Original Investigation

Does ischemic pre-conditioning during the recovery period between two successive matches preserve physical performance in badminton doubles players?

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Abstract

Changes in physical performance were assessed in response to two successive doubles badminton matches with implementation of ischemic pre-conditioning (IPC) or sham treatment during recovery period between matches. Eight French national team badminton players (4 males, 4 females) performed two successive doubles matches (2 × 45 min), with 60 min of recovery in-between, during which they received three 5-min cycles of either an IPC (220 mmHg) or a sham (SHAM) (50 mmHg) intervention. A series of physical tests was performed immediately following the first (Post 1) and second (Post 2) match. Jump height (squat and countermovement jumps), leg power (multi-rebound jumps) and sprint time (L-test) remained unchanged from Post 1 to Post 2 (all P>0.193), and did not differ between conditions (all P>0.173). During a badminton-specific repeated-agility test, neither performance-related variables (i.e., best time, total time and sprint decrement score) nor *vastus lateralis* muscle tissue saturation index displayed a main effect for condition (all P>0.116), time (all P>0.091) or time × condition interaction (all P>0.730). Implementing IPC during the recovery period between successive doubles badminton demonstrated no beneficial effect on physical performance and muscle oxygenation trends.

Keywords: *Blood flow restriction; Recovery strategy; Racket sports; On-court performance; Muscle oxygenation*

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INTRODUCTION

Badminton is a high-intensity, intermittent activity characterized by repeated movements involving starts, stops, jumps, leaps, lunges and rapid directional changes. It is recognized as the fastest racket sport in the world, and imposes high physiological and neuromuscular demands (Phomsoupha & Laffaye, 2015). Badminton tournaments have intense schedules and are fairly congested in nature, often requiring players to compete in 1-2 matches a day for a period of 2-4 consecutive days. The repetition of rapid and intense leg movements and a wide range of body postures likely result in profound lower limb fatigue (Phomsoupha & Laffaye, 2015). For instance, two successive 35 min badminton matches decreased maximal voluntary torque in both plantar flexors and extensors, with even larger decrements for explosive contractions (Girard, Behan, Cabello-Manrique, & Fernandez-Fernandez, 2019). Moreover, following fatiguing match-play, decreased control of the midfoot and increased arch collapse have been observed during lunge movements in both male and female players, resulting in increased injury risk during diagonal movement tasks (Valldecabres, Richards, & De Benito, 2020). As such, interventions that might enhance and/or preserve badminton-specific endurance and/or facilitate between-match recovery may be invaluable to maintain match competitiveness and minimize the risk of injury.

Ischemic pre-conditioning (IPC) is a technique which involves subjecting tissues to cycles of sub-lethal levels of ischemic stress followed by reperfusion. In clinical medicine, IPC has been shown to confer protective effects to various organs subsequently exposed to prolonged ischemic episodes (Stokfisz, Ledakowicz-Polak, Zagorski, & Zielinska, 2017). Within exercise science research, the use of IPC has emerged as an attractive ergogenic aid for athletes to improve exercise capacity. For instance, three to four intermittent cycles of brief (~5 min) arterial limb occlusions have been shown to improve maximal power output or time to exhaustion during incremental cycling tests (Cheung, Slysz, & Burr, 2019; De Groot, Thijssen, Sanchez, Ellenkamp, & Hopman, 2010), as well as running time-trial performance (Bailey et al., 2012). The effect of IPC on anaerobic-type performance is more controversial (Gibson, White, Neish, & Murray, 2013; Patterson, Bezodis, Glaister, & Pattison, 2015). For instance, no performance alterations for single (30 m) or repeated sprints (5 × 6 s) occurred following IPC (Gibson et al., 2013). However, in another study where repeated-sprint ability (RSA) sequences were prolonged (12 × 6 s), IPC significantly increased peak and mean power outputs for the initial portion of the sprint sequence (Patterson et al., 2015). Purported mechanisms underpinning the ergogenic effects of IPC include improved blood flow and oxidative metabolism (Incognito, Burr, & Millar, 2016). Indeed, improved muscle oxygenation profile has been shown to coincide with improved cycling RSA performance (Patterson et al., 2015) as well as repeated maximal knee extensor strength (Paradis-Deschênes, Joanisse, & Billaut, 2016).

Besides its acute effects on subsequent exercise capacity, there is emerging research investigating how IPC might accelerate the recovery of physical performance. Garcia, da Mota, Leicht, and Marocolo (2017) demonstrated that IPC does not improve recovery of jumps and agility performance acutely (within 1 h) within sub-elite rugby players following a rugby-specific exercise protocol. Conversely, beneficial effects on functional measures of athletic performance, including RSA and jump height, were observed 24 h after an IPC intervention (Beaven, Cook, Kilduff, Drawer, & Gill, 2012). There are, however, no reports currently detailing the influence of IPC on the recovery of badminton-specific physical performance (i.e., jumps, directional changes, repeated-agility test) and associated tissue oxygenation trends.

