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Acute Effects of Ischemic Preconditioning at Different Occlusion Pressures on Athletic Performance Indicators in Male Soccer Players

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ABSTRACT

Ischemic preconditioning (IPC) has been shown to improve exercise performance, but many factors related to IPC administration are unresolved. This study evaluated the effect of IPC performed with different pressures for exercise performance. Fifteen collegiate male soccer players completed five separate sessions in randomized order. For each session, blood pressure cuffs were placed on the thigh bilaterally, and IPC was administered in 2x5 minute cycles at cuff pressures of 0%, 25%, 50%, 75%, or 100% of each participant's limb occlusion pressure (LOP), the pressure needed to occlude arterial flow of blood to the leg. Participants then completed vertical jump, soccer passing accuracy, and 1,600 meter run tests. Repeated-measures analysis of variance was used to assess differences in outcomes across the five trials. There were no significant differences in vertical jump or passing accuracy across the five trials. However, 1,600 meter run times were significantly faster for the 50-75% trials than the 0-25% trials (mean difference 7.1-8.4 seconds). In summary, IPC pressures below LOP improved running times while not negatively influencing jumping or passing accuracy in collegiate soccer players. Improved comfort and reduced risk from using cuff pressures below LOP may facilitate more effective IPC use in field-based settings.

Keywords: limb occlusion pressure, arterial occlusion pressure, blood flow restriction, ergogenic aid, sport science

INTRODUCTION

Over the past 10-15 years, there has been interest in the use of ischemic preconditioning (IPC), the occlusion of blood to the limbs prior to exercise, in the hope of improving exercise performance (O'Brien & Jacobs, 2021). Early research in the field found that repeated 5-minute bouts of full occlusion to the lower limb, interspersed with reperfusion, could acutely improve maximal aerobic capacity, power output, or race/event times for activities such as cycling, running, and swimming (Bailey et al., 2012; de Groot et al., 2010; Jean-St-Michel et al., 2011). The possibility that wearing inflated blood pressure cuffs on the limbs prior to exercise can improve subsequent exercise performance is intriguing; however, several reviews have been published on the effects of IPC on exercise performance, arriving at differing conclusions on its efficacy as an ergogenic aid. A review by Marocolo et al. (2016) found that few high-quality studies demonstrated improvements in exercise performance following IPC, whereas reviews by Caru et al. (2019), Incognito et al. (2016), and Salvador et al. (2016) found evidence of some beneficial effect of IPC on exercise performance.

A recent review by O'Brien et al. (2021) posits that inconsistent findings on IPC's efficacy are likely related to differences in the parameters used for IPC as well as the variety in outcomes of interest. When designing an IPC protocol, researchers are faced with numerous protocol decisions: cuff location on the limbs (IPC [occluding the tissue that will simultaneously be focused on for exercise] vs. remote IPC [occluding a tissue different from the target tissue during exercise, for example occluding the arms prior to leg cycling]), cuff inflation pressure, cuff width and diameter, limb occlusion duration, number of cycles of ischemia and reperfusion, time between IPC and the initiation of exercise, whether the IPC is performed once (acute) or over multiple days (chronic), and whether the participants are passive (seated/lying) during IPC or active (engaged in light-intensity activity) during IPC. Additionally, outcomes of interest span different exercise types (running, cycling, swimming, resistance training) and intensities (maximal, submaximal performance). Lastly, there is currently a dearth of literature examining the impact of IPC on sport-specific activities and skills. Some of the inconsistency in past work is likely due to differences in such choices across studies, necessitating more research to identify which IPC parameters are most likely to produce ergogenic effects and which performance outcomes are most likely to be affected.

The recent review by O'Brien et al. (2021) highlights several trends in IPC protocols. For example, past research overwhelmingly used high absolute occlusion pressures (e.g., ≥220 mmHg) for cuffs placed on the thighs with the assumption that full limb occlusion pressure (LOP) would be achieved for essentially all individuals being tested. However, high cuff pressures are both uncomfortable and potentially dangerous, with high cuff pressures increasing risk for conditions such as bruising and limb numbness (Nakajima et al., 2006). Therefore, for compliance and safety it is important to tailor cuff pressures to individual needs. Additionally, with the exception of studies utilizing sham designs (trials with cuff pressures of 10-20 mmHg) to mitigate potential placebo effects (da Mota & Marocolo, 2016; M. Marocolo, da Mota, et al., 2016; M. Marocolo, Willardson, et al., 2016), we are unaware of research which has purposely used cuff pressures below LOP in order to understand the effects of partial arterial occlusion on exercise performance. Among the proposed mechanisms for IPC's effectiveness are local vasodilatory responses to shear stress or metabolite buildup (Gu et al., 2021; Lu & Kassab, 2011) as well as to hormonal or systemic effects (Addison et al., 2003; Wang et al., 2004). Many of these effects should occur even with lower cuff pressures, as venous outflow from the limb is occluded at lower pressures than arterial inflow due to the more superficial nature of veins as well as the lower pressures in the venous system. The appeal of lower cuff pressures is twofold. First, lower cuff pressures are more comfortable than high cuff pressures (Jessee et al., 2017; Mattocks et al., 2017), so use of lower cuff pressures may enhance compliance to IPC protocols. Additionally, higher cuff pressures have been shown to confer higher risk of cuff-related injury (Graham et al., 1993; Olivecrona et al., 2012), and using lower cuff pressures would mitigate such risk.

