# The effects of compression garment pressure on recovery from strenuous exercise

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## ABSTRACT

Compression garments are frequently used to facilitate recovery from strenuous exercise. **Purpose:** To identify the effects of two different grades of compression garment on recovery indices following strenuous exercise. **Methods:** Forty five recreationally active participants (n=26 males and n=19 females) completed an eccentric exercise protocol consisting of 100 drop jumps. Following the exercise protocol participants were matched for body mass and randomly but equally assigned to either a high (HI) compression pressure group, a low (LOW) compression pressure group, or a sham ultrasound group (SHAM). Participants in the high (HI) and low (LOW) compression groups wore the garments for 72 h post-exercise; participants in the SHAM group received a single treatment of 10 minutes sham ultrasound. Measures of perceived muscle soreness, maximal voluntary contraction (MVC), counter movement jump height (CMJ), creatine kinase (CK), C-reactive protein (CRP) and myoglobin (Mb) were assessed before the exercise protocol and again at 1, 24, 48 and 72 h post exercise. Data were analysed using a repeated measures ANOVA. **Results:** Recovery of MVC and CMJ was significantly improved with the HI compression garment ($p < 0.05$). A significant time by treatment interaction was also observed for jump height at 24 h post exercise ($p < 0.05$). No significant differences were observed for parameters of soreness and plasma CK, CRP and Mb. **Conclusions:** The findings of this study indicate that the pressures exerted by a compression garment affect recovery following exercise-induced muscle damage (EIMD), with a higher pressure improving recovery of muscle function.



**Key Words:** Sport, external pressure, stockings, muscle function, muscle damage

## INTRODUCTION

Exercise that is unaccustomed or unfamiliar in nature can lead to the experience of exercise-induced muscle damage (EIMD) (1,2). Symptoms associated with EIMD include decreased force production, decreased range of motion (ROM) and the experience of muscle soreness, all of which can negatively affect performance (3). Consequently, there is a growing interest in strategies that can minimise the experience of EIMD and accelerate recovery.

Compression garments are often used to aid recovery following strenuous exercise. The use of compression originates from clinical settings where limb compression is used to treat a range of inflammatory conditions including lymphedema (4), deep vein thrombosis (5) and chronic venous insufficiency (6). Research investigating the use of compression as a recovery modality in an athletic setting remains equivocal, with some research indicating favourable effects (7-10) and other research reporting no benefits (11-12). Whilst the exact mechanism for the benefit of compression garments remains unclear it is thought that application of compression can positively affect haemodynamics and attenuates swelling by facilitating lymphatic drainage and reducing the increase in osmotic pressure experienced as a result of tissue damage (13). In addition, compression is thought to provide mechanical support to the injured limb which may in turn prevent force decrements (13).

One methodological disparity between studies is the level of compression exerted by the garment. It is likely that the effects of a compression garment depend on the amount of compression applied (14), however if the degree of compression exerted by the garment is insufficient or too high, a beneficial effect is unlikely (15-16). Low levels of compression may be insufficient to modulate blood flow or osmotic pressure, and levels of compression that are too high may have a restrictive effect on blood flow. Optimal levels of compression beneficial to performance and recovery have yet to be determined, with current recommendations based upon clinical guidelines (17). However, pressures that are effective in a clinical population may not be effective in an athletic population.

Improved venous return has been observed at pressures of 20-25 mmHg at the calf and thigh respectively, with the authors of this study proposing pressures of 15.2-17.3 mmHg as the minimum required in order to achieve elevations in venous return (18). However it should be noted that these minimum pressures are estimations, calculated by assessing the cardiac output response to three different levels of compression garments (10-8, 15-12 and 20-16 mmHg at the calf and thigh respectively). Sperlich et al. (19) investigated the effects of knee-high socks that applied compression pressures of 0, 10, 20, 20 and 40 mmHg and observed no effect at any pressure on cardio-respiratory and metabolic parameters during submaximal running. In contrast to this, another study indicated that compression garments exerting pressures of 20 and 40 mmHg may improve alpine skiing performance by enabling a deeper tuck position with attenuated perceived exertion; however the authors indicated that the garment exerting 40 mmHg may reduce blood flow (20).

