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Original Research

Attenuation of Neuromuscular Fatigue by Ischemic Preconditioning with Moderate Cuff Pressure is Not Related to Muscle Oxygen Saturation in Men

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ABSTRACT

International Journal of Exercise Science 16(2): 1025-1037, 2023. Ischemic preconditioning (IPC) has been an excellent strategy for enhancing sports performance recovery, although there is still no consensus on the ideal protocol. Thus, this study aimed to evaluate the effects of IPC with different cuff pressures (low pressure, medium pressure, and high pressure) on the attenuation of neuromuscular fatigue after an isometric test protocol. And to verify whether this improvement was related to muscle oxygen saturation during the test protocol. Thirty males (18-35 years old) with experience in resistance training were allocated to three different groups: low pressure (20 mmHg), medium pressure (100 mmHg), and high pressure (190 mmHg). The individual occlusion pressure of each participant was identified using ultrasound. Each participant performed two test protocols (8 maximal isometric contractions lasting 20-s with a 10-s rest interval) in an extension chair; after the first test protocol, the participant received the IPC intervention with a low, medium, or high cuff pressure or received the noncuff intervention (randomized order). Only the medium-pressure group showed a smaller decrease in mean force change compared to the no-cuff condition (-4.40% vs. -13.10%, p=0.01, respectively), and the low- and high-pressure groups did not exhibit significant pressure differences (IPC vs. noncuff: -8.40% vs. -13.10%, p=0.11 and -9.10% vs. -14.70%, p=0.12, respectively). Muscle oxygen saturation across test protocols showed no significant differences in all IPC conditions (p>0.05). Although, IPC with medium pressure was effective at optimizing the recovery of neuromuscular performance, this improvement is not related to an increase in muscle oxygen saturation during exercise.

KEY WORDS: Blood flow, resistance exercise, isometric contraction, near-infrared spectrometry, hyperemia

INTRODUCTION

Ischemic preconditioning (IPC), involving brief repeated periods of occlusion followed by reperfusion of blood flow, has been shown to accelerate recovery after aerobic exercise (3) or power-specific testing (1). Experiments have tested this cuff intervention in various ways, including altering the time between intervention and exercise, manipulating the duration of occlusion and reperfusion, and modifying the applied cuff pressure (33). There is no consensus regarding its effect on resistance exercise (RE) performance or isometric force changes (14, 28, 37). The inconsistent results may be due to the heterogeneity of methodological protocols (27) and the lack of definition of a protocol with the ideal pressure to be used in performance recovery. It is worth noting that IPC presents certain aspects that require attention, such as discomfort proportional to the pressure of the inflated cuff and the duration of occlusion (35). Exploring shorter protocols with lower occlusion pressures may be more advantageous.
Decreases in isometric force during sustained muscular activation are considered one of the main characteristics of neuromuscular fatigue (38). Such a decrease occurs in athletes who engage in intense exercise sessions/competitions with short recovery intervals (1). Thereby, the production of isometric force can be an important component in several sports such as Judo and Handball (4, 5). Furthermore, the potential influence of IPC on the isometric force after protocols with incomplete recovery has not yet been tested.

Although the physiological mechanisms of the effects of IPC on performance and recovery are not well explained. It is believed that the interrupted blood flow, added to the energy demand of the exercise, can lead to an increase in mitochondrial activity (16, 33), improving the expression of the protein kinase activated by adenosine monophosphate and stimulating the glycolytic production of ATP in the muscle (17). Furthermore, the release of blood flow causes greater vasodilation, taking more local blood and consequently, greater oxygen supply (7). However, a current study found that during reperfusion, local oxygenation levels did not even return to baseline levels, becoming lower during reperfusion cycles (24). Given the complexity of measuring mitochondrial activity, as well as the amount of ATP consumed and available, an indirect method of measuring mitochondrial activity is to measure muscle oxygen saturation (SmO_2) (6). It should be noted that oxygen is a crucial component in recovery.

Recent studies have measured SmO_2 during exercise after IPC, however, both studies showed that even with the application of IPC, oxygenation decreases during exercise (13, 34). Thus, this performance improvement may be related to a neural effect (9), i.e., a reduction in discharge from type III/IV muscle afferents, which in turn would reduce the inhibition of central motor drive output with the attenuation in the rate of perceived exertion (RPE) (22). In turn, trapping muscle metabolites using a high-pressure cuff elicits substantial hemodynamic responses through type III/IV afferents, which may influence the voluntary exercise central command (25). Hence, research is needed to verify the influence of post-exercise IPC intervention on neuromuscular performance and SmO_2.

Due to the discrepancies in IPC protocols and inconsistent results related to isometric force changes, this study focused solely on male participants to ensure a more homogeneous sample. Participants were allocated to groups based on relative strength. Therefore, the objective of this study was to evaluate the effects of IPC with different cuff pressures on neuromuscular performance recovery and SmO_2 during an isometric knee extension testing protocol in men. We hypothesize that IPC with medium and high pressures can positively influence recovery performance, while IPC with low pressure will have no significant effect on recovery. Additionally, we expect only medium and high pressures to cause changes in SmO_2.

