Short Communication

The impact of a single bout of intermittent pneumatic compression on performance, inflammatory markers, and myoglobin in football athletes

Jeremie E. Chase, Jason D. Peeler, Matthew J. Barr, Phillip F. Gardiner, Stephen M. Cornish

Objective: Intermittent Pneumatic Compression (IPC) use as a tool for recovery after exercise has recently become widespread among athletes. While there is anecdotal support for IPC, little research has been done to show its effectiveness in recovery. This study examined the impact of IPC use for recovery on performance, markers of inflammation, and a marker of muscle damage.

Design: Eight university football athletes were recruited and subjected to IPC or passive recovery conditions in a randomized crossover manner following off-season training.

Methods: Countermovement jump and 10 m sprint were evaluated before training, at 3 and 24 hours following training. Self-reported soreness, blood markers of inflammation (interleukin-6, interleukin-10, and monocyte chemoattractant protein-1) and muscle damage (myoglobin) were measured before training, post-training, immediately after the recovery interventions, and at 3 and 24 hours post-training.

Results: Significant time effects were observed in monocyte chemoattractant protein-1 and myoglobin suggesting an inflammatory response and muscle damage. No group differences were observed between recovery interventions for all measures.

Conclusion: The results suggest that the IPC protocol used was not effective for the specific exercise paradigm and for the parameters measured in this population.

(*Journal of Trainology* 2020;9:33-38)

Key words: cytokine ■ countermovement jump ■ inflammation ■ recovery ■ soreness

INTRODUCTION

Stress resulting from training and competitions is used to improve the performance of an athlete in their given sport. Physical stress applied to muscle fibers can lead to muscle damage and a transient drop in performance.[1,2] To promote quicker recovery from these stresses, athletes have long utilised modalities such as cryotherapy, massage, stretching, and anti-inflammatory drugs in the hopes of restoring their baseline levels of performance after exhaustive training and competition.[3] Recently, intermittent pneumatic compression (IPC) has been introduced as a modality which putatively promotes recovery in athletes following intense training and competition.[4] That being said, research on IPC devices used for recovery is limited.

While there may be anecdotal support for IPC, there is a lack of evidence to support its effectiveness, particularly when examining physiological markers of immune activation.[4-6] The purpose of this study was to determine if a bout of IPC applied to the lower limbs was able to modulate the performance, muscle damage recovery, and inflammatory cytokine response from strenuous physical training in university football athletes. We hypothesized that the use of IPC would positively influence physical test performance and decrease muscle soreness post-training when compared to a control condition. Similarly, we also hypothesized that IPC would lead to an earlier increase in systemic cytokine concentrations than with the control condition.

METHODS

Participants

Canadian male university football players with at least one season of university football experience and one year resistance training experience were recruited for this study (mean ± standard deviation; $n = 8$, age 21.1 ± 2.1 years, height 183.2 ± 6.3 cm, weight 96.2 ± 15.8 kg). The following playing positions were represented in the sample: offensive linemen ($n = 1$), defensive backs ($n = 2$), wide-receivers ($n = 2$), linebackers ($n = 2$), and running backs ($n = 1$). Exclusion criteria included any musculoskeletal injury, use of anti-inflammatory drugs or supplements, auto-immune disorders, vascular conditions in the lower limb, cardiovascular disease, ankle brachial index of <0.8 or >1.4 or a positive response to a PARQ+ screening questionnaire (Canadian Society for Exercise Physiology, Ottawa, Canada). Ethical approval was granted by a university research ethics board, and participants were informed of the study purpose and methods before sign-

Received January 21, 2020; accepted May 29, 2020

From the Faculty of Kinesiology and Recreation Management, University of Manitoba, Winnipeg, Canada (J.E.C., P.F.G., S.M.C.), Canadian Sport Centre Manitoba, Winnipeg, Canada (J.E.C.), Department of Human Anatomy and Cell Sciences, University of Manitoba, Canada (J.D.P.), Centre on Aging, University of Manitoba, Winnipeg, Canada (J.D.P., S.M.C.), Spinal Cord Research Centre, University of Manitoba, Winnipeg, Canada (P.F.G.), and Rugby Canada, Richmond Hill, Canada (M.J.B.)

