Acute Effects of Peristaltic Pneumatic Compression on Repeated Anaerobic Exercise Performance and Blood Lactate Clearance

Jeffrey S. Martin,[1,2] Zachary D. Friedenreich,[1] Alexandra R. Borges,[1] and Michael D. Roberts[3]

[1]Department of Biomedical Sciences, Quinnipiac University, Hamden, Connecticut; [2]Department of Cell Biology and Physiology, Edward Via College of Osteopathic Medicine–Auburn Campus, Auburn, Alabama; and [3]School of Kinesiology, Auburn University, Auburn, Alabama

Abstract

Martin, JS, Friedenreich, ZD, Borges, AR, and Roberts, MD. Acute effects of peristaltic pneumatic compression on repeated anaerobic exercise performance and blood lactate clearance. *J Strength Cond Res* 29(10): 2900–2906, 2015 –External pneumatic compression (EPC) use in athletics is increasing. However, there is a paucity of evidence supporting the effectiveness of EPC in aiding recovery and performance. We sought to determine the efficacy of EPC for acute recovery of anaerobic power and lactate clearance following a fatigue protocol. Fourteen ($n = 14$; women = 7 and men = 7), apparently healthy, active subjects (aged 22.73 ± 4.05 years) were enrolled in this randomized crossover design study. After familiarization sessions, subjects completed 2 study trials separated by 3–7 days. Trials consisted of a fatigue protocol (two 30-second Wingate anaerobic tests (WAnTs) on a cycle ergometer separated by 3 minutes of rest), 30 minutes of treatment with EPC or sham, and, finally, a single 30-second WAnT. A peristaltic pulse EPC device was used with target inflation pressures of ~70 mm Hg applied to the lower limbs. Peak power (PkP), average power (AP), and the fatigue index (FI) were recorded for each WAnT. Moreover, blood lactate concentration (BLa) was evaluated at baseline and at regular intervals during recovery (5, 15, 25, and 35 minutes postfatigue protocol). No significant differences in PkP, AP, and FI were observed. However, BLa was significantly lower at 25 and 35 minutes of recovery (8.91 ± 3.12 vs. 10.66 ± 3.44 mmol·L^{-1} [$p = 0.021$] and 6.44 ± 2.14 vs. 7.89 ± 2.37 mmol·L^{-1} [$p = 0.006$] for EPC vs. sham, respectively). Application of EPC during recovery may be a viable alternative when "inactive" recovery is desirable.

Key Words Wingate, WAnT, power, recovery, BLa, EPC

Introduction

Athletes and practitioners are consistently seeking to gain an "edge" with regard to recovery and sports performance. As a result, novel/alternative treatment strategies are often explored and quickly adopted with anecdotal or limited scientific evidence. External pneumatic compression (EPC) is one treatment strategy that has been adopted for recovery from exertion and training or injury. Several models of EPC exist and can vary widely in site and surface area of application, compression pressures, duty cycles (e.g., static vs. intermittent cycles), and synchrony with the cardiac cycle. However, the rationale for applying EPC in compressive models of recovery includes creation of an external pressure gradient (3) to increase the lymphatic circulation, venous return, and tissue osmotic pressure.

One model of EPC used for recovery in athletics is the varying forms of dynamic (i.e., intermittent) pneumatic compression devices. Dynamic EPC has demonstrated favorable effects on flexibility (16), muscle soreness (15), muscle swelling (1), and lymphedema (9). In addition, dynamic EPC has been shown to improve local contractile capacity in a model of acute recovery from a fatigue protocol (23). However, to our knowledge, there are limited data available relative to the effects of dynamic EPC on subsequent athletic performance. Zelikovski et al. (24) demonstrated improved exercise time with dynamic EPC treatment between bouts of exhaustive exercise. However, cardiorespiratory parameters were significantly higher in exhaustive exercise bouts after dynamic EPC compared with control, which may suggest that psychological factors (e.g., effort) played a role in the observed difference between groups.

The mechanism of fatigue and subsequent recovery in repeated exercise efforts are numerous (5). One factor that

Address correspondence to Jeffrey S. Martin, jmartin@auburn.vcom.edu.

