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Acute effect of ischemic preconditioning with different pressures on training volume, work, and fatigue index in an upper limb session

Efecto agudo del precondicionamiento isquémico con diferentes presiones sobre el volumen de entrenamiento, el trabajo y el índice de fatiga en una sesión de miembro superior

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Abstract. This study aimed to assess the acute effects of ischemic preconditioning at varying pressures on training volume, work, and fatigue index during an upper limb workout session. The sample consisted of 13 participants, comprised of six women and seven men. Each subject was directed to two training sessions that included a bench press and a closed-row exercise. They executed three sets up to concentric failure at 75% of their one-repetition maximum, with two minutes of recovery between sets and exercises. Prior to each experimental session, participants underwent four cycles of five-minute ischemia-reperfusion applied unilaterally and alternately to the arms. In one protocol, the pressure point was set at 50 mmHg above the resting systolic blood pressure, while in the other, a fixed pressure of 220 mmHg was applied. The 50 mmHg protocol led to greater work ($p=0.02$) and volume ($p=0.01$) in the closed-row exercise, and additionally, it resulted in a higher overall work ($p=0.04$). For enhanced upper limb performance, the protocol of 50 mmHg above resting systolic blood pressure proved more effective.
Keywords: Ischemic Preconditioning, Strength Training, Upper Limbs, Training Volume, Pressure Occlusion

Resumen. Este estudio tuvo como objetivo evaluar los efectos agudos del precondicionamiento isquémico a diferentes presiones sobre el volumen de entrenamiento, el trabajo y el índice de fatiga durante una sesión de entrenamiento de las extremidades superiores. La muestra estuvo compuesta por 13 participantes, conformada por seis mujeres y siete hombres. Cada sujeto fue dirigido a dos sesiones de entrenamiento que incluían un press de banca y un ejercicio de remo cerrado. Ejecutaron tres series hasta el fallo concéntrico al 75% de su máximo de una repetición, con dos minutos de recuperación entre series y ejercicios. Antes de cada sesión experimental, los participantes se sometieron a cuatro ciclos de isquemia-reperfusión de cinco minutos aplicados unilateralmente y alternativamente en los brazos. En un protocolo, el punto de presión se fijó en 50 mmHg por encima de la presión arterial sistólica en reposo, mientras que en el otro se aplicó una presión fija de 220 mmHg. El protocolo de 50 mmHg condujo a un mayor trabajo ($p=0,02$) y volumen ($p=0,01$) en el ejercicio de remo cerrado y, además, resultó en un mayor trabajo general ($p=0,04$). Para mejorar el rendimiento de las extremidades superiores, el protocolo de 50 mmHg por encima de la presión arterial sistólica en reposo resultó más eficaz.
Palabras clave: Precondicionamiento Isquémico, Entrenamiento de Fuerza, Miembros Superiores, Volumen de Entrenamiento, Oclusión por Presión.

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Introduction

Ischemic preconditioning (IPC) is defined as minor episodes of ischemia followed by reperfusion and was initially described in the scientific literature as a protective intervention against damage to cardiomyocytes caused by myocardial infarction (Murry et al., 1986). Furthermore, this method is currently emerging as an interesting strategy for improving performance in different sports (Caru et al., 2019) and different types of exercises (Gorman et al., 2023).

Given the ergogenic physiological hypotheses of the method, some investigations concentrated their efforts on investigating the IPC on sports performance and were divergent in the methodological scope. However, at the methodological level, there is no consensus on the pressure values used in IPC ischemia cycles. In cycling, variations are observed ranging from fixed values of 220 mmHg to 250 mmHg (Paixão et al., 2014; De Groot et al., 2010; Clevence et al., 2012) to values that exert occlusion pressure, having as a reference to the subjects' resting systolic blood pressure (SBP) (Lalonde & Curnier, 2015; Crisafulli et al., 2011). Runners and swimmers have also been investigated under this scope and showed improved performance with occlusion pressures of a fixed 220 mmHg and 15 mmHg above resting SBP, respectively (Jean-St-Michel et al., 2011; Bayle et al., 2012; Marocolo et al., 2015).

