TITLE
Ischemic preconditioning using 2x5' or 4x5' bouts of occlusion does not improve 2km rowing time-trial performance in trained athletes.

AUTHOR
Reed, Tom

DATE DEPOSITED
13 October 2017

Ischemic preconditioning using 2x5' or 4x5' bouts of occlusion does not improve 2km rowing time-trial performance in trained athletes.

Principle Researcher: Tom Reed

Project Supervisors: Dr Stephen Patterson and Jessica Hill

This Research Project is submitted as partial fulfilment of the requirements for the degree of Master of Science, St Mary's University

Department of Health, Post-Graduate Programme in Strength and Conditioning, St Mary's University, Twickenham, United Kingdom.

Corresponding author: Tom Reed, 54 Albany Road, Bath, BA21BP, United Kingdom, reedtom86@gmail.com

Table of Contents

List of figures

List of tables

ACKNOWLEDGEMENTS

The authors would like to thank all participants who volunteered to take part in the study and Welsh Institute of Sport for hosting the experimental trials.

ABSTRACT

Purpose: Ischemic preconditioning has been shown to have a positive effect on exercise performance. No studies to date have investigated whether there is a dose-response relationship evident in the IPC phenomenon. This study tested the hypothesis that ischemic preconditioning (IPC) would improve 2 kilometre (km) rowing time trial performance, and aimed to investigate whether a dose-response relationship existed.

Methods:

In a single-blind study, twelve healthy, injury-free subjects (8 males, 4 females; mean ± SD age; 19 ± 3 years, height 1.70 ± 0.11 m; mass 69 ± 12 kg), active to an elite level in Judo (Welsh National team) performed 3 rowing time trials. At the initial trial all participants performed the control study with no IPC intervention, for trial two 6 subjects were randomly allocated to either the 2 x 5' IPC or 4x5' IPC protocol. For the third trial a crossover was applied meaning that each participant completed the other IPC protocol. The IPC protocol was applied 45 minutes prior to completing a 2km rowing ergometer time trial.

Results: The time taken (mean ± SD) to complete the 2km row was 487 (±47), 486 (±45) and 481 (±40) seconds for control, 2x5' cycles and 4x5' cycles of occlusion groups, respectively Repeated measures analysis of variance (ANOVA) revealed that overall 2km time trial performance did not differ statistically significantly between the three trials ($F_{1.446,\ 15.910}$ = 1.416, p = 0.265). There were statistically significant differences between the first 500m split times ($F_{1.586,\ 17.444}$ = 14.799, p = 0.00); control trial (118 ± 12s) and 2 x 5' IPC trial (117 ± 12s) were significantly faster than the 4 x 5' IPC trial (122 ± 11s, p = 0.029 and p = 0.000, respectively). There were some significant differences between the results of individual 500m splits within the 2km row; the first split in the control trial (118 ± 12s) and in the 2 x 5' IPC trial (117 ± 12s) were both significantly faster than the 4 x 5' IPC trial (122 ± 11s, p = 0.029 and p = 0.00, respectively). Split three in the control trial (125 ± 11s) was significantly slower

than the 4 x 5’ IPC trial (121 ± 9s, $p = 0.048$). Power (W) in split one was significantly higher in the 2x5’ IPC trial than the 4x5’ IPC trial (235 ± 79W and 203 ± 66W, $p = .03$). Calculation of effect sizes showed that all effects were classified as trivial (ES < 0.2)

Conclusion: The data suggests that the IPC protocols utilized were not affective at improving overall 2km rowing time trial performance in elite trained Judoka.

CHAPTER ONE: INTRODUCTION

Ergogenic preconditioning and priming strategies have increasingly studied in pursuit of marginal gains to improve sporting performance and IPC presents a potentially affective and practical strategy in this regard (23).

Ischemic preconditioning (IPC) consists of short intermittent bouts of ischemia induced via arterial blood flow occlusion performed in order to reduce the negative effects of subsequent prolonged exposure to ischemia (typically of 3-4 x 5 minutes of occlusion interspersed with 5 minutes of reperfusion) (18). IPC can be applied locally and remotely and is defined as a hermetic biphasic dose-response phenomenon whereby the protective affects to reduce infarct size on the myocardium are induced in subsequent prolonged exposure to ischemia (34,38). IPC has been shown to protect several organs from infarct in subsequent prolonged ischmia, including the myocardium (34), liver (36) and skeletal muscle (14). IPC has more recently been investigated for its potential benefits to sporting performance, with the first evidence shown by increased repeated force outputs in a forearm gripping test following IPC (27).

A recent systematic review and meta-analysis of studies on IPC across all exercise types reported a small positive overall effect on performance (ES = 0.43; 90% confidence interval [CI], 0.28 to 0.51); with effect to aerobic (ES = 0.51; 90% CI, 0.35 to 0.67) and anaerobic (ES = 0.23; 90% CI, -0.12 to 0.58) exercise being larger than those observed for power and sprint related activities (ES = 0.16; 90% CI, -0.20 to 0.52). (37). In another review of 21 studies (18), 10 reported statistically significant benefits, with affects including; improved time trial performance (2,19,25), increased power output (7,8,37) and decreased perceived rate of exertion (2,9,26).

The first study in the context of endurance exercise performance found an increased time to exhaustion in a cycling ramp test, which the authors postulated could be due to changes in

fatigue perception (8). Positive performance effects have subsequently been shown in several studies; these include a 34s improvement (95% confidence interval, 5–64 s; P = 0.027) in running time trial performance, attributed to a higher work rate allowed by an attenuated rise in blood lactate accumulation (2), 1000m rowing ergo time trial performance (from 186.5 ± 3.6 to 185.7 ± 3.6 s; $p < 0.05$), (25), and increased (+3.7%, $p < 0.05$) power output at $V0_{2max}$ (7). Studies investigating the mechanisms behind IPC have found enhanced vasodilation and increased oxygen delivery (3,20), attenuation of blood lactate accumulation (1,12,36), improvements in endothelial function (2) and ATP sparing effects (28). These effects are pertinent to improvements in exercise of an endurance nature thus research has predominantly focused on using IPC as a priming strategy for endurance based exercise.