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has been shown to contribute to muscle fatigue and impairment of repeated performance is the acute increase in blood lactate concentration (BLa) (12). Therefore, treatment strategies that improve BLa clearance during recovery in repeated exercise performance would be of interest. It has been suggested that manual massage improves the rate of BLa clearance, although the more recent literature is less supportive (8,11,14). Given that dynamic EPC acts as a form of mechanical "massage" on the limbs, and may be superior in alteration of limb blood flow, it follows that EPC may have an effect on BLa and recovery. Indeed, dynamic EPC devices promote circulation in limbs, lymphatic flow, and clearance of metabolites, which have been implicated as major players in repeated sports performance (2,13). Therefore, the purpose of this study was to investigate the acute effects of a dynamic EPC device on performance recovery and BLa clearance in a model of repeated supramaximal exercise performance.

Methods

Experimental Approach to the Problem

This study used a randomized crossover design to identify whether EPC acutely improved repeated anaerobic exercise performance and BLa clearance compared with a sham condition. All subjects participated in a total of 3 visits: (a) a familiarization session, (b) testing session 1, and (c) testing session 2. All visits were separated by at least 3 days, but not more than 1 week. At study entry, each subject was randomly assigned to 1 of the 2 groups: EPC at testing session 1 and sham at session 2, or sham at session 1 and EPC at session 2. Familiarization and testing sessions used a 30-second Wingate anaerobic test (WAnT) on a cycle ergometer with a resistance equivalent to 7.5% of the subject's body weight. A single familiarization session was performed by all subjects in which subjects completed the same fatigue protocol later used for testing sessions 1 and 2. At sessions 1 and 2, subjects consecutively completed (a) a fatigue protocol consisting of 2 WAnTs separated by 3 minutes of active rest, (b) 30 minutes of treatment with EPC or sham, and (c) a single WAnT. Blood lactate concentration was measured through fingertip capillary blood samples at baseline and 5, 15, 25, and 35 minutes of recovery. A 5-minute transition time was standardized for transition between WAnTs to application of the EPC or sham treatment. All measurements were made in the Cardiovascular Laboratory at Quinnipiac University between May and August of 2014.

Subjects

Fourteen (7 women and 7 men) apparently healthy active (participation in off-season collegiate organized sports training or a structured exercise program on at least 3 days per week) participants were recruited for participation in this study. Sixty-four percent ($n = 9$) of the subjects were Division I collegiate athletes. Subject characteristics were as follows (mean ± *SD*): age, 22.7 ± 4.1 years (range: 19.3–32.2 years); body mass, 72.6 ± 11.1 kg; height, 174.6 ± 9.5 cm; and body fat, 18.4 ± 6.1. This study was approved by the Quinnipiac University Institutional Review Board, and written informed consent was obtained from all participants before their voluntary participation.

Procedures

Familiarization Session. At least 72 hours before the first testing session, all participants reported to laboratory to become familiarized with the WAnT and expectations for the protocol. At this time, the investigator explained the procedures, demonstrated the WAnT, and instructed the subject through a 30-second WAnT, 3 minutes of active rest (pedaling at 70 rpm against minimal resistance), and initiation of a second WAnT. All subjects were instructed, on the investigators verbal command, to maximally accelerate at the start of the WAnT and maintain a maximal effort throughout the 30-second test. For all sessions, subjects were instructed to arrive in a rested, hydrated, postprandial state (≥2 hours) and to avoid caffeine, alcohol, and strenuous exercise in the 48 hours preceding a session. Participants were also instructed to maintain normal dietary habits throughout the study and replicate their 24-hour diet for subsequent visits. All testing was performed at the same time of the day for each subject to control for diurnal variation.

