TITLE: Effect of ischemic preconditioning on acute recovery in elite judo athletes: a randomised, single-blind, crossover trial

Submission type: Original Investigation

Authors: Bayram Ceylan[1], Hasan Basri Taşkın[2] and Jožef Šimenko[3]

[1] Department of Coaching Education, Faculty of Sport Sciences, Kastamonu University, Kastamonu, Türkiye

[2] Department of Physical Education and Sport Teaching, Faculty of Sport Sciences, Kastamonu University, Kastamonu, Türkiye

[3] School of Life and Medical Sciences, University of Hertfordshire, Hatfield AL10 9EU, UK

Correspondence: Dr. Bayram Celyan; Department of Coaching Education, Faculty of Sport Sciences, Kastamonu University, Kastamonu, Türkiye; Email: bceylan@kastamonu.edu.tr

Preferred running head: ***IPC recovery in elite judo athletes***

ABSTRACT

Purpose: The ischemic preconditioning (IPC) method has been shown to aid the recovery processes; however, no studies have been done to assess its acute recovery usage in judo. This study aimed to examine the IPC of lower limbs effects on recovery after a judo-specific performance in highly trained male judokas and its applicability during a competition day**.** **Methods:** A single-blind, placebo (PLA)-randomised crossover study was carried out on a sample of 13 elite male judo athletes. They undertook measurements of body composition, judo-specific task (special judo fitness test), jump performance, handgrip strength, lactate, blood pressure, perceived exertion and delayed onset of muscle soreness. IPC was applied on the legs and inflated 50 mmHg above the systolic blood pressure for 5 min and repeated three times for each leg, with 5 min of reperfusion. Two-way ANOVA with repeated measurements was used to determine changes between interventions and measurement times. Paired sample t-test and one-way repeated measures ANOVA was used to determine the difference among measurement times. Statistical significance was set at $p<0.05$. **Results:** IPC intervention resulted in a) decreased HR at 30 and 60 min during recovery ($p=0.002$; $p=0.001$), b) better CMJ performance at 60min ($p=0.05$), c) lower DOMS scores ($p=0.006$); d) maintained HGS compared to PLA**. Conclusions:** The present study revealed that IPC applied to judo athletes following judo-specific exercise resulted in better cardiovascular and neuromuscular recovery and could be a useful tool to enhance recovery during judo competitions break between preliminaries and final block.

Key Words: *combat sports, SJFT, lower limbs, occlusion preconditioning, performance*

Word count: 3469 *Number of Figures:4* *Number of Tables:3*

INTRODUCTION

Sports professionals constantly search for new training methods that may increase performance [1]. In this context, ischemic preconditioning (IPC) has been used to improve physical performance [2]. Additionally, IPC was shown to be useful in aiding the recovery processes [3,4] via increased blood flow, activating the ATP-sensitive potassium channels [5], elevating adenosine levels [6], reducing the inflammatory response [7], lowering the increase in creatine kinase and muscle soreness [8]. Furthermore, it was reported that a single application of IPC can improve strength recovery and reduce muscle swelling following exercise-induced muscle damage [9]. IPC's positive effects on recovery have been shown in very short (30s – 60s) [10] or long (24h – 48h) [11] periods with high-intensity efforts such as repeated sprints. However, to the best of our knowledge, no study has shown intermittent (30min – 60 min) positive effects of recovery after an IPC protocol.

The mechanisms involved in these athletic improvements are likely related to both metabolic and vascular pathways, as it was reported that IPC acts through 3 main pathways (i.e., neuronal, humoral, and systemic response) [12]. It has been reported that IPC affects the physiological mechanisms where it slows the consumption of adenosine triphosphate (ATP) and phosphocreatine (PCr) energy by the muscle while increasing its tolerance during myocardial ischemia and the activation of adenosine receptors and nitric oxide secretion that cause vasodilation after reperfusion [13,14].

IPC in judo was found to be an effective strategy for improving performance through the increased performance of special judo fitness test (SJFT), decreased rate of perceived exertion, and increased anaerobic power [15]. However, to the best of our knowledge, there hasn't been any research in judo investigating the IPC use for acute recovery. IPC is a non-invasive, easy-to-use tool that was recommended to be used by athletes during tournaments to facilitate athletes' readiness [9]. Furthermore, it was also recommended to enhance judo performance during training or competition [15]. The high-performance judo competition typically consists of two sessions, preliminaries and the final block, with an average break on Grands Slams and Grand-Prix between 1-2h [16]. This time gap before the final block represents the optimum time when the IPC could be of greatest use in helping to speed up the recovery. Therefore, the acute loads should be removed quickly and athletes ready for the final block fights.

From the aforementioned, the study hypothesised that IPC could lead to a rapid reversal in recovery kinetics after a judo-specific performance. Therefore, this study aimed to examine the IPC of lower limbs' effects on recovery after a judo-specific performance in highly trained male judokas and its hypothetical applicability during a competition day.

METHODS

Subjects

Thirteen elite male judo athletes from ……… National Judo Team, regularly involved in high-level competitions, voluntarily participated in this study. Athletes' characteristics can be found in Table 1. The sample size was justified by a priori analysis in G*power software (Version 3.1.9.7; Universität Kiel, Kiel, Germany) with a type I error of 0.05 and 80% statistical power. Analysis indicated that 12 participants are needed to observe significant, large-sized effects (Cohen's d = 0.80). The participants trained twice daily for six days per week and were free of musculoskeletal injuries. All athletes were black belts with 12.1 ± 0.1 years of judo experience. Measurements occurred during the preparatory period, and athletes were not engaged in weight loss. The study was conducted following the Declaration of Helsinki and was approved by the ……… University Clinical Research Ethics Committee (KAEK-143-17.01). Each athlete signed a written informed consent form.