Additionally, improvements in laboratory-based performance parameters (e.g., maximal aerobic or anaerobic power, fatigue resistance) may not directly translate to field-based settings and/or may be offset by decrements in skill performance, especially if participants experience residual effects of IPC such as temporary numbness of the occluded area (Nakajima et al., 2006). As such, it is important to directly assess sport-specific outcomes (e.g., shooting, passing, kicking, and/or dribbling). Soccer (association football) is among the most popular sports in the world and requires a mix of endurance (often running 8-12 km or more in a match), jumping ability, and prowess in kicking a ball with high accuracy (Bangsbo et al., 1991; Helgerud et al., 2001). The required high-level proficiency in both aerobic and anaerobic power make it a sport that could directly benefit from IPC given IPC's previously observed benefits. Additionally, players are seated during halftime and when on the bench waiting to be substituted into a match, offering periods where IPC, if found to have efficacy, could be performed both prior to and during competition. One study by Marocolo et al. (2017) found no improvement in running performance on a high-intensity intermittent running test when using IPC vs. a sham condition, but we are unaware of other studies assessing function in soccer players or examining other outcomes relevant to soccer performance. Therefore, research seeking to determine if IPC is effective in athletes of specific sports (such as soccer) and if sport-specific outcomes are affected by IPC is warranted and necessary.

The purpose of this study was to examine the effect of lower limb IPC using different cuff pressures on vertical jump performance, soccer passing accuracy, and 1,600 meter run time in collegiate male soccer players. We hypothesized that inflation of cuffs to 50% of LOP and greater would result in improvements in running and jumping performance without negatively affecting soccer passing accuracy.

MATERIALS AND METHODS

Participants

Male soccer players aged 18-24 years who were currently on the roster of a collegiate team were recruited for the study, with data collected during the fall of 2021. Participants were excluded if they had an injury or health condition that precluded their ability to exercise at maximal or near-maximal capacity or if they had conditions which increased blood clotting risk. In total, 20 participants consented to be in the study, but only 15 completed all five protocols and were therefore eligible for inclusion in the final analysis. Of the five who did not complete all testing, one elected not to be in the study after initially consenting and the other four either got injured during practices/ games, were too sore (due to being in-season) to complete a session, or contracted COVID-19 and were ineligible to complete the remaining sessions. Demographic information for the players who started and completed the study can be found in Table 1. Prior to participant recruitment, all study methods were approved by the Alma College Institutional Review Board (IRB#: R_2TtaSTU4NaUEYd2), and all participants provided written informed consent expressing willingness to be in the study.

With a desired alpha level of 0.05 and power of 80%, our original sample size was sufficiently powered to detect medium effect size (≥0.50). However, the loss of potential participants to 15 increased the minimum effect size to ≥0.65 for determining statistically significant difference across conditions (determined using G*Power version 3.1.9.7).

Procedures

This study utilized a case crossover experimental design. Participants completed five trials in randomized, counterbalanced order, thereby acting as their own control and minimizing potential learning effects or effects of weather changes on outcome measures. Trials took place at least 48 hours apart and were performed at similar time of day to eliminate potential circadian effects on physiologic function. Aside from collecting demographic information on the first visit only, visits were identical, other than for the amount of pressure applied in the cuffs prior to testing.

Participants were to refrain from exercise, stimulants (e.g., caffeine), and consuming Caloric foods or beverages for at least three hours prior to their scheduled visit. Upon arrival to the Human Performance Laboratory at Alma College, participants self-reported their age, height, weight, and playing position. Next, participants laid supine on a yoga mat and were fitted as proximally as possible on the right thigh with a cuff (11.5 cm width) connected to a Delfi Personalized Tourniquet System (Delfi Medical Innovations, Inc., Vancouver, BC, Canada), which has been validated for assessment of LOP (Masri et al., 2016). Once fitted, the "Personalized Tourniquet

Table 1. Demographic information for participants in study.

	Participants who began study (n=20)	Participants who completed study (n=15)
Age (years)	20.4 ± 1.1	20.5 ± 1.1
Height (cm)	179.0 ± 6.7	177.8 ± 6.3
Weight (kg)	74.1 ± 8.4	72.3 ± 6.1
Body mass index (kg/m2)	23.1 ± 1.9	22.9 ± 1.7
Player position		
- Defenders	n=9	n=7
- Midfielders	n=5	n=5
- Attackers	n=5	n=2
- Goalkeepers	n=1	n=1

Data are shown as mean ± standard deviation.

Pressure" program was run on the Delfi system, which increases pressure in the cuff by 10 mmHg every 2-3 seconds while simultaneously checking for cessation of blood flow (Masri et al., 2016). Once the LOP, defined as the amount of pressure needed to fully occlude the femoral artery, was found, the process was repeated on the left thigh. The LOPs from the participant's two limbs were averaged to determine a single LOP for the participant.