Testing Sessions. Within 3–7 days of completing the familiarization session, participants reported for testing sessions. On reporting to the laboratory, adherence with dietary and physical activity guidelines was confirmed with each subject. Thereafter, subjects were evaluated for height and weight (weigh beam scale with height rod; Detecto 439, Detecto Scale, Webb City, MO, USA), body fat (bioelectrical impedance analysis; OMRON HBF306C body fat analyzer, Kyoto, Japan), heart rate (Polar FT1 heart rate monitor; Polar Electro, Kempele, Finland), and blood pressure (manual sphygmomanometry). In addition, resting BLa and plasma glucose was evaluated through fingertip blood sample collected with a single-use contact-activated lancet. A Lactate Scout portable lactate analyzer (EKF Diagnostics, Cardiff, Wales, United Kingdom) and an Accu-Chek Aviva Blood Sugar Monitor (Rosche Diagnostics, Indianapolis, IN, USA) were used for BLa and plasma glucose measurement, respectively. Fingertip capillary blood sampling was performed after cleaning and drying of the site with sterile techniques using an alcohol swab and gauze pad, respectively.

Following baseline measurements, the cycle ergometer (Monark 894E Peak Test Cycle; Monark Exercise AB, Vansbro, Sweden) seat height and position were adjusted for the subject and they began a 5-minute warm-up period by pedaling against minimal resistance at ~70 rpm. After the warm-up, subjects were instructed to start the WAnT as described in the familiarization test and the brake weight resistance was applied automatically when the subject

Table 1. Subject characteristics.*†

	Overall ($n = 14$)	Males ($n = 7$)	Females ($n = 7$)
Age (yrs)	22.7 ± 4.1	23.7 ± 4.0	21.8 ± 4.2
Height (cm)	174.6 ± 9.5	180.3 ± 6.2	168.9 ± 9.0
Body mass (kg)	72.7 ± 11.1	80.3 ± 6.5	65.2 ± 9.6
BMI ($kg \cdot m^{-2}$)	23.7 ± 1.8	24.7 ± 1.2	22.7 ± 1.6
Body fat (%)	18.4 ± 6.3	13.2 ± 2.3	23.5 ± 4.4

*BMI = body mass index.
†Data are represented as mean ± *SD*.

reached 100 rpm. Immediately after the completion of the 30-second WAnT, brake weight resistance was removed and the subject was instructed to pedal at ~70 rpm until the second WAnT commenced 3 minutes after the first WAnT. After the second WAnT, subjects were instructed to pedal at ~70 rpm for 1 minute followed by dismount from the bike and preparation for application of the EPC or sham treatment. At exactly 5 minutes after the second WAnT, EPC or sham treatment began and BLa concentration was evaluated using fingertip capillary blood sampling as described previously. Moreover, BLa concentration was evaluated at 10-minute intervals throughout the EPC or sham treatment session (15, 25, and 35 minutes postfatigue protocol). Immediately after completion of EPC or sham treatments, subjects returned to the cycle ergometer and completed another 30-second WAnT. Heart rate was recorded before and immediately after each of the WAnTs. Peak power (PkP), mean power, and the fatigue index (FI) were measured as parameters of anaerobic cycling performance and recorded through a PC interface. Peak power was calculated as the highest running average of 1 second (Watts), average power (AP) was calculated as the mean power of the entire 30-second test (Watts), and the FI was calculated as the percentage change in power output between the first 5 seconds and the last 5 seconds of the 30-second test. Total work for each bout was calculated as the product of test time (30 seconds) and mean power for the respective WAnT bout. Total work for the fatigue protocol was calculated as the sum of WAnT 1 and 2.