The optimal protocol (how to actually perform IPC) used in order to yield positive affects to exercise performance is still not clear (39). To date there are no studies directly investigating the effectiveness of IPC through comparison of different protocols. In the existing research doses of 3 x 5 minute or 4 x 5 minute periods of occlusion have been used and studies utilizing these doses have produced mixed results, with both beneficial and negligible effects to performance being shown (6,7,8,19,35). Recent systematic reviews of all the eligible studies suggest that there is no clear relationships between the use of either 3 or 4 sets of IPC and the size of the effect on subsequent exercise performance (18, 39).

Studies using 4 x 5’ IPC prior to time trials of an endurance nature have observed statistically significant ($p < .05$) improvements in; 5km treadmill running time (-2.5%, using 220 mmHg occlusion) (2), 1km rowing sprint time (-0.4%, 40 mmHg above resting systolic blood pressure RSBP) (26) and time to failure in constant load cycling (+7.9%, 220 mmHg occlusion) (9). 4 x 5’ IPC has also been observed to have no effect on: time to failure in graded maximal cycling (220 mmHg occlusion) (2) and time taken to cycle 100 kJ (20 mmHG above RSBP) (11).

Studies using 3 x 5' IPC on endurance time trials have observed statistically significant ($p <$ .05) improvements in: time to failure in maximal graded cycling (+3.6%, occlusion at 50 mmHg above RSBP) (7), time to failure in constant load cycling (+15.8%, 300 mmHg occlusion) (25). 3 x 5' IPC has also been observed to have no effect on: 5km outdoor running time (50 mmHg above RSBP) (41), (2) and time to failure in graded maximal cycling (220 mmHg occlusion) (6). The studies on endurance time trials have all used 2x5' and 4x5' IPC, with no studies using fewer cycles, however a study on RIPC (31) observed that 2 cycles of IPC in the legs, but not arms was enough to prevent endothelial ischemia-reperfusion dysfunction in the brachial artery, although no test was performed on to exercise performance, meaning conclusions cannot be drawn on whether performance would be effected from this lower IPC dose. RIPC is characterised by inducing an effect in organs that are non-local to the limbs where the occlusion is applied, for example effects on the myocardium after inducing ischemia on the legs. Research has also shown positive effects on power production in the squat jump (ES = 0.63) immediately following just 2 x 3 minutes unilateral leg occlusion at 220 mmHg (3), indicating that fairly low-dose IPC can yield meaningful effects

The aim of this study is to investigate whether improved endurance rowing performance can be achieved following IPC. The aforementioned studies show that 3x5' IPC can be effective and this study aims to go further and see if as few as 2 x 5' yields improvements; it is hypothesized that 2 x 5' will improve time trial performance. The unique aim of this study is to directly compare 2 sets of 5' occlusion-reperfusion with 4 x 5' in order to investigate whether a dose-response exists. Due to the limited amount of existing research it is not known whether 4 x 5' IPC will yield greater improvements in time trial performance than 2 x 5'IPC, thus this is a secondary aim of the study.

CHAPTER TWO: METHODS

2.0 Participants

In a single-blind, crossover study, twelve healthy, injury-free subjects (8 males, 4 females; mean ± SD age; 19 ± 3 years, height 1.70 ± 0.11 m; mass 69 ± 12 kg), active to an elite level in Judo (Welsh National team) were recruited to participate. Participants had a minimum training age of 8 years, with 2 years in a full time training environment; training time per week was 15 hours for all participants. The subjects were naïve about the effects of IPC, as assessed by a short questionnaire to assess their knowledge prior to testing. Participants and their legal guardians where appropriate were fully informed about the procedures involved and any associated risks and they were able to withdraw from the study at any time. Approval for the study's procedures was granted by St Mary's University Ethics Committee which conformed to the Declaration of Helsinki.

2.1 Experimental Overview

The subjects reported to the Welsh institute of Sport High Performance gym on four separate occasions. The initial visit was used to obtain anthropometric data on the participants and to gage their current level of knowledge about IPC. There was no need for a familiarization trial because all of the subjects had been tested on the 2km rowing time trial as part of their normal training program on at least three occasions prior to the study, The coefficient of variation (cv) from previous 2km rowing tests within Welsh Judo has always been measured at <10. The time trial itself required subjects to carry out a 2km row on a wind-braked rowing ergometer (Concept2, Morrisville, VT) as fast as possible following a standardized warm up. The concept2 rower has been found to be highly reliable at accurately recording distance rowed, average power and average stroke rate (30), thus it was deemed appropriate for the study. The first trial acted as the control for all subjects and no IPC procedure was performed, trials two

and three were the experimental trials and were preceded with either of the two IPC procedures in a randomized crossover fashion. The participants were randomly allocated to either of the protocols by pulling identification numbers out of a cup, with the first 6 subject drawn completing the 2x5' IPC first and the remaining 6 completing 4x5'. This was followed by a crossover in the next experimental trial. Immediately following each 2km row participants indicated their rating of perceived exertion (RPE, 6–20; Borg scale). The trials were separated by 7 days in order to eliminate the carry-over of latent effects from the previous IPC protocol (28) and to allow time for full recovery. Following recommendations from previous research caffeine, alcohol, and exercise were restricted prior to the study for 24, 12 and 48 hours respectively (18). Each participant performed all of their trials using the same rowing ergometer at the same time of day (±1 h) and the temperature within the high performance gym was controlled at approximately 19° throughout all trials.

2.2 Experimental Measures

2.2.1 Ischemic Preconditioning

In each of the experimental trials the 2km rowing time trial was preceded by ischemic preconditioning using an occlusion cuff (The Occlusion Cuff, Birmingham, UK). The occlusion cuff dimensions are 100cm long x 8 cm wide bladder with a 40cm extension for secure fastening. The cuff pressures were standardized to 220 mmHg, which has been shown to be an affective cuff pressure for inducing IPC effects in numerous studies (2,10,26). The lower limbs were alternately cuffed for 5 minutes of occlusion and 5 minutes of reperfusion and each IPC protocol was followed by a 25 minute break which preceded the standardised warm up. The warm up is then followed by a 2 minute break, meaning that the time trial started approximately 45 minutes after the IPC protocol was completed. This 45 minute window of time between the IPC protocol and the exercise test has previously been shown to be

appropriate for yielding positive performance effects (19). The format of the trials, including the timing of each IPC protocol is illustrated clearly in figures 1-3.