In addition to the sports activities reported, some studies within the scope of strength training have also analyzed the effect of IPC as an intervention aiming to improve performance (Marocolo et al., 2016; Telles et al., 2020). Likewise, there is still no consensus in the literature regarding vascular occlusion pressure values in the IPC; values vary from 10 to 300 mmHg (Tanaka et al., 2016; Carvalho; Barros, 2019, Da Silva Telles et al., 2023; Dantas et al., 2024), and it appears that both vascular occlusion partial (low pressure) and total occlusion (high pressure) are capable of positively affecting muscle performance.

Some studies compared the effects of IPC with 220 mmHg and SHAM with 20 mmHg on muscular endurance in resistance exercise for the lower limbs and upper limbs and found that IPC increased the number of maximum repetitions for both occlusion pressures. (Marocolo et al. 2016a; 2016b). Souza et al. (2021) reported improvement in repetition performance for high pressure (220 mmHg) and low pressure (20 mmHg) when compared to control. However, Paradis-Deschênes et al. (2016; 2017) found results only for high-pressure IPC (200 mmHg) on force production for knee extensions. Additionally, da Silva Novaes et al. (2021) demonstrated that only high-pressure IPC (220mmHg) increased repetition performance and total volume in a resistance exercise session.

Even though the use of low occlusion pressure in the IPC (e.g., 20 mmHg) has been applied and understood as a placebo protocol, which is called "SHAM" (Marocolo et al., 2016; Da Silva Novaes et al., 2021) and some authors (Marocolo et al. 2016a,b, Souza et al. 2021) suggest that there is a psychophysiological effect when low pressures are used (for example, 20 mmHg), which could justify the increase in performance. On the other hand, Mouser et al. (2018) demonstrated that even a pressure of 15 mmHg induces a significant reduction of 30% in blood flow and almost 50% in resting values with a pressure of 30 mmHg. Furthermore, Telles et al. (2022) recently demonstrated that IPC applied with 20 or 220 mmHg could alter the autonomic response and acutely increase maximum strength in resistance exercises of the upper and lower limbs.

However, the discrepancy between the protocols in occlusion pressures suggests a gap in the literature in regarding the optimal pressure applied for strength training performance. Therefore, the aim of the present study was to compare the acute effect of ischemic preconditioning with different pressures on training volume, work, and fatigue index in an upper limb training session.

Methods

Sample

The sample consisted of thirteen individuals (six women and seven men) experienced in resistance exercise (RE). All sample descriptive characteristics, as well as information related to their training routine, are described in Table 1. Individuals who presented a positive PAR-Q questionnaire, osteoarticular injury that compromised the execution of the movements necessary for the study, individuals who presented any diagnosed cardiovascular impairment, as well as chronic degenerative diseases such as hypertension and diabetes and use of any medication or ergogenic aid that could interfere with the tests were excluded from the sample. The inclusion criterion considered was that individuals had at least one year of experience in strength training.

Individuals were instructed not to use any substance that could affect the performance of the tests, such as caffeine, thermogenic, and tranquilizers, and not to perform physical exercises 24 hours before the experimental sessions. The techniques for performing the exercises were standardized and followed in all tests and sessions.

Table 1.
Descriptive sample characteristics.

Characteristics	Mean ± Standard Deviation
Age (years)	25.61 ± 4.07
Heigth (cm)	171.15 ± 11.85
Body Mass (kg)	70.38 ± 15.60
Training Experience (years)	3.03 ± 2.64
Training Frequency (days/week)	3.61 ± 1.12

Experimental Design

The initial screening consisted of an anamnesis to apply the inclusion and exclusion criteria. Thus, the individuals selected to compose the sample group made four non-consecutive visits to the testing site, with a minimum interval of 48 hours between load tests and 72 hours between experimental sessions. During the first and second visits, the test and retest of one maximum repetition (1 RM) for the bench press and closed row were performed; on the third and fourth visits, the protocol was performed with occlusion of 50 mmHg above the resting SBP (IPC-50) and the protocol with fixed 220 mmHg occlusion (IPC-220) with random entry of the protocols.

Before starting each protocol, the participant was instructed to sit for 10 minutes to stabilize resting blood pressure. Then, blood pressure was measured using the oscillometric method using an ambulatory blood pressure monitor (ABPM) model (PM50 NIBP/Spo2; CONTEC, USA). After removing the monitor, cuffs were placed on both arms (Missouri-Mikatos, ref. 102 NYL), the device pressure was adjusted according to the protocol to be performed by the participant, and then the occlusion maneuver was performed. Afterward, the exercise session was initiated.