A variety of compression pressures have been used in current research ranging from 10-12 mmHg (21) up to 40 mmHg (19). A major limitation with current research investigating the efficacy of compression is that a large number of studies have failed to measure exact interface pressures applied by the garments (4, 22-25). Previous research has highlighted large variations in the degree of pressure exerted by compression garments across a population, with a number of individuals receiving low levels of compression (26). This variation is likely due to differences in limb size and tissue structure within a particular size category of garment (22). Thus it is possible the degree of compression exerted was insufficient to enhance recovery in several studies that have observed no benefit (2). Knowledge of the pressures applied by compression garments is fundamental to developing understanding on how a garment affects parameters of performance and recovery. Without knowledge on the precise pressures applied in research studies we cannot accurately interpret or compare findings (15). Therefore the aim of this investigation was to assess whether garments exerting a higher degree of pressure are more effective in facilitating recovery compared to garments exerting a lower pressure.

## METHODOLOGY

### Participants

Forty five recreationally active participants from any sport or training background (n=26 male, n=19 female) volunteered to participate in this study. Following ethical approval all participants completed a health screening questionnaire and gave written informed consent. Individuals with a history of musculoskeletal injury and inflammatory disorders were excluded from participating in this study. All participants were asked to arrive at the laboratory in a rested state and refrain from heavy exercise in the 48 h preceding the study and for 72 h following the muscle damaging protocol; in addition, participants were required to refrain from using any recovery strategy for the duration of the investigation. Participant characteristics are presented in table 1.

### Experimental overview

Participants were matched for weight and randomly, but equally assigned, to either a low (LOW, n=15), or high (HI, n=15) compression treatment group, or a sham-ultrasound group (SHAM, n=15). Participants reported to the laboratory for familiarisation and baseline testing 1 h prior to the muscle damaging protocol. During the familiarisation participants were given a full verbal explanation of how each variable was to be measured and were required to undertake practice attempts of the muscle function tests until performance in each of the tests reached a plateau. Following the familiarisation participants sat with their feet up for 20minutes before the collection of baseline data commenced. Base line data was collected for the dependent variables creatine kinase (CK), high sensitivity C-reactive protein (CRP), myoglobin (Mb), global lower limb muscle soreness and quadriceps soreness, counter movement jump (CMJ), and maximum voluntary contraction (MVC) of the knee extensors. These variables were analysed again 1, 24, 48 and 72 h post muscle damaging protocol. Participants were required to attend the laboratory for post testing at the same time of day and variables were always collected in the same order.

### Muscle damage procedure

The muscle damaging protocol consisted of 100 drop jumps from a 0.6 m platform. Participants performed 5 sets of 20 drop jumps, with 10 seconds between each jump and a 2 minute rest period between sets. Participants were instructed to jump maximally upon landing each jump.

### Treatment groups

Participants in the LOW compression group were fitted with a full length, lower limb, commercially available compression garment (MA1551b men's compression tights, 2XU, or WA1552b women's compression tights, 2XU, Melbourne, Australia) fitted according to manufacturer's guidelines based upon participants' height and weight. Pressure exerted by the compression garment was measured using a pressure-measuring device (Kikuhime, TT Medi Trade, Søleddet, Denmark), validated for use in this setting (6). Pressure was measured at the front thigh at the mid-point between the superior aspect of the patella and the inguinal crease and at the medial aspect of the calf at the site of maximal girth. Measurements were taken at each site whilst the subject was standing in the anatomical position. Measurements were repeated three times with the mean value recorded. Average pressures exerted by the garments were reported as 8.1 ± 1.3 mmHg at the thigh and 14.8 ± 2.1 mmHg at the calf.

