RESEARCH ARTICLE

Open Access

The effect of intermittent sequential pneumatic compression on recovery between exercise bouts in well-trained triathletes

Shannon O'Donnell[1] and Matthew W Driller[1]✉

Abstract

To evaluate the effectiveness of one method of intermittent sequential pneumatic compression (ISPC) on the recovery between exercise bouts in well-trained triathletes. Ten well-trained male triathletes (mean ± SD; age = 29 ± 9 y, mass = 72kg ± 11kg) completed a familiarization trial and two experimental trials in a randomized, cross-over design. Participants performed a 40-minute high-intensity interval session on a cycle ergometer, followed by a 30-minute recovery period where participants completed either passive recovery (CON) or ISPC recovery. Following the recovery period, participants performed a 5km run time-trial on a treadmill (5kmTT). Blood lactate concentration, 5kmTT time and total quality recovery (TQR) were used to examine the effect of ISPC compared to CON. The 5kmTT resulted in a non-significant difference ($P = 0.31$, ES = 0.07) between groups of 8.2 ± 23.7 seconds in favour of the ISPC trial (ISPC; 1189.7 ± 94.9 and CON; 1197.9 ± 101.9). There were no significant differences between trials for blood lactate concentrations or TQR. The current study reports that ISPC was not effective in improving recovery between a cycling and running bout in well-trained triathletes.

Keywords: recovery boots, fatigue, running, cycling, performance

✉ **Contact email:** shannonleaodonnell@gmail.com (S. O'Donnell)

[1] *University of Waikato, Hamilton, New Zealand*

Received: 10 September 2015. Accepted. 11 December 2015.

Introduction

As the training requirements for elite athletes increase, the role of adequate recovery becomes an integral component of improving athletic performance between training sessions and competitions (Argus et al. 2013; Coffey et al. 2004). It is thought that incorporating recovery strategies following exercise will enhance subsequent training quality, improve competition performance, reduce the risk of developing overtraining syndrome and reduce the risk of acquiring an injury (Argus et al. 2013). The role of recovery is to restore physiological and psychological processes, as well as rehydrate and refuel energy stores (Montgomery et al. 2008) so that the athlete can complete or train at the required level again (Halson 2013).

Competitive sports that require athletes to train multiple times a day, such as triathlon, have a high demand for physical recovery. Triathlon is a three-event endurance sport, where athletes compete sequentially in swimming, cycling and running (O'Toole and Douglas 1995). Competing in three different sporting disciplines often requires the athlete to perform multiple training sessions within a single day. Therefore ensuring adequate recovery occurs between training sessions is crucial to allow for high quality training sessions. During exercise, metabolic waste products are produced in the muscle and are released into the blood, perhaps contributing to fatigue in the working muscle (Zelikovski et al. 1993). Therefore, the aim of many recovery strategies used between training sessions is to enhance the removal of metabolites from the muscle and to increase blood-flow, leading to enhanced recovery and subsequent exercise performance (Zelikovski et al. 1993).

At present there are numerous acute strategies used by athletes and coaches to enhance recovery and performance. These strategies include hydrotherapy (Ingram et al. 2009), massage (Halson 2013), active recovery (Wiener et al. 2001) and compression garments (Driller and Halson 2013b). Compression garments (also known as static compression) are used as a recovery tool in a variety of sports to aid athletic performance, largely due to their practicality and availability. Originating from the medical setting, compression has been effective in the treatment of numerous circulatory disorders (Driller and Halson 2013b). Within the sporting sector, it is claimed that compression improves venous return, redistributing blood from the periphery to the deep venous system, aiding in increased blood flow following exercise (Brophy-Williams et al. 2014b; Davies et al. 2009; Driller and Halson 2013b). However, research supporting the efficacy of compression garments for athletic recovery remains equivocal, warranting further investigation (MacRae et al. 2011; Marqués-Jiménez et al. 2016).