Communicated by Takashi Abe, PhD

Correspondence to: Dr. Stephen M. Cornish, Room 117, Frank Kennedy Centre, University of Manitoba, Winnipeg, Canada.
Email: Stephen.Cornish@umanitoba.ca

ing an informed consent to participate.

Experimental Procedures

The study was designed as a single-blind randomized crossover trial, where participants were randomly allocated to either IPC or passive recovery (control) after strenuous exercise, followed by the opposite intervention a week later. The countermovement jump (CMJ) and 10 m sprint performance tests were done at baseline (pre-training), and at 3 hours and 24 hours post-training. Blood draws to measure inflammatory cytokines (interleukin-6 [IL-6], interleukin-10 [IL-10], and monocyte chemoattractant protein 1 [MCP-1]) along with muscle damage marker myoglobin (Mb) were performed at the same time points as the performance tests, as well as immediately following exercise (post-exercise) and immediately after the recovery interventions (post-recovery). Self-perceived muscle soreness was assessed at all blood draws (see Figure 1).

For the strenuous exercise intervention, participants underwent a warm-up lasting approximately ten minutes, then subjected to a sprint training session lasting approximately one hour. Sprints were maximal, but short (~30-40 m) with quick deceleration phases. Cutting, acceleration, and deceleration drills were also part of the sessions, with ten repetitions of

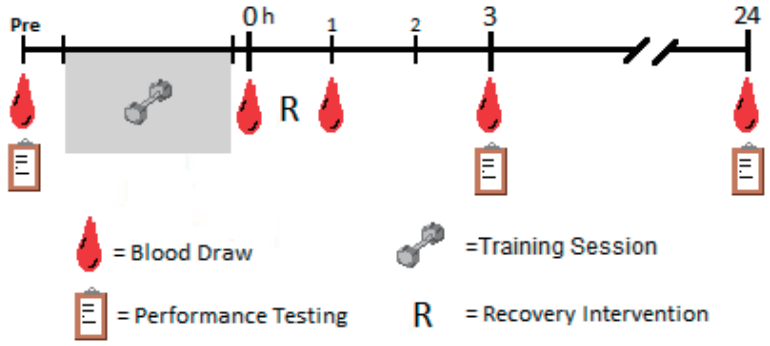

Figure 1 Timeline of subject flow through one intervention. Time points are relative to the completion of the training session. Recovery interventions were either Intermittent Pneumatic Compression treatment or control intervention.

Table 1 Strength training metrics.

Exercise	Position	Sets	Repetitions	%1RM
Power Clean	OL, DB1, WR1, LB1	1-1-1-1-4	4-4-4-3-2	50-60-70-75-80
Split Squat	OL, DB1, WR1, LB1	3	6	AL
Good Morning	OL, DB1, WR1, LB1	3	10	AL
Power Clean and Split Jerk	DB2, WR2, LB2, RB	5	6-6-4-3-2*	50-60-70-80-85
Bench Press	DB2, WR2, LB2, RB	5	5-5-4-3-2	50-60-70-80-90
Pull-Up	DB2, WR2, LB2, RB	5	8	AL
Approach Box Jump	All	3	5	BW
SL Approach Box Jump	All	3	3	BW
SL Land and Cut	All	3	4	BW
Jump Lunge - Cut - Jump Lunge	All	3	3	BW
Jump Lunge	All	3	3	BW
Kneeling Lateral Drive	All	3	4	BW
Neck Flexion	OL, LB, RB	3	10	BW
Wrestler Bridge	OL, LB, RB	3	30 s	BW
Back Extension Twist	OL, DB	3	6	BW
Candlesticks	OL	1	10	BW
Hanging Bicycle	DB	3	10	BW
Medball Sit-up	DB, LB, RB	3	10	AL
Nordic Hamstring	DB, WR, LB, RB	3	6	BW
SL Back Extension	WR	3	8	BW
Windshield Wipers	WR	3	8	BW
SL Decline Sit-Up	WR	3	8	BW
Washing Machine	OL, LB, RB	3	6	BW