Therefore, the aim of this study was to investigate the effect of IPC on between-match recovery in physical performance, as well as associated changes in muscle oxidative profile during successive badminton matches.

METHODS

Participants

Eight players (4 males, 4 females; age 21.3 ± 2.7 years, body mass 70.0 ± 10.0 kg, height 177 ± 12 cm) from the French national badminton doubles team were recruited. Sample size estimation required n=10 players, assuming a power of 0.80, α level of 0.05 and expected change in performance to be small (i.e., effect size = 0.25). However, due to our stringent inclusion criteria (i.e., national level doubles players), player availability, injury and logistical constraints, only 8 players were assessed. One player withdrew from the second trial due to injury (finger) and therefore final data set is presented as n=7. The local committee waived the requirement for ethical approval for this study, given that all measurements were performed in the context of their national team's daily routine training monitoring (Winter & Maughan, 2009). Written informed consent was obtained from players prior to participation.

Experimental design

All measurements were conducted during the competitive season (November 2018) at the French Institute of Sport's badminton training facility (Paris, France). Players were tested on two separate occasions 2-3 days apart to minimize the effect of residual fatigue on the subsequent test results. After a 15 min warm-up, they played two simulated matches lasting 45 min each, with 60 min rest in-between (total of 150 min). The players were paired according to level of play (similar national rankings) and gender, and competed against the same pair of opponents. The matches were played according to the Badminton World Federation rules, and a (minor) reward was offered to the winning player to ensure maximal "competitive" effort by all participants. The players were supplied with pure water at the sidelines with *ad libitum* intake during the matches. Following (i.e., 3-5 min) the first match (Post 1), players performed a series of performance tests including vertical jumps [squat jumps (SJ), countermovement jumps (CMJ) and multi-rebound jumps (MRJ)], the 'L' agility sprint test (L-test), and lastly a badminton-specific repeated-agility test. Thereafter, they received three 5-min cycles of either IPC or SHAM (single-blind, crossover design) administered in a bilateral manner (i.e., alternating between thighs every 5 min during 30 min), whilst in a seated position. The time delay between the end of the first match and the commencement of IPC procedure was exactly 15 min. Players then proceeded with a 5 min badminton re-warm-up before playing the second 45 min match, following which, the performance tests were repeated again (Post 2). All trials were performed at the same time of day to avoid potentially confounding circadian rhythm effects. Players were asked to perform tests with their usual competition court shoes. All players were familiar with the testing protocols and procedures, which are part of their regular serial physical fitness assessments. Care was taken to advise the players to avoid high-intensity and strenuous training within 24 h of their scheduled test.

Ischemic preconditioning

Immediately after the performance tests following the first match, players were administered three 5-min cycles of either IPC or SHAM in each thigh whilst in a seated position, alternating thighs, totaling 30 min. A 13.5 cm wide cuff, connected to an automated rapid cuff inflator (Hokanson, Washington, USA) was positioned bilaterally on the most proximal regions of the thighs. The occlusion pressure was held constant at 220 mmHg and 50 mmHg for IPC and SHAM conditions, respectively. This light level of inflation (50 mmHg) has been shown to elicit the sensation of pressure around the thigh without preventing blood flow (De Groot et al., 2010). To minimize any placebo effect, players were told that the purpose of the study was to compare the impact of two different cuff pressures that could both alter performance.

Performance tests

Vertical jumps

Players performed the following jump tests twice starting with the SJ, followed by the CMJ and MRJ. All jumps were recorded (flight times for SJ, CMJ and MRJ and ground contact for MRJ) using a sensor system (Optojump Next, Microgate, Bolzano, Italy). Jump height for the SJ and CMJ tests was determined from flight times (Lehance, Croisier, & Bury, 2005). Leg power (W.kg^{-1}) during the MRJ test was calculated, as described elsewhere (Dalleau, Belli, Viale, Lacour, & Bourdin, 2004). The coefficient of variation (CV) for jump height during SJ and CMJ using the Optojump system is 3.1 % and 2.2 %, respectively (Glatthorn et al., 2011).

'L' agility test

The L-test was adapted from previous work (Gabbett, 2006). Three markers were positioned 5 m apart in the shape of an 'L', with electronic timing gates (Polifemo, Microgate, Italy) placed 1 m above the ground level and positioned at the start/finish line of the course. The players assumed position just before the start line, and once ready, ran forward for 5 m, before making a 90° turn to their left, after which ran a further 5 m before making a 180° turn to resume the same course back to the start/finish line. Two trials interspersed by 1 min of rest were performed, with the fastest time achieved included for analysis. The CV for this test is 1.96 % (Stewart, Turner, & Miller, 2014).

