Original Article

Effects of immediate post-exercise recovery after a high intensity exercise on subsequent cycling performance

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ABSTRACT

The aim of the study is to investigate the comparative effect of compression sleeves, rest and active recovery on performance and immediate recovery from high-intensity cycling performance (HICP). Eight recreationally trained male cyclists completed three trials, each separated by one week. Each trial consisted of two 10-min high intensity exercise task (30-20-10 s maximal HICP bouts with 3 min 1 W/kg recovery) separated by application one of the three 24-min recovery strategies (active – cycling 1W/kg, ACT; passive – supine position, PAS; passive – sitting with compression sleeves; PAS+CS). Applied recovery strategy effectiveness was assessed via changes in blood lactate clearance (LA), acid-base changes and performance parameters (fatigue index, FI; peak power, PP and relative peak power). Fatigue index was significantly improved by ACT for 30s and 20s HICP. There was a significant decrease in FI for PAS + CS (p = 0.041) and PAS (p = 0.026) showing a negative impact of PAS + CS and PAS for keeping PP during 10s task. The rate of decrease in plasma LA concentration over the 24-min recovery period was significantly higher in ACT (0.50 ± 0.1 mmol/min) compared to PAS and PAS+CS (0.31 ± 0.07 mmol/l, p = 0.001, 0.37 ± 0.09 mmol/min, p = 0.024, respectively). The passive recovery strategies decreased the ability of keeping repeated maximal intensity cycling performance in contrast to active recovery. The use of compression calf sleeves has no significant

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additional effect on plasma lactate clearance after high intensity anaerobic exercise above resting condition.
Keywords: Blood lactate; Regeneration; Compression garment; Wingate test; Anaerobic workout.

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INTRODUCTION

Previous research has suggested several recovery procedures that may increase the athletes ability to return to their normal pre exercise state, following high intensity exercise bout (HICP) (Peterson et al., 2015).

Several recovery strategies such as contrast water immersion (Wilcock, Cronin, & Hing, 2006), cryotherapy (Hohenauer, Taeymans, Baeyens, Clarys, & Clijsen, 2015), pneumatic compression (Haun et al., 2017) or compression garment (Zinner et al., 2017) have been compared with either passive or active recovery scenarios.

However it was observed that the use of compression garments predominantly reduce levels of perceived muscle soreness (Hill, Howatson, van Someren, Leeder, & Pedlar, 2014). Nevertheless concomitant effects on performance or post-exercise levels in muscle metabolites, are inconsistent (MacRae, Cotter, & Laing, 2011; Duffield et al., 2008).

A number of metabolic events involved in the damage-inflammation-recovery process are activated immediately following the damaging bout. Acid-base disturbances after HICP is known to be augmented by active recovery strategies (Spencer, Bishop, Dawson, & Goodman, 2005).

As a result, athletes and coaches are trying to find an effective recovery strategy that should be initiated very quickly after exercise. Where an active recovery strategy (e.g. jogging) cannot be applied, passive alternatives, such as compression sleeves (CS) are widely used by athletes. The anecdotal beliefs of athletes' appear to evidence that CS limit the decrease in performance for repeated bouts of exercise with short time for recovery (<30 min) through the hastening of muscle metabolites clearance (e.g. plasma lactate). Vast majority of studies however failed to demonstrate an significant effect of CS on performance (Struhar & Kumstat, 2017) or immediate post-exercise recovery (Beliard et al., 2015).

Current literature indicates that active recovery is the best strategy to sustain HICP (Wahl et al., 2013; Barnett, 2006; Spierer, Goldsmith, Baran, Hryniewicz, & Katz, 2004) and that the importance of both active and passive recovery strategies can have benefits for athletes (Frikha, Chaâri, Mezghanni, & Souissi, 2016; Kriel, Kerhervé, Askew, & Solomon, 2016; Mika et al., 2016; Wahl, Mathes, Achtzehn, Bloch, & Mester, 2014; Patrick Wahl, Bloch, Mester, Born, & Sperlich, 2012).

Therefore, we aim to investigate the comparative effect of using compression calf sleeves with active recovery and passive rest on immediate recovery and high intensity repeated cycling performance.

