clearance, decreased blood pH, and the individual responsiveness to IPC treatment.

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