Treatments (EPC and Sham). A peristaltic pulse dynamic compression device (NormaTec, Newton Center, MA, USA) was used for EPC treatments. The EPC device consists of 2 separate "leg sleeves" which contain 5 circumferential inflatable chambers (arranged linearly along the limb) encompassing the leg from the feet to the hip/groin. The "leg sleeves" are connected to an automated pneumatic pump at which target inflation pressures for each zone and the duty cycle can be controlled. However, the unit is commercially marketed with preprogrammed defaults for the duty cycle and recommended inflation pressure settings for recovery. Therefore, in this study, we chose to use the recovery protocol recommended by the manufacturer, which consists of target inflation pressures of ~70 mm Hg for each chamber. In brief, the distal chamber (which covers from the high ankle to toes) inflated to approximately 70 mm Hg, whereas the remaining zones were not inflated. For approximately 1 minute, this chamber "pulsed" after which the pressure was held constant at 70 mm Hg and the same process occurred in the zone above (calves) for another minute. After this minute, the ankle zone deflated completely, the calf remained at a constant pressure of approximately 70 mm Hg, and the process occurred in the next highest zone (high claves/lower thighs). This continued until the highest zone (fifth zone/upper thighs) finished the process at which point all zones were completely deflated for approximately 30 seconds and a full compression cycle was completed. This entire cycle of compression was repeated continuously over the course of the treatment session which lasted for 30 minutes.

Table 2. Subject vitals and plasma glucose and blood lacatate concentrations at baseline.*†

	EPC ($n = 14$)	Sham ($n = 14$)	p
HR ($b \cdot min^{-1}$)	78 ± 12	76 ± 10	0.542
SBP (mm Hg)	118 ± 12	119 ± 12	0.254
DBP (mm Hg)	67 ± 7	69 ± 6	0.422
Glu ($mg \cdot dl^{-1}$)	101 ± 25	102 ± 25	0.880
BLa ($mmol \cdot L^{-1}$)	1.7 ± 0.8	1.8 ± 0.6	0.632

*EPC = external pneumatic compression; HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; Glu = plasma glucose concentration; BLa = blood lactate concentration.
†Data are represented as mean ± *SD*. p values are from paired Student's t-tests of EPC vs. sham conditions.

The sham treatment condition consisted of application of the EPC "leg sleeves" and connection to the pneumatic pump but was devoid of actual

compression. This protocol was used to control for any thermogenic effect of wearing the leg sleeves as heat loss from the legs is likely affected. A lower pressure sham treatment was not used for the sham treatment given the potential for even very low pressures having an effect on the study outcomes.

Statistical Analyses

A priori power analyses were performed based on previous reports of the reliability of repeated sprint cycling tests (19). Assuming a typical error of 4.5 and 3.7% for PkP and AP, respectively, it was determined that a study population of 14 subjects would provide sufficient power (approximately 0.8 and 0.9 for peak and AP, respectively) to detect a 5% between bout difference. Moreover, based on the work of Tanner et al. (17), with 9.5% typical error for test-retest reliability of a Lactate Scout portable BLa analyzer across a variety of concentrations, a study population of 14 would result in a power of 0.8 to detect a clinically significant difference of >10%. In this study, we observed an intraclass correlation coefficient of 0.964, 0.994, and 0.856 ($p < 0.001$ for all) and a typical error of 7.3, 2.85, and 5.91% for peak and AP between trials at bout 1 and peak BLa, respectively.

Continuous primary outcome variables were analyzed by 2-way repeated-measures analysis of variance. Student's paired *t*-tests were used to analyze subject characteristics at baseline between trials and between time point differences when there was a main effect of time. When a significant time × treatment interaction was found, between treatment differences at each time point were evaluated by Student's paired *t*-tests. Area under the curve (AUC) analysis using the trapezoidal method was performed for BLa from 5 to 35 minutes of recovery following the fatigue protocol (after completion of WAnT bouts 1 and 2). An alpha level of $p \leq 0.05$ was required for statistical significance. All statistical analyses were performed using SPSS version 22.0 for Windows (SPSS, Chicago, IL, USA).