METHODS

Participants

Assuming a moderate effect size (ES) of f = 0.49 based on a previous systematic review and meta-analysis (1), an a priori power analysis (α = 0.05), study power (1 – β) = 0.80, test family = t tests, statistical test = difference between two dependent means (matched pairs), (G*Power 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany; http://www.gpower.hhu.de/) was performed. The required sample size was 35 volunteers. We recruited 36 young men (18-35 years old) with at least six months of experience in resistance exercises. However, six participants withdrew from the study, resulting in a sample size of 30 participants. Thus, we performed a statistical power calculation based on the mean effect size of the principal outcome from three conditions (force change ES= 0.87). Assuming a moderate effect size (ES) of dz = - 0.88, a post hoc computation of achieved power was conducted (α = 0.05), test family = t tests, statistical test = difference between two dependent means (matched pairs), and the study power was found to be (1 – β err prob) = 0.99.

Table 1. Characteristics of the participants of each experimental group.

	LP (n=10)	MP (n=10)	HP (n=10)	*P* value
Age (yrs)	22.70 ± 2.80	23.90 ± 5.80	20.30 ± 2.40	0.07
Height (m)	1.76 ± 0.10	1.80 ± 0.10	1.71 ± 0.10	0.01*
Body mass (kg)	76.80 ± 9.50	85.20 ± 14.10	73.30 ± 5.90	0.05
Body fat (%)	12.60 ± 4.60	16.30 ± 6.90	14.80 ± 4.90	0.86
RE experience (yrs)	4.70 ± 4.50	4.90 ± 4.80	4.4 ± 2.50	0.21
RE hours/week	4.10 ± 1.40	4.30 ± 0.90	5.00 ± 1.10	0.21
Relative force (N/kg)	0.52 ± 0.14	0.51 ± 0.12	0.52 ± 0.18	0.94
IOP (mmHg)	165.50 ± 20.00	177.00 ± 33.70	169.50 ± 22.70	0.61
Occlusion pressure group (mmHg)	20.00	100.00	189.50 ± 22.70	-
Occlusion pressure (% of the IOP)	11.20 ± 1.50	58.30 ± 10.70	112.00 ± 1.40	-

Data are presented as mean ± SD. IOP: Individual occlusion pressure; HP: high pressure; MP: medium pressure; LP: low pressure; RE: resistance exercise. *Differences between group.

To ensure the homogeneity of the groups, the participants were allocated (by convenience) into one of three groups based on the values of relative isometric strength achieved in a prior test. The exclusion criteria were as follows: a) presenting any cardiovascular or metabolic diseases; b) intake of exogenous anabolic-androgenic steroids or dietary supplements with potential effects on physical performance (self-reported); c) consuming caffeine supplementation and alcohol during the test period; d) history of smoking; and e) history of injuries on the lower limbs that could impair the execution of the exercise proposed (i.e., knee extension). Prior to data collection, all participants were informed about the procedures and signed a consent form. The study was approved by the local ethical committee for human research (n. 2.250.458). It was carried out in accordance with the Declaration of Helsinki and adhered to the ethical policies set by the Editorial Board of the International Journal of Exercise Science (26). Table 1 presents the characteristics of the participants.

Protocol

To ensure the study's single-blind design, the main researcher left the room immediately after the initial testing protocol (pre), unaware of each participant's group allocation and the type of intervention (IPC or noncuff) administered to them to them by other researchers. Force change (%), muscle oxygen saturation, and perceived scales were measured during testing protocols (pre- and postintervention).

Participants visited the laboratory three times, 48 hours apart (Figure 1). The 1st visit was dedicated to anthropometric measurements, individual occlusion pressure (IOP) measurement, and familiarization with the testing protocol (isometric knee extension). During the 2nd visit, they performed a testing protocol (preintervention). And then, they received an IPC condition (with cuff pressure according to the allocated group) or the noncuff condition, and after this performed the test protocol again (post-intervention). Finally, at the 3rd visit, the volunteers repeated the same procedures as the 2nd visit, alternating the intervention received from the second visit.