Design

This was a single-blind (the athletes were blind to the protocol interventions), placebo (PLA)-randomised crossover study with three sessions separated by 7-day washout. Athletes were randomly assigned to either PLA or ischemic preconditioning (IPC) interventions using a random-numbers generator (www.randomization.com). Three measurements were performed: 1) anthropometrical measurements and familiarisation with tests; 2-3) sessions included the Special Judo Fitness Test (SJFT), post-exercise tests and PLA and IPC interventions, as presented in Figure 1.

Figure 1 about here

Physical, physiological, and perceptual markers were measured before (T1), immediately after (T2), and 30 min (T3) and 60 min (T4) after SJFT. Athletes were instructed not to participate in any training session during the washout period, to refrain from alcohol and caffeinated beverages 24 h prior to testing, and to maintain their daily dietary habits during the study. All measurements were performed in the same judo hall between 10:00 and 12:00 AM in controlled conditions (temperature: 23-25ºC; relative humidity: 45-60%).

Body composition

The body height was measured in a standing position barefoot to the nearest 0.1 cm using a stadiometer (Seca 213, Germany). Body composition was determined using a bioelectrical impedance (BIA) device (Tanita, BC-545, Tokyo, Japan). Measurements were performed in the standing position, barefoot, with legs and thighs not touching. The skin and the electrodes were precleaned and dried before the measurement. The general measurement guidelines for BIA were followed: 1) the measurements were taken in the morning (between 10 AM and 12 AM); 2) the respondents were asked to abstain from large meals after 9 PM the evening before the test, and on the day of the measurement they neither ate nor drank before the end of the procedure; 3) participants were asked to refrain from extreme physical exertions 24 hours prior to measuring, and last training should have been performed at least 12 hours prior to testing; 4) the respondents did not consume alcohol 48 hours before the measurement; 5) the respondents were asked to empty their bowels and bladder at least 30 min before the measurement; 6) the respondents were in the standing position for at least 5 minutes before the measurement to redistribute the tissue fluids; 7) hands were not touching the torso and were placed 15 cm laterally from the body [17,18].

The high test-retest, reliability and accuracy of BC-545 were reported with ICC=0.99 [19] and correlations with DXA $r > 0.9$ [19]. Variables of body mass, body fat percentage, muscle mass, and body fat percentage were recorded for each athlete.

Judo specific performance

Judo-specific performance was measured with a judo-specific task named the Special Judo Fitness Test (SJFT). This judo-specific task simulated similar physiological responses to a judo match [20] and reported high reliability (ICC=0.88) [21]. Two judokas (uke) were positioned at a distance of 6 m from each other, and test executor (tori) was positioned 3 m from the judokas. The procedure was divided into three sets − 15 s (A), 30 s (B) and 30 s (C) − with 10-s rest intervals between them. The aim was to throw the uke's using the ippon-seoi-nage technique in each set as many times as possible. Performance was determined based on the total throws completed during the three sets (A + B + C). The heart rate (HR) was measured with an HR monitor (Seego, Realtrack Sytems, Spain) immediately after the test and then 1 min later to calculate the index using the following equation:

$$\text{Index (bpm.throws}^{-1}) = \frac{\text{final HR (bpm)} + \text{HR at 1 min after the test (bpm)}}{\text{Number of throws}}$$

Handgrip strength

The handgrip strength was measured in a standing position, with starting hand randomly chosen by athletes, alternating three times on each side. A handgrip dynamometer (TKK 5401, Takei, Japan) was used with 1-min intervals between attempts [22] and 30 seconds between hands during PLA and IPC interventions. Athletes were instructed to generate the greatest force during 3-5 seconds with fully extended elbow and self-selected wrist and leg positions [22]. The highest value measured for each side was used in further analysis [22].

Jump Performance

The test started with a 5 min warm-up composed of callisthenics and ballistic movements. This was followed by a CMJ demonstration. The participants were instructed to use fast-counter movement to a self-selected depth, followed immediately by explosive upward propulsion to reach maximal jump height movement with the same take-off and landing positions. Two familiarisation trials were performed prior to testing. Each participant performed three maximal CMJs with a 1 min break [23]. The same researcher recorded the jumps with a mobile phone fixed on a tripod (iPhone Xs; Apple, Cupertino, CA, USA) at a sampling rate of 240 Hz, using the My Jump 2 App, set 1.5 meters apart from the athlete. Maximum jump height was taken into further analysis. Application has been shown to be a reliable tool to measure jump performance (ICC = 0.948, TEM = 1.15, CV% = 10.096) [24].

Physiological responses

Resting blood lactate (LA) and heart rate (HR) of the athletes were measured following a 30 min rest in the supine position. Immediately, 30 and 60 minutes following SJFT application LA and HR was measured again. LA was measured with a lactate device (Edge Blood Lactate Monitoring System, ApexBio Inc., Taipei City, Taiwan) by the same experienced researcher. Before each measurement, the site was cleaned with alcohol and dried with cotton, obtaining a 0.3 µl blood sample from the fingertip of the middle finger. HR was monitored with an HR monitor (Seego, Realtrack Sytems, Spain).

Blood pressure (BP) was monitored with Omron M7 Intelli (Germany) before and 60 min after the experiment.

Perceptual scales

After the SJFT, perceived exertion (RPE) was rated on a 15-point scale, ranging from 6 (very light) to 20 (very hard). Also, perceived muscle soreness (PMS) of the lower limbs was measured immediately and 60 minutes following SJFT with a scale from 0 (absence of soreness) to 10 (very intense soreness).