Participants in the HI compression group wore a full length lower limb clinical medical grade II compression garment (Alleviant clinical class II medical stockings, Jobskin, Nottingham, UK) fitted according to manufacturer's guidelines based upon leg circumference measured at 7 locations on the leg. These garments exerted an average pressure of 14.8 ± 2.2 mmHg at the thigh and 24.3 ± 3.7 mmHg at the calf. All garments were worn for 72 h post exercise, participants were only allowed to remove them to shower. Participants were each given two pairs of the same garments to allow rotation when washing.

Participants in SHAM received 10 min of sham ultrasound comprised of 5 minutes each thigh (Combined therapy ultrasound/inferential, Shrewsbury Medical, Shropshire, UK). A water soluble ultrasound gel (Aquasonic 100 ultrasound transmission gel, Parker Laboratries, Fairfield, USA) was applied to the thigh, using the ultrasound head the gel was spread across the skin using circular movements. Throughout the duration of the ultrasound treatment the unit was turned off and obscured from view of the participants. All treatments were applied immediately following the muscle damaging protocol.

**Dependent variables**

**Muscle soreness**: Global lower limb muscle soreness and localised soreness in the quadriceps muscle group was analysed using a 200 mm visual analogue scale (VAS) with 'no pain' at 0 mm and 'unbearable pain' at 200 mm. Participants stood with their feet shoulder width apart with hands on hips and were asked to perform a squat to 90°, return to standing and mark their subjective feelings of pain on the scale.

**Muscle function:** Maximal voluntary contraction was assessed using a strain gauge (MIE Medical Research Ltd., Leeds, UK). Participants were seated on a platform in a standardised position, with their hip and knee joints flexed at 90°. The strain gauge was attached 2 cm above the malleoli of the left ankle and participants were required to maximally extend the knee against the device for 3 s, verbal encouragement was given for the duration. Participants performed three repetitions, each separated by 1 min, with the greatest value recorded as MVC. Measurements were recorded in newtons.

Counter movement jump height was assessed using a force plate (Kistler 9287BA force platform, Kistler Instruments Ltd, Hamshire, UK). Participants were instructed to stand with their hands on their hips and perform a maximal jump on command. Participants performed three jumps the best of which was taken for analysis. Data from 5 participants (n=2 LOW, n=1 HI and N=2 SHAM) were not included in the jump data analysis due to technical issues with the equipment.

**Blood measures:** CK, high sensitivity CRP, and Mb were analysed from plasma blood samples. Approximately 8.5 mL of blood was collected from the antecubital vein into lithium heparin vacutainers. Following collection, the sample was immediately placed in a refrigerated centrifuge and spun at 3500 rpm, a relative centrifugal force of 3000 g, for 20 minutes at 4°C to enable the separation of plasma. The plasma was immediately frozen at -80°C for later analysis. Plasma CK and CRP Mb were measured using an automated analyser (Advia 2400, Chemistry System, Siemens Health Care Diagnostics, USA). Manufacturer's report an intra-sample CV for the analyser of <3% at high and low concentrations and expected baseline sample ranges of 32-294 $IU.L^{-1}$ and < 3 $pg.mL^{-1}$ for CK and CRP, respectively. Plasma Mb was analysed using an electrochemiluminescence immuno assay (ECLIA) (Elecsys 2010, Roche Diagnostics GmbH, Germany). Manufacturer's report an intra-sample CV for the analyser of <4% and expected values of 25-72$ng.ml^{-1}$.