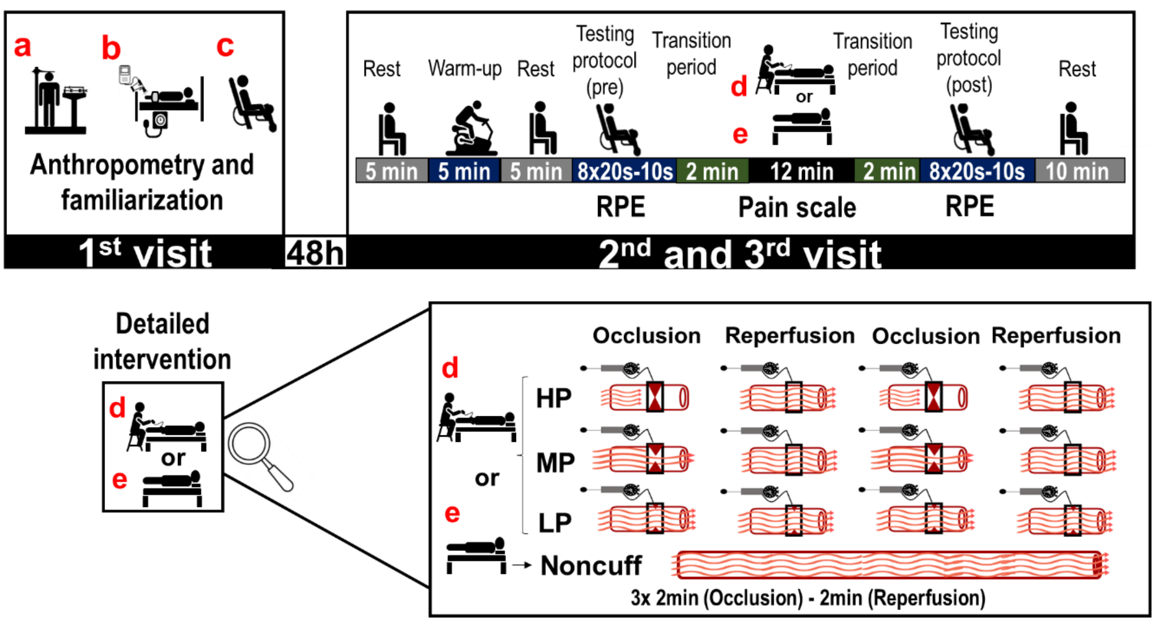

Figure 1. Experimental design of the study. a: anthropometric measures, b: check of individual occlusion pressure, c: isometric testing protocol, d: ischemic preconditioning with different pressures, e: noncuff; HP: high pressure group; MP: medium pressure group; LP: low pressure group; RPE: rating of perceived exertion.

Individual occlusion pressure (IOP) was determined with the subject in rest supine position. The cuff (positioned at the proximal part of the thigh) was inflated (from 100 mmHg with 10 mmHg increments) until the absence of blood flow (identified by no sound of a portable Doppler, MedPeg DV-2001, Ribeirão Preto, Brazil), positioned on the tibial anterior artery.

Testing protocol**:** The testing protocol was performed on a knee extension machine with a load cell attached (Cefise Biotechnology, Nova Odessa, SP, Brazil). The equipment was adjusted to a relative knee angle of ~90° (19, 20). The protocol consisted of eight maximal voluntary isometric contractions of ~20 seconds, with ~10 seconds of rest, totaling four minutes (24). Prior to the test, a 5-minute warm-up was performed in a cycle ergometer, with a fixed power of 40 W. During the session, the volunteers were instructed to exert force as "hard" as possible, maintain for 20 s and then soon relax. A real-time biofeedback of the force–time curves obtained was provided on a computer monitor. Pilot tests confirmed the effectiveness of the testing protocol in inducing neuromuscular fatigue. The force signal was acquired at a rate of 50 Hz, and this frequency was fixed by the load cell (Cefise Biotechnology in Sports, Nova Odessa, SP, Brazil, maximum capacity of 2000 N) attached to the knee extension machine. Prior to each data collection, the load cell was calibrated, and during the late off-line analysis, signals were converted to newtons. Changes in neuromuscular performance were observed by the analysis of the mean force acquired during the eight force–time curves.

Ischemic preconditioning (IPC) with different cuff pressures: IPC interventions were executed with the participants lying in supine position at 2 min after the testing protocol (preintervention). This rest time was necessary for the participant to leave the isometric chair and to apply the cuffs for the intervention, if applicable. The IPC interventions consisted of three 2-minute cycles of simultaneous occlusion followed by 2 min of reperfusion, totaling 12 minutes. The cuffs (Riester®, Germany, 96 x 13 cm) were applied to the subinguinal region of the thigh. The occlusion and reperfusion pressures were also verified by a portable Doppler (MedPeg DV-2001, Ribeirão Preto, Brazil) placed over the anterior tibial artery during the interventions. The high pressure (HP) group experienced a pressure of 20 mmHg above the IOP (40), corresponding to ~112% of the IOP. The medium (MP) and low pressure (LP) groups consisted of fixed pressures of 100 mmHg (39) and 20 mmHg (1), corresponding to ~56 and 12% of the IOP, respectively (Table 1). The objective of applying 20 mmHg above the IOP in the HP group was to ensure occlusion. The 100 mmHg pressure applied in the MP group is a consolidated pressure employed in the literature to induce restriction (decrease) in arterial and blockade of venous blood flow (15). The 20 mmHg in the LP group was used as placebo, similar to previous studies (11, 23). None of the participants complained about discomfort caused by the cuff interventions.