2.2.2 Rowing Time-Trial

The warm up used was the standard protocol used in all British Judo performance centres, including Sport Wales. The prescribed warm up consisted of a 10-minute general dynamic warm up, then 1km rowing at a self-selected 'easy' pace, followed by 2 sets of 10 seconds of max effort separated by 50 seconds of 'easy' rowing. Following British Judo guidelines, the ergometer drag factor was set at 130 for males and 110 for females at all times. Following the time trial the participants completed a 20-minute cool down of low intensity cycling on a stationary bike. For the duration of the 2km row the all information on the ergometer display, other than distance remaining, was shielded from view of the participant in order to avoid the effect of pacing. Timekeeping devices of any sort were also not visible to the participant for the same reason. At the onset of the trial participants were instructed to "complete the 2km row as fast as you can" and no verbal encouragement was given once the 2km row was started.

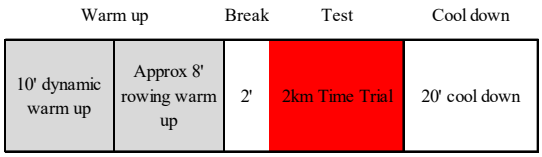

Figure 1. Control testing protocol.

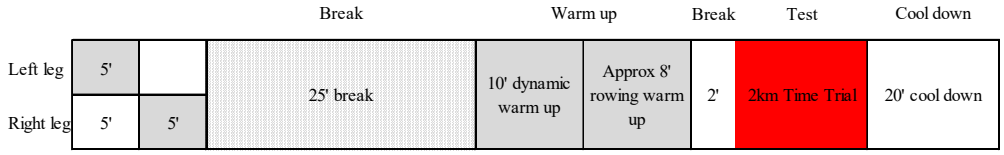

Figure 2. IPC testing protocol with 2 x 5' occlusion.

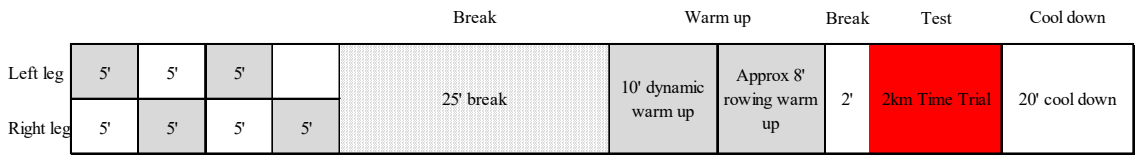

Figure 3. IPC testing protocol with 4 x 5' occlusion.

Data was also recorded for on average for each 500m split and average for the 2km row on stroke rate per minute (SR) and power (W). The time it took to complete each 500m split was also measured. Rate of perceived exertion was measured by Borg Scale (4) immediately following each time trial.

2.3 Statistical Analysis

Power analysis was used to calculate the necessary number of participants; time trial performance was used as the main endpoint in one-way repeated measures ANOVA (G*Power 3.1 Dusseldorf University, Germany), considering a mean difference of 2% between interventions (*P* value at 0.05 and power at 0.80), indicating that 5 subjects would be necessary. Data was analysed using the SPSS statistical software package (IBM SPSS Statistics 10.0 New York, USA); data was checked for normality using Shapiro-Wilk normality test. Following this a one-way repeated measures ANOVA with three levels was used to examine if there were significant differences in the groups mean scores for 2km rowing for the experimental time trials using IPC, in comparison to the control trial. The significance level for assessing any differences in performance was set at 5%. Due to the importance of identifying marginal gains in the context of sport competition, effect sizes (Cohen's d) were also applied to the data. Effect sizes of <0.2, <0.6, <1.2, <2.0 and >2 were considered to be trivial, small, moderate, large and very large, respectively (15).

CHAPTER THREE: RESULTS

All participants completed all three of the time trials according to the schedule set at the outset of the study, the different scores between each trial are illustrated in figure 4. The mean scores of each measure in each 500m split across the three trials are shown in table 1. A one way repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean 2km rowing time did not differ statistically significantly between the three time trials ($F_{1.446, 15.910}$ = 1.416, p = 0.265)There was a statistically significant difference between time taken to complete the first 500m split, between the three 2km rowing trials ($F_{1.586, 17.444}$ = 14.799, p = 0.00). The first split in the control trial (118 ± 12s) and in the 2 x 5' IPC trial (117 ± 12s) were both significantly faster than the 4 x 5' IPC trial (122 ± 11s, p = 0.029 and p = 0.00, respectively). There was a statistically significant difference between time taken to complete the third 500m split, between the three 2km rowing trials ($F_{1.899, 20.996}$ = 5.191, p = 0.016). Split three in the control trial (125 ± 11s) was significantly slower than the 4 x 5' IPC trial (121 ± 9s, p = 0.048).There was a statistically significant difference between SR of the first 500m split, between the three 2km rowing trials ($F_{1.904, 20.393}$ = 3.911, p = 0.038), though post hoc analysis did not show any significant pairwise comparisons. There was a statistically significant difference between SR of the third 500m split, between the three 2km rowing trials ($F_{1.267, 13.993}$ = 3.911, p = 0.018), though post hoc analysis did not show any significant pairwise comparisons.