MATERIAL AND METHODS

Participants

Eight healthy physically active male subjects participated in the study (age 27.1 ± 2.32 years; body mass 77.38 ± 5.43 kg; body height 1.78 ± 0.05 m; body fat 10.12 ± 2.23 %; maximum heart rate 182 ± 4 beats·min^{-1}; VO_{2max} 47.92 ± 7.16 mL·kg^{-1}·min^{-1}). At the time of enrolment, participants had been training 2-3 times per week in recreational sports (running, cycling and tennis) for at least 3 years. None of the participants suffered from any injury or were taking any medication. All participants were informed about the experimental procedures before giving their written consent to participate in the study.

Study design and ethical aspects

This investigation used a counterbalanced experimental design with repeated measures under three experimental conditions. We compared the frequently used recovery strategies (passive recovery, PAS; passive recovery + compression calf sleeves, PAS+CS; and active recovery, ACT). The Research Ethics Committee of Masaryk University approved the study.

The three experimental conditions consisted of a two high-intensity cycling performance (HICP) tests (TEST I, TEST II) separated by application of one of the three recovery strategy.

All tests were conducted in the Human Performance Laboratory where the temperature and humidity during testing were set up at 22 °C and 44 % relative humidity.

On the day of testing, each participant randomly chose one type of recovery strategy (Figure 1). Participants were asked to abstain from alcohol and caffeine beverages and strenuous exercise for the 24 h prior to each testing session. The experimental tests were carried out at the same time of day and were separated by 7 days wash-out period.

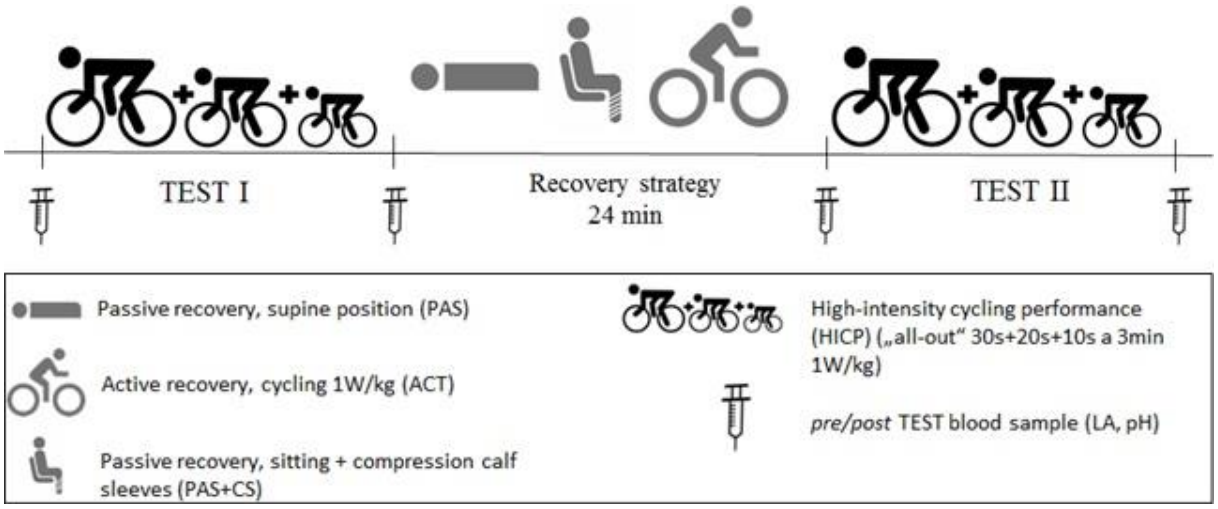

Figure 1. Schematic illustration of experimental design

Characteristics of the recovery strategies used in the study

Each of the recovery strategy were randomly applied between TEST I and TEST II, for 24 min (exact time was measured by stop watch).

A. Passive recovery (PAS) - control

This strategy consists of passive lying in supine position. The participant was asked to stay calm without saying anything.