**Statistical Analysis**

All data analyses was carried out using SPSS for Windows version 21, and values are reported as mean ± SD. Independent samples t-tests were used to identify any differences in group characteristics at baseline. All dependent variables were assessed using a treatment by time repeated measures analysis of variance (ANOVA). Where a significant effect was observed, interaction effects were further examined using a Bonferroni *post hoc* analysis. A significance level of $p \leq 0.05$ was applied throughout. Effect sizes, using Cohen's *d*, and 90% confidence intervals (CI) were calculated to assess magnitude of effect on the change from baseline at 1, 24, 48 and 72 h post exercise. Threshold values were set at 0.2, small; 0.5, moderate; and 0.8, large.

# RESULTS

Effect sizes and 90% CI comparing change from baseline with 1, 24, 48 and 72 h post exercise can be seen for each variable in table 2. A significant time effect was observed for global lower limb muscle soreness ($F_{2.639,1}$=31.509, $p < 0.001$) and soreness of the quadriceps ($F_{2.988,1}$=45.865, $p < 0.001$) indicating that there was a change in muscle soreness over time. Further post hoc Bonferroni tests indicated significant differences from baseline occurred at all time points in both global and quadriceps soreness ($p < 0.05$). No significant group ($F_{2, 42}$ =1.081, $p = 0.325$) or interaction effects ($F_{5.278,2=}$0.861, $p = 0.515$) were observed for global lower limb soreness. This was consistent with the group ($F_{2,42}$=0.972, $p = 0.387$) and interaction effects observed for quadriceps soreness ($F_{5.976, 2}$ =0.855, $p = 0.530$) (Figures 1a and 1b).

Significant time effects were observed for MVC ($F_{3.084, 1}$=49.760, $p < 0.001$), Bonferroni post hoc tests indicated that a significant difference from baseline occurred at all time points ($p <$ 0.05). Values reduced to 81.6 ± 9.0, 84.3 ± 6.3 and 81.4 ± 9.2 % of baseline 1 h after the damaging protocol and returning to 90.6 ± 11.6, 99.9 ± 9.9 and 91.2 ± 9.7% of baseline at 72 h post in the LOW, HI and SHAM groups respectively. A significant treatment effect was observed for MVC ($F_{2,42}$ = 3.832, $p = 0.030$), however there was no significant time by treatment interaction ($F_{6.169,2}$ = 1.824, $p = 0.097$). Further post hoc analysis indicated the significant difference occurred between the HI and SHAM groups ($p = 0.036$) (figure 2).

Significant time effects were observed for Jump height ($F_{4,1}$ = 11.202, $p < 0.001$), further post hoc analysis indicated that significant differences from baseline occurred at all time points ($p$ < 0.05) figure 3. A significant time by treatment effect ($F_{8,2}$ = 2.99, $p$ = 0.004) and a significant treatment effect ($F_{2,37}$ = 3.741, $p = 0.33$) was observed for jump height. Further, post hoc analysis indicated the significant treatment effect occurred between the HI and LOW compression groups ($p = 0.032$) and the time by treatment interaction occurred at 24 h post exercise between the HI and LOW compression groups ($p = 0.002$) (figure 3).

Whilst an overall significant time effect was observed for CK ($F_{2.353,1}$ = 2.980, $p$ = 0.021), further post hoc analysis failed to indicate a significant effect at any time point ($p$ > 0.05). Post exercise plasma CK values were elevated 1 h post exercise in all experimental groups and remained raised for the duration of the study. No significant group ($F_{2,42}$ = 0.174, $p$ = 0.841) or interaction effects were observed for CK ($F_{4.706,2}$ = 1.383, $p$ = 0.240), data is presented in table 3.

There was no significant time effect ($F_{4,1}$ = 0.615, $p$ = 0.570), group effect ($F_{2,11}$ = 0.511, $p$ = 0.558) or time by group effect ($F_{8,2}$ = 0.217, $p$ = 0.858) for CRP. This was also consistent with Mb where there was also no significant time ($F_{4,1}$ = 1.915, $p$ = 0.110), group ($F_{2,11}$ = 0.387, $p$ = 0.681) or time by group effect ($F_{8,2}$ = 1.016, $p$ = 0.462) (table 3).