In each experimental session, the bench press (BP) and closed-row (CR) work (sum of repetitions of the three sets in each exercise), total work (sum of the BP work with that of the CR), BP and CR separated volume (multiplication of the work of each exercise by the load corresponding to 75% 1-RM of each individual), total volume (sum of the volume of the BP and the CR), and fatigue index of each exercise ([repetitions performed in the first sets/repetitions of the third series] * 100) were recorded.

One Repetition Maximum Test

For maximal load testing purposes (1-RM), both the BP and CR exercises were conducted over two days, with a minimum interval of 48 hours between testing sessions. On the first day, the 1-RM test was performed in the BP and CR, with a ten-minute interval between them. On the second day, after a minimum of 48 hours, the tests were repeated to compare the measurement's reproducibility. A maximum of three attempts were made for each exercise daily, with a five-minute interval between them. The highest load achieved between the test days was considered the load of 1-RM (Paz et al., 2013).

In order to minimize the margin of error in the tests, the following strategies were adopted: (a) standardized instructions were provided before the test so that the person being evaluated was aware of the entire routine that involved data collection; (b) the person being evaluated was instructed on the technique for performing the exercise; (c) the evaluator was attentive to the position adopted by the practitioner at the time of the test, as slight variations in the positioning of the joints involved in the movement could activate other muscles, leading to erroneous interpretations of the scores obtained; (d) verbal stimuli were carried out to maintain a high level of motivation (Miranda et al., 2013).

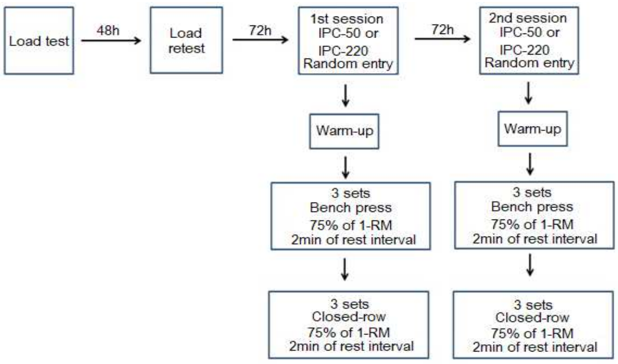

Figure 1. Design of the study; IPC-50: ischemic preconditioning with 50 mmHg above systolic arterial pressure; IPC-220: ischemic preconditioning with 220 mmHg; 1RM: one maximum repetition.

Training Sessions

The pressure cuffs were placed on both arms on the medial portion of the biceps. The device pressure was adjusted according to the protocol to be performed by the participant, and the cuff inflation cycles started alternately. For the IPC-50 protocol, the adjusted pressure was 50 mmHg above the individual's resting SBP, consisting of four cycles of five minutes of alternating unilateral ischemia followed by five minutes of reperfusion, totaling 20 minutes of occlusion in each arm (Souza et al., 2021). For the IP-220 protocol, the adjusted pressure was a fixed 220 mmHg overall and the procedure also consisted of four cycles of five minutes of alternating unilateral ischemia followed by five minutes of reperfusion, totaling 20 minutes of occlusion in each arm (da Silva Novaes et al., 2021). The beginning of each protocol was preceded by a warm-up consisting of a series of 20 repetitions with 40% of the 1-RM load (Simão et al., 2012). After a two-minute break, three sets of the bench press were performed with 75% of the 1-RM load, followed by three sets of the close row with 75% of the 1-RM load, with a two-minute rest interval between sets and exercises. During all sets, the number of completed repetitions performed with the correct technique and maximum amplitude was recorded to compare each group's volume. Figure 1 illustrates the data collection procedures.

Statistical Analysis

Descriptive statistics were applied to characterize the sample, using the mean and standard deviation as central tendency and dispersion measures, respectively. The intraclass correlation coefficient (ICC) was applied to evaluate the load tests' reproducibility. The inferential procedure was initially carried out using the Shapiro-Wilk normality and homoscedasticity tests. Following normality not being rejected, the paired t-test was applied to determine whether there were significant differences between the two protocols on the variables: number of repetitions per set and total, volume of the bench press and closed row, total volume and fatigue index). For all inferential analyses, a value of $p < 0.05$ was adopted. Statistical treatment was performed using SPSS software version 18.0 (Chicago, IL, USA).