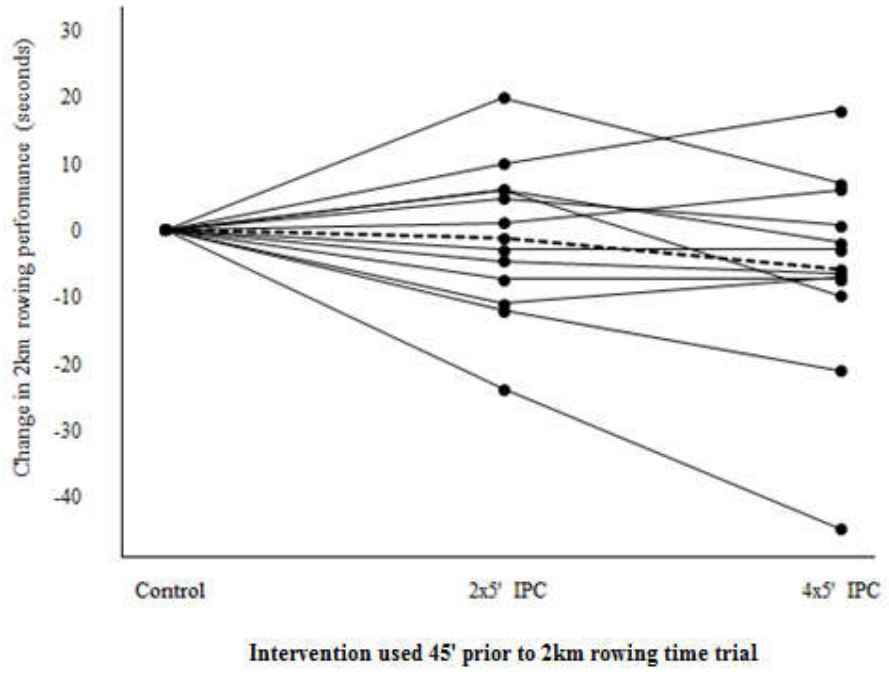

Figure 4. Change in 2km rowing time trial performance by individual participants following ischemic preconditioning. Mean change (P >0.05) for the group displayed via dashed line. Table 1. Full results for 2km rowing time trial under each of the trial conditions; Control (No IPC), 2x5' IPC and 4x5' IPC. Table shows mean score for each group, Standard deviation and Effect sizes compared to control condition. Effect sizes <0.2, <0.6, <1.2, <2.0 and >2 were considered to be trivial, small, moderate, large and very large, respectively.

There was a statistically significant difference between W of the first 500m split, between the three 2km rowing trials ($F_{1.370,\ 15.073} = 9.801$, $p = 0.04$), W in split one was significantly higher in the 2x5' IPC trial than the 4x5' IPC trial (235 ± 79W and 203 ± 66W, $p = .03$). Results are shown in Table 1.

Measure	Control	IPC 2x5’	IPC 4x5’	df	F	Sig.
RPE	8.8 ± 1.11	9.5 ± .52	9.4 ± .79	1.69	1.990	.169
2km time	487 ±13	486 ± 13	481 ± 12	1.446	1.416	.265
Split 1 time	118 ± 12	117 ± 12	122 ± 11	1.586	14.799	.000*
Split 2 time	123 ± 12	124 ± 12	124 ± 10	1.975	1.226	.313
Split 3 time	125 ± 11	124 ± 11	121 ± 9	1.899	5.191	.016*
Split 4 time	122 ± 12	121 ± 10	120 ± 10	1.151	1.410	.263
Split 1 stroke rate	37 ± 5.4	38 ± 5.4	36 ± 4.3	1.904	3.911	.038*
Split 2 stroke rate	35 ± 4.4	36 ± 4.8	36 ± 5.0	1.590	1.431	.262
Split 3 stroke rate	34 ± 4.4	35 ± 4.7	37 ± 5.5	1.267	6.544	.018*
Split 4 stroke rate	35 ± 5.3	37 ± 5.7	36 ± 5.3	1.454	2.596	.117
Split 1 power (W)	226 ± 77	235 ± 79	203 ± 66	1.370	9.801	.004*
Split 2 power (W)	199 ± 59	194 ± 63	191 ± 50	1.922	1.462	.252
Split 3 power (W)	190 ± 53	191 ± 58	205 ± 45	1.677	3.476	.240
Split 4 power (W)	205 ± 59	208 ± 58	210 ± 55	1.256	.927	.475

Table 1. Full results with ANOVA for 2km rowing time trial under each of the trial conditions; Control (No IPC), 2x5’ IPC and 4x5’ IPC. Table shows mean score for each group, Standard deviation and results of ANOVA between the three trial conditions. Post hoc tests using the Bonferroni correction applied to identify where significant differences occurred. Alpha level for significance was set at $p<.05$.

Neither IPC protocol had a statistically significant effect on overall 2km rowing time-trial performance, though there were some significant differences observed between the individual 500m splits. All of the effect sizes were calculated by Cohen’s d are classified as trivial (ES <

0.2), apart from RPE where a small effect was observed between control and IPC trials (ES < 0.4) as shown in Table 2.

	Control		2 x 5' cycles			4 x 5' cycles		
	Mean	SD	Mean	SD	ES	Mean	SD	ES
RPE	8.8	±1.11	9.5	±.52	.37	9.4	.79	.29
Time								
2km time	487.30	± 46.81	484.34	± 42.61	.03	482.69	± 42.75	.06
Split 1 time	117.93	± 12.49	115.89	± 12.07	.08	115.14	± 11.24	.13
Split 2 time	122.87	± 11.57	123.17	± 12.10	.00	123.15	± 11.45	.00
Split 3 time	124.55	± 11.37	124.05	± 10.06	.05	124.37	± 11.12	.05
Split 4 time	121.73	± 11.67	121.40	± 9.27	.05	120.11	± 9.68	.09
Stroke rate								
2km average	34.98	± 4.59	36.42	± 4.62	.01	35.83	± 5.02	.01
Split 1	36.92	± 5.43	38.00	± 4.22	.01	37.92	± 5.25	.01
Split 2	34.67	± 4.36	36.17	± 4.20	.01	35.50	± 4.87	.00
Split 3	33.58	± 4.36	35.75	± 4.86	.02	35.17	± 4.90	.02
Split 4	35.42	± 5.33	36.83	± 5.77	.18	36.33	± 5.33	.09
Power (W)								
2km average	206.55	± 60.16	206.46	± 59.73	.00	208.88	± 61.39	.02
Split 1	226.17	± 76.60	240.58	± 86.46	.09	242.67	± 76.63	.10
Split 2	198.58	± 59.11	199.25	± 68.32	.00	197.42	± 60.71	.02
Split 3	189.86	± 52.87	190.50	± 50.47	.00	191.08	± 57.39	.00
Split 4	204.75	± 58.71	202.42	± 47.73	.03	210.08	± 55.41	.04

Table 2. Full results with effect sizes for 2km rowing time trial under each of the trial conditions; Control (No IPC), 2x5' IPC and 4x5' IPC. Table shows mean score for each group, Standard deviation and effect size between the three trial conditions.