Recovery protocol

IPC was conducted in the supine position, according to Daab et al.[4], using a pneumatic cuff (77.0 cm length x 21.5 cm width) (Reister, 5255, Germany). The cuff was placed around the upper thigh and inflated to a pressure of 50 mmHg above the systolic blood pressure to inhibit arterial flow for 5 min. Cuff inflation generally took 15–25 s. Occlusion time started to be counted after the target pressure was achieved. This procedure was repeated three times for each leg, with each episode interspersed with 5 min of reperfusion. In PLA, a pressure of 20 mmHg was applied during the occlusion period. The blood flow of the anterior tibial artery was checked throughout the IPC using auscultation to confirm the occlusion. The occlusion was achieved in all participants. The mean pressure was 180±12 mmHG for IPC and 20 mmHG for PLA, respectively.

Statistical analysis

Statistical analysis was performed using JASP software (0.15.0.0 Version, The Netherlands). The Shapiro-Wilk test and descriptive methods using skewness and kurtosis coefficients were used to check for the normality of data. Descriptive statistics and 95% confidence intervals (CI) were used to present subjects' characteristics. Two-way ANOVA with repeated measurements (intervention x time) was used to determine changes in HR (2 x 4), LA (2 x 4), PMS (2 x 2), HGS right and left (2 x 3), CMJ (2 x 3) and BP (2 x 2) between interventions and measurement times. Partial eta squared (η^2_p) was calculated to determine the effect size, using the 0.0099, 0.0588, and 0.1379 considered as small, medium, and large effect sizes [25]. In case of significant differences between interventions, paired sample t-test was used, while one-way repeated measures ANOVA was used to determine the difference among measurement times. Cohen’s d for paired sample t-test was automatically provided by JASP software and classified as 0.2 (small), 0.5 (medium) and 0.8 (large) [26]. Statistical significance was set at $p<0.05$.

RESULTS

The descriptive data for mean baseline participant characteristics can be found in Table 1.

Table 1 about here

There was no significant difference in SJFT throw numbers, $SJFT_{index}$ and RPE between interventions ($p>0.05$). The data regarding SJFT variables can be found in Table 2. Athletes rated RPE as 14.9 ± 2.1 during PLA intervention and 15.3 ± 1.8 during IPC intervention ($p=0.05$, $d=-0.5$ [medium]).

Table 2 about here

RPE responses following SJFT performances before IPC and PLA intervention were similar ($p=0.037$, Cohen’s $d=-0.651$). Athletes classified the exercise intensity as 15.0±2.1 before PLA and 16.2±1.8 before IPC intervention.

The results of the two-way ANOVA presented that there was a significant interaction of intervention and time factors ($F_{3-36}=5.50$, $p<0.02$, $\eta^2_p=0.31$, ES= Large) for HR. There was also a significant main effect of intervention and time separately ($F_{1-12}=5.24$, $p=0.04$, $\eta^2_p=0.30$, ES= Large; $F_{3-36}=5.50$, $p<0.001$, $\eta^2_p=0.96$, ES= Large). When paired sample t-test was applied, there was significant difference in HR_{T1} (PLA=64.7±7.4, IPC=59.4±6.1, $p=0.02$, $d=0.7$ [medium]), HR_{T3} (PLA=87.1±10.9, IPC=73.3±11.6, $p=0.01$, $d=1.1$ [large]) and HR_{T4} (PLA=80.5±9.5, IPC=65.7±10.2, $p<0.001$, $d=0.5$ [medium]) while there was no difference in

HR values between interventions following SJFT application (HR_{T2}) (PLA=163.9±31.6, IPC=172.6±12.5, p=0.31, d=-0.3 [small]). According to one-way repeated measures ANOVA results, there was a significant difference in HR among all measurement times for both PLA and IPC conditions (F_{3-36}=92.87, p<0.001, η^2_p= 0.89, ES=Large; F_{3-36}=755.29, p<0.001, η^2_p= 0.98, ES=Large, respectively). Figure 2 presents HR changes in both interventions.

Figure 2 about here

According to two-way ANOVA results, there was no significant interaction of intervention and time factors on LA (F_{1-12}=, p<0.16, η^2_p=0.15, ES= Large). While there was significant effect of time factor (F_{3-36}=119.4, p<0.001, η^2_p=0.90, ES= Large), there was no significant effect of intervention (F_{3-36}=1.94, p<0.14, η^2_p=0.14, ES= Large). The results of one-way repeated measures ANOVA revealed a significant main effect of time in LA in both PLA (F_{3-36}=59.0, p<0.001, η^2_p= 0.83, ES=Large) and IPC groups (F_{3-36}=129.82, p<0.001, η^2_p= 0.92, ES=Large). LA changes between interventions can be found in Figure 3. As highlighted with percentage changes in Figure 3, LA following IPC intervention decreased by 11.6% more than PLA.

Figure 3 about here

There was a significant interaction of intervention and time on HGS_{right} (F_{2-24}=5.14, p=0.014, η^2_p= 0.30, ES=Large) which indicates differences in HGS_{right} between both groups at different measurement times. However, there was no significant effect of intervention and time factors separately (F_{1-12}=0.48, p=0.499, η^2_p= 0.03, ES=Small; F_{2-24}=1.20, p=0.318, η^2_p= 0.09, ES=Small, respectively). In contrast to HGS_{right}, there was no significant interaction of intervention and time factors on HGS_{left} (F_{2-24}=5.83, p=0.061, η^2_p= 0.20, ES=Small). Moreover, there was no significant effect of intervention and time factors on HGS_{left} separately (F_{1-12}=0.45, p=0.513, η^2_p= 0.03, ES=Small; F_{2-24}=2.00, p=0.156, η^2_p= 0.14, ES=Large, respectively). Changes in athletes' HGS_{right} and HGS_{left} performances can be found in Table 3.