Intermittent sequential pneumatic compression (ISPC) is a form of dynamic compression, and is a relatively new method of recovery being implemented in the

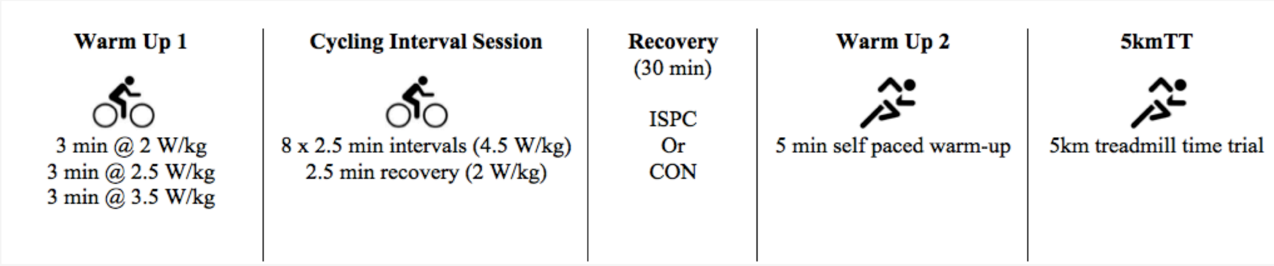

Figure 1. Experimental testing protocol. ISPC = Intermittent sequential pneumatic compression; CON = passive control.

sporting industry. Like static compression, it also originates from the medical field, where several studies have shown similar devices to be used in the treatment of lymphedema (Morris and Woodcock 2002; Zelikovski et al. 1993). ISPC devices involve relatively high levels of compression (up to ~80mmHg of pressure) through inflatable sleeves placed on the legs. The level of pressure in ISPC devices is significantly higher to that of compression garments (~20mmHg). The sleeves inflate sequentially from distal to proximal through separate chambers, before deflating and repeating this process to provide a 'milking' like effect as used in massage.

Research investigating dynamic compression in an exercise-recovery setting is limited and results remain unclear with a range of modalities and protocols used (Northey et al. 2015; Sands et al. 2015; Wiener et al. 2001; Zelikovski et al. 1993). Wiener et al. (2001) investigated the enhancement of tibialis anterior recovery following ISPC of the legs in eight male participants after performing a fatiguing weight-lifting exercise. Tibialis anterior muscle activity was measured through electromyography a sustained weight lifting fatigue protocol. A three minute-recovery period consisted of an ISPC device using 80mmHg of pressure applied to one leg, with the other leg acting as a passive control. Following the fatigue protocol and recovery period, the same sustained tibialis anterior weight lifting protocol was performed, resulting in a higher mean power frequency of the ISPC leg when compared to the control leg. Northey et al. (2015) also studied the effect of ISPC following a fatigue-inducing weight-lifting session, with contrasting results. The researchers found no improvements in strength and power measures following 30-minutes of ISPC (~80mmHg of pressure) after 10 sets of 10 back squats (70% of predicted 1RM with three minutes rest between sets). While no performance measures were taken, Sands et al. (2015) reported improved pressure-to-pain perceptual ratings following 15-minutes of dynamic compression in a group of elite athletes following a range of training sessions. To our knowledge, only one study has assessed dynamic compression as a performance-recovery tool in an endurance-based sport (Zelikovski et al., 1993). Eleven male participants performed a constant workload test until exhaustion on a cycle ergometer, followed by a 20-minute recovery period with or without the use of dynamic compression. The ISPC device used by Zelikovski et al (1993) involved a continuous cycle of ascending pressure (50mmHg) on the lower limbs. Participants subsequently exercised at the same workload until exhaustion in bout two, resulting in a 45% improvement in the ISPC trial. While these results would suggest that ISPC is a promising recovery tool for endurance athletes, these findings are yet to be confirmed in any other study.

Therefore, the aim of the current study was to investigate the effect of intermittent sequential pneumatic compression on recovery in well-trained triathletes between a cycling interval session and a 5km time-trial run.