CHAPTER FOUR: DISCUSSION

The primary focus of the study was to examine whether ischemic preconditioning had an effect on 2km rowing time trial performance. A secondary aim was to investigate whether there was a dose-response relationship between the number of cycles of occlusion-reperfusion performed and the subsequent time trial performance. The 2km rowing test is suitable as it is the standard aerobic capacity test used by British Judo and this study's sample was made up of elite Judoka who are all familiar with the test. A 2km row is characterized by the reliance mainly on aerobic metabolism, with rowers typically working at a rate greater than 90% of their maximal aerobic capacity throughout a period of approximately six to nine minutes of activity (21). In consideration of the aforementioned existing literature, and based on the duration of a 2km row and the intensity of sustained effort the hypothesis of this study was that IPC would have a positive effect on time trial performance. The study aimed to establish whether there was a dose-response relationship between the number of cycles of occlusion-reperfusion applied, and the size of any observed effects.

This study does not any significantly significant difference between the overall time trial performance under the three trial consitions, with neither IPC protocols having any affect on performance, either positive or negative. The individual performances for each participant were also variable, as shown in table 1. It is however worth noting that within the context of elite performance coaches and athletes still might consider that even tiny differences would represent some degree of 'competitive significance', thus effects that are classified as trivial in a statistical analysis may still be deemed worthy of further examination within the context of elite sport. Although in this same regard the small detrimental effects on some participants should be considered.

The improvements observed in power, time and SR indicate that the subjects generally employed a better pacing strategy for the 4x5' IPC trial, as shown by improved performance in split three, compared to a reduction in pace, power and SR in split one. The lack of significant change in the overall 2km time trial performance indicates that any changes were likely a result of changes in pacing, rather than genuinely improved performance.

The randomised crossover design of the study aimed to reduce the potential for any influence deriving from test order, however it would be more accurate to treat the control study as part of the crossover too, in order to avoid learning or pacing effects that may have benefited the subsequent IPC trials. The limited pool of elite Judoka with which this study had to recruit from resulted in a fairly small group of 12 which may also contribute to the lack of significance. Thus it is worth examining the potential reasons behind the lack of statistical significance and exploring whether adjustments to the methodology might yield more meaningful results.

Initially it is worth questioning the accuracy of the time trial results as a true representation of maximal performance. The 2km rowing time trial is an extremely demanding test, both physically and psychologically. The participants would normally complete this test once every 2-3 months as part of their normal training in regime, whereas they were required to complete it 3 weeks running for the purpose of this study. Although anecdotal, it was evident that the participants did not always seem fully motivated at the onset of each trial. To avoid this prior to each trial, participants were always asked if they were ready to give their best effort, and also asked to record a RPE following each trial. Although subjects always reported that they gave their best effort and recorded RPE's of >8 (Table 1), these self-reported measures of motivation and effort are arguably open to subject bias. Furthermore, actual fatigue from residual training effects is very hard to control in a study on this type of group and despite all

participants avoiding training for 48 hours per-test, the chronic fatigue experienced from elite level training cannot be underestimated.

The cohort of participants are highly trained athletes and are well accustomed to this particular rowing test. Previous research has indicated that trained individuals are more resistant to the effects of ischemia than non-trained (22,31), therefore the scope for improvement following IPC might be reduced. However, research on IPC has shown improvements in performance in both trained and non-trained groups, and have indicated that the effect may actually be higher in trained individuals (19, 25,13). Indeed, the 4x5' IPC protocol has been shown to provide positive effects in "well-trained" individuals with a $V0_{2max}$ averaging 56.8ml/kg/min (8). In consideration of the existing research it is unlikely that the effects of IPC were inhibited by the trained-state of the participants. It could also be the case that the athletes are so familiar with the 'feeling' of their usual 2km rowing pace that they stayed very close to this for all trials.

Several studies have shown that IPC can improve performance in endurance tests measuring aerobic capacity (2,6,7,25). One particularly pertinent study (2), found improved 5km running time trial performance of 34 seconds following IPC compared to a control condition, despite no significant changes to heart rate, $V0_{2max}$ or blood lactate accumulation in the trial following IPC. Following IPC a phenomenon of reactive hyperemia occurs, whereby there is a substantially increased level of blood flow to the muscles (42). This effect has been shown as one of the contributing factors that facilitates protection from subsequent prolonged ischemia (32), and may explain potentially increased exercise performance (8). Though research has also found reduced time to fatigue during an incremental biking test, despite no change in cardiac output, stroke volume or oxygen uptake; indicating that blood flow may not be a contributing factor (7). In this study anecdotally, almost all of the participants reported that their legs felt "slow", "sore" and "heavy" during the experimental trials following IPC. Subjective pain from

IPC has been shown as higher in the legs (41) and this may have contributed to a sense of fatigue that impacted on participants' performances, thus reducing the potential for significantly improved performance. If remote occlusion was performed, to the arms for example, then perceived pain would be lower which may have reduced subsequent reported 'soreness' at the onset of the time trial. This approach may have led to improvements due to the yielding of possible RIPC effects observed in research (1), combined with a potential reduction in the negative effects of perceived muscle soreness.