Note: AL: *Ad Libitum*; BW: Bodyweight; DB: Defensive Back; LB: Linebacker; OL: Offensive Linemen; RB; Running Back; SL: Single-Leg; WR: Wide-Receiver. Sets, repetitions and/or % of one-repetition maximum (%1RM) with values separated by a dash indicate different repetition and intensity for a given exercise, respectively. Number behind position indicates different participant of the same playing position. *indicates sum of repetitions for each set. Odd repetition numbers indicate one side (left or right) had one more repetition completed than the other.

each drill performed. Sprinting volume was approximately 300 meters. Following the sprint training, athletes underwent a resistance training session. Strength training programs were first divided by playing position to meet positional requirements, and subsequently, each participant was given individual exercises to address individual needs. Average volume of training was 262 ± 18 repetitions and the average intensity was 70% of one repetition maximum (see Table 1). Once their exercise was complete, participants were given their assigned recovery intervention. The IPC recovery intervention involved wearing the IPC devices (NormaTec MVP Pro, NormaTec, Newton Centre, USA) using the pre-programmed proprietary "recovery flush" protocol. Devices were applied and administered using manufacturer guidelines. The devices covered the entire lower limb and were divided into five cells that were each independently inflated by a central pump, which generated pressures between 60 and 80 mmHg. Participants were seated in office chairs, with feet elevated at the same level as the hips. For the control conditions, participants were seated with feet elevated to hip height without the use of the IPC devices.

Performance Testing

Three trials of the performance tests were evaluated at each testing time point, with the best of the three trials being used for analysis at that time point. Participants were given up to ten minutes of self-selected warm-up exercises (consisting of light cycling and/or dynamic warm-up). Ten metre sprints were recorded using a photo-electric timing system (SmartSpeed Pro, Fusion Sports, Sumner, Australia) which were placed at either end of a ten metre distance. Using a standing or three-point stance, participants set up one meter behind the first set of gates, and sprinted once they felt ready. CMJs were assessed using a force platform (Quattro Jump, Kistler Instrument Corporation, Amherst, USA) at a sampling rate of 500 Hz. CMJ variables analyzed were vertical jump height (cm), peak and average power (Watts), force instantaneous (N/kg of bodyweight at transition from eccentric to concentric), velocity (m/s), and impulse (N·s).

Blood Draw and Assay Procedures

Blood draws from the antecubital vein were done by certified phlebotomists and samples were used to determine systemic IL-6, IL-10, MCP-1 and Mb concentrations. Blood collection tubes were centrifuged for 15 minutes at 3000 rpm at 4°C, with plasma sample tubes being centrifuged immediately after collection and serum sample tubes after resting at room temperature for 30 minutes. Once centrifuged, samples were aliquoted into microtubes and stored in a -80°C freezer until analysis.

Luminex bead-based multiplex analysis kits (EMD Millipore, Billerica, USA) were used to evaluate inflammatory marker concentrations in the plasma samples. Microscopic beads coated with antibodies specific to the three cytokines investigated were added to the solution, on which the corresponding cytokines would bind. Detection antibodies were added, and the kits were placed in a laser-optic reader (Luminex MagPix, Luminex Corp., Toronto, Canada) that determined the type and concentrations of the cytokines. Mb concentrations in the serum samples were determined using enzyme-linked immunosorbent assay kits (Abnova, Walnut, USA). Procedures for inflammatory markers and Mb analyses were done according to manufacturer instruction, and all samples were run in duplicate.

Self-Perceived Soreness Testing

Before each blood draw, participants were asked to rate their self-perceived soreness using a 100 millimeter visual analogue scale (VAS) from a seated position. The scale ranged from no soreness at the "0" mark, to extreme soreness at the "100" mark.

Dietary Log and Pre-Recovery Measures

Participants were asked to fill out a three-day dietary log of food consumption due to dietary potential influence on immune parameters.[7] Likewise, resting heart rate and blood pressure were taken immediately before the recovery interventions as potential confounders on participant response to the recovery interventions.