Materials and methods

Experimental Approach to the Problem

The current study was performed using a randomized cross-over design where participants were required to complete a familiarisation trial followed by two experimental trials. In order to minimize the learning effect, participants were familiarised with the standardised warm up, cycle interval session, ISPC recovery protocol and the 5km treadmill run. The familiarization and two experimental trials were completed within 14 days, with each trial separated by >48 hours. To control any dietary variables, subjects completed a 24-hour food diary before their first trial and were instructed to replicate their diet as closely as possible before the subsequent trials. Training was also controlled for, with subjects keeping all training the same < 48 hours before testing on all occasions. Subjects were asked to respect a 24-hour rest period prior to each trial. Subjects were asked to refrain from caffeine (< 12 h) and to arrive in a fully rested, hydrated state. All testing was performed at the same time of day (± 1 h) to minimize diurnal variation, and on the same cycle ergometer and treadmill.

Participants

Ten well-trained male triathletes (mean ± SD; age = 29 ± 9 y, mass = 72kg ± 11kg) partaking in at least two sessions of both cycling and running per week, volunteered to participate in the current study. The participants all had personal best 5km run times of < 20 minutes and the study took part during the competition phase of the triathlon season. All participants provided informed written consent before taking part and ethical approval for the study was obtained from institutions Human Research Ethics Committee.

Procedures

High-intensity cycling interval session

The cycle interval session consisted of a standardized warm-up (3 x 3-minute intervals at 2.0, 3.0, 4.0 W.kg^{-1}) followed by a high-intensity interval session on an air-braked cycle ergometer (Wattbike Pro, Nottingham, UK). The interval session consisted of 8 x 2.5 minute intervals at 4.5W.kg^{-1}, with 2.5-minutes between each interval at 2W.kg^{-1}. Heart rate (Polar Electro Oy, Finland) and RPE (Borg's 6-20 scale) were recorded at the completion of each interval. The cycling interval session, including workloads and intervals was chosen to simulate a typical training session as designed in consultation with a triathlon coach working with a number of the athletes in the current study.

Recovery Interventions

Following the cycling interval session, participants undertook one of the two recovery conditions;

i) Control/passive recovery (CON) – participants remained seated in a temperature-controlled room (21 ± 1°C) for 30 minutes.
i) Intermittent sequential pneumatic compression (ISPC) – participants remained in a seated position with dynamic compression leggings (Recovery Boots, Recovery Pump, L.LC, USA) fitted to each leg, in a temperature-controlled room (21 ± 1°C). The ISPC device was set to a pressure of 80 mmHg with a deflation time of 30 seconds for a total duration of 30 minutes, as used previously (Northey et al. 2015). The ISPC device was fitted according to the manufacturers instructions and individuals were sized appropriately to ensure that the leggings covered from the toes to the inguinal crease of the upper leg. While not measured in the current study, unpublished observations from our laboratory suggest that the recovery boots have a typical error of ±9mmHg when measured using the validated Kikuhime pressure monitor (Brophy-Williams et al. 2014a).

During the recovery period, participants consumed a standardised recovery snack and volume of fluid that was kept the same for both trials. At 10, 20 and 30 minutes, participants were asked to rate their perceived recovery on the Total Quality Recovery scale (TQR). The TQR scale ranged from 6 (very, very poor recovery) to 20 (very, very good recovery) (Argus et al. 2013). Blood lactate concentration was measured at the start (1-minute post the cycle interval session) and at the end (at 30-minutes) of the recovery period via a capillary fingertip sample and was analyzed with a Lactate Pro 2 analyzer (Shiga, Japan).

5km run performance test (5kmTT)

Following the recovery period, participants performed a warm-up and a timed 5km run test (5kmTT) on a motorized treadmill (HP Cosmos, Cosmed, USA). A 5-minute self-paced warm-up prior to the 5kmTT was used, which was replicated for subsequent trials. During the 5kmTT, participants were blinded to their elapsed time and run speed/pace and no verbal encouragement was given by the researcher. Participants were to indicate to the researcher for the speed to increase or decrease at any stage of the test by saying 'faster' or 'slower'. Participants were also partially blinded to distance covered and were only told every 500m, with full access to their distance remaining in the final kilometer. Total time was recorded at the completion of the 5kmTT and used as the main performance outcome measure. The reliability of the 5kmTT has been previously determined in a similar population in our laboratory, with a typical error of 10.9 seconds and coefficient of variation of 1.0% (unpublished observations).