Muscle oxygen saturation (SmO_2) measurements: Muscle oxygen saturation was assessed by validated near-infrared spectroscopy (NIRS; Moxy, Fortiori Design LLC, Hutchinson, USA) during test protocols under all conditions (IPC and noncuff). The device was accurately positioned on the vastus lateralis muscle of the dominant leg. Markings were made at the midpoint between the greater trochanter and the lateral epicondyle, as well as at the midpoint between the inguinal fold and the patella. Subsequently, the device was placed precisely between these two markings the protocol was adapted according to the study that validated the Moxy (8). A specific pen (Freehand Skin Marker Pen®) was used to mark anatomical points on the skin, and the marks were preserved during the three visits. Before fixing the NIRS, trichotomy and cleaning of the area with 70% alcohol and cotton were performed.

The NIRS was inserted in a specific black silicone cover capable of isolating interference from external light (i.e., ambient light). To attach the cover to the skin, we used adhesive tape. Before collecting data, the average of the values recorded for one minute was used so that we would have a value always close to the three interventions and ensures reproducibility. The sample frequency acquisition of the NIRS device is 0.5 Hz (12). Previous studies have reported a high reproducibility for SmO_2 measurement using NIRS (8).

Perceived Recovery Status, Pain Scale, and Perceived Exertion: Perceived recovery status was evaluated prior to each performance test (0-10 score) to ensure that participants would be in good condition to undertake the tests. The lower values indicate a poorly recovered individual with an expectation of impaired performance and higher values indicate a very well-recovered individual expecting a good performance (21).

Pain perception was assessed immediately postintervention through a numerical rating scale (0–10 score), where 0 indicates "no pain" and 10 indicates "unbearable pain". The following instructions were used after cuff removal: "Select a single number that best represents the pain intensity felt during this intervention" (11).

Perceived exertion was assessed through the OMNI Perceived Exertion Scale (values from 0 to 10) and was evaluated at the end of each isometric contraction (31). After each set of maximal isometric contractions, each subject was instructed as follows: "Please pay close attention and tell me how hard you think it was to perform this set. This feeling should reflect the sensations and feelings of physical stress, fatigue and the difficulty you had in carrying it out" (11).

Statistical Analysis

The Shapiro–Wilk test was used to determine the normality of the data; data were reported as the mean ± standard deviation (SD) or median and interquartile range when necessary. One-way ANOVA or Kruskal–Wallis followed by Bonferroni's post hoc test was conducted to examined differences in the characteristics of the participants. The mean isometric force change of the eight maximal voluntary isometric contractions at pre- and post-IPC with different cuff pressures and noncuff interventions were compared using the paired Student's t test or the Wilcoxon test. Two-way repeated-measures ANOVA (intervention x time) followed by Bonferroni's post hoc test was conducted to compare perceived recovery, pain scale, rating perceived exertion and SmO_2 behavior between IPC with different cuff pressures and noncuff interventions at pre- and postintervention protocols. A significance level of 0.05 was adopted. The effect size (ES) was calculated by the difference between the means of both the pre- and postintervention values divided by the means of the pre- and postintervention SDs. The meaningfulness of the difference was considered as follows: <0.2 (trivial), >0.2–0.6 (small), >0.6–1.2 (moderate), >1.2–2.0 (large), and >2.0–4.0 (very large) (2). All statistical analyses were performed using SPSS, version 25 (SPSS, IC., Chicago, IL, USA). The figures were constructed using GraphPad software (Prism 8.0.0; San Diego, CA, USA).

RESULTS

Although we recruited 36 volunteers, the analyzed data included 30 participants because six subjects withdrew from the study. Thus, we performed a statistical power calculation based on the mean effect size of the principal outcome from three conditions (force change ES= 0.87). Assuming a moderate effect size (ES) of dz = - 0.88, a post hoc computation of achieved power was conducted (α = 0.05), test family = t tests, statistical test = difference between two dependent means (matched pairs), and the study power was found to be (1 – β err prob) = 0.99 (18).

MP intervention was significant on attenuation of fatigue loss (-18.2 N) while LP and HP led to greater losses of -36.1N and -34.7 N, respectively. Effect size and delta % are depicted in figure 2.