Next, participants were fitted with two thigh blood pressure cuffs (21 cm width; EverDixie, Dixie EMA Supply Co., Brooklyn, NY, United States) as proximally as possible (i.e., as close to the iliac crest as possible) on the thigh. The blood pressure cuff on the thigh of the dominant leg was inflated to the desired level for the given testing day (0%, 25%, 50%, 75%, or 100% of LOP determined by the Delfi) for five minutes, after which the pressure was released and the cuff on the thigh of the non-dominant leg was inflated to the same pressure for five minutes. This process then was repeated, resulting in 10 total minutes of occlusion for each limb. When used in previous research to occlude arterial blood flow to the lower limb, the EverDixie blood pressure cuffs have been shown to have mean differences of less than 10mmHg compared to commonly used Hokanson blood pressure cuffs (Montoye et al., 2023).

Upon completion of the leg occlusion, participants moved to performance testing, where they performed a brief, self-paced warm-up (walking, dynamic stretches recommended) before completed jumping, soccer passing, and running assessments. These assessments allowed for determination of power, sport-specific skill, and aerobic endurance, respectively, as is common when performing physiologic evaluations of soccer players (Hoff, 2005; Stølen et al., 2005). Additionally, these tests were chosen in consultation with local collegiate players and coaches and were similar to drills and tests conducted by their teams. This served two important purposes, 1) to confirm that the tests reflected important attributes related to soccer performance and, 2) to reduce the likelihood of learning effects since participants were already familiar with the types of testing being performed.

The first test completed was the vertical jump test, where participants performed three trials of standing vertical jump, jumping as high as possible from a stationary position and touching the highest possible flags on the Vertec vertical jump tester (Sports Imports, Hilliard, OH, USA). The maximal height of the three jumps was used for data analysis. Prior to this test, participants were allowed to complete practice trials to ensure test familiarity. For all participants and sessions, vertical jump testing was completed within ~10 minutes of completion of the IPC protocol.

Next, participants walked ~5 minutes to an outdoor turf field for a soccer passing accuracy test. For the test, cones were set 2.0 meters apart (chosen because this would be roughly the length of one stride left or right from a standing position), and the participant was positioned ~20 meters from the cones with a pile of 20 regulation size soccer balls. When the participant was ready, a timer was started, and participants had 15 seconds to complete as many passes as possible where the ball would travel between the two cones. The total number of passes successfully passed between the cones, and the percentage of attempted passes which traveled successfully between the cones, were recorded for analysis. Participants completed a practice trial before completing the passing test to ensure familiarity with the test procedures. This testing protocol was developed in consultation with collegiate soccer players and coaches as described above. The aim was to assess passing speed and accuracy, which is critical in high level soccer performance. The passing test was completed within ~15-20 minutes of completion of the IPC protocol.

Finally, following a short rest, participants completed a maximal 1,600 meter run by completing four laps around a 400-meter outdoor track. Participants were instructed to complete the run as quickly as possible, and their time on the run was recorded to the nearest second for analysis. The 1,600 meter run was completed within ~30-40 minutes of completion of the IPC protocol.

As mentioned earlier, the five visits were identical save for the amount of pressure placed in the cuffs prior to testing. Participants had one visit each where the pressure in the cuffs was 0%, 25%, 50%, 75%, and 100% of LOP. Order of pressures was randomized to avoid potential learning or time-order effects.

Statistical analyses

For each outcome (vertical jump height, passing accuracy, 1,600 meter run time) a repeated-measures analysis of variance test was performed. In the event of a significant test statistics, post hoc pairwise comparisons were conducted using a least significant difference correction, and a *p*-value of *p*<0.05 used to denote statistical significance. Additionally, a smallest worthwhile change analysis was conducted, where a practically meaningful difference between trials was determined when the difference between trials exceeded 0.6*standard deviation of the difference between trials (M. Marocolo et al., 2019). Finally, effect sizes were calculated, with effect sizes interpreted as < 0.20 = trivial, 0.20 ≤ and < 0.50 = small, 0.50 ≤ and < 0.80 = medium, 0.80 ≤ and <1.30 = large, and > 1.30 = very large (Cohen, 1988). Using G*Power with a desired power of 0.8, our sample size of 15 allowed significant differences to be determined for effect sizes of ~0.5 or larger (Faul et al., 2007). All analyses were performed in SPSS version 24.0 (IBM Corp., Armonk, NY, USA) and Microsoft Excel 2016 (Microsoft Corp, Redmond, WA, USA).

RESULTS

Data from the three tests are shown in Table 2. There were no significant differences in vertical jump height across the five trials [F(4, 65) = 0.071, *p* = 0.989], and the smallest worthwhile change analysis (Table 3) revealed no meaningful differences across any trials. Additionally, effect sizes were trivial. Similar results were found for passing accuracy, expressed both as a percentage [F(4, 65) = 0.600, *p* = 0.671]

Table 2. Results of vertical jump, soccer passing, and 1,600m run tests across trials preceded by ischemic preconditioning using 0%, 25%, 50%, 75%, and 100% of limb occlusion pressure.