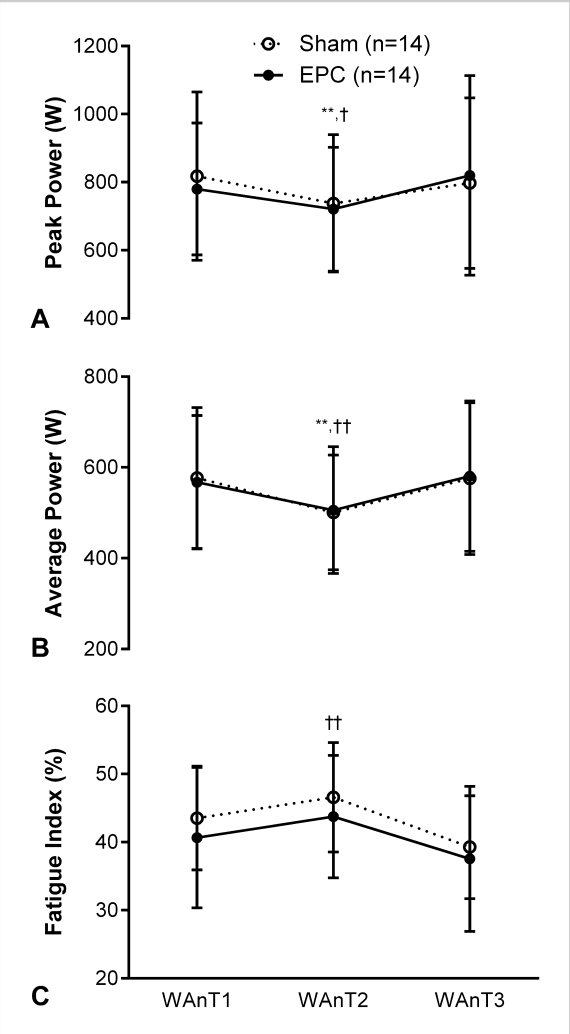

Figure 1. Parameters of anaerobic cycling performance during Wingate tests (WAnT). WAnT1 and 2 were performed as a fatigue protocol. WAnT3 demonstrates performance after 30 minutes of treatment with EPC or sham. A) Peak anaerobic power (highest 1 second running average during 30-second WAnT) in Watts, (B) average power (mean power for the entire 30-second WAnT) in Watts, and (C) the FI (percent drop in power from first 5 seconds of the test to the last 5 seconds of the test). When a significant main effect of time was observed, post hoc analysis for between time points comparisons was performed using Student's paired *t*-tests. **Significantly different from WAnT1, independent of treatment ($p < 0.01$); † and ††, significantly different from WAnT3, independent of treatment ($p \leq 0.05$ and <0.01, respectively). Values are presented as mean ± *SD*.

Results

Subject characteristics are presented in Table 1.

Table 2 contains subject vitals and plasma glucose and BLa concentrations at baseline for each trial. No significant

Table 3. Pre and post heart rate values for each WAnT.*†

	EPC ($n = 14$)	Sham ($n = 14$)	p
WAnT1			
Pre	102 ± 15	104 ± 17	0.604
Post	170 ± 8	170 ± 9	0.415
WAnT2			
Pre	136 ± 16	133 ± 16	0.262
Post	171 ± 7	172 ± 8	0.600
WAnT3			
Pre	116 ± 20	108 ± 15	0.134
Post	173 ± 9	171 ± 9	0.190

*EPC = external pneumatic compression; WAnT = Wingate anaerobic test.

†Heart rate values are represented as mean ± *SD*. *p* values are from paired Student's *t*-tests of EPC vs. sham conditions.

differences between trials were observed at baseline for HR, SBP, DBP, plasma glucose, and BLa concentrations.

All subjects completed the entire study protocol (familiarization session and 2 trials) without incident. Parameters of anaerobic cycling performance are shown in Figure 1. The total energy expended during the fatigue protocol (WAnT bouts 1 and 2) was similar between trials (31.2 ± 8.5 vs. 31.3 ± 8.1 kJ for EPC and sham, respectively; $p = 0.919$). A main effect of time (i.e., independent of treatment) was observed for PkP, AP, and the FI ($p < 0.01$ for all). Moreover, post hoc analysis revealed that PkP for WAnT2 was significantly lower than WAnT1 ($p < 0.001$) and WAnT3 ($p = 0.016$). Similarly, AP for WAnT2 was significantly lower than WAnT1 ($p < 0.001$) and WAnT3 ($p < 0.001$). The FI was found to be significantly higher for WAnT2 compared with WAnT3 ($p = 0.008$) and approached being significantly higher than WAnT1 ($p = 0.055$). However, no main effect of treatment or time × treatment interaction was observed for PkP (Figure 1A; $p = 0.290$ and 0.159, respectively), AP (Figure 1B; $p = 0.953$ and 0.218, respectively), and the FI (Figure 1C; $p = 0.139$ and 0.893, respectively).