Badminton-specific repeated-agility test

Players performed six agility efforts with 20 s of recovery in-between, in a pre-determined sequence along the four corners of the court. The start/finish line was positioned at the mid-point of the baseline, whilst the service (i.e., forecourt) and baseline (i.e., rear court) corners of the court were affixed with markers. A 10 × 10 cm square was marked at the mid-point between the service and baseline (i.e., center), and electronic timing gates (Polifemo, Microgate, Italy) were positioned at the start/finish line. Each sprint involved the following running sequence: start/finish, center, right forecourt, center, left forecourt, center, left rear court, center, right rear court, center, start/finish line. Three scores were calculated during the test: the best sprint time, the total sprint time and the percent sprint decrement (S_{dec}) [{(total sprint time)/(best sprint time×6)−1×100]. Players were reminded to adhere to badminton-specific movements, start by moving towards the direction of their dominant hand (racket-holding hand), and to strike the up-turned shuttlecock also with their dominant hand. The CVs for mean sprint times for a similar badminton-specific agility test ranged from 3.9 % to 5.2 % in elite to skilled players (Phomsoupha, Berger, & Laffaye, 2018).

Physiological and perceptual measurements

Blood lactate

Capillary blood samples were taken from the players' fingertip prior to commencing the first match, as well immediately following the cessation of the first and second match. All samples were immediately analyzed for blood lactate concentration via a handheld analyzer (Lactate Pro 2, Arkray Inc, Japan).

Perceptual ratings

Rating of perceived exertion (RPE) and perceived fatigue were recorded following the first and second match using a 10-point scale. Zero was anchored as the positive (i.e., no exertion/fatigue, respectively), and 10 (i.e., maximal exertion/fatigue, respectively) the negative end of the continuum.

Near-infrared spectroscopy

Muscle oxygenation of the *vastus lateralis* was monitored using a wireless NIRS system weighing 75 g with approximate dimensions (i.e., W x D x H) of 84 x 43 x 17 mm. (Portamon, Artinis Medical Systems, The Netherlands). The Portamon simultaneously uses the modified Beer-Lambert and spatially-resolved spectroscopy methods to determine changes in oxygenated haemoglobin and de-oxygenated haemoglobin, expressed in micromolar units (μM). This system also provides a measure of oxyhaemoglobin saturation indicated by the tissue saturation index [TSI (%)], which reflects the dynamic balance between O_2 demand and supply within the muscle microcirculation (Ihsan, Abbiss, Lipski, Buchheit, & Watson, 2013). The Portamon unit consists of three emitter diodes positioned 30, 35, and 40 mm from the detector, and emitting infrared light at wavelengths of 760 and 850 nm. All analyses were undertaken on data gathered from the 35 mm emitter-detector distance, corresponding to a NIRS signal penetration depth of approximately 17.5 mm (McCully & Hamaoka, 2000). The Portamon unit was secured on the players' 'lunge' limb, using adhesive tape reinforced with elasticated bandages to prevent movement and signal contamination from external light sources. The probe site was marked for accurate re-positioning. Prior to test commencement, players unweighted their 'lunge' leg, and stood for a 30 s period during which baseline TSI was obtained. Muscle de-oxygenation during the repeated-agility test were characterized by obtaining the mean (CV = 4.6 %), minimum and area under the curve (AUC) of TSI signals during work-intervals (Ihsan et al., 2013). Finally, we calculated the i-TSI index as follows: $iTSI = (TSI_{Baseline} - TSI_{Mean}) \times$ exercise duration. All analysis and interpretation were undertaken using the TSI, given that this variable has been suggested to provide a better indication of muscle oxygenation status when blood flow is not constant (Wolf, Ferrari, & Quaresima, 2007).

Statistical Analysis

Two-way repeated measures ANOVAs [Time (Post 1 and Post 2) × Condition (IPC and SHAM)] were used to compare data followed by *Bonferroni* post-hoc analysis procedure adjusted for multiple comparisons. For each ANOVA, partial eta-squared (η_p^2) were calculated as measures of effect size. Values of 0.01, 0.06, and above 0.14 were considered as small, medium, and large, respectively. All statistical calculations were performed using SPSS statistical software V.24.0 (IBM Corp., Armonk, NY, USA). The significance level was set at $P<0.05$.