Table 3 about here

According to two-way ANOVA results, there was a significant interaction of intervention and time on CMJs (F_{2-24}=5.34, p=0.012, η^2_p= 0.30, ES=Large). Nevertheless, there was no main effect of intervention factor on CMJs (F_{1-12}=0.17, p=0.685, η^2_p= 0.01, ES=Small) while there was a significant main effect of time factor (F_{2-24}=3.69, p=0.04, η^2_p= 0.23, ES=Large). When a one-way ANOVA was carried out, there was a significant difference among measurement times during PLA intervention, i.e. T_1, T_2 and T_4, (F_{2-24}=3.55, p=0.04, η^2_p= 0.23, ES=Large) and also during IPC intervention (F_{2-24}=4.77, p=0.018, η^2_p= 0.28, ES=Large). Athletes presented better CMJ performance at 60 min following IPC intervention compared to PLA (p=0.013). CMJs performance of the athletes is presented in Figure 4.

Figure 4 about here

There was no significant interaction of intervention and time on PMS (F_{1-12}=0.31, p=0.584, η^2_p= 0.026, ES=Medium). There was a main effect of intervention factor on PMS (F_{1-12}=5.55, p=0.002, η^2_p= 0.57, ES=large), there was also a significant main effect of time factor (F_{1-12}=93.16, p<0.001, η^2_p= 0.88, ES=Large). When paired sample t-test was carried out to see differences between interventions, there was no significant difference in PMS_{T2}

(PLA=7.0±1.6, IPC=6.5±1.5, p=0.08, d=0.5 [medium]) while there was significant difference in PMS_{T4} (PLA=3.6±1.2, IPC=2.8±0.8, p=0.006, d=0.9 [large]).

There was no significant interaction of intervention and time factors on BP_{sis} (F_{1-12}=0.02, p=0.893, η^2_p= 0.002, ES=Small). Moreover, there was no significant main effect of intervention and time separately (F_{1-12}=4.02, p=0.068, η^2_p= 0.025, ES=Small; F_{1-12}=0.01, p=0.921, η^2_p= 0.001, ES=Small, respectively). As for BP_{dia}, there was also no significant interaction of intervention and time factors (F_{1-12}=1.22, p=0.291, η^2_p= 0.092, ES=Small). In addition, there was no significant main effect of intervention and time separately (F_{1-12}=2.41, p=0.147, η^2_p= 0.167, ES=Large; F_{1-12}=0.60, p=0.453, η^2_p= 0.048, ES=Small, respectively).

DISCUSSION

This study aimed to investigate the effect of IPC on acute recovery following a judo-specific performance in elite judo athletes. To the best of our knowledge, this is the first study investigating the acute effects of IPC on recovery kinetics in elite judo athletes. The study's main findings were a) IPC resulted in decreased HR at 30 and 60 min during recovery, b) CMJ performance was better at 60 min with IPC intervention compared to PLA intervention, c) IPC intervention resulted in lower PMS compared to PLA intervention.

In the present study, judo-specific task measured via SJFT performance resulted in the same physical, physiological and perceptual responses as those reported after simulated or official judo matches [20,27]. This confirms the appropriateness of the study's specific-judo task performed as the SJFT test. Furthermore, the SJFT index achieved by study participants with PLA's 11.4 and IPC's 11.1 ranked ''GOOD'' in the test normative values [28], which indicated a high level of physical fitness even though athletes were in the preparation period. Moreover, RPE showed no difference following SJFT before IPC and PLA interventions, indicating athletes were exposed to the same intensity during SJFT. In addition, blood pressure showed no significant differences between IPC and PLA protocols which is in line with current literature [29].

As seen in Figure 4 and Table 3, athletes in the present study demonstrated significantly better CMJ performance which aligns with studies that reported faster recovery in CMJ and explosive movements with IPC [11]. Furthermore, the IPC has been shown to improve the recovery of muscle force production [30], which could explain the better CMJ performance. The possible mechanisms leading to better CMJ performance with IPC could be increased blood flow due to its effects on activating ATP-sensitive potassium channels [5] and increasing adenosine levels [7]. The current study is the first one that reports better CMJ performance 60 min after high-intensity exercise or 30 min after the IPC. The current study's findings are important as they showed an acute beneficial effect of IPC on performance within 1 hour, which is of utmost importance for judo athletes who perform 5-7 fights in a day with high-intensity effort [31].

IPC group showed a slight trend of increased HGS at 60 min of IPC recovery compared to PLA intervention; however still statistically insignificant. Nevertheless, this is still of great importance because the previous research reported that HGS decreased in the middle of the competition [32]. In addition, IPC was shown to delay the development of fatigue during handgrip exercise and prolonged time to task failure [33]. This information is essential for judo, where elite athletes have 5-7 fights [31] if they want to be in the contest for medals and therefore, maintaining HGS is of great importance. IPC use between the preliminary and final block of the competition could help maintain high initial HGS, delay the development of fatigue and speed up the recovery.

The IPC impacts HR with faster heart rate recovery (HRR) after exercise [10] with significant HRR at the 30s [29] and 60s [10]. Only one IPC study from sub-elite rugby players demonstrated no acute impact on HRR after 1h [34]. Therefore, the current study is the first one using IPC for acute recovery that reported significantly higher HRR in an intermittent period at 30 min (PLA=87.1±10.9, IPC=73.3±11.6, p=0.01, d=1.1 [large]) and 60 min (PLA=80.5±9.5, IPC=65.7±10.2, p<0.001, d=0.5 [medium]) after high-intensity exercise. It was discussed that IPC-induced acceleration of HRR 30min and 60min could be explained by faster cardiac vagal reactivation as studies showed that HRR in short- and long-term is largely determined by cardiac vagal reactivation post-exercise, with a negligible influence of the sympathetic branch [10]. It was also suggested that a greater increase in parasympathetic activity is an important factor in HRR after IPC [10].