B. Passive recovery + compression calf sleeves (PAS+CS)

The selected strategy was similar than passive recovery, but the participant was exposed to controlled sitting with back straight, 90 degrees angle at hip joint, thighs parallel to the floor, feet flat on the floor wore the compression sleeves on both calves. A graduated compression calf sleeves was used. A higher pressure at the ankle gradually lowering toward the widest part of calf: 25 mmHg ankle, 21 mmHg calf. The size of

compression pressure was chosen according to the calf circumference of each participant. The pressure profile was controlled in vitro (the measuring device, MST MK IV SALZMANN AG from ST. GALLEN, Switzerland).

C. Active recovery (ACT)

The selected strategy was done on the cycle ergometer. The seat height was individually adjusted for the participant's comfort. The external loading was set at 1 W/kg of the participant's body weight.

Measures

Preliminary VO_{2max} test

To determine maximum oxygen uptake, participants performed a graded test until voluntary exhaustion two weeks before the study. The maximal incremental exercise test was conducted on an electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). The seat height of ergometer was adjusted for each participant. At the beginning, the participant warmed up at the self-selected pace for 6 min (70-130 W). The pedal rate was set at 70-75 rpm. The test started with an initial workload (70-130 W) and increased thereafter by 25 W/min until the participant was unable to continue (the pedal rate fell by > 10 rpm). Oxygen consumption was measured continuously through an automated breath-by-breath system (Cortex METALYZER® 3B). The system was calibrated before performing exercise according to the manufacturer's instructions.

At the time of VO_{2max} test body height, weight, and body composition were measured for each subject two weeks before the study. Body composition was determined using the bioelectric impedance technique (Inbody 230 device).

High intensity cycling performance (HICP) protocol

Two high intensity cycling performance tasks, TEST I and TEST II followed exactly the same protocol and were separated by chosen recovery strategy. Prior the onset of the TEST I the optimal seat height of ergometer and handlebar positioning were adjusted for each participant. The knee was slightly bent when the pedal was at its lowest position.

Then, the participants warmed up for 5 min on a cycle ergometer (1 W/kg; a pedal rate of 70–80 rpm). After the warm-up, the TEST consisted of three maximal bouts (30-20-10 s; the external loading was set at 7.0% of the individual's body mass). The participants were instructed to pedal ''all-out'' for 30, 20 and 10 s. Between the maximum cycling performance (30-20-10 s) participants had the 3 min recovery phase (1W/kg; a pedal rate of 70–75 rpm).

Following the TEST I, participant were exposed for 24 min to the randomly selected recovery strategy. After that, exactly the same protocol (TEST II) was repeated.

The cycling performance was determined by cycle ergometer (Lode Excalibur Sport). Peak power (PP), relative peak power (RPP), fatigue index (FI), were evaluated for the 30, 20 and 10 s maximum cycling performance tasks (workload was set up to the 0.070 kg per kg of the body weight for each participant). To ensure maximum of the each participant´s capacity eencouragement was given during the TESTs via playing of the Rocky movie motivational music.

Blood sampling
Fingertip capillary blood samples for LA and blood gas (pH) analysis were obtained on four occasions: before TEST I (TEST I $_{pre}$), 2 min after TEST I (TEST I $_{post}$), before TEST II (TEST II $_{pre}$) and 2 min after TEST II (TEST II $_{post}$).

LA concentration was measured by Lactate Plus device (manufactured by Nova Biomedical, measuring range 0.3 to 25 mmol/l whole blood). After cleaning the fingertip with sterile alcohol and a swab, the blood sample (0.7 µl) was obtained from the distal phalanx of the finger. The finger prick was made by using a lancet.

Acid-base balance was conducted by an electrochemical apparatus Gastat Navi (Techno MedicaCo., Ltd.). Whole blood samples were collected by finger prick using a sterile single-use lancing device with 2.3 mm penetration depth. Amount of ~60 µl of blood was collected into plain heparinized capillary tubes, immediately injected into sensor cards and analysed for pH. Time needed for blood sample collection was ~2-3 min depending on each participant finger prick bleeding. Each blood analysis took 165s before results were automatically printed.

Statistical analysis
All statistical analyses were conducted using Statistica 12.0 software (StatSoft CR s.r.o., Czech Republic) and Microsoft Excel. Descriptive statistics (mean ± SD) for the different variables were calculated. Normality for all data (pre and post) were assessed with Shapiro-Wilk test. One-way ANOVA with Tukey's post-hoc test to show inter-group changes, was used to detect significant changes across three different recovery procedures.