RESULTS

Compared to the first match, RPE was significantly elevated ($P=0.050$, $\eta_p^2=0.48$) during the second match, independently of conditions ($P=0.689$, $\eta_p^2=0.03$) (Table 1). Badminton did not induce any change in blood lactate concentrations between matches ($P=0.972$, $\eta_p^2=0.05$), nor resulted in any difference in blood lactate concentrations between conditions ($P=0.833$, $\eta_p^2=0.01$).

Physical performance indices are presented in Figure 1 and Table 2. There was no main effect of time (all $P>0.272$, $\eta_p^2 > 0.20$), condition (all $P>0.173$, $\eta_p^2 > 0.28$) or time × condition interaction (all $P>0.379$, $\eta_p^2 > 0.13$) for jump height during SJ and CMJ tests, as well as for leg power during the MRJ test (Table 2). Sprint time during the L-test remained unchanged from Post 1 to Post 2 ($P=0.193$, $\eta_p^2 = 0.26$), and did not differ between conditions ($P=0.362$, $\eta_p^2 = 0.14$) (Table 2).

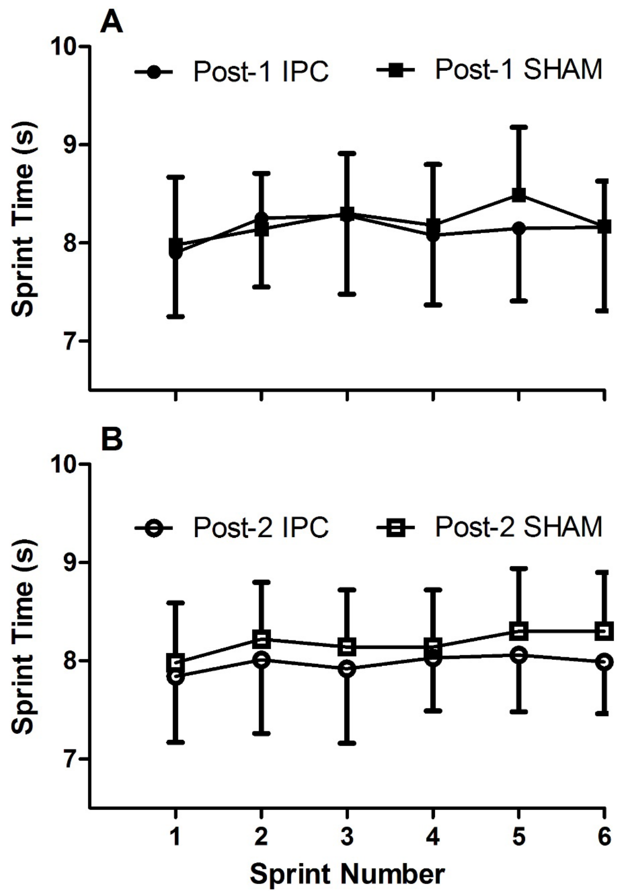

Figure 1. Changes in 'L-test' sprint time from the first (Post 1, *panel A*) to the second (Post 2, *panel B*) 45-min badminton match with ischemic preconditioning (IPC) or sham (SHAM) interventions implemented between matches.

Table 1.
Match characteristics for the first (post-1) and the second (post-2) 45-min badminton match with ischemic preconditioning (IPC) or sham (SHAM) interventions implemented between matches.

	IPC			SHAM		
	Pre	Post-1	Post-2	Pre	Post-1	Post-2
HR (bpm)	98 ± 22	130 ± 15	138 ± 23	100 ± 21	144 ± 23	153 ± 19
Blood lactate (mmol.L^{-1})	1.4 ± 0.7	1.6 ± 0.7	1.4 ± 0.6	1.6 ± 0.7	1.5 ± 0.9	1.6 ± 0.9
RPE (0-10)	-	4.1 ± 1.8	5.9 ± 1.8*	-	3.7 ± 0.8	5.1 ± 1.2*
ROF (0-10)	-	5.5 ± 2.6	6.7 ± 1.7	-	4.5 ± 1.8	5.9 ± 1.8

Data are mean ± SD. HR, heart rate; RPE, ratings of perceived exertion; ROF, ratings of fatigue.
** different from Post-1 (P<0.05).*

Table 2.
Vertical jump ability, L-test and repeated-agility test performance after the first (post-1) and the second (post-2) 45-min badminton match with ischemic preconditioning (IPC) or sham (SHAM) interventions implemented between matches.