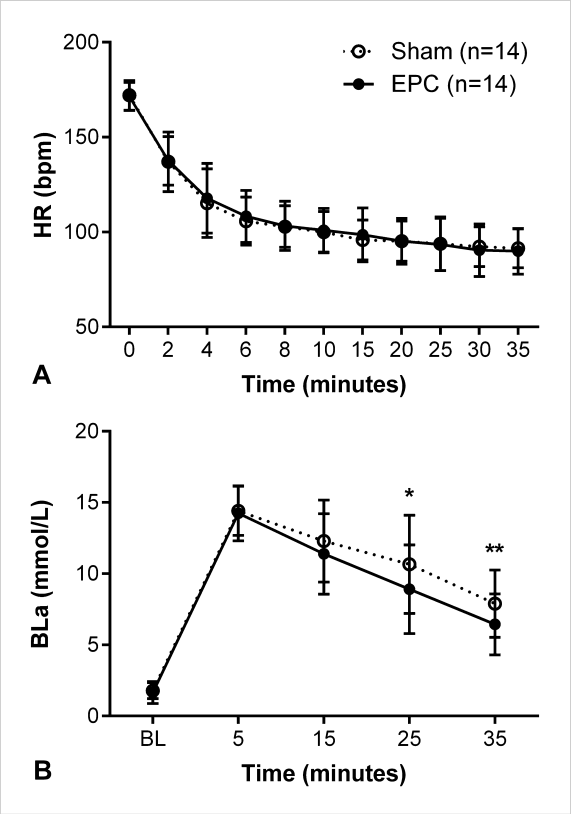

Figure 2. Heart rate (HR) and blood lactate concentration (BLa) following the fatigue protocol and throughout treatment (EPC or sham) during the recovery period. A 5-minute period was standardized for all subjects to "transition" from the cycle ergometer to application of the treatment during the recovery period. A) HR immediately following the fatigue protocol (recorded at the conclusion of the second Wingate anaerobic test, 0 minute) and every 2 minutes for the first 10 minutes and at 5-minute intervals thereafter during the recovery period and (B) BLa at baseline (BL) and 5 minutes after completion of the fatigue protocol and at 10-minute intervals thereafter during the recovery period. *$p \leq 0.05$ and **$p < 0.01$ for Student's paired *t*-tests of EPC vs. sham for time point differences. Values are presented as mean ± *SD*.

Heart rates immediately before and immediately after each WAnT were not significantly different between trials (Table 3). Moreover, no significant main effect of treatment or time × treatment interaction was observed for heart rate response during the recovery period (Figure 2A; $p = 0.741$ and 0.638 for treatment main effect and time × treatment interaction, respectively). A significant main effect of treatment ($p = 0.009$) and a significant time × treatment interaction ($p = 0.049$) was observed for BLa during the recovery period. Indeed, the AUC for BLa concentrations was significantly lower during recovery in the EPC treatment condition compared with sham (10.2 ± 2.5 vs. 11.4 ± 2.6 $mmol \cdot L^{-1} \cdot min^{-1}$ for EPC and sham, respectively; $p = 0.019$). Moreover, BLa was found to be significantly lower with EPC treatment compared with sham at the 25-minute (−23.0 ± 30.6%, $p = 0.021$) and 35-minute (−26.0 ± 29.6%, $p = 0.006$) time points of recovery (Figure 2B).

Discussion

EPC was found to significantly improve BLa clearance during recovery from a fatigue protocol compared with a sham condition. However, the significantly reduced BLa after recovery was not associated with any differences in parameters of anaerobic performance.