## DISCUSSION

The aim of this study was to investigate the effects of different compression pressures on indices of recovery following EIMD in a recreationally active population. The main finding was that a garment exerting higher levels of compression is more effective in modulating muscle function following exercise that induces muscle damage when compared to a garment exerting lower levels of compression and a sham treatment group.

In this study muscle function decreased following the damaging protocol, this was evidenced by a significant time effect for both MVC and jump height ($p<0.05$). Recovery of strength was greatest in the HI compression group with participants recovering to 99.9 ± 9.9% of baseline MVC values at 72 h post exercise compared to 90.6 ± 11.6 and 91.2 ± 9.7% in the LOW and SHAM group. A significant difference between treatment groups was observed for MVC with the difference occurring between the HI compression group and the SHAM group This observation is supported by the large effect sizes observed between the HI and SHAM group between 24 – 72 h post exercise and the moderate to large effect sizes observed between the LOW and HI group at the same time points. These observations suggest that strength recovered at an accelerated rate over 72 h in the HI compression group.

Additionally Jump height was significantly higher 24 h post exercise in the HI group compared to the LOW group, indicating that compression garments exerting higher levels of compression may be beneficial in improving recovery of muscle function. The failure to observe a significant treatment effect between the HI and SHAM group was unexpected, however a large effect size was seen at 24h post exercise. Although this study attempted to control for a placebo effect by using sham ultrasound, it is possible that the observation of improved recovery in the HI group may be linked to the participant's belief that tighter compression garments have a positive response on recovery; this is a limitation of the study.

Improved recovery of muscle function has been observed in previous research (9,13,27), and has been attributed to an enhanced repair of the contractile elements of the muscle (13). Furthermore the application of compression may provide mechanical support to the limb resulting in reduced movement of the tissues and offering 'dynamic immobilisation', whilst still enabling use of the limb, this has been proposed to increase motor unit activation during tissue injury (13, 28). However, the exact mechanism responsible for this is unclear. Several studies have failed to observe improved muscle function with the use of a compression garment (11,21-22). However as the exact level of compression exerted by the garments was not measured in these studies it is possible the garments used did not exert enough pressure to be of benefit.

No significant between group differences were observed for global lower limb soreness and soreness in the quadriceps, this is similar to previous findings (11-12,21). However, moderate effect sizes were observed at 48 h post exercise between the HI and SHAM group for global muscle soreness and at 24 h post exercise between the LOW and HI group for quadriceps muscle soreness, indicating soreness was lower in the HI group.

The experience of DOMS arises as a result of damage to the soft tissue leading to an inflammatory response which causes localised oedema in the affected limb. The presence of oedema can stimulate pain afferents bringing about the experience of soreness (28). The application of compression may reduce the level of oedema by attenuating the magnitude of the inflammatory response thus reducing the severity of the soreness experienced (21,27). Whilst a large body of research has observed reductions in perceived muscle soreness with the use of compression garments (13,24,27), these studies failed to control for placebo effect, this needs to be considered when interpreting findings.

Creatine kinase and Mb are released from the muscle during the experience of muscle damage and as such are frequently used as markers of EIMD (21-22). Given the absence of a significant time effect for Mb and a non-significant post hoc results for the time effect in CK it is likely that the muscle damage protocol in this study did not cause sufficient enough muscle damage for a large CK and Mb response. Previous investigations have observed reductions in concentrations of CK with the application of compression (2,22). It is worth noting the peak concentrations of CK observed within the control group of this study (586 $IU.L^{-1}$), is much smaller than the values observed in other studies (2194 $IU.L^{-1}$(7) and ~1750 $IU.L^{-1}$ (13)) all of whom found beneficial effects of compression. It is possible compression is not effective at modulating clearance of CK at lower concentrations.