	IPC		SHAM	
	Post-1	Post-2	Post-1	Post-2
Vertical jump ability				
SJ (cm)	38.9 ± 8.2	39.5 ± 7.5	38.4 ± 7.5	38.4 ± 7.9
CMJ (cm)	41.1 ± 8.0	40.7 ± 7.7	39.9 ± 7.8	40.1 ± 7.5
MRJ (cm)	36.0 ± 6.2	34.7 ± 7.5	36.5 ± 7.3	35.9 ± 6.5
Leg power (W.kg^{-1})	49.4 ± 7.4	48.1 ± 8.4	49.6 ± 8.4	48.5 ± 7.0
L-test				
Time (s)	5.18 ± 0.29	5.17 ± 0.38	5.16 ± 0.35	5.09 ± 0.33
Repeated-agility test				
Best time (s)	7.83 ± 0.72	7.90 ± 0.63	7.85 ± 0.68	7.93 ± 0.62
Total time (s)	48.82 ± 4.23	48.51 ± 3.86	48.91 ± 3.71	48.92 ± 3.68
S_{dec} (%)	3.97 ± 2.48	2.28 ± 0.86	4.02 ± 3.31	2.84 ± 2.00
Post-exercise RPE (6-20)	16.0 ± 1.7	16.8 ± 2.2	15.8 ± 1.2	16.4 ± 2.1

Data are mean ± SD. SJ, squat jump; CMJ, countermovement jump; MRJ, multirebound jump; S_{dec}, sprint decrement score; RPE, ratings of perceived exertion.

During the repeated-agility test, none of the RSA-related variables displayed a main effect of time (all P>0.091, η_p^2>0.40), condition (all P>0.600, η_p^2>0.05) or any significant time × condition interaction (all P>0.730, η_p^2>0.10) (Table 2). RPE tended to be elevated in response to the repeated-agility test performed post-2 *versus* post-1 (P=0.076, η_p^2=0.44). Sprints 1-6 averaged TSI-min (P=0.031, η_p^2=0.57), TSI-mean (P=0.042, η_p^2=0.52) and TSI-AUC (P=0.089, η_p^2=0.41) values were lower during the repeated-agility test performed Post 1 *versus* Post 2, irrespectively of condition (all P>0.466, η_p^2>0.10) (Table 3). Changes in i-TSI between Post 1 and Post 2 were not significant (P=0.116, η_p^2=0.36), with also no effect of condition (P=0.951, η_p^2=0.01).

DISCUSSION

Success in a badminton tournament requires winning consecutive matches on the same day sometimes separated by less than 1-2 h. Recovery strategies are therefore crucial to sustain optimal on-court performance during matches repetitions, as well as to preserve the health and wellness of the player. In this regard, we asked the original question whether IPC can promote the recovery in physical performance when administered in-between consecutive bouts of badminton match-play. Implementing IPC during the recovery period between successive badminton double matches had no significant effect on the recovery of physical performance in doubles badminton played by elite players.

One common measure to reflect explosive power is vertical jump ability. This fitness component is crucial in badminton, as it results in the player being able to move quickly and explosively to the shuttle in various directions and to jump high to execute overhead strokes. In our study, vertical jump ability (SJ and CMJ heights or leg power, all in the vertical plane) changes were not significant from successive matches with or without IPC application. Our mixed-gender cohort could at least partially account for the lack of an ergogenic effect, as IPC seemed to enhance muscle force production in males but not in females (Paradis-Deschênes, Joanisse, & Billaut, 2017). Alternatively, it can be postulated that IPC was ineffective due to the prior lack of performance decrement demonstrated following match-play. Indeed, physical performances were not appreciably altered by successive badminton matches, indicating that the ability of the lower extremity to produce explosive force was probably not significantly impaired in our double players. Here, with simulated matches undertaken competitively, we observed comparable SJ and CMJ, as well as HR and RPE values to previous studies documenting the physical profiles (Ooi et al., 2009) and match-play characteristics (Liddle, Murphy, & Bleakley, 1996) of elite singles and doubles badminton players. Unfortunately, further comparisons are limited, as to the best of our knowledge no previous studies examining muscle fatigue following either simulated or actual doubles match-play. It is hence pertinent to address whether fatigue is a limiting factor in elite doubles match-play, at least with regards to two successive matches. Findings from singles match-play supports this notion, as Abián-Vicén, Del Coso, González-Millán, Salinero, and Abián (2012) reported no decrements in jump height (which actually increased by 4.5%) and mean power in the push-off phase of CMJ in their analysis of 70 singles matches played during the national Spanish championships. However, there is now emerging evidence showing that in elite players, muscle fatigue may be evident through subtle measures such as loading characteristics, rather than changes in force or power (Herbaut & Delannoy, 2020; Valldecabres et al., 2020). As such, future studies examining the effects of match-play fatigue or recovery interventions should extend their measurement tools to include players' movement re-organisation or compensatory mechanisms.