Statistical Analyses

Performance, biochemistry, and soreness data were analysed using two-way (group by time) repeated measures analysis of variance (ANOVA), with significance set at $p \leq 0.05$. Greenhouse-Geisser corrections were applied to data that did not pass Mauchley's test of sphericity. Post-hoc Bonferroni p-value corrections were applied to significant results to account for multiple comparisons. Additionally, Cohen's d effect size statistical test was utilized to determine the magnitude of difference between the means of each recovery intervention. Values of d less than 0.2 were deemed trivial; 0.2 - 0.5 as small differences; 0.5 - 0.8 as moderate; and greater than 0.8 as large.

ANOVA, Mauchley, Greenhouse-Geisser, and post-hoc tests were computed using Statistica, software version 13.3 (Statsoft Inc., Tulsa, USA), while descriptive statistics, standard deviations, and Cohen's d were calculated using Excel 2010, software version 14.0 (Microsoft Corporation, Redmond, USA).

A sample size analysis was completed with data from Waller et al.[8] comparing change in vertical jump in an IPC and control group after a shuttle run. The IPC group lost 1.9 ± 1.4 cm compared to a loss of 5.9 ± 3.4 cm in the control group, indicating a minimum sample size of six was required for adequate statistical power ($\alpha = 0.05$, $\beta = 0.80$). A recruitment goal of eight participants was set to account for potential attrition in the study.[9] For scheduling reasons, some participants were unable to make some of the measurement timepoints, resulting in missing data ($n = 4$ missing cases; $n = 1$ baseline measure, $n = 1$ at 3 hours post-training, and $n = 2$ at 24 hours post-training). The assumptions of a repeated measures ANOVA require equal number of cases for all comparison, and thus it was decided to utilize the k-Nearest Neighbour algorithm with a $k = 3$ and using the Euclidian dis-

tance function to impute missing participant data.

RESULTS

Performance Tests

Figure 2 illustrates the sprint times and three outcome variables of the CMJ. No significant group, time, or group by time differences were observed for both the 10 m sprint and all outcome measures of the CMJ ($p > 0.05$).

Biochemistry

Figure 3 demonstrates the participant systemic concentrations of the three cytokines and Mb. No differences were observed between recovery groups ($p > 0.05$) for all measures, however significant main time effects were observed for MCP-1 and Mb ($p < 0.05$). MCP-1 concentrations were significantly greater at post-training, post-recovery, and 3 hours post-training than at pre-training, while post-recovery concentrations were greater than 24 hours post-training. Similarly, Mb concentrations were significantly greater at post-training, post-recovery, and 3 hours post training than both pre-training and 24 hours post training. No time effects were observed for IL-6 and IL-10 ($p > 0.05$).

Self-Reported Soreness

No recovery group or time effect were observed for soreness ($p > 0.05$). Effect sizes ranged from trivial to small for all time points except for 24h post-training where a moderate (d = -0.53) effect size was observed.

Control Measures

No significant differences were observed in total kilocalorie or macronutrient intake (carbohydrate, protein, fat) between the two interventions ($p > 0.05$). Likewise, no significant differences were observed with pre-recovery resting heart rate and blood pressure measurements.

DISCUSSION

The main purpose of the study was to investigate the effectiveness of an IPC protocol on measures of recovery in university football athletes. No significant group differences were observed between IPC and passive recovery (control) interventions.

No significant differences were found in any of the CMJ parameters measured, as well as the 10 m sprint. The lack of change on the performance tests differ from the findings by Johnston et al.,[10] who found a significant decrease in post-training jump height, power, and rate of force development in CMJs measured following strenuous training in elite rugby players.[10] Contrasting the current study, Johnston et al.[10] had given the participants two days of rest preceding the training day, which might have elicited more accurate baseline test performance scores.[10] Another possible explanation for the