Wilcoxon paired test was used to compare the LA changes under experimental conditions at different sampling times. Relative LA changes were expressed as a percent decrease from peak lactate concentration to the end of the treatment.

Statistical significance was accepted at $p \leq 0.05$ with data (LA and pH absolute values, LA removal [(TEST II $_{pre}$ -TEST I $_{post}$)/24)] and cycling performance parameters) presented as mean ± standard deviation (SD).

RESULTS

Biochemical analysis
The absolute LA levels were significantly different across three recovery condition only for the TEST II $_{pre}$ measurement time point (p = 0.001, F 9.4). Active recovery produced a highest mean decrease (TEST II $_{pre}$ -TEST I $_{post}$) of 12.23 ± 2.5 mmol/L, compared with 7.5±1.8mmol/l and 9.05±2.26 mmol/L for the PAS and PAS+CS, respectively (Fig. 3).

Similarly, when considering relative LA clearance (mmol/min of recovery), the rate of decrease in plasma lactate concentration over the 24-min recovery period [(TEST II $_{pre}$ -TEST I $_{post}$)/24)] was significantly higher in ACT 0.50 ± 0.1 mmol/min compared to PAS 0.31 ± 0.07 mmol/l (p = 0.001) and PAS+CS 0.37 ± 0.09 mmol/min (p = 0.024). No significant difference was found between PAS and PAS+CS (p = 0.362) (Fig. 2).

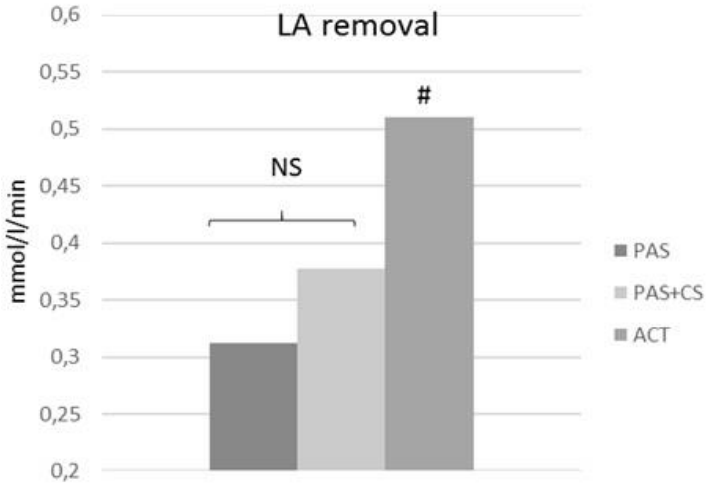

Figure 2. Blood LA elimination rate during recovery period; # significantly different ($p < 0.05$) from PAS and PAS+CS; NS, not significant