Previously, it was also observed that IPC of the thigh muscles did not improve the short-term recovery of performance or perceived recovery status for amateur rugby players following a simulated match (Garcia et al., 2017). Moreover, the current findings demonstrate no beneficial effects of IPC treatment during the recovery between successive games on player's ability to jump. Accordingly, well preserved leg power values (as derived from MRJ jumps) from successive matches with IPC application would indicate that this intervention probably had no effect on acceleration and speed when lifting off the floor when moving or jumping to the shuttle. However, horizontal power is also an important quality in taking lunge jumps to net shots (Phomsoupha & Laffaye, 2015). Hence, a greater horizontal power would result in the player being able to reach the shuttle more quickly, and thus force a faster pace of play. Future studies should determine whether successive matches and/or an IPC intervention likely modify this aspect of the match.

On-court movements are influenced by players' ability to accelerate, decelerate and change direction, in order to generate optimal stroke production. Whereas vertical jump ability (SJ and CMJ heights or leg power, all in the vertical plane) changes were not significant, it cannot be ruled out that a less efficient ground force application may then decrease the change of direction performances, as indirectly evaluated here from L-test. Unchanged performance during the L-test would suggest that the ability to move to and from the shuttle was probably not modified as a result of fatigue and/or application of the IPC treatment. A previous study showed that a 45 min simulated singles badminton match produced moderate-to-high levels of indirect markers of muscle damage (e.g., myoglobin, CK, and LDH), yet it was not associated with decreased agility T-test performance (Abián et al., 2016). We did not measure the extent of muscle damage in our cohort of double players. A possible explanation is that the neuromuscular demand (intensity of change of direction movements) associated with doubles badminton is typically less intense than singles (Alcock & Cable, 2009). Although unknown, the lack of a performance change could also be a consequence of movement reorganisation (force orientation, joint angles) via compensatory strategies (Bonnard, Sirin, Oddsson, & Thorstensson, 1994). Thus, future studies should determine how this might be brought about biomechanically. Finally, it cannot be ruled out that IPC had a beneficial effect, resulting in a higher match intensity (and eventually fatigue incurred, which was not controlled for) in the second simulated game after treatment.

Several badminton tests of multiple RSA bouts involving maximal effort accelerations, decelerations and badminton-specific directional changes have been developed to reflect the most intense period of a match (Phomsoupha & Laffaye, 2015). In the current study, we adapted a recently developed test (Phomsoupha et al., 2018) to investigate whether IPC might improve fatigue resistance in a badminton-specific repeated-sprint protocol. Our findings indicate that IPC intervention had no beneficial effect on the ability to break and re-accelerate rapidly during a multiple change of direction task, since repeated-agility performance indices did not differ. In contrast, IPC was shown to improve peak and mean power outputs for the initial 3 cycling efforts of a sequence of twelve 6 s sprints (Patterson et al., 2015). Improved muscle oxygen delivery and extraction has been suggested as key mechanism by which IPC might improve exercise performance (Incognito et al., 2016). Moreover, improved muscle oxygenation profile has been shown to coincide with improved cycling RSA performance (Patterson et al., 2015), as well as repeated maximal knee extensions (Paradis-Deschênes et al., 2016). In line with unchanged performance, the present findings demonstrate no influence of IPC on muscle oxygenation trends during repeated-agility test.

This study is not without limitations. Strength of findings may be limited by the small sample size, albeit in elite players, with the specificity directed towards doubles match-play. Moreover, the test battery was focused towards force production and agility, and did not examine movement re-organization (force orientation, joint angles) or compensatory loading which might occur as fatigue develops (Bonnard et al., 1994). Lastly, recovery was assessed following simulated match-play, which increases the ecological validity of our findings. However, it cannot be ruled out that IPC could have resulted in higher match intensities in the second simulated game. That said, it is interesting to observe that jump and agility performance did not differ between conditions.

Table 3.
NIRS-related parameters during the repeated-agility test performed after the first (post-1) and the second (post-2) 45-min badminton match with ischemic preconditioning (IPC) or sham (SHAM) interventions implemented between matches.