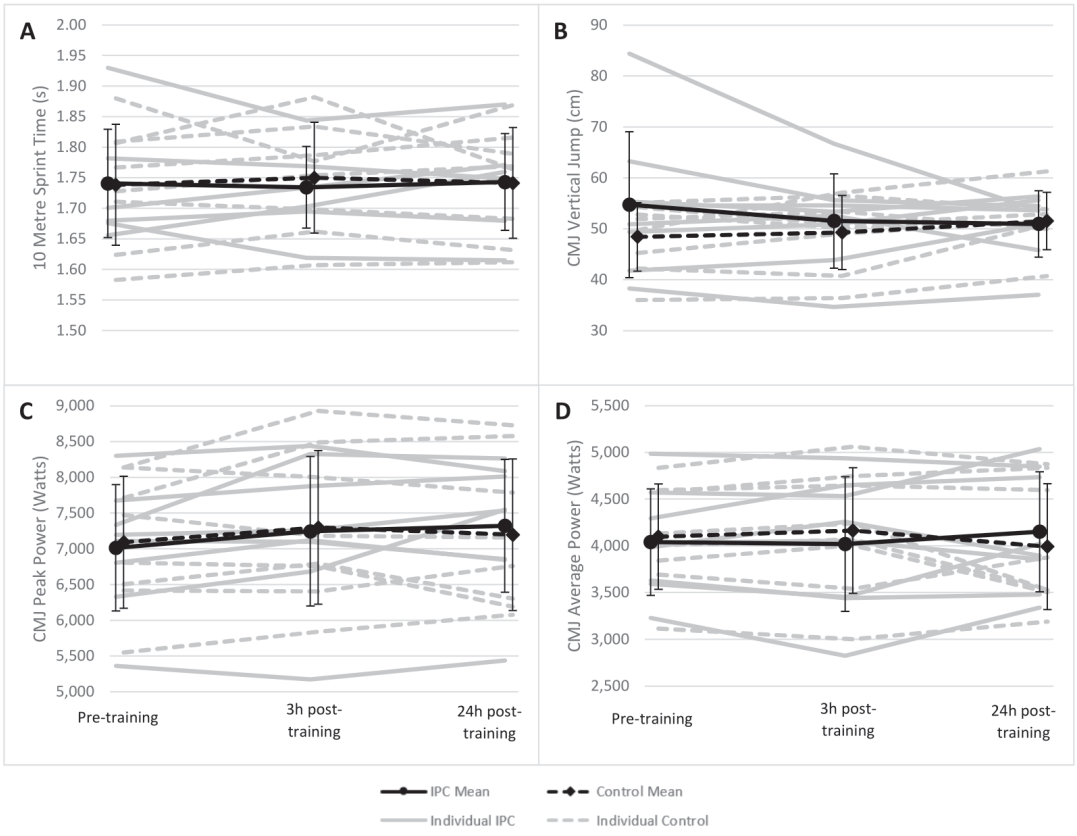

Figure 2 Mean (± SD) and individual data for physical test results. Sprint time (**A**), countermovement jump height (**B**), countermovement jump peak power (**C**), and countermovement jump average power (**D**). CMJ: countermovement jump. No statistically significant results were observed.