Statistical Analysis

Simple group statistics are shown as means ± between-subject standard deviations. A Microsoft Excel spreadsheet was used to estimate the mean effects and 90% confidence intervals of the intervention, when a value for the smallest worthwhile change was entered and provided the likelihood of true effects being practically positive/trivial/negative when comparing the ISPC to CON (Hopkins 2006). As identified in our laboratory, the smallest worthwhile change for the 5kmTT was deemed to be 10.9 seconds (1.0%). Excluding TQR, data were log-transformed to reduce non-uniformity of error and presented as percentage changes (Hopkins 2006). Magnitudes of the standardized effects were also calculated using Cohen's *d* and interpreted using thresholds of 0.2, 0.6, 1.2 and > 2.0 for *small, moderate, large* and *very large*, respectively (Batterham and Hopkins 2006). An effect size of 0.2 was considered the smallest worthwhile positive effect with an effect size of <0.2 considered to be *trivial*. The effect was deemed *unclear* if its confidence interval overlapped the thresholds for small positive and negative effects. T-tests were used to compare trials and statistical significance was set at $P \leq 0.05$.

Results

There were no significant differences between recovery interventions (ISPC and CON) on 5kmTT time ($P = .30$). The 5kmTT time between the ISPC trial and the CON trial showed an average difference of 8.2 ± 23.7 seconds (1,190 ± 94.9 and 1,198 ± 101.9, respectively—Table 1). This difference was associated with a *trivial* effect size of 0.07 and a 28%/71%/1% practical likelihood of ISPC producing a positive, trivial and negative effect, respectively, compared to CON (Table 1).

TQR resulted in an *unclear* effect between the CON trials and the ISPC trials. The magnitude based inference for TQR showed a 68%/25%/7% likelihood that ISPC was positive, trivial and negative compared to CON (Table 1).

There was a *small* but not statistically significant difference in the pre- to post- recovery blood lactate concentration between ISPC and CON (-5.2 ± 1.9 and -

Table 1. Mean (± SD) values for the measured variables in the two trials (CON and ISPC), including the difference between trials (% ±90% confidence limits), Effect Size, P-values and the practical likelihoods of ISPC being positive/trivial/negative when compared to CON.

	CON	ISPC	ISPC - CON (% ±90% Confidence Limits and Effect Size)	P-Value	Likelihood (%) of ISPC being positive/trivial/negative (Compared to CON)
5kmTT (secs)	1198 ± 101.9	1190 ± 94.9	-0.6 ±1.3 ES = -0.07 *Trivial*	0.30	28 / 71 / 1
Δ Total Quality Recovery (pre to post recovery)	1.1 ± 0.9	1.7 ± 1.7	0.6 ±1.0* ES = 0.37 *Unclear*	0.31	68 / 25 / 7
Δ Blood lactate# (pre to post recovery)	-4.4 ± 1.9	-5.2 ± 1.9	-16.3 ±20.5 ES = -0.43 *Small*	0.13	94 / 1 / 5

*Total Quality Recovery is expressed as raw difference (90% ±CL) rather than % difference between ISPC and CON.

Change in blood lactate concentration (mmol.L-1) from post cycle to the end of the 30-minute recovery period.

4.4 ± 1.9 mmol.L^{-1}, respectively, ES: -0.43, P = 0.13). There was also a trend toward ISPC being effective for blood lactate clearance with a 94%/1%/5% likelihood that it was positive, trivial and negative compared to CON.

Discussion

The findings in the current study suggest that relative to the control trial, the use of dynamic compression in an exercise-recovery setting provides little additional benefit. While 5km run time was on average 8.2 seconds faster in the ISPC trial, these results were not statistically significant and resulted in a *trivial* effect size. Indeed, this difference was within the aforementioned smallest worthwhile change for 5km run performance. Blood lactate removal/clearance and perceived recovery also yielded statistically insignificant results for ISPC. The ability to alter the application of ISPC in terms of the protocols used and the mode of exercise from which fatigue has been caused, does not preclude further scope for their use in an athletic environment and warrants further research.