	IPC		SHAM	
	Post-1	Post-2	Post-1	Post-2
TSI-min				
Baseline	56.7 ± 2.5	52.5 ± 6.3	55.4 ± 4.7	53.9 ± 3.8
RSA-1	30.4 ± 7.8	27.0 ± 10.5	29.7 ± 7.8	28.3 ± 8.2
RSA-2	20.7 ± 9.1	18.2 ± 11.2	19.9 ± 11.4	18.5 ± 10.9
RSA-3	21.2 ± 8.7	18.6 ± 11.4	21.1 ± 12.6	19.8 ± 11.4
RSA-4	20.2 ± 10.3	19.9 ± 11.2	20.7 ± 11.9	20.2 ± 11.7
RSA-5	22.1 ± 11.0	19.2 ± 11.6	21.2 ± 11.0	20.1 ± 11.3
RSA-6	22.4 ± 11.8	21.0 ± 11.0	21.8 ± 11.3	21.2 ± 11.3
TSI-mean				
RSA-1	48.2 ± 3.8	45.1 ± 6.5	47.8 ± 4.0	46.0 ± 5.1
RSA-2	25.9 ± 9.0	23.3 ± 11.4	24.4 ± 10.8	24.3 ± 10.0
RSA-3	25.6 ± 8.5	23.6 ± 11.2	25.1 ± 11.8	24.7 ± 10.5
RSA-4	24.9 ± 10.2	24.6 ± 11.3	25.7 ± 11.9	25.7 ± 10.8
RSA-5	26.6 ± 11.0	23.9 ± 11.4	25.7 ± 11.8	25.1 ± 10.6
RSA-6	27.9 ± 10.8	25.6 ± 10.6	26.7 ± 11.4	25.9 ± 10.8
TSI-AUC				
RSA-1	371 ± 35	350 ± 67	376 ± 25	355 ± 62
RSA-2	195 ± 79	177 ± 97	185 ± 92	181 ± 91
RSA-3	193 ± 76	179 ± 95	193 ± 102	185 ± 95
RSA-4	189 ± 89	188 ± 96	196 ± 102	193 ± 96
RSA-5	200 ± 97	183 ± 99	195 ± 101	188 ± 97
RSA-6	210 ± 93	193 ± 91	205 ± 95	191 ± 96

Data are mean ± SD. TSI, tissue saturation index

CONCLUSION

In summary, the present study indicates that implementing IPC during the recovery period between successive badminton doubles had no significant effect on physical performance and muscle oxygenation trends at the group average level in elite badminton players. However, its use does not follow a 'one-size-fits-all' approach. Perhaps an individually-focused application of IPC (e.g., altering the number of cycles, pressure of cuffs, timing or duration of application into recovery) may reduce 'non-response' to this ergogenic recovery intervention. Future studies should verify if IPC would be beneficial in sub-elite players where the development of fatigue likely is more pronounced. Moreover, future studies examining the effects of match-play fatigue or recovery interventions should extend their measurement tools to assess loading characteristics, movement re-organisation or compensatory mechanisms.

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REFERENCES

Abián-Vicén, J., Del Coso, J., González-Millán, C., Salinero, J.J., & Abián, P. (2012). Analysis of dehydration and strength in elite badminton players. *PloS one, 7*(5), e37821.

Abián, P., Coso, J.D., Salinero, J.J., Gallo-Salazar, C., Areces, F., Ruiz-Vicente, D., Lara, B., Soriano, L., Muñoz, V., & Lorenzo-Capella, I. (2016). Muscle damage produced during a simulated badminton match in competitive male players. *Research in Sports Medicine, 24*(1), 104-117.

Alcock, A., & Cable, N.T. (2009). A comparison of singles and doubles badminton: heart rate response, player profiles and game characteristics. *International Journal of Performance Analysis in Sport, 9*(2), 228-237.

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. *Medicine & Science in Sports & Exercise*, 44, 2084-2089.

Beaven, C.M., Cook, C.J., Kilduff, L., Drawer, S., & Gill, N. (2012). Intermittent lower-limb occlusion enhances recovery after strenuous exercise. *Applied Physiology, Nutrition & Metabolism, 37*(6), 1132-1139.

Bonnard, M., Sirin, A.V., Oddsson, L., & Thorstensson, A. (1994). Different strategies to compensate for the effects of fatigue revealed by neuromuscular adaptation processes in humans. *Neuroscience Letters, 166*(1), 101-105.

Cheung, C.P., Slysz, J.T., & Burr, J.F. (2019). Ischemic Preconditioning: Improved Cycling Performance Despite Nocebo Expectation. *International Journal of Sports Physiology & Performance*, Epub ahead of print. doi: 10.1123/ijspp.2019-0290

Dalleau, G., Belli, A., Viale, F., Lacour, J-R., & Bourdin, M. (2004). A simple method for field measurements of leg stiffness in hopping. *International Journal of Sports Medicine, 25*(03), 170-176.

De Groot, P.C., Thijssen, D.H.J., Sanchez, M., Ellenkamp, R., & Hopman, M.T. (2010). Ischemic preconditioning improves maximal performance in humans. *European Journal of Applied Physiology, 108*(1), 141-146.

Gabbett, T. J. (2006). Performance changes following a field conditioning program in junior and senior rugby league players. *Journal of Strength & Conditioning Research, 20*(1), 215-221.

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 Medicine International Open, 1*(03), E107-E112.

Gibson, N., White, J., Neish, M., & Murray, A. (2013). Effect of ischemic preconditioning on land-based sprinting in team-sport athletes. *International Journal of Sports Physiology & Performance, 8*(6), 671-676.