Lactate levels when IPC was applied before exercise have been reported to attenuate blood lactate accumulation [35], or no significant effect was noted [5,10]. The present study's LA levels align with the literature, as LA levels did not significantly differ between conditions. However, a decreasing trend in LA by 11.6% in IPC intervention compared to PLA was noted. This could still have practical implications for judo recovery as more than 10% lower LA levels entering a final block fights could have an essential impact on judokas performance. PMS scale after 60 min presented a significantly lower score after the IPC intervention vs PLA (PLA=3.6 ± 1.2, IPC=2.8 ± 0.8, p=0.006, d=0.9 [large]). Similar findings have been reported in studies conducted on physically active men [30] and soccer players [4]. Additionally, no significant changes in RPE and BP were noted.

Literature noted that post-exercise Ischemic preconditioning (PEIPC) protocols for recovery had not been standardised yet. Therefore, it was recommended that a higher dose of PEIPC should be administered in highly trained subjects to elucidate beneficial effects. We recommend future studies exploring higher than > 50 mmHg above SBP in elite athletes with a 60-90 mmHg above SBP. Additionally, the higher IPC pressure could be combined with a shorter duration. The current study protocol targeted the break between preliminaries and the final block (30-min per leg; 3 x 5-min occlusion and 5-min reperfusion). However, shorter protocols (e.g., 2 × 2–3 min occlusion/reperfusion), which could be more time-efficient (e.g., 8–12 min)[36] and performed bilaterally, should be investigated. This would hypothetically mean that IPC could be applied between fights where breaks could vary from 10min (minimum break between fights by IJF rules) [16] to 30min - 45 min, varying on weight category, the number of competitors and the format of the competition.

It was reported that the use of IPC in various forms on healthy individuals carries a small risk as it produces trauma to major vessels and direct stress to the target organ/part of the body [37]. It was also reported that it might potentially increase the risk for deleterious cardiovascular events (e.g., cardiac arrhythmia, myocardial infarction) [38] and excessive venous compression could elevate venous pressure, which could damage the valves in veins and lead to chronic venous insufficiency [39]. Nonetheless, the IPC has been shown to attenuate Platelet-Mediated Thrombosis [40] and the data from numerous research suggest that it is a simple, safe, and feasible method capable of improving aerobic and anaerobic performance [1,41–43].

As the literature on IPC recovery is limited to team sports, this study sheds light on its acute effects during recovery in combat sports, specifically in judo, where athletes have limited time for recovery between fights. Another strength of this study is that the participants were high-level athletes. As for limitations, our participants were in the preparation period; however, a high SJFT index was achieved, demonstrating the participants' good physical fitness. There was no SJFT after 1h of IPC recovery, which could better imitate the competition environment. Therefore, further studies should investigate IPC in real-world or simulated competition. Also, BP kinetics was not measured, which could give a better insight into the IPC mechanisms. In addition, previous studies have not investigated IPC usage on acute recovery in elite judo athletes, limiting the findings' discussion. Additionally, further studies connected to IPC performance in athletic populations should also include parameters such as heart rate variability (HRV) to analyse vagal reactivation or/and the use of Muscle Oxygen Monitors to monitor oxygen levels in the muscles before, during and after the intervention as this would give a broader understanding of IPC effects.

PRACTICAL APPLICATION

The IPC in judo could be a valuable tool for coaches and athletes to enhance recovery during breaks between preliminaries and final blocks in judo competitions, as IPC is an affordable and widely available method. It could also be used in high-intensity randori training camps in between training sessions to speed up recovery and in other combat sports.

CONCLUSION

The current study demonstrated that IPC could be beneficial for improved recovery between judo competition blocks (preliminary and final). Furthermore, the results of this study were the first to show IPC's positive intermittent acute recovery in 30 and 60 min after the intensive sport-specific exercise. However, further studies should investigate the influence of shorter but higher-pressure IPC protocols that could be used in between fights where the breaks are shorter and unpredictable.

ACKNOWLEDGEMENTS

The authors thank all athletes and their coaches who volunteered to participate in this study. The study was funded by Türkiye Bilimsel ve Teknolojik Araştırma Kurumu (TUBİTAK), grant number 1919B012003058.

REFERENCES

1. Salvador AF, De Aguiar RA, Lisbôa FD, Pereira KL, Cruz RS de O, Caputo F. Ischemic Preconditioning and Exercise Performance: A Systematic Review and Meta-Analysis. *Int J Sports Physiol Perform*. 2016;11(1):4-14. doi:10.1123/ijspp.2015-0204

2. Gepfert M, Krzysztofik M, Kostrzewa M, et al. The Acute Impact of External Compression on Back Squat Performance in Competitive Athletes. *Int J Environ Res Public Health*. 2020;17(13):4674. doi:10.3390/ijerph17134674

3. Arriel RA, Meireles A, Hohl R, Marocolo M. Ischemic preconditioning improves performance and accelerates the heart rate recovery. *J Sports Med Phys Fitness*. 2020;60(9):1209-1215. doi:10.23736/S0022-4707.20.10822-3

4. Daab W, Bouzid MA, Lajri M, Bouchiba M, Rebai H. Brief cycles of lower-limb occlusion accelerate recovery kinetics in soccer players. *Phys Sportsmed*. 2021;49(2):143-150. doi:10.1080/00913847.2020.1785260

5. de Groot PCEE, Thijssen DHJJ, Sanchez M, Ellenkamp R, Hopman MTEE. Ischemic preconditioning improves maximal performance in humans. *Eur J Appl Physiol*. 2010;108(1):141-146. doi:10.1007/s00421-009-1195-2

6. Liu GS, Richards SC, Olsson RA, Mullane K, Walsh RS, Downey JM. Evidence that the adenosine A3 receptor may mediate the protection afforded by preconditioning in the isolated rabbit heart. *Cardiovasc Res*. 1994;28(7):1057-1061. doi:10.1093/cvr/28.7.1057

7. Konstantinov IE, Arab S, Kharbanda RK, et al. The remote ischemic preconditioning stimulus modifies inflammatory gene expression in humans. *Physiol Genomics*. 2004;19(1):143-150. doi:10.1152/physiolgenomics.00046.2004