	Percentage of limb occlusion pressure				
	0%	**25%**	**50%**	**75%**	**100%**
Jump height (cm)	57.9±7.7 (54.0; 61.8)	57.3 ±7.7 (53.4; 61.2)	57.5 ±7.9 (53.5; 61.5)	57.4 ±7.4 (53.7; 61.2)	57.2 ±9.1 (52.5; 61.8)
Pass accuracy (%)	68.9 ±23.3 (57.0; 80.7)	74.5 ±20.0 (64.4; 84.6)	69.5 ±17.3 (60.7; 78.3)	76.0 ±18.7 (66.5; 85.5)	69.6 ±12.6 (63.3; 76.0)
Pass accuracy (# completed)	6.9 ±2.8 (5.4; 8.3)	7.3 ±3.7 (5.4; 9.2)	6.8 ±3.0 (5.3; 8.3)	7.4 ±3.7 (5.6; 9.3)	7.1 ±4.0 (5.1; 9.2)
1,600m run (s)	391.2 ±25.2 (378.4; 403.9)	391.1 ±28.2 (376.8; 405.4)	381.5 ±22.9*^ (369.9; 393.0)	382.9 ±27.5* (369.0; 396.9)	385.8 ±27.5 (372.8; 398.9)

Data are shown as mean ± standard deviation (95% confidence interval).
**Indicates significant difference from 25% occlusion (p<0.05).*
^Indicates significant difference from 0% occlusion (p<0.05).

Table 3. Smallest worthwhile change and effect size analyses for differences in performance across trials preceded by ischemic preconditioning using 0%, 25%, 50%, 75%, and 100% of limb occlusion pressure.

	Vertical jump (cm)			Successful pass percentage (%)			Successful pass number			1,600 meter run time (s)		
Trials	**SWC**	**MD**	**ES**	**SWC**	**MD**	**ES**	**SWC**	**MD**	**ES**	**SWC**	**MD**	**ES**
0 vs. 25	0.8	0.3	0.16	19	10	0.20	1.7	0.6	0.14	6.8	0.1	0.01
0 vs. 50	0.9	0.0	0.10	16	4	0.03	1.5	0.1	0.03	7.3	8.4*	0.69
0 vs. 75	0.8	0.3	0.15	14	9	0.31	1.8	0.7	0.18	7.6	7.1	0.56
0 vs. 100	1.7	0.3	0.10	12	1	0.04	1.9	0.4	0.09	9.2	4.6	0.30
25 vs. 50	1.0	0.3	0.05	16	6	0.17	1.8	0.5	0.16	10.4	8.3	0.48
25 vs. 75	0.8	0.0	0.03	15	1	0.06	1.3	0.1	0.06	6.4	7.1*	0.66
25 vs. 100	1.8	0.1	0.02	13	5	0.23	0.9	0.2	0.09	9.7	4.5	0.28
50 vs. 75	0.8	0.3	0.04	14	5	0.27	1.8	0.6	0.20	9.9	1.3	0.08
50 vs. 100	1.7	0.1	0.05	10	0	0.01	1.8	0.3	0.11	7.5	3.8	0.30
75 vs. 100	1.8	0.1	0.04	10	6	0.39	1.3	0.3	0.13	8.5	2.5	0.18

XX vs. XX: trials being compared. For example, 0 vs. 25 is the 0% occlusion trial compared to the 25% occlusion trial.
SWC: smallest worthwhile change.
MD: mean difference between trials.
ES: effect size.
**Indicates that difference between trials exceeded the smallest worthwhile change.*

and as a total number of passes [F(4, 65) = 0.275, *p* = 0.892]. Additionally, smallest worthwhile change analyses (Table 2) found no meaningful differences across trials for either passing variable, and all effect sizes were trivial or small.

For the 1,600 meter run, the analysis of variance was statistically significant [F(4,65) = 2.355, *p*=0.048]. Post hoc testing revealed no differences in run times among the 0%, 25%, and 100% occlusion trials. However, run times in the 50% trial were significantly faster than the 25% trial (mean ± standard deviation of differences was 8.3 ± 17.3 seconds; *p*=0.017). Additionally, run times in the 75% occlusion trial were significantly different than both the 25% (mean difference 7.1 ± 6.4 seconds; *p*=0.021) and 0% trials (mean difference 7.1 ± 7.6 seconds; *p*=0.047). The smallest worthwhile change analysis (Table 3) indicated practically meaningful differences between the 0% vs. 50% trials and the 25% vs. 75% trials. Furthermore, there were medium effect sizes for differences between the 0 % vs. 50%, 0% vs. 75%, and 25% vs. 50% trials.

DISCUSSION

Our study's purpose was to evaluate the effects of different IPC pressures on jumping, ball passing, and running performance in collegiate soccer players. Our data revealed run times that were ~1.8-2.2% faster following IPC at 50-75% compared to 0-25% of LOP and medium effect sizes, and there was no impact on vertical jump or soccer passing accuracy. Thus, both the 50 and 75% trials provide evidence that running times were significantly improved following a sub-occlusive administration of IPC.