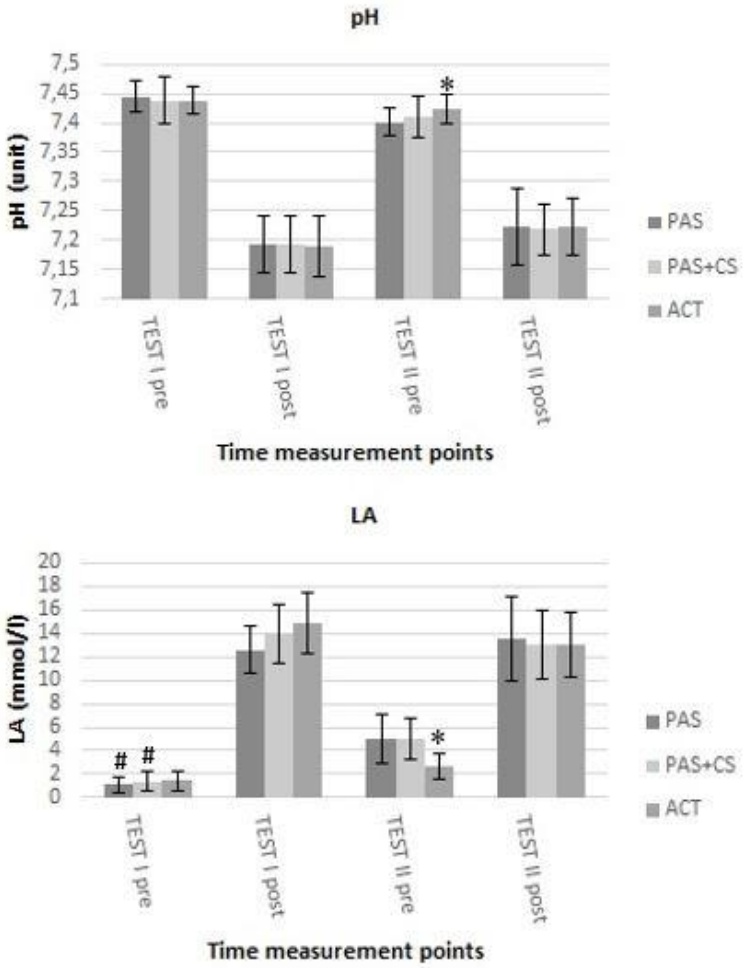

Figure 3. Blood pH and LA concentration; * significantly different ($p < 0.05$) from PAS and PAS+CS within TEST II *pre* time condition; # significantly different ($p < 0.05$) from PAS and PAS+CS between TEST I *pre and* TEST II *pre* time condition

pH change

Analysis of variance indicated significant differences for absolute values of pH concentration among the three recovery condition only for the TEST II $_{pre}$ measurement time point (F 89.7, p = 0.000). Post-hoc analysis indicated significant change (p < 0.01) between ACT and PAS and ACT and PAS+CS with no change between PAS and PAS+CS (p = 0.882) (Fig. 3).

Performance parameters

Summary of mechanical power indices recorded during TEST I and TEST II are presented in Table 1.

Table 1. Descriptive data from repeated high-intensity cycling performance (HICP)

PAS+CS	**30 s**		*p*	**20 s**		*p*	**10 s**		*p*
	TEST I	**TEST II**		**TEST I**	**TEST II**		**TEST I**	**TEST II**	
Peak Power (W)	877.91 ± 88.50	869.75 ± 139.11	*NS*	938.93 ± 121.90	932.32 ± 174.80	*NS*	846.96 ± 127.21	909.27 ± 166.00	*0.029**
Relative Peak Power (W)	11.39 ± 1.71	10.68 ± 1.85	*NS*	11.54 ± 2.01	12.09 ± 2.49	*NS*	10.95 ± 1.75	11.07 ± 2.25	*NS*
Fatigue Index (%)	59.08 ± 11.43	60.03 ± 15.70	*NS*	54.50 ± 10.40	57.71 ± 11.26	*NS*	29.47 ± 5.66	34.45 ± 10.51	*0.041**
ACT	**30 s**		*p*	**20 s**		*p*	**10 s**		*p*
	TEST I	**TEST II**		**TEST I**	**TEST II**		**TEST I**	**TEST II**	
Peak Power (W)	934.36 ± 108.49	925.14 ± 129.58	*NS*	918.05 ± 184.34	920.93 ± 156.01	*NS*	881.94 ± 144.82	927.34 ± 107.01	*0.037**
Relative Peak Power (W)	12.23 ± 1.87	11.98 ± 1.95	*NS*	12.06 ± 2.85	11.93 ± 2.28	*NS*	11.57 ± 2.33	11.70 ± 1.94	*NS*
Fatigue Index (%)	61. 32 ± 14.71	53.95 ± 12.55	*0.031**	54.04 ± 11.70	41.32 ± 11.60	*0.029**	34.19 ± 9.17	35.22 ± 13.50	*NS*
PAS	**30 s**		*p*	**20 s**		*P*	**10 s**		*p*
	TEST I	**TEST II**		**TEST I**	**TEST II**		**TEST I**	**TEST II**	
Peak Power (W)	865.51 ± 107.30	806.74 ± 124.64	*0.048**	832.72 ± 127.00	840.89 ± 95.94	*NS*	833.60 ± 144.92	862.16 ± 97.42	*0.033**
Relative Peak Power (W)	11.31 ± 1.33	10.91 ± 1.52	*NS*	10.94 ± 1.95	11.13 ± 1.45	*NS*	10.94 ± 2.11	11.14 ± 1.31	*NS*
Fatigue Index (%)	51.66 ± 12.82	51.58 ± 13.65	*NS*	45.60 ± 15.38	48.78 ± 10.61	*NS*	30.53 ± 12.43	41.14 ± 11.74	*0.026**