8. Arriel RA, Rodrigues JF, Souza HLR de, et al. Ischemia–Reperfusion Intervention: From Enhancements in Exercise Performance to Accelerated Performance Recovery—A Systematic Review and Meta-Analysis. *Int J Environ Res Public Health*. 2020;17(21):1-16. doi:10.3390/ijerph17218161

9. Patterson SD, Swan R, Page W, Marocolo M, Jeffries O, Waldron M. The effect of acute and repeated ischemic preconditioning on recovery following exercise-induced muscle damage. *J Sci Med Sport*. 2021;24(7):709-714. doi:10.1016/j.jsams.2021.02.012

10. Lopes TR, Sabino-Carvalho JL, Ferreira THN, Succi JE, Silva AC, Silva BM. Effect of ischemic preconditioning on the recovery of cardiac autonomic control from repeated sprint exercise. *Front Physiol*. 2018;9(OCT):1-11. doi:10.3389/fphys.2018.01465

11. Beaven CM, Cook CJ, Kilduff L, Drawer S, Gill N. Intermittent lower-limb occlusion enhances recovery after strenuous exercise. *Appl Physiol Nutr Metab*. 2012;37(6):1132-1139. doi:10.1139/h2012-101

12. Caru M, Levesque A, Lalonde F, Curnier D. An overview of ischemic preconditioning in exercise performance: A systematic review. *J Sport Heal Sci*. 2019;8(4):355-369. doi:10.1016/j.jshs.2019.01.008

13. Pang CY, Yang RZ, Zhong A, Xu N, Boyd B, Forrest CR. Acute ischaemic preconditioning protects against skeletal muscle infarction in the pig. *Cardiovasc Res*. 1995;29(6):782-788. doi:10.1016/0008-6363(96)88613-5

14. Telles LG da S, Vianna JM, Kingsley JD, et al. Ischemic Preconditioning Improves Autonomic Modulation After Session of Resistance Exercise. *Brazilian Journals Dev*. 2021;7(8):85451-85470. doi:10.34117/bjdv7n8-652

15. De Souza Ribeiro AA, Novaes JDS, Martinez D, et al. Acute effect of ischemic preconditioning on the performance of judo athletes. *Arch Budo Sci Martial Arts Extrem Sport*. 2019;14(January 2020):161-170.

16. IJF. *Sport and Organisation Rules*.; 2020. https://www.eju.net/download-file?id=179647

17. Rauter S, Simenko J. Morphological Asymmetries Profile and the Difference between Low- and High-Performing Road Cyclists Using 3D Scanning. *Biology (Basel)*. 2021;10(11):1199. doi:10.3390/biology10111199

18. Ceylan B, Kons RL, Detanico D, Šimenko J. Acute Dehydration Impairs Performance and Physiological Responses in Highly Trained Judo Athletes. *Biology (Basel)*. 2022;11(6):872. doi:10.3390/biology11060872

19. Jebb SA, Cole TJ, Doman D, Murgatroyd PR, Prentice AM. Evaluation of the novel Tanita body-fat analyser to measure body composition by comparison with a four-compartment model. *Br J Nutr*. 2000;83(2):115-122. doi:10.1017/S0007114500000155

20. Ceylan B, Balci SS. The comparison of judo-specific tests. *Ido Mov Cult*. 2018;18(4):54-62. doi:10.14589/ido.18.4.7

21. Franchini E, Del Vecchio FB, Sterkowicz S. Special judo fitness test: Development and results. In: *Advancements in the Scientific Study of Combative Sports*. ; 2010:41-59.

22. Franchini E, Schwartz J, Takito MY. Maximal isometric handgrip strength: comparison between weight categories and classificatory table for adult judo athletes. *J Exerc Rehabil*. 2018;14(6):968-973. doi:10.12965/jer.1836396.198

23. Sole CJ, Mizuguchi S, Sato K, Moir GL, Stone MH. Phase Characteristics of the Countermovement Jump Force-Time Curve: A Comparison of Athletes by Jumping Ability. *J Strength Cond Res*. 2018;32(4):1155-1165. doi:10.1519/JSC.0000000000001945

24. Cruvinel-Cabral RM, Oliveira-Silva I, Medeiros AR, Claudino JG, Jiménez-Reyes P, Boullosa DA. The validity and reliability of the "my Jump App" for measuring jump height of the elderly. *PeerJ*. 2018;2018(10). doi:10.7717/peerj.5804

25. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd Editio. L. Erlbaum Associates; 1988.

26. Sullivan GM, Feinn R. Using Effect Size—or Why the P Value Is Not Enough. *J Grad Med Educ*. 2012;4(3):279-282. doi:10.4300/JGME-D-12-00156.1

27. Detanico D, Pupo JD, Franchini E, Dos Santos SG. Effects of successive judo matches on fatigue and muscle damage markers. *J Strength Cond Res*. 2015;29(4):1010-1016. doi:10.1519/JSC.0000000000000746

28. Sterkowicz-Przybycień K, Fukuda DH, Franchini E. Meta-Analysis to Determine Normative Values for the Special Judo Fitness Test in Male Athletes: 20+ Years of Sport-Specific Data and the Lasting Legacy of Stanisław Sterkowicz. *Sports*. 2019;7(8):194. doi:10.3390/sports7080194

29. Morley WN, Coates AM, Burr JF. Cardiac autonomic recovery following traditional and augmented remote ischemic preconditioning. *Eur J Appl Physiol*. 2021;121(1):265-277. doi:10.1007/s00421-020-04526-y

30. Page W, Swan R, Patterson SD. The effect of intermittent lower limb occlusion on recovery following exercise-induced muscle damage: A randomized controlled trial. *J Sci Med Sport*. 2017;20(8):729-733. doi:10.1016/j.jsams.2016.11.015

31. Franchini E, Takito MY, Nakamura FY, Matsushigue KA, Kiss MAPDM. Effects of recovery type after a judo combat on blood lactate removal and on performance in an intermittent anaerobic task. *J Sports Med Phys Fitness*. 2003;43(4):424-431.