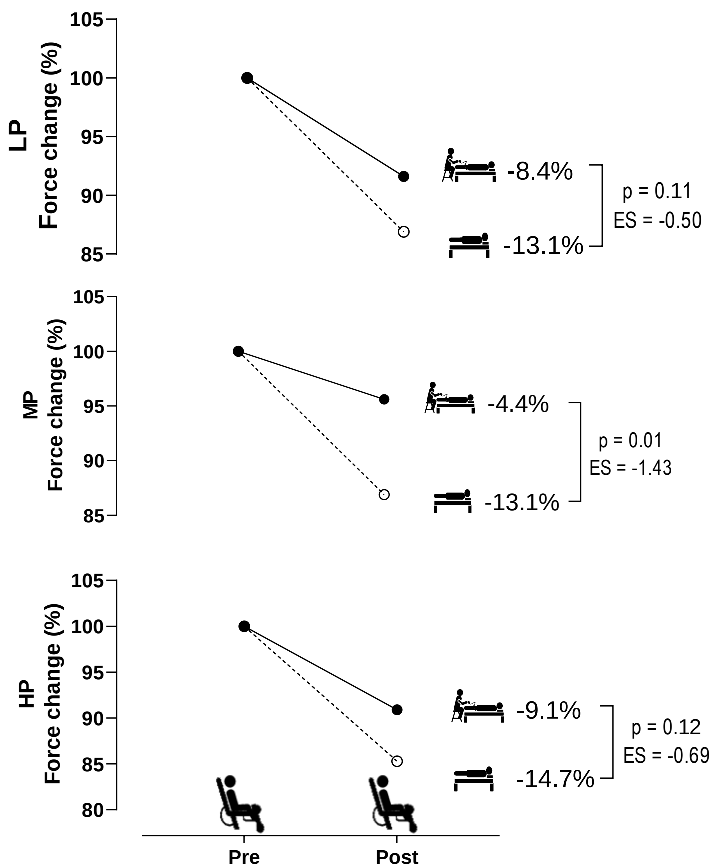

Figure 2. The percentage of changes in mean isometric force between IPC with different cuff pressures and noncuff. The design with cuff application denotes IPC; the design without cuff application denotes noncuff. Pre: testing protocol before the IPC maneuver with different cuff pressures. Post: testing protocol after IPC maneuver with different cuff pressures.

There were no differences in SmO_2 (Table 2) among IPC interventions with different cuff pressures and the noncuff condition during test protocols (p>0.05).

Table 2. Muscle oxygen saturation (SmO_2 %) during the testing protocol.

LP		Non-cuff	IPC
	Pre	27.51 ± 10.95	25.36 ± 12.83
	Post	26.20 ± 10.85	25.92 ± 13.21
MP			
	Pre	41.49 ± 25.64	44.67 ± 20.77
	Post	38.96 ± 21.49	40.84 ± 18.58
HP			
	Pre	33.24 ± 26.89	26.69 ± 12.64
	Post	30.92 ± 26.93	29.12 ± 11.65

Data are presented as the mean ± SD. HP, high pressure; MP, medium pressure; LP, low pressure. IPC: ischemic preconditioning. Pre: testing protocol before the IPC maneuver with different cuff pressures. Post: testing protocol after IPC maneuver with different cuff pressures. SmO_2: muscle oxygen saturation.

Perceived recovery status: The perception of recovery showed no significant difference between the LP (noncuff median: 7 [7-8], LP median: 7 [6-8]; p=0.68), MP (noncuff median: 7 [5-8], MP median: 7 [6-9]; p=0.40) and HP conditions (noncuff median: 7 [6-8], HP median: 7 [6-7]; p=0.78).

Pain perception (Table 3) was higher for the HP group than for the LP group in all cycles of ischemia ($p<0.01$). When comparing LP and MP, only in the third ischemia cycle did MP present higher pain scores ($p<0.01$).

Table 3. Pain perception during IPC with different cuff pressures.

Ischemia	LP	MP	HP	LP vs. MP	LP vs. HP	MP vs. HP
1st	0 (0-2)	3 (1-5)	6 (5-6)	p=0.10	p=0.01	p=0.22
2nd	0 (0-2)	2 (1-4)	5 (2-6)	p=0.16	p=0.01	p=0.29
3rd	0 (0-1)	3 (1-4)	3 (2-5)	p=0.04	p=0.01	p=1.00

Data are presented as median and interquartile range. LP, low pressure; MP, medium pressure; HP, high pressure.

The perceived exertion during the session showed no significant difference (p=0.73) among LP, MP and HP, in both conditions with and noncuff (table 4).

Table 4. Rating of Perceived Exertion during testing protocols:

LP			**Noncuff**
Pre	Post	Pre	Post
8 [6-9]	8.5 [7-10]	8 [7-10]	8.5 [8-10]
MP		**Noncuff**	
Pre	Post	Pre	Post
9 [5.75-10]	9 [7.25-9.25]	9 [5.75-10]	9 [7.25-10]
MP		**Noncuff**	
Pre	Post	Pre	Post
8.5 [5-9.25]	8 [5-9.25]	8 [6.75-10]	7.5 [6.75-9]

Data are presented as median and interquartile range. LP, low pressure; MP, medium pressure; HP, high pressure; Pre, testing protocol 1; Post, testing protocol 2.