**p < 0.05; NS: not statistically significant.*

Using a fatigue index parameter, we reported significant improvements for 30s and 20s HICP in TEST II after applying ACT strategy, in contrast to both passive strategies (p < 0.05).

Data for 10s HICP interestingly show significant improvements in peak power for all recovery strategies. Despite this, there was a significant impairment in fatigue index for PAS + CS (p = 0.041) and PAS (p = 0.026) but not recorded after applying ACT strategy. This result suggests a negative impact of PAS + CS and PAS for sustaining peak power during repeated high intensity exercise in contrast to the ACT recovery strategy.

DISCUSSION

The purpose of the present study was to determine the effect of active recovery (cycling 1W/kg of body weight, ACT) and two passive recovery strategies (siting, PAS and sitting with compression calf sleeves, PAS+CS) on changes in blood lactate clearance, acid-basis and subsequent cycling performance

parameters. Previous research has documented that the importance of active and passive recovery does exist and can have benefits for athletes (Frikha et al., 2016; Kriel et al., 2016; Mika et al., 2016; Wahl et al., 2014; Wahl et al., 2012). We support the superiority of active recovery choices methods over passive ones (with and without compression sleeves).

We show that after high intensity anaerobic exercise, passive recovery with compression sleeves (CS) has no beneficial effect over the complete passive rest condition in terms of reduced plasma lactate levels. Moreover, ACT strategy was shown to be clearly effective in sustaining repeated HICP in comparison to the passive forms.

The key question is a real application into the praxis. Specifically, the efficacy of various recovery modalities for elite athletes during repeated bouts of exercise with short time (<30 min) for recovery in an attempt to quickly return the body to its pre-exercise state have been stressed by this study. For this reason, we designed the protocol focused not only on the acute changes in LA and pH, but also on subsequent performance. The study is one of the first to assess the selected combination of recovery strategies on subsequent high intensity cycling performance (HICP).

The protocol required the participant to perform three maximal bouts of cycling performance 30-20-10 s with a resistance of 0.070 kg per kg of the body weight separated by recovery phase 3 min (1W/kg). The selected HICP protocol was effective in disturbing acid-base balance as indicated by significant changes ($p < 0.05$) in both blood LA increase (peak LA concentration ~ 13,8 mmol/l) and pH drop (~7,1) after the initial HICP test.

All mechanical power inputs are presented in Table 1. What is interesting in our data is that the statistical analyses revealed significance for ACT recovery in two bouts of HICP in values of Fatigue Index (30 s, $p = 0.031$; 20 s, $p = 0.029$). No significant differences were found (30 and 20 s) for PAS + CS and PAS. Interestingly, there were differences in values of TESTS during 10 s HICP for PAS + CS and PAS (PAS + CS, $p = 0.041$; PAS, $p = 0.026$). However, attention has been paid to the difference between TESTS. The data showed considerable differences for FI (PAS + CS, $\Delta_{\text{TEST II – TEST I}} = + 4.98$ %; PAS, $\Delta_{\text{TEST II – TEST I}} = + 10.61$ %). This is a clear evidence that our two forms or passive strategy decreased the ability of participant keep 10 s HICP. The FI represents a drop in power from **PP** to the lowest power. We did not observe it in 10 s HICP for ACT. It is important to state that the pedal revolution findings were interesting. Active recovery produced approximately 10 % higher pedal revolutions compared with PAS+CS and PAS which is associated with the lowest FI. If the participant was able to produce higher pedal revolutions, it is probable that the highest and lowest performance would be improved. This fact was confirmed in our study. Another factor, which must be considered, is higher blood flow during ACT compared with PAS + CS and PAS.