32. Kons RL, Dal Pupo J, Ache-Dias J, et al. Effect of official judo matches on handgrip strength and perceptual responses. *J Exerc Rehabil*. 2018;14(1):93-99. doi:10.12965/jer.1835156.578

33. Barbosa TC, Machado AC, Braz ID, et al. Remote ischemic preconditioning delays fatigue development during handgrip exercise. *Scand J Med Sci Sports*. 2015;25(3):356-364. doi:10.1111/sms.12229

34. Garcia C, da Mota G, Leicht A, Marocolo M. Ischemic Preconditioning and Acute Recovery of Performance in Rugby Union Players. *Sport Med Int Open*. 2017;01(03):E107-E112. doi:10.1055/s-0043-111082

35. Bailey TG, Jones H, Gregson W, Atkinson G, Cable NT, Thijssen DHJ. Effect of Ischemic Preconditioning on Lactate Accumulation and Running Performance. *Med Sci Sport Exerc*. 2012;44(11):2084-2089. doi:10.1249/MSS.0b013e318262cb17

36. Marocolo M, Billaut F, da Mota GR. Ischemic Preconditioning and Exercise Performance: An Ergogenic Aid for Whom? *Front Physiol*. 2018;9(December):9-12. doi:10.3389/fphys.2018.01874

37. Kraemer R, Lorenzen J, Kabbani M, et al. Acute effects of remote ischemic preconditioning on cutaneous microcirculation - a controlled prospective cohort study. *BMC Surg*. 2011;11(1):32. doi:10.1186/1471-2482-11-32

38. Spranger MD, Krishnan AC, Levy PD, O'Leary DS, Smith SA. Blood flow restriction training and the exercise pressor reflex: a call for concern. *Am J Physiol Circ Physiol*. 2015;309(9):H1440-H1452. doi:10.1152/ajpheart.00208.2015

39. Eberhardt RT, Raffetto JD. Chronic Venous Insufficiency. *Circulation*. 2005;111(18):2398-2409. doi:10.1161/01.CIR.0000164199.72440.08

40. Przyklenk K, Whittaker P. Ischemic Conditioning Attenuates Platelet-Mediated Thrombosis. *J Cardiovasc Pharmacol Ther*. 2017;22(5):391-396. doi:10.1177/1074248417724871

41. Incognito A V., Burr JF, Millar PJ. The Effects of Ischemic Preconditioning on Human Exercise Performance. *Sport Med*. 2016;46(4):531-544. doi:10.1007/s40279-015-0433-5

42. Kimura M, Ueda K, Goto C, et al. Repetition of Ischemic Preconditioning Augments Endothelium-Dependent Vasodilation in Humans. *Arterioscler Thromb Vasc Biol*. 2007;27(6):1403-1410. doi:10.1161/ATVBAHA.107.143578

43. Cocking S, Jones H, Cable NT, Thijssen DH. Enhancing Sports Performance Through Ischemic Preconditioning. In: Rattan SIS, Kyriazis M, eds. *The Science of Hormesis in Health and Longevity*. Elsevier; 2019:213-222. doi:10.1016/B978-0-12-814253-0.00019-X

Table 1. Baseline characteristics of participants (Mean ± SD) with confidence intervals (95% CI)

Variables (n=13)	Mean ± SD	95% CI
Age (years)	18.6 ± 0.9	18.1 – 19.2
Body mass (kg)	72.4 ± 7.1	68.1 – 76.7
Height (cm)	1.74 ± 0.05	1.71 – 1.77
Body fat percentage (%)	7.6 ± 2.4	6.1 – 9.0
Fat-free mass (kg)	63.4 ± 4.9	60.5 – 66.4

Table 2. Athletes' SJFT throw numbers before PLA and IPC interventions

Variables (n=13)	PLA	95% CI	IPC	95% CI	t	*P*	ES
SJFT A (throws)	6.0 ± 0.4	5.7-6.2	6.2 ± 0.4	5.9-6.5	1.361	1.199	0.377
SJFT B (throws)	11.6 ± 0.7	11.2-12.0	11.4 ± 0.9	10.9-11.9	0.693	0.502	0.192
SJFT C (throws)	10.5 ± 0.8	10.0-11.0	11.0 ± 0.8	10.6-11.5	1.620	0.131	0.449
SJFT A HR	154 ± 17	144-164	152 ± 15	144-161	0.766	0.458	0.213
SJFT B HR	169 ± 15	160-178	169 ± 14	161-178	0.116	0.910	0.032
SJFT C HR	171 ± 12	164-179	173 ± 13	165-180	0.899	0.386	0.249
SJFT HR 1min	149 ± 10	143-155	146 ± 12	145-153	0.945	0.363	0.262
SJFT index	11.4 ± 0.8	10.9-11.9	11.1 ± 0.8	10.6-11.6	1.361	0.198	0.378

Legend: SJFT – special judo fitness test; PLA – placebo protocol; IPC – ischemic preconditioning protocol; CI – confidence interval; HR – heart rate; ES – Effect size as Cohen's d

Table 3. Handgrip strength performance of the athletes during PLA and IPC interventions

Variable (n=13)		Intervention			
		PLA	95% CI	IPC	95% CI
	T_1	46. 9 ±8.0	(42.2-51.8)	44.8 ± 4.9	(41.9-47.8)
HGS_{right}	T_2	43.2 ± 3.8	(41.6-46.2)	45.7 ± 4.5	(43.1-48.5)
(kgf)	T_4	43.8 ± 3.7	(41.6-46.0)	45.7 ± 4.7	(42.9-48.6)
	T_1	46.1 ± 5.5	(42.8-49.5)	45.6 ± 5.2	(42.5-48.8)
HGS_{left}	T_2	44.8 ± 4.5	(42.0-47.6)	44.8 ± 4.7	(42.0-47.7)
(kgf)	T_4	44.8 ± 5.6	(41.5-48.3)	46.0 ± 4.9	(43.0-49.0)