Girard, O., Behan, F.P., Cabello-Manrique, D., & Fernandez-Fernandez, J. (2019). Badminton preferentially decreases explosive over maximal voluntary torque in both the plantar flexors and extensors. *Translational Sports Medicine, 2*(1), 39-46.

Glatthorn, J. F., Gouge, S., Nussbaumer, S., Stauffacher, S., Impellizzeri, F. M., & Maffiuletti, N. A. (2011). Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. *Journal of Strength & Conditioning Research, 25*(2), 556-560. doi: 10.1519/JSC.0b013e3181ccb18d

Herbaut, A., & Delannoy, J. (2020). Fatigue increases ankle sprain risk in badminton players: A biomechanical study. *Journal of Sports Science*, 38(13):1560-1565. doi: 10.1080/02640414.2020.1748337

Ihsan, M., Abbiss, C. R., Lipski, M., Buchheit, M., & Watson, G. (2013). Muscle Oxygenation and Blood Volume Reliability during Continuous and Intermittent Running. *International Journal of Sports Medicine, 34*(7), 637-645. doi: 10.1055/s-0032-1331771

Incognito, A. V., Burr, J. F., & Millar, P. J. (2016). The Effects of Ischemic Preconditioning on Human Exercise Performance. *Sports Medicine, 46*(4), 531-544. doi: 10.1007/s40279-015-0433-5

Lehance, C., Croisier, J.L., & Bury, T. (2005). Optojump system efficiency in the assessment of lower limbs explosive strength. *Science & Sports, 20*(3), 131-135.

Liddle, S.D., Murphy, M.H., & Bleakley, E.W. (1996). A comparison of the demands of singles and doubles badminton among elite male players: a heart rate and time/motion analysis. *Journal of Human Movement Studies, 29*(4), 159-176.

McCully, K. K., & Hamaoka, T. (2000). Near-infrared spectroscopy: what can it tell us about oxygen saturation in skeletal muscle? *Exercise & Sports Science Review, 28*(3), 123-127.

Ooi, C.H., Tan, A., Ahmad, A., Kwong, K.W., Sompong, R., Mohd Ghazali, K.A., Liew, S.L., Chai, W.J., & Thompson, M.W. (2009). Physiological characteristics of elite and sub-elite badminton players. *Journal of Sports Sciences, 27*(14), 1591-1599.

Paradis-Deschênes, P., Joanisse, D.R., & Billaut, F. (2016). Ischemic preconditioning increases muscle perfusion, oxygen uptake, and force in strength-trained athletes. *Applied Physiology, Nutrition & Metabolism, 41*(9), 938-944.

Paradis-Deschênes, P., Joanisse, D.R., & Billaut, F. (2017). Sex-specific impact of ischemic preconditioning on tissue oxygenation and maximal concentric force. *Frontiers in Physiology, 7*, 674.

Patterson, S.D., Bezodis, N.E., Glaister, M., & Pattison, J.R. (2015). The effect of ischemic preconditioning on repeated sprint cycling performance. *Medicine & Science in Sports & Exercise, 47*(8), 1652-1658.

Phomsoupha, M., Berger, Q., & Laffaye, G. (2018). Multiple repeated sprint ability test for badminton players involving four changes of direction: validity and reliability (Part 1). *Journal of Strength & Conditioning Research, 32*(2), 423-431.

Phomsoupha, M., & Laffaye, G. (2015). The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports Medicine, 45*(4), 473-495.

Stewart, P. F., Turner, A. N., & Miller, S. C. (2014). Reliability, factorial validity, and interrelationships of five commonly used change of direction speed tests. *Scandinavian Journal of Medicine & Science in Sports, 24*(3), 500-506. doi: 10.1111/sms.12019

Stokfisz, K., Ledakowicz-Polak, A., Zagorski, M., & Zielinska, M. (2017). Ischaemic preconditioning–Current knowledge and potential future applications after 30 years of experience. *Advances in Medical Sciences, 62*(2), 307-316.

Valldecabres, R., Richards, J., & De Benito, A. M. (2020). The effect of match fatigue in elite badminton players using plantar pressure measurements and the implications to injury mechanisms. *Sports Biomechanics*, Epub ahead of print. doi: 10.1080/14763141.2020.1712469

Winter, E. M., & Maughan, R. J. (2009). Requirements for ethics approvals. *Journal of Sports Science, 27*(10), 985. doi: 10.1080/02640410903178344

Wolf, M., Ferrari, M., & Quaresima, V. (2007). Progress of near-infrared spectroscopy and topography for brain and muscle clinical applications. *Journal of Biomedical Optics, 12*(6), 062104. doi: 10.1117/1.2804899