Results

The ICC for the BP and CR were 0.998 and 0.991, respectively, demonstrating excellent reproducibility.

A significant difference was identified between the occlusion pressures of the two protocols ($p = 0.00$), thus ensuring that the occlusion pressures were significantly different. Significant differences were found in relation to CR exercise for the following performance measures: work ($p = 0.02$) and volume ($p = 0.01$). There was also a significant difference between the IPC protocols for total work ($p = 0.04$). For the other performance measures, whether for BP or CR, no significant differences were found between the experimental protocols ($p > 0.05$). Table 2 illustrates the results of each measurement for each exercise, as well as portraying the level of significance found for each experimental protocol in each dependent variable.

Table 2.
Experimental sessions performance. *

Variables	Females			Males		
	IPC-50	IPC-220	% difference (ES)	IPC-50	IPC-220	% difference (ES)
1st set of the bench press	14.0 ± 4.2	11.7 ± 3.9	20% 0.59	11.1 ± 3.0	9.9 ±3.3	13% 0.39
2nd set of the bench press	8.3 ± 3.4	6.8 ± 3.2	22% 0.47	6.0 ± 1.5	4.1 ± 1.9	44.8% 1.00
3rd set of the bench press	7.0 ± 4.4	5.3 ± 3.1	31.3% 0.54	4.6 ± 1.3	3.6 ± 1.1	28% 0.88
Bench press work	29.3 ± 11.8	23.8 ± 9.6	23.1% 0.57	21.7 ±5.4	17.6 ± 5.3	23.6% 0.78
1st set of the closed row	15.5 ± 2.4	13.5 ± 5.4	14.8% 0.37	13.3 ± 2.1	11.9 ± 1.9	12% 0.77
2nd set of the closed row	11.5 ± 2.4	8.8 ± 4.6	30.2% 0.58	8.7 ± 1.9	7.4 ± 1.0	17.3% 1.32
3rd set of the closed row	8.8 ± 1.9	7.8 ± 2.7	12.8% 0.37	7.4 ± 1.4	5.7 ± 1.6	31.1% 1.08
Closed-row work	34.8 ± 3.8	30.2 ± 12.0	18.8% 0.47	29.4 ± 5.2	24.1 ± 2.6	21.9% 2.03
Total work	65.2 ± 10.0	54.0 ± 20.2	20.7% 0.55	51.1 ± 8.6	41.7 ± 5.9	22.6% 1.60
Bench press fatigue index	240.8 ± 105.7	260.6 ± 115.8	8.2% 0.15	250.0 ± 58.1	295.0 ± 113.6	18% 0.77
Closed-row fatigue index	183.4 ± 51.6	173.1 ± 44.5	5.6% -0.12	180.6 ± 16.0	239.6 ± 91.7	32.7% 0.97

*Significant difference between experimental protocols ($p > 0.05$); IPC-50: preconditioning ischemia at 50 mmHg above the individual's resting systolic pressure; IPC-220: preconditioning ischemia at 220mmH; Fatigue Index: (number of repetitions in the first set/number of repetitions in the third set) *100; m = mean; sd = standard deviation; mmHg = millimeters of mercury.

Discussion

The objective of the present study was to compare the acute effect of ischemic preconditioning with different pressures on training volume, work, and fatigue index in an upper limb RE session. The main findings suggest significant differences with a greater volume of repetitions, closed-row exercise work and total work in the IPC-50 protocol compared to the IPC-220.