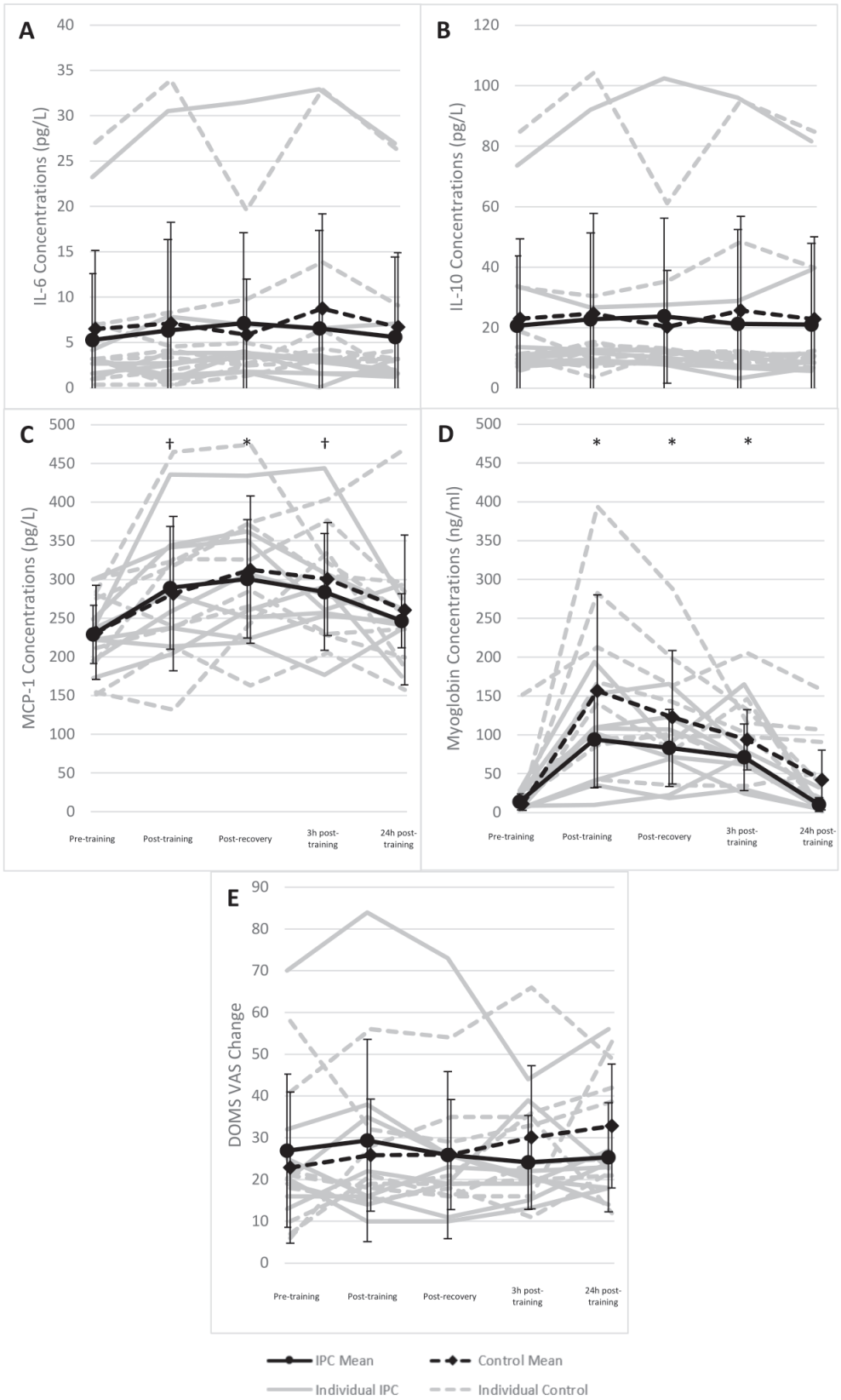

Figure 3 Mean (± SD) and individual data for systemic concentrations of interleukin-10 (**A**), interleukin-6 (**B**), monocyte chemoattractant protein 1 (**C**) myoglobin (**D**) as well as self-reported soreness (**E**). DOMS: Delayed-onset muscle soreness; IPC: Intermittent Pneumatic Compression; VAS: Visual Analogue Scale. * Significant time effect ($p < 0.05$) compared to pre-training and 24 hours post-training; † Significant time effect ($p < 0.05$) compared to pre-training only. No group differences were observed.

lack of change in performance is that the training stimulus may have been inadequate to cause a significant decrease in test performance, as has been shown in other studies.[10-12]

The lack of rest from training prior to the study or inadequate exercise stimulus might also explain the lack of changes in self-perceived soreness. Other strenuous exercise protocols have led to significant increase in participant rating of soreness.[11-13] A moderate between-group effect size was noted at 24 hours post-training, where control reported greater soreness than IPC, however, this difference was deemed not clinically meaningful based on previous research examining VAS-reported soreness.[14]

No group differences were observed between recovery interventions for the inflammatory cytokines and muscle damage marker measured. There were significant time effects with MCP-1 concentrations, where concentrations were significantly greater than baseline measures at the time points immediately post-training, post-recovery, and 3 hours post-training. Post-recovery concentrations were also significantly greater than 24 hours post-training. This suggests that an inflammatory response occurred as a result of the training. Similarly, muscle damage was likely sustained from the training sessions, as indicated by the significant increase in systemic Mb concentrations. The Mb response was significantly greater between post-training and 3 hours post-training than both pre-training and 24 hours post-training measurements. Unlike MCP-1 and Mb, no time effects were observed in IL-6 and IL-10 concentrations, which is consistent with some but not all muscle damaging protocols.[9,15]

In summary, the results of the present study indicate that our IPC protocol was ineffective for altering performance, immune and muscle damage markers, and self-reported muscle soreness following strenuous training in university football athletes. No detriments were observed on the CMJ or 10 m sprint performance tests, nor were any changes noted in IL-6, IL-10 and self-reported soreness. Increases in MCP-1 and Mb suggest systemic and muscular stress occurred in both groups as a result of training. Therefore, our results suggest the IPC protocol was ineffective for recovery in this population, and under the described conditions of the experiment. Future research should be directed at exploring IPC under different pressure or time settings, with different outcome measures, and/or with participants of different athletic backgrounds.