The results of the current study offer little support to two previous studies reporting positive effects from the use of similar dynamic compression devices as a recovery tool for performance (Wiener et al. 2001; Zelikovski et al. 1993) and instead, are consistent with the overall findings of the Northey et al. (2015) study. Zelikovski et al. (1993), showed a significant improvement in a time to exhaustion test on a cycle ergometer following the use of an ISPC device when compared to passive recovery. These improvements in cycling performance did not translate to any differences between groups for the blood measures taken during recovery (blood lactate, pH, bicarbonate and ammonia). The second study by Wiener et al. (2001) reported an increase in mean power frequency of the tibialis anterior muscle following the use of ISPC. Where the current study and the two mentioned papers differ, and a consistency between the current study and the Northey et al. study, is the training status of the individuals that participated. Wiener et al. (2001) and Zelikovski et al. both used untrained, healthy males as participants. Similar to Northey et al., the current study used well-trained athletes. Indeed, it has been shown that trained athletes have faster recovery rates between exercise bouts than their lesser-trained counterparts. It is probable that the interval cycling stimulus implemented in the current study did not provide sufficient fatigue to the participants. A greater degree of fatigue may have allowed a greater scope for the recovery strategies to show an improved recovery profile compared to the control condition. However, the authors would like to acknowledge that the nature of this study reflects the real-world application of such a recovery intervention and a protocol that would likely mimic the training of triathletes. Therefore, while numerous other studies investigate the efficacy of recovery strategies by inflicting and ensuring a maximal level of fatigue, this approach is not often realistic and rarely experienced by athletes in their daily training environment and thereby does not have high levels of ecological validity.

It has been suggested that the use of ISPC acts to increase venous blood flow and venous return (Morris and Woodcock 2002). While it is yet to be seen in an athletic setting, findings in the clinical field would suggest that ISPC can not only increase blood-flow but also aid in the removal of lymph fluid (Zelikovski et al. 1982; Zelikovski et al. 1986). Due to the milking effect, ISPC is thought to accelerate the removal of metabolites from the muscles and therefore improve the performance of a subsequent exercise bout. As a relatively crude measure of metabolite clearance, we evaluated changes in blood lactate concentration during the recovery period of the current study. The results showed a *small* (ES - 0.43) change in the blood lactate concentration after the use of ISPC as the recovery intervention when compared to the CON trial. The change in blood lactate concentration during the recovery period in the current study is similar to that of Driller & Halson (2013), who demonstrated a *moderate*

(-26.1 ± 17.9%) effect for change in blood lactate concentration in favour of a compression garment trial compared to a control trial between two cycling bouts. The authors of this previous study concluded that the benefit to blood lactate clearance may be attributed in part to the improved performance in the second exercise bout when wearing compression garments for one hour during recovery (Driller and Halson 2013a). In contrast to the Driller and Halson study, the current study did not find that the improved clearance of blood lactate following ISPC translated to performance improvements.

The findings of the current study in regards to the perception of total quality recovery show *unclear* (ES-0.37) results, however, there was a trend towards a positive effect of the ISPC, with a 68% likelihood that it was beneficial when compared to CON. The study by Sands et al. also showed altered perceptions of recovery following the use of a similar ISPC device for 15 minutes post-training in 24 elite athlete (Sands et al. 2015). Similar to many studies in the literature examining the use of recovery strategies between exercise bouts, a limitation of the current study is that it did not attempt to control for the placebo effect. Indeed, strategies such as ISPC can be difficult to design a placebo condition for. Therefore, when there are any differences in performance, albeit trivial, the placebo effect cannot be discounted. It is recommended that future research would consider introducing a placebo condition to the study design.

Practical applications

Despite anecdotal support from athletes for the benefits of intermittent, sequential, pneumatic compression on performance recovery, the current study indicates that this strategy was not able to expedite the physical or perceptual recovery between exercise bouts any further than passive rest following a bout of high-intensity interval cycling. It is proposed that the protocol used in the current study may not have caused enough fatigue to warrant any type of recovery strategy and therefore, observe any benefit. Given this is the first study to evaluate ISPC in a between-bout protocol in well-trained endurance athletes, further research is warranted to confirm these findings.