Due to the relatively young age and small size of the participants (19 ± 3 yr, height 1.70 ± 0.11 m; mass 69 ± 12 kg) it could be that the cuff inflation pressure used (220 mmHg) was too high. Research has shown that a significant increase in blood lactate levels was noted once cuff inflation pressure reached 180 mmHg in the lower limb, and that 5 minutes reperfusion is enough to see levels return to baseline (38). These findings show that ischemia can be induced at lower pressures than we used, though the researchers did not study whether these lower pressures would still induce any exercise improvements. Cuff pressures for IPC have also been set by working from RSBP; with pressures set at increments ranging from 15 mmHg (19) and 20 mmHg; (11) right up to 50 mmHg (7) above RSBP. This method has been used as the preferred method in studies using children as subjects (5). Considering the age and size of the subjects in this study it is possible that the buildup of metabolites within the muscle was high and that levels had not returned to baseline by the time the time trial started, though no lactate readings were taken so this is mere speculation. Additionally, some studies have actually reported decreased levels of phosphocreatine (PCr), adenosine triphosphate (ATP), and reduced buffer capacity shortly following IPC, (36,40) highlighting the importance of sufficient recovery to allow levels to return to baseline prior to exercise. However, in this study 45 minutes was allocated and this time has generally been shown to be sufficient to yield performance gains (19).

Conversely to the above, it may actually be that there were no significant effects because true ischemia was never obtained during IPC. Indeed, some studies have shown that arterial blood flow in some cases could not be blocked even at pressures as high as 250 mm Hg (17,29). A major limitation to our study was that no scientific equipment was used to measure and ensure that ischemia was actually achieved. Based on meta-analysis of existing research it is recommended that studies use near-infrared spectroscopy or Doppler flow measurement to establish whether the arterial blood flow has been fully blocked (39). We did not perform any kind of measurement to check whether arterial blood flow was blocked, thus, although it is likely, we cannot be truly certain that IPC was performed affectively.

In conclusion, IPC performed on the legs using standardized cuff pressures off 220 mmHg for doses of both 2 x 5' and 4 x 5' occlusion-reperfusion did not have an effect on overall 2km rowing ergometer time-trial performance. There were some significant changes to the time taken, power exerted and stroke rate maintained in the individual 500m splits, though it is possible that this was due to improved pacing strategy, rather than the effects of IPC. The study requires a broader and more accurate range of scientific measures to identify the reasons behind the findings, in order to conclude whether effects, or lack of effects arose from methodological error, or through true ineffectiveness of IPC in this particular context.

CONFLICT OF INTEREST

There are no conflicts of interest

REFERENCES

1. Addison PD, Neligan PC, Ashrafpour H, Khan A, Zhong A, Moses M, Forrest CR, Pang CY. Noninvasive remote ischemic preconditioning for global protection of skeletal muscle against infarction. *Am J of Physiol-Heart and Circul Physiol*. 2003;285(4):1435-43.
2. Bailey TG, Jones H, Gregson W, Atkinson G, Cable NT, Thijssen DH. Effect of ischemic preconditioning on lactate accumulation and running performance. *Med Sci Sports Exerc.* 2012;44(11):2084-9.
3. 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):1132-9.
4. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377-81.
5. Cheung MM, Kharbanda RK, Konstantinov IE, Shimizu M, Frndova H, Li J, Holtby HM, Cox PN, Smallhorn JF, Van Arsdell GS, Redington AN. Randomized controlled trial of the effects of remote ischemic preconditioning on children undergoing cardiac surgery. *J Am Coll Cardiol*.2006;47(11):2277-82.
6. Clevidence MW, Mowery RE, Kushnick MR. The effects of ischemic preconditioning on aerobic and anaerobic variables associated with submaximal cycling performance. *European J of Appl Physiol*. 2012;112(10):3649-54.
7. Crisafulli A, Tangianu F, Tocco F, Concu A, Mameli O, Mulliri G, Caria MA. Ischemic preconditioning of the muscle improves maximal exercise performance but not maximal oxygen uptake in humans. *J Appl Physiol* 2011;111(2):530-6.

8. De Groot PC, Thijssen DH, Sanchez M, Ellenkamp R, Hopman MT. Ischemic preconditioning improves maximal performance in humans. *Eur J Appl Physiol*. 2010;108(1):141-6.
9. de Oliveira Cruz RS, De Aguiar RA, Turnes T, Pereira KL, Caputo F. Effects of ischemic preconditioning on maximal constant-load cycling performance. *J of Appl Physiol*. 2015;119(9):961-7.
10. Ferreira TN, Sabino-Carvalho JL, Lopes TR, Ribeiro IC, Succi JE, Da Silva AC, Silva BM. Ischemic Preconditioning and Repeated Sprint Swimming: A Placebo and Nocebo Study. *Med Sci Sports Exerc*. 2016;48(10):1967-75.
11. Foster GP, Westerdahl DE, Foster LA, Hsu JV, Anholm JD. Ischemic preconditioning of the lower extremity attenuates the normal hypoxic increase in pulmonary artery systolic pressure. *Respiratory Physiol & Neurobiol*. 2011;179(2):248-53.
12. Gibson N, Mahony B, Tracey C, Fawkner S, Murray A. Effect of ischemic preconditioning on repeated sprint ability in team sport athletes. *J Sports Sci.* 2015;33(11):1182-8.
13. Gibson N, White J, Neish M, Murray A. Effect of ischemic preconditioning on land-based sprinting in team-sport athletes. *Int J Sports Physiol Perf*. 2013;8(6):671-6.
14. Gürke L, Marx A, Sutter PM, Frentzel A, Salm T, Harder F, Seelig J, Heberer M. Ischemic preconditioning improves post-ischemic skeletal muscle function. *Am Surgeon*. 1996;62(5):391-4.
15. Hopkins W, Marshall S, Batterham A, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*.. 2009;41(1):3.
16. Horswill CA, Miller JE, Scott JR, Smith CM, Welk G, Van Handel P. Anaerobic and aerobic power in arms and legs of elite senior wrestlers. *Int J Sports Med*. 1992;13(08):558-61.