Our findings add to a mixed evidence base. Improved maximal running capacity is supported by Bailey et al. (2012), who found a 2.3% improvement in 5,000 meter run performance following IPC compared to a sham condition. However, other studies found no effect of IPC on 2,400 or 5,000 meter run performance when the IPC was performed immediately and five minutes prior to the exercise, respectively (Montoye et al., 2020; Tocco et al., 2015), and a study by Marocolo et al. (2017) found no improvement in intermittent running performance in soccer players six minutes after IPC administration compared to a sham condition. A study by Seeger et al. (2017) found that IPC performed one hour prior to a 5,000 meter run was more strongly linked to performance than IPC performed 24 hours prior, suggesting that IPC timing may be important. Another study by Seeley et al. (2021) found that a 45-minute delay between IPC administration and exercise resulted in better recovery following sprint exercise than a 5-minute delay between IPC and exercise, and in our study the running trial took place within 30-40 minutes following completion of IPC. These studies together suggest that there might be an optimal time delay where IPC is most effective for improving running performance.

Our finding that maximal jump height did not improve with IPC is in accordance with a meta-analysis by Salvador et al. (2016) as well as original research studies by Garcia et al. (2017) and two by Gibson et al. (2013, 2015), all of which were in athlete populations. Despite one study showing improved force production during countermovement jump (Beaven et al., 2012), the majority of evidence suggests that IPC has little effect on jump performance. Our study was also the first to our knowledge to assess effects of IPC on a skill-based activity such as soccer ball passing accuracy. While there is not necessarily a reason to believe IPC would improve such activities given the purported physiologic mechanisms for IPC's effects on the body, it is encouraging to see that IPC did not negatively affect jump performance or passing accuracy. Given the need for high aerobic endurance for successful participation in competition soccer (Bangsbo et al., 1991), our findings provide preliminary evidence of efficacy of IPC for improving training and/or match play for male soccer players.

Aside from studies showing placebo effects in sham conditions, to our knowledge, our study is the first to show that occlusion pressures below that required for full arterial occlusion have ergogenic effects on exercise performance. The pressures used in the 50% and 75% trials in our study ranged from 36-105 mmHg. Past research by Hunt et al. (2016) found that, using a 13 cm width cuff, popliteal artery diameter was unchanged from baseline in a sample of men at pressures below 130 mmHg but that both blood velocity and total blood flow in the popliteal artery were decreased by ~30-40% at 90 mmHg (the lowest pressure they evaluated) and were decreased by ~70-75% at 130 mmHg. Hunt's study provides insight that, even in the absence of full arterial occlusion, there is substantial reduction in blood flow to the limb with lower IPC pressures, likely due to a backup of blood in the occluded venous system and/or reduction in available blood due to third spacing effects (Holcomb, 2008). Encouragingly, this implies that IPC pressures sufficient to occlude venous outflow from the limb should still activate many of the proposed local responses to IPC triggered by mechanisms related to metabolite buildup.

Additionally, participants in our study anecdotally reported more discomfort and dislike of the highest cuff pressure, and such emotional states may be detrimental to exercise performance (Lochbaum et al., 2021) and thereby counteract IPC's ergogenic benefit in some athletes. Improved comfort and lower injury risk with lower cuff/tourniquet pressures have also been shown in past work (McEwen et al., 2002), suggesting that lower cuff pressures are likely to improve compliance with field-based IPC protocols. Therefore, it may not be necessary mechanistically to use high cuff pressures to elicit favorable responses to IPC, and our study provides the first evidence supporting that field-based outcomes can be improved using pressures below those needed to achieve full arterial occlusion.

We note that due to the differences in cuff width in our study, it may not be the case that, for example, 50% LOP administered in the 21 cm cuff was truly 50% of LOP (as LOP was determined using a 11.5 cm cuff). However, a recent study from our lab revealed only a ~20 mmHg (~12%) lower LOP determined from the 21 cm cuff than the 11.5 cm cuff, indicating a high likelihood that each of the 0, 25%, 50%, and 75% trials in the present study were below LOP for participants (Montoye et al., 2023). Yet, from a practical standpoint, the fact that pressures set to 50% and 75% of LOP showed favorable outcomes in the current study, coupled with past research showing that pressures at or above LOP can improve performance (Caru et al., 2019; Incognito et al., 2016; Salvador et al., 2016), suggests that a range of cuff pressures can be used to achieve ergogenic effects when implementing IPC protocols.

Additionally, while past research has shown that cuff width affects LOP especially for narrow cuffs (McEwen et al., 2002; Mouser et al., 2017; Younger et al., 2004), with some cuffs unable to achieve LOP (Weatherholt et al., 2019), it may not be critically important to match cuff widths and pressures to those used in past research or to carefully control pressures used to get ergogenic benefit from IPC. However, our study and past work suggests that there is a certain minimum pressure necessary to elicit ergogenic effects, and future research should seek to identify the minimum pressure needed to improve exercise performance, which may also help to elucidate mechanisms most responsible for IPC's ergogenic effects on exercise. Moreover, it may be that the optimal pressure varies by training status and sport/activity performed, and this should be examined in future research. Clinical fields such as radiology use the concept of "as low as reasonably achievable" (ALARA) with the understanding that minimizing radiation and/or medication dose to achieve the desired diagnostic/therapeutic effect will optimize treatment strategies while minimizing risk of adverse side effects (Frane & Bitterman, 2022). The ALARA paradigm seems a reasonable way to approach IPC, where it is desirable to identify the minimal duration, cuff pressure, number of cycles, etc. in order to maximize effectiveness and feasibility of IPC while minimizing its burden, discomfort, and potential for negative side effects. While our study cannot shed light on IPC characteristics such as minimum bout duration or number of cycles, our data strongly suggest that pressures below LOP can produce ergogenic benefit. Further research should confirm this finding as well as identify minimal levels of other aspects of IPC administration to optimize its use.