Analysis of variance indicated significant effects for absolute values of blood LA concentration among the three treatment groups only for the TEST II $_{pre}$ measurement time point ($F = 4.9$, $p = 0.017$). Post hoc analysis indicated significant differences between ACT and PAS ($p = 0.029$), ACT and PAS+CS ($p = 0.037$) with no significant change between PAS and PAS+CS ($p = 0.992$). This supports the superiority of ACT strategy in promoting LA elimination.

Equally, statistically non-significant difference between the resting TEST I $_{pre}$ and TEST II $_{pre}$ blood LA levels of ~3.6 and ~3.9 mmol was observed in PAS or PAS+CS recovery condition, respectively. In comparison, ACT condition nearly restore blood LA levels, with the difference of 1.2 mmol/l ($p = 0.07$) which was accompanied by the highest initial pH level in TEST II $_{pre}$. Therefore, the ~30 min duration of passive recovery after HICP was not sufficiently long to restore blood LA concentration and/or compression garment does not

bring any additional benefit. To summarize ~ 2.3 mmol lower levels of blood LA concentration after ACT in comparison to either PAS or PAS+CS may be expected. It was shown that contrast water immersion produce similar results, 1.8 mmol/l difference from baseline levels after 30 min of recovery from four successive 30-s Wingate tests (Morton, 2007). In other words, we demonstrate that ACT helped compensate ~ 91 % of the elevation of the LA concentration, in comparison to the comparable effect of PAS and PAS+CS strategies (~ 65 % and ~ 71 %, respectively). Our results are in accordance with previous findings, showing that compression calf sleeves, even with varied pressure applied, does not influence immediate post exercise lactate clearance (Struhar & Kumstat, 2017).

It can, therefore, be assumed that the higher blood flow during ACT increases translocation of LA from muscles to the blood. Subsequently, lower values of LA before the TEST II were observed in our study. This fact has the practical importance of work performance during repeated bouts of supramaximal or maximal anaerobic exercises with restricted and often unpredictably long recovery time (e.g. competitions with heats, semi-finals, finals).

The return from significant metabolic acidosis after TEST I to the baseline levels may be considered as a measure of effectiveness of selected recovery strategies. Blood pH was nearly compensated after ACT ($p < 0.05$) but not PAS or PAS+CS condition before the onset of the TEST II. It is also interesting to mention peak power (PP) changes for each recovery strategy. The highest 10s PP difference ($\Delta_{TEST\ II - TEST\ I}$) was recorded for PAS + CS (+ 62.31 W). The values for PAS (+ 28.56 W) and ACT (+ 45.4 W) also confirmed better performance. On the other hand, the highest negative difference in 30 s PP was found for PAS (-58.77 W). Overall, these results indicate that ACT was the best strategy in regards to sustaining HICP. These findings are also supported by current literature (Wahl et al., 2013; Barnett, 2006; Spierer et al., 2004).

To summarize, there was no difference in any of the measured biochemical variable between control condition (PAS) and PAS+CS condition. Both the absolute and relative LA changes were the same. This may be translated as there is no additional effect of wearing CS in the immediate post-exercise recovery above the no-intervention (resting) condition.

In our future research we intend to concentrate on hormonal response during repeated bouts of HICP in regards to recovery strategy (the level of cortisol, human growth hormone and testosterone from venous blood) as this is of great concern in recent literature (Wahl et al., 2014).

CONCLUSIONS

Our results demonstrated that after high intensity cycling performance, ~ 30 min of passive rest with and without compression calf sleeves, there was no significant effect on recovery, when compared with the active recovery condition. Active recovery cycling at 1 W/kg significantly increased blood lactate removal by comparisons to the passive and passive with compression calf sleeves recovery strategies. A negative impact of the passive < 30 min recovery strategies observed the difficulty in sustaining peak power and tolerating fatigue during repeated high intensity exercise.

In terms of immediate recovery and sustaining high intensity performance, coaches and athletes are highly encouraged to prioritize an active form of recovery, instead of using compression garments.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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AUTHORS' CONTRIBUTION

MK and IS designed research; MK, IS and AT drafted a manuscript; MK, IS and TH collected all data; IS analysed the data and performed the statistical analysis. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

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