DISCUSSION

The main purpose of this study was to measure the effects of different IPC cuff-pressure interventions on neuromuscular performance recovery and SmO_2. The main findings were that the MP group accelerated the recovery of neuromuscular performance. However, this improvement is not related to the increase in SmO_2 during exercise.

The purpose of using the MP was precisely to test whether lower pressure on the tourniquet would cause positive effects. MP reduces arterial blood flow, and HP completely blocks arterial blood flow. After exercise, energy demand and mitochondrial activity are high, resulting in increased production of reactive oxygen species, which is a factor that impairs performance (22). Thus, by decreasing oxygen delivery during MP application, we hypothesized that MP due to its reduced arterial flow, promoted a mitochondrial braking mechanism, decreasing mitochondrial activity and ROS production. Consistent with our findings, a previous study also observed increases in performance with a relatively medium cuff pressure (65 ± 2 mmHg) after IPC on RE (36). Also, a possible mediated effect of the occlusion intervention could not be due to changes in blood flow, but caused by the basic idea that the cuff could modify bidirectional brain-muscle integration by altering cognitive appraisal and motor behavior by increasing activity (22).

High- and low-pressure protocols have presented controversial effects in the literature. Previous studies have shown that HP was either similar or not enough to enhance the performance of the subjects compared to the LP group in different testing protocols (11, 32). It is postulated that this discrepancy is attributed, at least partially, to different methodological aspects among the studies, as well as the possibility of placebo or motivational effects (27). When we consider the HP effect in the literature, we see that the result is favorable in relation to low pressure. However, most studies consider LP and noncuff as the same thing. Regardless, both show similar positive effects (11, 32). And the current study showed that HP and LP did not influence recovery. It is postulated that this discrepancy is attributed, at least partially, to different methodological aspects among the studies, as well as the possibility of placebo or motivational effects (27).

Perhaps, the occlusion/reperfusion time of HP, used in the present study was insufficient to cause a positive effect on recovery. Studies that found positive effects use longer-lasting protocols, in addition to the time of application being prior to exercise. Our hypothesis is that there is no benefit in causing total occlusion of blood flow with the individual in post-exercise hyperemia, in addition to fatigue and feeling of muscle pain, as opposed to MP, which promoted a decrease in arterial flow and local blood retention.

Disregarding the occlusion/reperfusion effect of the LP, there is a possibility of placebo or motivational effects solely resulting from the mere contact between the cuff and the participants' skin. This contact may induce the participant to think that is receiving some kind of "treatment" (22). However, since the LP was not enough to accelerate recovery, we hypothesize that because the participant was fatigued, they ignored the cuff with LP due to the presence of stimuli such as a feeling of muscle acidosis and tiredness caused by intense exercise.

Researchers have hypothesized that hyperemia resulting from HP and MP may trigger the most substantial release of nitric oxide. This phenomenon is associated with greater vasodilation, leading to increased SmO_2 levels and improved nutrient delivery (10), thus accelerating exercise recovery. However, our findings demonstrated no significant alteration in SmO_2 levels during the tests, which is consistent with previous studies that have also failed to observe this increase (13, 29). In this sense, it appears that IPC has an insignificant influence on SmO_2 levels during exercise. This suggests that the improvement in recovery with the application of MP is not related to the increase in SmO_2.

The perception of recovery did not present a significant difference on any occasion. It could be highlighted that HP and MP cuff interventions promoted significantly higher pain perception than the LP cuff intervention. Regardless, this was expected since LP is considered a placebo strategy. However, no difference was found in pain between HP and MP, consolidating the idea of using IPC with lower pressure. In addition, although it could be hypothesized that a neural effect related to desensitization by reducing discharge from type III/IV muscle afference could influence RPE, this fact was not confirmed due to the nonsignificant difference between conditions.

In conclusion, ischemic preconditioning with medium cuff pressure (100 mmHg) was effective for improving neuromuscular performance in men, while low (20 mmHg) and high (190 mmHg) cuff pressures did not improve performance. Muscle oxygen saturation did not differ between the cuff pressure conditions, suggesting that the beneficial effects of IPC on the attenuation of neuromuscular fatigue are not related to changes in oxygenation.

Specifically, the influence of IPC on fatigue in women and men has yet to be clarified. According to a study (30), women reach fatigue faster than men and are more susceptible to pain caused by the maneuver. This difference in the mechanism of fatigue between men and women may influence the results of studies, leading maybe to other findings regarding the ergogenic effects of IPC on muscle performance (30). Thus, as a possible limitation, our results only apply to men. Therefore, future research should investigate the effect of IPC on women. In this way, it will contribute to the scientific literature, as there is a scarcity of studies on IPC and sports performance that include women as participants.