Our study had several notable strengths. First, our inclusion of a 0% occlusion trial acted as a sham condition, and our use of three different outcomes additionally allowed us to assess potential placebo effects on our findings (de Souza et al., 2021). Second, our study used a specific population along with outcomes of relevance in their sport. Third, the smallest worthwhile change analysis added context for whether potential changes were practically meaningful, thereby complementing the formal statistical analysis.

Study limitations should also be considered. Our study did not assess physiologic mechanisms, so the reasons for the improvements in running performance following occlusion at 50-75% of LOP are unclear. Second, use of a force plate for jumping would have provided more insight into power production and may have yielded additional insights beyond simply testing jump height. Third, we standardized the order of physical tests to avoid potential warm-up or fatigue effects from affecting our results differently across trials. However, this meant that the jump and passing tests occurred closer in time to the IPC administration than the running test. Given the potential for a timing effect discussed earlier in this section, further testing should evaluate potential effects on jump and passing performance with a longer delay between IPC administration and testing. Finally, our study did not include female soccer players, and further research should determine if findings are different for females (possibly due to differences in tissue composition or limb size) and in other levels (e.g., elite, recreational) of skill.

In conclusion, our study found no effect of IPC on jumping or soccer passing drills but small improvements in endurance running performance when using cuff pressures of 50% and 75% of LOP, suggesting that there is a potential ergogenic effect of IPC performed at pressures below LOP when used in collegiate male soccer players. Our findings are promising but add to a limited research base related to athletes in specific sports. More research should be conducted to evaluate optimal IPC parameters, keeping in mind the balance between a protocol that achieves ergogenic benefit with one designed for practicality and ease of use. For example, our study found that lower cuff pressures, which are often reported as being more comfortable and better tolerated, yielded ergogenic benefit. However, our protocol required 20 minutes to complete, and it may be informative to see if shorter protocols (e.g., occluding both legs simultaneously instead of one at a time) can still achieve ergogenic benefits. Additionally, while running times improved in soccer players our study, it is likely that some participants benefited more than others, and identification of factors (e.g., player age, skill level, training status, sport being played) that may be related to if and how much IPC improves performance would allow for better determination on how to effectively use IPC in sport settings.

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REFERENCES

1. Addison, P. D., Neligan, P. C., Ashrafpour, H., Khan, A., Zhong, A., Moses, M., Forrest, C. R., & Pang, C. Y. (2003). Noninvasive remote ischemic preconditioning for global protection of skeletal muscle against infarction. Am J Physiol Heart Circ Physiol, 285(4), H1435-43. https://doi.org/10.1152/ajpheart.00106.2003
2. Bailey, T. G., Jones, H., Gregson, W., Atkinson, G., Cable, N. T., & Thijssen, D. H. (2012). Effect of ischemic preconditioning on lactate accumulation and running performance. Med Sci Sports Exerc, 44(11), 2084–2089. https://doi.org/10.1249/MSS.0b013e318262cb17
3. Bangsbo, J., Nørregaard, L., & Thorsø, F. (1991). Activity profile of competition soccer. Can J Sport Sci, 16(2), 110–116.
4. Beaven, C. M., Cook, C. J., Kilduff, L., Drawer, S., & Gill, N. (2012). Intermittent lower-limb occlusion enhances recovery after strenuous exercise. Appl Physiol Nutr Metab, 37(6), 1132–1139. https://doi.org/10.1139/h2012-101
5. Caru, M., Levesque, A., Lalonde, F., & Curnier, D. (2019). An overview of ischemic preconditioning in exercise performance: A systematic review. J Sport Health Sci, 8(4), 355–369. https://doi.org/10.1016/j.jshs.2019.01.008
6. Cohen, S. S. (1988). Statistical Power Analysis for the Behavioral Sciences (2nd ed.). Lawrence Erlbaum Associates.
7. da Mota, G. R., & Marocolo, M. (2016). The effects of ischemic preconditioning on human exercise performance: A counterpoint. Sports Med, 46(10), 1575–1576. https://doi.org/10.1007/s40279-016-0595-9
8. de Groot, P. C., Thijssen, D. H., Sanchez, M., Ellenkamp, R., & Hopman, M. T. (2010). Ischemic preconditioning improves maximal performance in humans. Eur J Appl Physiol, 108(1), 141–146. https://doi.org/10.1007/s00421-009-1195-2
9. de Souza, H. L. R., Arriel, R. A., Mota, G. R., Hohl, R., & Marocolo, M. (2021). Does ischemic preconditioning really improve performance or it is just a placebo effect? PLoS One, 16(5), e0250572. https://doi.org/10.1371/journal.pone.0250572
10. Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods, 39(2), 175–191. https://doi.org/10.3758/bf03193146
11. Frane, N., & Bitterman, A. (2022). Radiation Safety and Protection. In StatPearls. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK557499/
12. Garcia, C. A., da Mota, G. R., Leicht, A. S., & Marocolo, M. (2017). Ischemic preconditioning and acute recovery of performance in rugby union players. Sports Med Int Open, 1(3), E107–E112. https://doi.org/10.1055/s-0043-111082
13. Gibson, N., Mahony, B., Tracey, C., Fawkner, S., & Murray, A. (2015). Effect of ischemic preconditioning on repeated sprint ability in team sport athletes. J Sports Sci, 33(11), 1182–1188. https://doi.org/10.1080/02640414.2014.988741
14. Gibson, N., White, J., Neish, M., & Murray, A. (2013). Effect of ischemic preconditioning on land-based sprinting in team-sport athletes. Int J Sports Physiol Perform, 8(6), 671–676. https://doi.org/10.1123/ijspp.8.6.671
15. Graham, B., Breault, M. J., McEwen, J. A., &