ACKNOWLEDGEMENTS

The authors also wish to thank Tim Beaver, Eric Bugera, and David Turczyn for assistance during data collection.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

FUNDING

The study was funded by the University of Manitoba University Research Grants Program (Grant #43880).

DATA

Study data are publicly available at Open Science Framework research repository and can be found using the following identifier: DOI 10.17605/OSF.IO/3K879

AUTHOR CONTRIBUTION STATEMENT

All authors designed the research protocol, JEC conducted the experiment, JEC and SMC analyzed the data and wrote the manuscript. All authors read, edited, and approved the manuscript.

REFERENCES

1. Ispirlidis I, Fatouros IG, Jamurtas AZ, et al. Time-course of changes in inflammatory and performance responses following a soccer game. *Clin J Sport Med* 2008;18:423-431.
2. Poprzęcki S, Staszkiewicz A, Hübner-Woźniak E. Effect of eccentric and concentric exercise on plasma creatine kinase (CK) and lactate dehydrogenase (LDH) activity in healthy adults. *Biol Sport* 2004;21:193-203.
3. Cheung K, Hume PA, Maxwell L. Delayed onset muscle soreness: Treatment strategies and performance factors. *Sports Med* 2003;33:145-164.
4. Cochrane DJ, Booker HR, Mundel T, et al. Does intermittent pneumatic leg compression enhance muscle recovery after strenuous eccentric exercise? *Int J Sports Med* 2013;34:969-974.
5. Haun CT, Roberts MD, Romero MA, et al. Concomitant external pneumatic compression treatment with consecutive days of high intensity interval training reduces markers of proteolysis. *Eur J Appl Physiol* 2017;117:2587-2600.
6. Haun CT, Roberts MD, Romero MA, et al. Does external pneumatic compression treatment between bouts of overreaching resistance training sessions exert differential effects on molecular signaling and performance-related variables compared to passive recovery? An exploratory study. *PLoS One* 2017;12:e0180429.
7. Rowlands DS, Rössler K, Thorp RM, et al. Effect of dietary protein content during recovery from high-intensity cycling on subsequent performance and markers of stress, inflammation, and muscle damage in well-trained men. *Appl Physiol Nutr Metab* 2008;33:39-51.
8. Waller T, Caine M, Morris R. Intermittent pneumatic compression technology for sports recovery. *Eng Sport* 2006;3:391-396.
9. Cornish SM, Johnson ST. Systemic cytokine response to three bouts of eccentric exercise. *Results Immunol* 2014;4:23-29.
10. Johnston MJ, Cook CJ, Drake D, et al. The neuromuscular, biochemical and endocrine responses to a single session verses double session training day in elite athletes. *J Strength Cond Res* 2016;30:3098-3106.
11. French DN, Thompson KG, Garland SW, et al. The effects of contrast bathing and compression therapy on muscular performance. *Med Sci Sports Exerc* 2008;40:1297-306.
12. Andersson H, Raastad T, Nilsson J, et al. Neuromuscular fatigue and recovery in elite female soccer: Effects of active recovery. *Med Sci Sports Exerc* 2008;40:372-380.
13. Twist C, Eston R. The effects of exercise-induced muscle damage on maximal intensity intermittent exercise performance. *Eur J Appl Physiol* 2005;94:652-658.
14. Visconti L, Capra G, Carta G, et al. Effect of massage on DOMS in ultramarathon runners: A pilot study. *J Bodyw Mov Ther* 2015;19:458-463.
15. Izquierdo M, Ibañez J, Calbet JAL, et al. Cytokine and hormone responses to resistance training. *Eur J Appl Physiol* 2009;107:397-409.