To further expand our understanding of this strategy, the effects of IPC on muscle performance in other sports should be investigated. Regarding the results of this study, it is interesting to highlight that MP is an ergogenic strategy that is easy to handle and low cost. Therefore, its application in modalities that require short rest intervals, as in the case of Jiu-jitsu competitions, can be interesting, as athletes perform an average of four fights with short rest intervals. Thus, it would be ideal to use IPC with MP between combats.

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REFERENCES

1. Arriel RA, Rodrigues JF, Souza HLR, Meireles A, Leitao LFM, Crisafulli A, Marocolo M. Ischemia-reperfusion intervention: From enhancements in exercise performance to accelerated performance recovery-a systematic review and meta-analysis. Int J Environ Res Public Health 17(21):8161, 2020.

2. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. Int J Sports Physiol Perform 1(1):50-57, 2006.

3. Beaven CM, Cook CJ, Kilduff L, Drawer S, Gill N. Intermittent lower-limb occlusion enhances recovery after strenuous exercise. Appl Physiol Nutr Metab 37(6):1132-1139, 2012.

4. Bonitch-Góngora JG, Bonitch-Domínguez JG, Padial P, Feriche B. The effect of lactate concentration on the handgrip strength during judo bouts. J Strength Cond Res 26(7):1863-1871, 2012.

5. Bragazzi NL, Rouissi M, Hermassi S, Chamari K. Resistance training and handball players' isokinetic, isometric and maximal strength, muscle power and throwing ball velocity: A systematic review and meta-analysis. Int J Environ Res Public Health 17(8):2663-2663, 2020.

6. Campbell MD, Marcinek DJ. Evaluation of in vivo mitochondrial bioenergetics in skeletal muscle using nmr and optical methods. Biochim Biophys Acta 1862(4):716-724, 2016.

7. Cheng CF, Kuo YH, Hsu WC, Chen C, Pan CH. Local and remote ischemic preconditioning improves sprint interval exercise performance in team sport athletes. Int J Environ Res Public Health 18(20)2021.

8. Crum EM, O'Connor WJ, Van Loo L, Valckx M, Stannard SR. Validity and reliability of the moxy oxygen monitor during incremental cycling exercise. Eur J Sport Sci 17(8):1037-1043, 2017.

9. Cruz RS, de Aguiar RA, Turnes T, Salvador AF, Caputo F. Effects of ischemic preconditioning on short-duration cycling performance. Appl Physiol Nutr Metab 41(8):825-831, 2016.

10. Daab W, Bouzid MA, Lajri M, Bouchiba M, Rebai H. Brief cycles of lower-limb occlusion accelerate recovery kinetics in soccer players. Phys Sportsmed 0(0):1-8, 2020.

11. de Souza HLR, Arriel RA, Hohl R, da Mota GR, Marocolo M. Is ischemic preconditioning intervention occlusion-dependent to enhance resistance exercise performance? J Strength Cond Res 35(10):2706-2712, 2021.

12. Feldmann A, Schmitz R, Erlacher D. Near-infrared spectroscopy-derived muscle oxygen saturation on a 0% to 100% scale: Reliability and validity of the moxy monitor. J Biomed Opt 24(11):1-11, 2019.

13. Griffin PJ, Ferguson RA, Gissane C, Bailey SJ, Patterson SD. Ischemic preconditioning enhances critical power during a 3 minute all-out cycling test. J Sports Sci 36(9):1038-1043, 2018.

14. Halley SL, Marshall P, Siegler JC. The effect of ipc on central and peripheral fatiguing mechanisms in humans following maximal single limb isokinetic exercise. Physiol Rep 7(8):e14063-e14063, 2019.

15. Iida H, Kurano M, Takano H, Kubota N, Morita T, Meguro K, Sato Y, Abe T, Yamazaki Y, Uno K, Takenaka K, Hirose K, Nakajima T. Hemodynamic and neurohumoral responses to the restriction of femoral blood flow by kaatsu in healthy subjects. Eur J Appl Physiol 100(3):275-285, 2007.

16. Incognito AV, Burr JF, Millar PJ. The effects of ischemic preconditioning on human exercise performance. Sports Med 46(4):531-544, 2016.

17. Jackson CW, Escobar I, Xu J, Perez-Pinzon MA. Effects of ischemic preconditioning on mitochondrial and metabolic neruoprotection: 5' adenosine monophosphate-activated protein kinase and sirtuins. Brain Circ 4(2):54-61, 2018.

18. Johnson SL, Stone WJ, Bunn JA, Lyons TS, Navalta JW. New author guidelines in statistical reporting: Embracing an era beyond p < .05. Int J Exerc Sci 13(1):1-5, 2020.

19. Katoh M, Isozaki K. Reliability of isometric knee extension muscle strength measurements of healthy elderly subjects made with a hand-held dynamometer and a belt. Phys Ther Sci 26(12):1855-1859, 2014.