Our findings demonstrated that the IPC with 50 mmHg above SBP (165.76 ± 11.51 mmHg) significantly increased the number of repetitions and total work in the closed row exercise compared to the IPC protocol with 220 mmHg. Several studies have investigated the effects of IPC applied with different pressures on the number of repetitions in resistance training (Marocolo et al., 2016; da Silva Novaes et al., 2021; Souza et al., 2021; Telles et al., 2022). Marocolo et al. (2016) compared three experimental protocols, IPC with 20 mmHg, 220 mmHg, and control, before the elbow flexion exercise on the *Scott machine*. The results demonstrated that both pressures could increase the number of repetitions and total training volume compared to the control. Souza et al. (2021) compared the effect of applying IPC for five consecutive days in 3 different protocols, high IPC (220 mmHg) and low pressure (20 mmHg) and control, on the performance of repetitions in the knee extension exercise. The results demonstrated that both high-pressure IPC and low-pressure IPC significantly increased the number of repetitions in knee extension. Recently, Telles et al. (2022) compared the acute effect of IPC with three experimental protocols, IPC with 20 mmHg, 220 mmHg, and control on the performance of maximum strength tests in 6 multi-joint exercises (bench press, leg press 45, front pull, hack squat machine, press, Smith squat). The results demonstrated that both pressures could significantly increase maximum strength performance in resistance exercises compared to the control, not corroborating to our findings.

On the other hand, da Silva Novaes et al. (2021) investigated the acute effect of IPC in a training session in 3 protocols, IPC with 20mmHg, 220 mmHg, and control, on the number of repetitions and total training volume in 6 multi-joint exercises (bench press, leg press 45, front pull, squats on the hack machine, press, squats on the Smith machine). The results of this study demonstrated that the IPC with 220 mmHg was able to significantly increase the number of repetitions and total volume in all resistance exercises compared to the IPC with 20 mmHg and the control, contradicting the results of the present study, as the protocol with more significant occlusion pressure that was able to generate a positive effect on performance.

However, most studies that showed positive effects of IPC at higher occlusion pressure (Tanaka et al., 2016; Paradis-Deschenês et al., 2016; da Silva Novaes et al., 2021) or at different occlusion pressures (20- 220 mmHg) (Marocolo et al., 2016; Souza et al., 2021; Telles et al., 2022) did not consider the individuals' blood pressure values when applying the IPC, mainly, considering that a restriction made to 15 mmHg induces a significant reduction of 30% in blood flow followed by almost 50% of resting values with a pressure of 30 mmHg. Therefore, determining a fixed occlusion pressure value (e.g., 220 mmHg) may not be effective in all individuals, given that individuals will present different blood pressure values.

Therefore, when pressure values are based on individuals' SBP, the protocol seems more efficient by generating personalized occlusion. Jean St-Michel et al. (2012) tested the effect of IPC with a pressure of 15mmHg above the resting SBP of individuals in their sample group. This maneuver was performed on the upper limbs of swimmers, and an improvement in time in the 200-meter test was observed. Telles et al. (2022) applied IPC with a pressure of 15 mmHg above resting SBP in active older women, and an improvement in isometric handgrip strength and functional capacity was observed when compared to protocols with 20 mmHg pressure and control.

Furthermore, Sharma et al. (2014) concluded that vascular occlusion in the upper limbs occurs when pressures reach around 30 mmHg above SBP, while in the lower limbs, they occur close to 55 mmHg. Thus, using exacerbated pressures to block blood flow ultimately might not be necessary, however, it is crucial to clarify in the literature whether pressures far above those sufficient to perform occlusion have a reverse effect on individuals' performance. One should observe that fatigue is a multifactorial and complex phenomenon involving the central and peripheral nervous system, whose reduction in contraction and relaxation is due to the increase in hydrogen ions, ADP, and inorganic phosphate concentration at muscle levels. This accumulation is dependent on the blood flow and oxygen transport during exercise (Amann & Calbet, 2008).

The current study has some limitations, such as the sample consisting of men and women. Thus, Paradis-deschenês et al. (2017) demonstrated that the application of IPC generated a greater effect on improving strength in men when compared to women. It is known that different genders have different characteristics concerning strength training due to the different concentrations of hormones, mainly testosterone, which influence strength production (Casadio et al., 2017). Furthermore, familiarization with the cycles of ischemia in the upper limbs was not carried out, which may have caused psychological interference in individuals during the execution of the protocols. Future research could compare different IPC protocols to make it more practical and viable, in terms of time, as a potential legal ergogenic resource to improve athletes' performance before competitions.

Conclusion

Applying IPC with a pressure of 50 mmHg above SBP in the upper limbs improved CR work, volume, and total work when compared to the application with a pressure of 220 mmHg. Thus, the results suggest that the physiological effects promoted by IPC may be more efficient when applied to the upper limbs with more individualized pressures.

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