Acknowledgment

The authors would like to thank each of the subjects for their participation. No funding was provided which contributed to the development of this manuscript.

References

1. Argus C, Driller M, Ebert T, Martin D, Halson S (2013) The effects of 4 different recovery strategies on repeat sprint-cycling performance. International Journal of Sports Physiology and Performance 8: 542-548
2. Batterham A, Hopkins W (2006) Making meaningful inferences about magnitudes. International Journal of Sports Physiology and Performance 1: 50-57
3. Brophy-Williams N, Driller M, Halson S, Fell J, Shing C (2014a) Evaluating the Kikuhime pressure monitor for use with sports compression clothing. Sports Engineering 17: 55-60
4. Brophy-Williams N, Gliemann L, Fell J, Shing C, Driller M, Halson S, Askew C (2014b) Haemodynamic changes induced by sports compression garments and changes in posture. Proceedings of the 19th Annual Congress of the European College of Sport Science. European College of Sport Science
5. Coffey V, Leveritt M, Gill N (2004) Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables. Journal of Science and Medicine in Sport 7: 1-10
6. Davies V, Thompson K, Cooper S (2009) The effects of compression garments on recovery. Journal of Strength and Conditioning Research 23: 1786-1794
7. Driller M, Halson S (2013a) The effects of lower-body compression garments on recovery between exercise bouts in highly-trained cyclists. J Sci Cycling 2
8. Driller M, Halson S (2013b) The effects of wearing lower body compression garments during a cycling performance test. International Journal of Sports Physiology and Performance 8: 300-306
9. Halson S (2013) Recovery techniques for athletes. Sports Science Exchange 26: 1-6
10. Hopkins W (2006) Analysis of a post-only crossover trial (Excel spreadsheet). newstats org/PostOnlyCrossover xls
11. Ingram J, Dawson B, Goodman C, Wallman K, Beilby J (2009) Effect of water immersion methods on post exercise recovery from simulated team sport exercise. Journal of Science and Medicine in Sport 12: 417-421
12. MacRae BA, Cotter JD, Laing RM (2011) Compression garments and exercise: garment considerations, physiology and performance. Sports Med 41: 815-843
13. Marqués-Jiménez D, Calleja-González J, Arratibel I, Delextrat A, Terrados N (2016) Are compression garments effective for the recovery of exercise-induced muscle damage? A systematic review with meta-analysis. Physiology & behavior 153: 133-148
14. Montgomery P, Pyne D, Hopkins W, Dorman J, Cook K, Minahan C (2008) The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. Journal of Sports Sciences 26: 1135-1145
15. Morris R, Woodcock J (2002) Effects of supine intermittent compression on arterial inflow to the lower limb. American Medical Association 137: 1269-1273
16. Northey JM, Rattray B, Argus CK, Etxebarria N, Driller MW (2015) Vascular occlusion and sequential compression for recovery post resistance exercise. J Strength Cond Res In Press
17. O'Toole M, Douglas P (1995) Applied physiology of triathlon. Sports Medicine 19: 251-267
18. Sands W, McNeal J, Murray S, Stone M (2015) Dynamic compression enhances pressure-to-pain threshold in elite athlete recovery: exploratory study. Journal of Strength and Conditioning Research In Press
19. Wiener A, Mizrahi J, Verbitsky O (2001) Enhancement of tibialis anterior recovery by intermittent sequential pneumatic compression of the legs. Basic and Applied Myology 11: 87-90
20. Zelikovski A, Deutsch A, Reiss R (1982) The sequenital pneumatic compression device in surgery for lymphedema of the limbs. The Journal of Cardiovascular Surgery 24: 122-126
21. Zelikovski A, Haddad M, Reiss R (1986) Non-operative therapy combined with limited surgery in management of peripheral lymphedema. Lymphology 19: 106-108
22. Zelikovski A, Kaye C, Fink G, Spitzer S, Shapirot Y (1993) The effects of the modified intermittent sequential pneumatic device (MISPD) on exercise performance following an exhaustive exercise bout. British Journal of Sports Medicine 27: 255-259