20. Koral J, Oranchuk DJ, Wrightson JG, Twomey R, Millet GY. Mechanisms of neuromuscular fatigue and recovery in unilateral versus bilateral maximal voluntary contractions. Appl Physiol 128(4):785-794, 2020.

21. Laurent CM, Green JM, Bishop PA, Sjökvist J, Schumacker RE, Richardson MT, Curtner-Smith M. A practical approach to monitoring recovery: Development of a perceived recovery status scale. J Strength Cond Res 25(3):620-628, 2011.

22. Marocolo M, Hohl R, Arriel RA, Mota GR. Ischemic preconditioning and exercise performance: Are the psychophysiological responses underestimated? Eur J Appl Physiol 123:683–693, 2023.

23. Marocolo M, Simim MAM, Bernardino A, Monteiro IR, Patterson SD, da Mota GR. Ischemic preconditioning and exercise performance: Shedding light through smallest worthwhile change. Eur J Appl Physiol 119(10):2123-2149, 2019.

24. Meireles A, Oliveira GTd, de Souza HL, Arriel RA, Leitão L, Santos MPd, Marocolo M. Local muscle oxygenation during different cuff-pressures intervention: A punctual near-infrared spectroscopy measurement. Mot Rev de Educ Fis 28:e10220004122, 2022.

25. Mitchell JH, Kaufman MP, Iwamoto GA. The exercise pressor reflex: Its cardiovascular effects, afferent mechanisms, and central pathways. Annu Rev Physiol 45:229-242, 1983.

26. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1):1-8, 2019.

27. O'Brien L, Jacobs I. Methodological variations contributing to heterogenous ergogenic responses to ischemic preconditioning. Front Physiol 12:656980, 2021.

28. Paradis-Deschênes P, Joanisse DR, Billaut F. Ischemic preconditioning increases muscle perfusion, oxygen uptake, and force in strength-trained athletes. Appl Physiol Nutr Metab 41(9):938-944, 2016.

29. Patterson SD, Bezodis NE, Glaister M, Pattison JR. The effect of ischemic preconditioning on repeated sprint cycling performance. Med Sci Sports Exerc 47(8):1652-1658, 2015.

30. Pereira HM, de Lima FF, Silva BM, Kohn AF. Sex differences in fatigability after ischemic preconditioning of non-exercising limbs. Biol Sex Differ 11(1):59, 2020.

31. Robertson RJ, Goss FL, Rutkowski J, Lenz B, Dixon C, Timmer J, Frazee K, Dube J, Andreacci J. Concurrent validation of the omni perceived exertion scale for resistance exercise. Med Sci Sports Exerc 35(2):333-341, 2003.

32. Sabino-Carvalho JL, Lopes TR, Obeid-Freitas T, Ferreira TN, Succi JE, Silva AC, Silva BM. Effect of ischemic preconditioning on endurance performance does not surpass placebo. Med Sci Sports Exerc 49(1):124-132, 2017.

33. Salvador AF, Aguiar RAD, Lisbôa FD, Pereira KL, Cruz RSDO, Caputo F. Ischemic preconditioning and exercise performance : A systematic review and meta-analysis. Int J Sports Physiol Perform:4-14, 2016.

34. Seeger JPH, Timmers S, Ploegmakers DJM, Cable NT, Hopman MTE, Thijssen DHJ. Is delayed ischemic preconditioning as effective on running performance during a 5 km time trial as acute ipc? J Sci Med Sport 20(2):208-212, 2017.

35. Sharma V, Cunniffe B, Verma AP, Cardinale M, Yellon D. Characterization of acute ischemia-related physiological responses associated with remote ischemic preconditioning: A randomized controlled, crossover human study. Physiol Rep 2(11):e12200-e12200, 2014.

36. Surkar SM, Bland MD, Mattlage AE, Chen L, Gidday JM, Lee JM, Hershey T, Lang CE. Effects of remote limb ischemic conditioning on muscle strength in healthy young adults: A randomized controlled trial. PLoS ONE 15(2):1-19, 2020.

37. Tanaka D, Suga T, Tanaka T, Kido K, Honjo T, Fujita S, Hamaoka T, Isaka T. Ischemic preconditioning enhances muscle endurance during sustained isometric exercise. Int J Sports Med 37(8):614-618, 2016.

38. Westerblad H, Allen DG, Bruton JD, Andrade FH, LÄNnergren J. Mechanisms underlying the reduction of isometric force in skeletal muscle fatigue. Acta Physiol Scand 162(3):253-260, 1998.

39. Wilk M, Krzysztofik M, Jarosz J, Krol P, Leznicka K, Zajac A, Stastny P, Bogdanis GC. Impact of ischemic intra-conditioning on power output and bar velocity of the upper limbs. Front Physiol 12:626915, 2021.

40. Williams N, Russell M, Cook CJ, Kilduff LP. The effect of lower limb occlusion on recovery following sprint exercise in academy rugby players. J Sci Med Sport 21(10):1095-1099, 2018.