McGraw, R. W. (1993). Occlusion of arterial flow in the extremities at subsystolic pressures through the use of wide tourniquet cuffs. Clin Orthop Relat Res, 286, 257–261.
16. Gu, X., Liu, Z., Gao, S., Ma, L., Chen, J., Wang, Z., Lu, A., Wang, Z., Wang, B., & Li, Y. (2021). The Effects of ischemic preconditioning supplementation on endothelial function: A systematic review and meta-analysis. Evid Based Complement Alternat Med, 2021, 6690691. https://doi.org/10.1155/2021/6690691
17. Helgerud, J., Engen, L. C., Wisloff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. Med Sci Sports Exerc, 33(11), 1925–1931. https://doi.org/10.1097/00005768-200111000-00019
18. Hoff, J. (2005). Training and testing physical capacities for elite soccer players. J Sports Sci, 23(6), 573–582. https://doi.org/10.1080/02640410400021252
19. Holcomb, S. S. (2008). Third-spacing: When body fluid shifts. Nursing 2022, 38(7), 50–53. https://doi.org/10.1097/01.NURSE.0000325345.22694.44
20. Hunt, J. E., Stodart, C., & Ferguson, R. A. (2016). The influence of participant characteristics on the relationship between cuff pressure and level of blood flow restriction. Eur J Appl Physiol, 116(7), 1421–1432. https://doi.org/10.1007/s00421-016-3399-6
21. Incognito, A. V., Burr, J. F., & Millar, P. J. (2016). The effects of ischemic preconditioning on human exercise performance. Sports Med, 46(4), 531–544. https://doi.org/10.1007/s40279-015-0433-5
22. Jean-St-Michel, E., Manlhiot, C., Li, J., Tropak, M., Michelsen, M. M., Schmidt, M. R., McCrindle, B. W., Wells, G. D., & Redington, A. N. (2011). Remote preconditioning improves maximal performance in highly trained athletes. Med Sci Sports Exerc, 43(7), 1280–1286. https://doi.org/10.1249/MSS.0b013e318206845d
23. Jessee, M. B., Dankel, S. J., Buckner, S. L., Mouser, J. G., Mattocks, K. T., & Loenneke, J. P. (2017). The cardiovascular and perceptual response to very low load blood flow restricted exercise. Int J Sports Med, 38(8), 597–603. https://doi.org/10.1055/s-0043-109555
24. Lochbaum, M., Zanatta, T., Kirschling, D., & May, E. (2021). The Profile of Moods States and athletic performance: A meta-analysis of published studies. Eur J Investig Health Psychol Educ, 11(1), 50–70. https://doi.org/10.3390/ejihpe11010005
25. Lu, D., & Kassab, G. S. (2011). Role of shear stress and stretch in vascular mechanobiology. J R Soc Interface, 8(63), 1379–1385. https://doi.org/10.1098/rsif.2011.0177
26. Marocolo, I. C., da Mota, G. R., Londe, A. M., Patterson, S. D., Barbosa Neto, O., & Marocolo, M. (2017). Acute ischemic preconditioning does not influence high-intensity intermittent exercise performance. PeerJ, 5, e4118. https://doi.org/10.7717/peerj.4118
27. Marocolo, M., da Mota, G. R., Simim, M. A., & Appell Coriolano, H. J. (2016). Myths and facts about the effects of ischemic preconditioning on performance. Int J Sports Med, 37(2), 87–96. https://doi.org/10.1055/s-0035-1564253
28. Marocolo, M., Simim, M. A. M., Bernardino, A., Monteiro, I. R., Patterson, S. D., & da Mota, G. R. (2019). Ischemic preconditioning and exercise performance: Shedding light through smallest worthwhile change. Eur J Appl Physiol, 119(10), 2123–2149. https://doi.org/10.1007/s00421-019-04214-6
29. Marocolo, M., Willardson, J. M., Marocolo, I. C., da Mota, G. R., Simao, R., & Maior, A. S. (2016). Ischemic preconditioning and placebo intervention improves resistance exercise performance. J Strength Cond Res, 30(5), 1462–1469. https://doi.org/10.1519/JSC.0000000000001232
30. Masri, B. A., Day, B., Younger, A. S., & Jeyasurya, J. (2016). Technique for measuring limb occlusion pressure that facilitates personalized tourniquet systems: A randomized trial. J Med Biol Eng, 36(5), 644–650. https://doi.org/10.1007/s40846-016-0173-5
31. Mattocks, K. T., Jessee, M. B., Counts, B. R., Buckner, S. L., Grant Mouser, J., Dankel, S. J., Laurentino, G. C., & Loenneke, J. P. (2017). The effects of upper body exercise across different levels of blood flow restriction on arterial occlusion pressure and perceptual responses. Physiol Behav, 171, 181–186. https://doi.org/10.1016/j.physbeh.2017.01.015
32. McEwen, J. A., Kelly, D. L., Jardanowski, T., & Inkpen, K. (2002). Tourniquet safety in lower leg applications. Orthop Nurs, 21(5), 55–62. https://doi.org/10.1097/00006416-200209000-00009
33. Montoye, A. H. K., Mitchinson, C. J., Townsend, O. R., Nemmers, C. H., Serkaian, C. N., & Rider, B. C. (2020). Ischemic preconditioning does not improve time trial performance in recreational runners. Int J Exerc Sci, 13(6), 1402–1417.
34. Montoye, A. H. K., Neph, S. A., Plouffe, A. A., Vondrasek, J. D., Nordbeck, J. T., Cox, B. A., & Vranish, J. R. (2023). Understanding lower limb blood flow occlusion parameters for use in field-based settings. J Sports Sci.
35. Mouser, J. G., Dankel, S. J., Jessee, M. B., Mattocks, K. T., Buckner, S. L., Counts, B. R., & Loenneke, J. P. (2017). A tale of three cuffs: The hemodynamics of blood flow restriction. Eur J Appl Physiol, 117(7), 1493–1499. https://doi.org/10.1007/s00421-017-3644-7
36. Nakajima, T., Kurano, M., Iida, H., Takano, H., Oonuma, H., Morita, T., Meguro, K., Sato, Y., & Nagata, T. (2006). Use and safety of KAATSU training: Results of a national survey. Int J KAATSU Train Res, 2(1), 5–13. https://doi.org/10.3806/ijktr.2.5
37. O'Brien, L., & Jacobs, I. (2021). Methodological variations contributing to heterogenous ergogenic responses to ischemic preconditioning. Front Physiol, 12, 656980. https://doi.org/10.3389/fphys.2021.656980
38. Olivecrona, C., Ponzer, S., Hamberg, P., & Blomfeldt, R. (2012). Lower tourniquet cuff pressure reduces postoperative wound complications after total knee arthroplasty: A randomized controlled study of 164 patients. J Bone Joint Surg Am, 94(24), 2216–2221.