In this study, there were neither differences between conditions in HR throughout the protocol nor differences in total work performed during the fatigue protocols. Moreover, peak BLa was similar between conditions (14.24 ± 1.93 vs. 14.41 ± 1.72 $mmol \cdot L^{-1}$ for EPC and sham conditions, respectively). Therefore, we are reasonably confident that variation in BLa clearance and subsequent anaerobic performance was minimally confounded by prior effort. Despite improved BLa concentrations, anaerobic performance did not differ between treatment conditions following the recovery protocol. This is in agreement with several investigations that have demonstrated little to no relationship between BLa clearance and subsequent performance (12,18,21,22). Nevertheless, the potential role of altered limb circulation, lymphatic flow, and general metabolite clearance (2,10,13) by EPC is intriguing in the context of sport recovery. The fatigue protocol used herein did demonstrate significant reductions in peak and mean power between the consecutive WAnt bouts, but subsequent performance following the recovery protocol was essentially fully restored. Therefore, any potential effect of EPC may have been difficult to detect.

Zelikovski et al. (24) have previously reported no effect of EPC treatment on BLa clearance during a 20-minute period of recovery from a bout of exhaustive exercise. In contrast, Hanson et al. (6) recently demonstrated significantly greater BLa clearance at 20 minutes after a single WAnT with EPC

compared with passive recovery. However, BLa was only measured at two time points during recovery (0 and 20 minutes). Likely contributors to the disagreement between these 2 studies are the variability in the EPC devices used for treatment, sampling frequency during recovery, and target inflation pressures. In this study, BLa was sampled 5 minutes after completion of the recovery protocol as it has been suggested that BLa peaks approximately 3–7 minutes posteffort (4). In addition, we evaluated BLa at regular 10-minute intervals for a 30-minute treatment period. Our results extend those previously reported by Hanson et al. (6) as we observed a significantly improved BLa clearance (~25%) with EPC compared with sham BLa at 20 and 30 minutes of the recovery treatment (25 and 35 minutes postfatigue protocol, respectively) indicating that the effect persists further into recovery. Heinonen et al. (7) have previously noted that local heating increases skeletal muscle blood flow. Therefore, we included a sham treatment in which the EPC "leg sleeves" were worn over the limbs without compression in an effort to control for increased limb blood flow as a result of impaired heat loss. Although limb blood flow was not directly measured in this study, our results suggest that local limb temperature and resultant blood flow is not responsible for the observed differences in BLa clearance.

Although this study did not include an active recovery group, Hanson et al. (6) reported similar BLa clearance between EPC and active recovery conditions. Given recent evidence indicating that manual massage has little to no effect on BLa (20), our data suggest that EPC may be a superior option to sports massage when "inactive" BLa clearance is desirable (e.g., energy sparing). However, it is well accepted that active recovery is one of, if not, the most effective ways to increase BLa clearance. To our knowledge, there is a paucity of literature available comparing subsequent performance in repeated exercise bouts with EPC and active recovery groups/treatments, and this should be explored in future investigations.

As stated previously, complete recovery may have precluded a significant interaction in anaerobic performance parameters from being observed as the protocol may not have been intense enough to warrant a specialized recovery of this duration. However, the nature of the intervention (~5–6 minutes per "limb compression cycle") and transitions from exercise to recovery limits how short the recovery period can be. Moreover, subject tolerance for significantly greater fatigue workloads with supramaximal efforts would be limited. In the study performed by Watt et al. (19), it was determined that the typical errors for measurement of mean or peak anaerobic power are small enough to estimate the effects of 1–2% with modest sample sizes (~10) in crossover studies. However, despite the randomized crossover nature of study, the between-trials initial PkP variability herein was greater than expected. Finally, potential for variability may have been in the self-reporting of rest and dietary habits.

Practical Applications

In summary, EPC is significantly more effective than a passive recovery condition for BLa clearance. However, EPC did not have a significant effect on recovery compared with sham in a model of repeated anaerobic exercise with a relatively long recovery period. Therefore, when an acute reduction in BLa is desirable, EPC can provide a viable alternative and a superior option to passive recovery when active recovery is not indicated. Despite no difference in performance parameters in this study, differences in training load before treatment and treatment times need to be explored in a variety of contexts where anecdotal evidence in support of EPC can be tested.

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