Legend: T1= Rest; T2= 0 min; T4= 60 min; HGS – hand grip strength

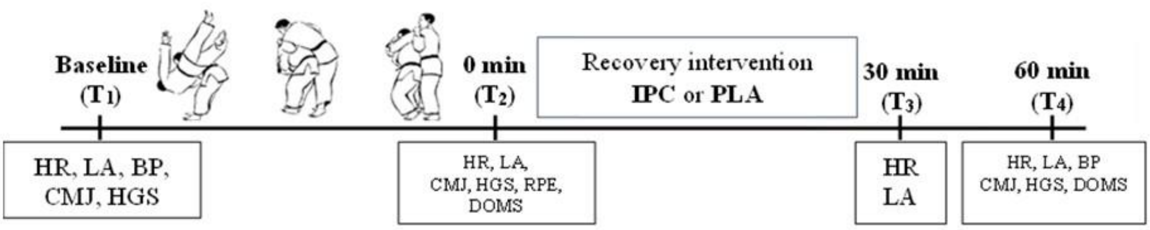

Figure 1. Design of the experimental protocol

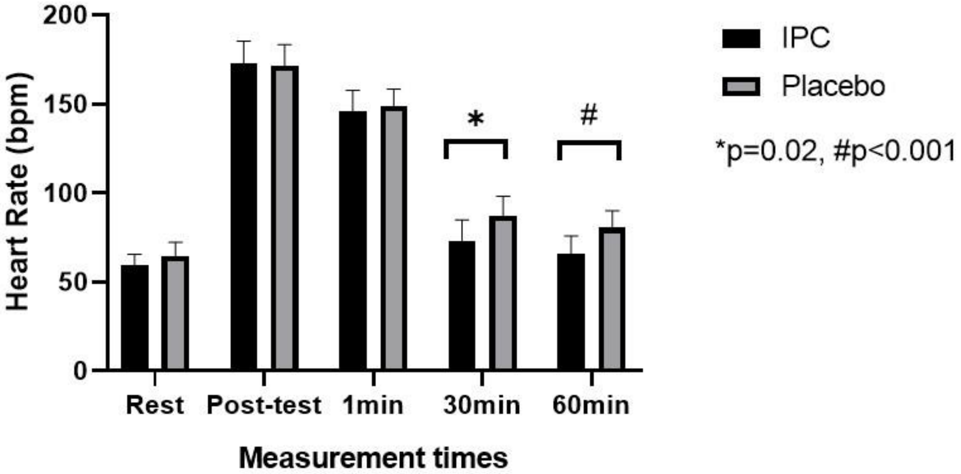

Figure 2. Heart rate changes in PLA and IPC interventions

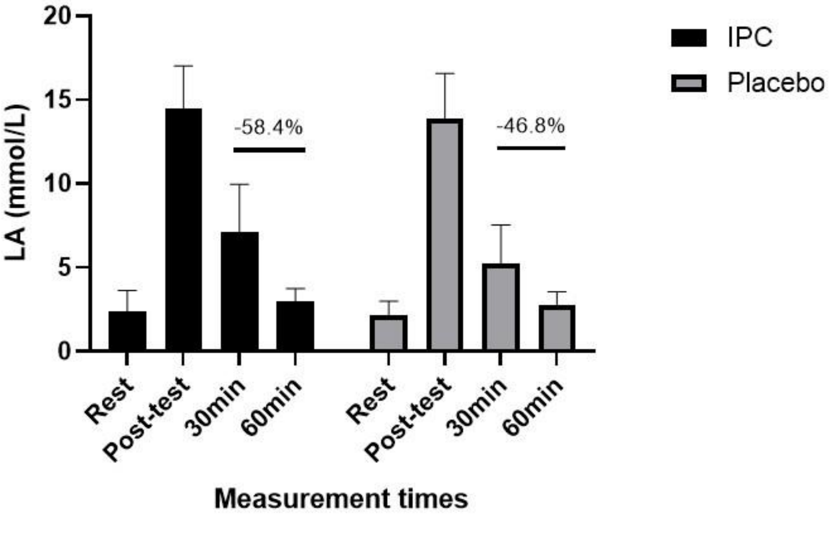

Figure 3. LA changes in PLA and IPC interventions.

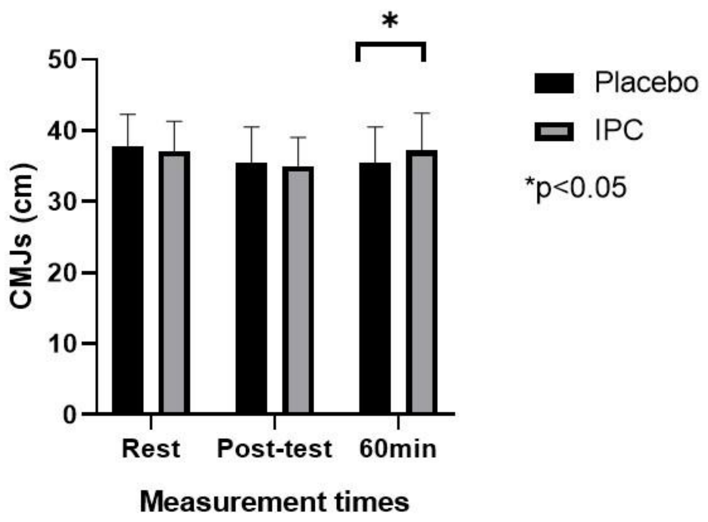

Figure 4. The CMJ performance in PLA and IPC interventions.

533