https://doi.org/10.2106/JBJS.K.01492
39. Salvador, A. F., De Aguiar, R. A., Lisboa, F. D., Pereira, K. L., Cruz, R. S., & Caputo, F. (2016). Ischemic preconditioning and exercise performance: A systematic review and meta-analysis. Int J Sports Physiol Perform, 11(1), 4–14. https://doi.org/10.1123/ijspp.2015-0204
40. Seeger, J. P. H., Timmers, S., Ploegmakers, D. J. M., Cable, N. T., Hopman, M. T. E., & Thijssen, D. H. J. (2017). Is delayed ischemic preconditioning as effective on running performance during a 5km time trial as acute IPC? J Sci Med Sport, 20(2), 208–212. https://doi.org/10.1016/j.jsams.2016.03.010
41. Seeley, A. D., & Jacobs, K. A. (2021). IPC recovery length of 45 minutes improves muscle oxygen saturation during active sprint recovery. Eur J Sport Sci, 1–8. https://doi.org/10.1080/17461391.2021.1939429
42. Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer: An update. Sports Med, 35(6), 501–536. https://doi.org/10.2165/00007256-200535060-00004
43. Tocco, F., Marongiu, E., Ghiani, G., Sanna, I., Palazzolo, G., Olla, S., Pusceddu, M., Sanna, P., Corona, F., Concu, A., & Crisafulli, A. (2015). Muscle ischemic preconditioning does not improve performance during self-paced exercise. Int J Sports Med, 36(1), 9–15. https://doi.org/10.1055/s-0034-1384546
44. Wang, W. Z., Stepheson, L. L., Fang, X. H., Khiabani, K. T., & Zamboni, W. A. (2004). Ischemic preconditioning-induced microvascular protection at a distance. J Reconstr Microsurg, 20(2), 175–181. https://doi.org/10.1055/s-2004-820775
45. Weatherholt, A. M., Vanwye, W. R., Lohmann, J., & Owens, J. G. (2019). The effect of cuff width for determining limb occlusion pressure: A comparison of blood flow restriction devices. Int J Exerc Sci, 12(3), 136–143.
46. Younger, A. S., McEwen, J. A., & Inkpen, K. (2004). Wide contoured thigh cuffs and automated limb occlusion measurement allow lower tourniquet pressures. Clin Orthop Relat Res, 428, 286–293. https://doi.org/10.1097/01.blo.0000142625.82654.b3