17. Iida H, Kurano M, Takano H, Kubota N, Morita T, Meguro K, Sato Y, Abe T, Yamazaki Y, Uno K, Takenaka K. Hemodynamic and neurohumoral responses to the restriction of femoral blood flow by KAATSU in healthy subjects. *Eur J Appl Physiol*. 2007;100(3):275-85.
18. Incognito AV, Burr JF, Millar PJ. The effects of ischemic preconditioning on human exercise performance. *Sports Med*. 2016;46(4):531-44.
19. Jean-St-Michel E, Manlhiot C, Li J, Tropak M, Michelsen MM, Schmidt MR, McCrindle BW, Wells GD, Redington AN. Remote preconditioning improves maximal performance in highly trained athletes. *Med Sci Sports Exerc*. 2011;43(7):1280-6.
20. Jennings RB, Sebbag L, Schwartz LM, Crago MS, Reimer KA. Metabolism of preconditioned myocardium: effect of loss and reinstatement of cardioprotection. *J Molec Cellul Cardiol*. 2001;33(9):1571-88.
21. Jensen RL, Freedson PS, Hamill J. The prediction of power and efficiency during near-maximal rowing. *Eur J Appl Physiol Occu Physiol*. 1996;73(1):98-104.
22. Kavazis AN. Exercise preconditioning of the myocardium. *Sports Med*. 2009;1;39(11):923-35.
23. Kido K, Suga T, Tanaka D, Honjo T, Homma T, Fujita S, Hamaoka T, Isaka T. Ischemic preconditioning accelerates muscle deoxygenation dynamics and enhances exercise endurance during the work-to-work test. *Physiol Reps*. 2015;3(5):e12395.
24. Kilduff LP, Finn CV, Baker JS, Cook CJ, West DJ. Preconditioning strategies to enhance physical performance on the day of competition. *Int J Sport Physio Perf,* 2013;8:677-681.
25. Kjeld T, Rasmussen MR, Jattu T, Nielsen HB, Secher NH. Ischemic preconditioning of one forearm enhances static and dynamic apnea. *Med Sci Sports Exerc*. 2014;46(1):151-5.

26. Lalonde F, Curnier DY. Can anaerobic performance be improved by remote ischemic preconditioning?.*J Strength Cond Res*. 2015;29(1):80-5.

27. Libonati JR, Cox M, Incanno N, Melville SK, Musante FC, Glassberg HL, Guazzi M. Brief periods of occlusion and reperfusion increase skeletal muscle force output in humans. *Cardiologia*. 1998;43(12):1355-60.

28. Liu GS, Thornton J, Van Winkle DM, Stanley AW, Olsson RA, Downey JM. Protection against infarction afforded by preconditioning is mediated by A1 adenosine receptors in rabbit heart. *Circulation*. 1991;84(1):350-6.

29. Loenneke JP, Fahs CA, Rossow LM, Sherk VD, Thiebaud RS, Abe T, Bemben DA, Bemben MG. Effects of cuff width on arterial occlusion: implications for blood flow restricted exercise. *Eur J Appl Physiol*. 2012;112(8):2903-12.

30. Loukogeorgakis SP, Panagiotidou AT, Broadhead MW, Donald A, Deanfield JE, MacAllister RJ. Remote ischemic preconditioning provides early and late protection against endothelial ischemia-reperfusion injury in humans. *J Am Coll Cardiol.* 2005;46(3):450-6.

31. Loukogeorgakis SP, Williams R, Panagiotidou AT, Kolvekar SK, Donald A, Cole TJ, Yellon DM, Deanfield JE, MacAllister RJ. Transient limb ischemia induces remote preconditioning and remote postconditioning in humans by a KATP channel–dependent mechanism. *Circulation*. 2007;116(12):1386-95.

32. MacFarlane DJ, Edmond IM, Walmsley A. Instrumentation of an ergometer to monitor the reliability of rowing performance. *J Sports Sci*. 1997;15(2):167-73.

33. Marongiu E, Crisafulli A. Cardioprotection acquired through exercise: the role of ischemic preconditioning. *Cur Cardiol Rev*. 2014;10(4):336-48.

34. Murry CE, Jennings RB, Reimer KA. Preconditioning with ischemia: a delay of lethal cell injury in ischemic myocardium. *Circulation*. 1986;74(5):1124-36.

35. Paixao RC, da Mota GR, Marocolo M. Acute effect of ischemic preconditioning is detrimental to anaerobic performance in cyclists. *Int J Sports Med*. 2014;35(11):912-5.
36. 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):782-8.
37. Patterson SD, Bezodis NE, Glaister M, Pattison JR. The effect of ischemic preconditioning on repeated sprint cycling performance. *Med Sci Sports Exerc*. 2015;47(8):1652-8.
38. Przyklenk K, Bauer B, Ovize M, Kloner RA, Whittaker P. Regional ischemic'preconditioning'protects remote virgin myocardium from subsequent sustained coronary occlusion. *Circulation*. 1993;87(3):893-9.
39. Salvador AF, De Aguiar RA, Lisbôa FD, Pereira KL, Cruz RS, Caputo F. Ischemic preconditioning and exercise performance: a systematic review and meta-analysis. *Int J Sports Physiol Perf*. 2016;11(1):4-14.
40. Sharma V, Cunniffe B, Verma AP, Cardinale M, Yellon D. Characterization of acute ischemia-related physiological responses associated with remote ischemic preconditioning: a randomized controlled, crossover human study. *Physiol Reps*. 2014;2(11):e12200.
41. Tocco F, Marongiu E, Ghiani G, Sanna I, Palazzolo G, Olla S, Pusceddu M, Sanna P, Corona F, Concu A, Crisafulli A. Muscle ischemic preconditioning does not improve performance during self-paced exercise. *Int J Sports Med*. 2015;36(01):9-15.
42. Tóth A, Pal M, Intaglietta M, Johnson PC. Contribution of anaerobic metabolism to reactive hyperemia in skeletal muscle. *Am J Physiol-Heart Circul Physiol*. 2007;292(6):H2643-53.

St Mary's University Twickenham London

13 February 2017 Unique Ref: SMEC_2016-17_044

Tom Reed (SHAS): 'IPC and 2km rowing time trial performance: two versus four cycles of occlusion-reperfusion'

Dear Tom

University Ethics Sub-Committee

Thank you for submitting your ethics application for the above research.

I can confirm that your application has been considered by the Ethics Sub-Committee and that ethical approval is granted.

Yours sincerely

Prof Conor Gissane
Chair, Ethics Sub-Committee

Cc Dr Stephen Patterson

Tom Reed

125281@live.smuc.ac.uk

Section A: The Research Project

Title of project

IPC and 2km rowing time trial performance: two versus four cycles of occlusion-reperfusion.

Purpose and value of study

This study compares the effects of two different ischemic preconditioning (IPC) protocols which will be undertaken prior to completing respective 2km rowing time trials. The study aims to provide further data on the effect of IPC on time trial performance and to provide further direction on whether there is a does-response relationship between IPC and time trial performance.

Invitation to participate

You are invited to be a participant in this study. If you accept this invitation you will be asked to come in to the Sport Wales sport science lab for three testing days which are 9th, 16th and 23rd January 2017.

Who is organising the research

The research is being organised by Tom Reed as part of a Masters Degree dissertation through St Mary's University. Supervisors are Dr Stephen Patterson and Jess Hill.

What will happen to the results of the study

Your results will be anonymised and then used in the analysis of data to be presented in the dissertation. Results will be presented as a group, meaning that no individual scores are shown and that it will not be possible to recognise the performance of specific participants.

Source of funding for the research

There are no sponsors or other sources of funding for this research. Any associated costs will be borne by the researcher, Tom Reed.

Contact for further information

I, the researcher, can be contacted by email or telephone using the details listed below. Please feel free to approach me for any further information that you require.

Email: reedtom86@gmail.com, 125281@live.smuc.ac.uk

Phone: 07853386580

Section B: Your Participation in the Research Project

Why you have been invited to take part

All the participants for the study will be taken from the athlete's on the Welsh Judo Talent Cymru development squad.

Whether you can refuse to take part

Your participation in this study is voluntary and you may refuse to take part. However, it is expected that once you agree to take part in the study that you are committed to attending the three testing days.

Whether you can withdraw from the project at any time, and how

You are able to withdraw from the study at any time, by completing the section on the Consent Form entitled 'I wish to withdraw from this study' and returning it to the researcher in person or by email on the given contact details.

What will happen if you agree to take part (brief description of procedures/tests)

This study looks at your performance in a 2km rowing time trial on a concept 2 rowing machine. We are comparing the effects of two different IPC protocols which you will undergo before completing the 2km rowing tests. IPC stands for Ischemic Pre-Conditioning and is a technique that involves using a pressure cuff that is wrapped around a limb, in this case one leg at a time, in order to restrict the blood flow to the muscles.

You will be asked to come in to the Sport Wales sports science lab on three occasions to do the 2km row, which will separated by seven days. Prior to each row, just before the warm up you will

undergo one of the IPC protocols using an occlusion cuff. In the first testing day you will perform the time trial without IPC in order to obtain a baseline score.

The occlusion cuff IPC procedure will be administered by the researcher, Tom Reed, under the supervision of the Welsh Judo strength and conditioning coach. The 2km rowing time trial warm up and testing format will be the same as the normal format you follow in your regular fitness monitoring program. The cuff will be used to temporarily restrict your blood flow using pressures no greater than what you would have experienced during a normal blood pressure measurement. The cuff will be applied to one leg for five minutes, then the other, for either 2 or 4 cycles per leg.

Whether there are any risks involved (e.g. side effects) and if so, what will be done to ensure your wellbeing/safety

There are no known risks involved with the testing protocol. You may experience moderate discomfort due to the restriction of blood flow. Experienced strength and conditioning professionals will be present at all times to mitigate the possibility of unforeseen risks.

Agreement to participate in this research should not compromise your legal rights if something goes wrong

??

Whether there are any special precautions you must take before, during or after taking part in the study

You should refrain from caffeine, alcohol, and exercise prior to the study for 24, 12 and 48 hours respectively.

What will happen to any information/data/samples that are collected from you

All information received from you and all testing data will be kept confidential, only the researcher and strength and conditioning coach will have access to data relating to your testing. Data will be

stored on the secure server on the St Mary's University server, and any paper documents will be kept in a locked cupboard at all time that only the researcher can access.

Whether there are any benefits from taking part

The 2km time trial will count as your winter fitness monitoring test for your normal Talent Cymru testing, and an analysis of your performance can be provided at your request.

How much time you will need to give up to take part in the project

you will be asked to come in to the Sport Wales sport science lab for three testing days which are 9th, 16th and 23rd January 2017. Therefore by agreeing to take part in this study you should be available on those days. Each testing day will take approximately 90 minutes in total.

How your participation in the project will be kept confidential

As mentioned previously, your results will be anonymised and no record of your name or participation will appear on any of the study documents. You will be assigned a participant number and will be referred to using this on all of the documentation. The results will be presented in the final write up as a group. Only the researcher and the coaches at Welsh Judo will know about your participation in the study.

St Mary's University Twickenham London

Name of Participant: _____

Title of the project: _

IPC and 2km rowing time trial performance: two versus four cycles of occlusion-reperfusion._

Main investigator and contact details: _Tom Reed, reedtom86@gmail.com, 125281@live.smuc.ac.uk, 07853386580_____

Members of the research team: Dr Stephen Patterson, Jess Hill

1. I agree to take part in the above research. I have read the Participant Information Sheet which is attached to this form. I understand what my role will be in this research, and all my questions have been answered to my satisfaction.

2. I understand that I am free to withdraw from the research at any time, for any reason and without prejudice.

3. I have been informed that the confidentiality of the information I provide will be safeguarded.

4. I am free to ask any questions at any time before and during the study.

5. I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of participant (print).....

Signed..... Date.....

If you wish to withdraw from the research, please complete the form below and return to the main investigator named above.

Title of Project: _____

I WISH TO WITHDRAW FROM THIS STUDY

Name: _____

Signed: _____ Date: _____