A number of investigations have observed reduced inflammation with the use of a compression garment (9,13,21), however this study failed to observe any significant group differences for the inflammatory marker CRP. Furthermore no significant time effect was observed for this marker, it is possible that muscle damage was not severe enough to cause a large inflammatory response. Regardless of the magnitude of the inflammatory response it appears the exercise protocol was severe enough to cause pronounced performance decrements and elevations in muscle soreness.

## PRACTICAL APPLICATION

Whether compression garments exert sufficient pressure to be effective has been raised by a number of investigators (21-22). This study provides evidence for the importance of compression pressure in modulating parameters of recovery. The majority of previous research has failed to measure exact pressures exerted by compression garments, until the reporting of interface pressure occurs in research on compression it is difficult to identify optimal levels of compression necessary for improving recovery. More knowledge is needed on the effects of different compression pressures in order to assist practitioners in the selection of a garment for a particular role.

## CONCLUSIONS

In conclusion, a compression garment exerting higher compression pressures (14.8 ± 2.2 and 24.3 ± 3.7 mmHg at the thigh and calf respectively) is more effective at improving muscle function than a compression garment exerting lower pressures (8.1 ± 1.3 mmHg at the thigh and 14.8 ± 2.1 mmHg at the calf) and a SHAM treatment group. Furthermore, no treatment group was superior in aiding the removal of plasma markers of muscle damage or inflammation. The degree of pressure exerted by the garment is an important factor in determining the efficacy of compression garments in recovery. These findings highlight the importance of wearing a correctly fitting garment when using compression as a recovery modality.

## REFERENCES


1. Armstrong RB. Initial events in exercise-induced muscular injury. *Med Sci Sports Exerc* 1990; *22*:429–435.
2. Brophy-Williams N, Driller MW, Shing S, et al. Confounding compression: the effects of posture, sizing and garment type on measured interface pressure in sports compression clothing. *J Sport Sci* 2015;33:1403-1410.
3. Fridén J, Lieber RL. Eccentric exercise-induced injuries to contractile and cytoskeletal muscle fibre components. *Acta Physiol Scand* 2001;171:321–326.
4. Brennan MJ, Miller LT. Overview of treatment options and review of the current role and use of compression garments, intermittent pumps, and exercise in the management of lymphedema. *Cancer* 1998;83:2821–2827
5. Byrne B. Deep vein thrombosis prophylaxis: The effectiveness and implications of using below-knee or thigh-length graduated compression stockings. *Heart Lung* 2001;30: 277–284.
6. Agu O, Baker D, Seifalian AM. Effect of graduated compression stockings on limb oxygenation and venous function during exercise in patients with venous insufficiency. *Vascular* 2004;12:69–76.
7. Gill N, Beaven CM, Cook C. Effectiveness of post-match recovery strategies in rugby players. *Brit J Sport Med* 2006;40:260–263.
8. Hill JA, Howatson G, Van Someren K, et al. Compression garments and recovery from exercise-induced muscle damage: a meta-analysis. *Brit J Sport Med* 2013;48:1340-1346.
9. Kraemer WJ, Flanagan SD, Comstock BA, et al. Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. *J Strength Cond Res* 2010;24:804–814.
10. Hill J, Howatson G, van Someren K, et al. The influence of compression garments on recovery following Marathon running. *J Strength and Cond Res* 2014;28:2228-2235.
11. Ali A, Creasy RH, Edge J. Physiological effects of wearing graduated compression stockings during running. *Eur J Appl Physiol* 2010;109:1017–1025.
12. Carling J, Francis K, Lorish C. The effects of continuous external compression on delayed-onset muscle soreness (DOMS). *Int J Rehabil Health* 1995;1:223–235.
13. Kraemer WJ, Bush JA, Wickham RB, et al. Continuous Compression as an Effective Therapeutic Intervention in Treating Eccentric- Exercise-Induced Muscle Soreness. *Journal Sport Rehabil* 2001;10:11–23.
14. Partsch H, Clark M, Bassez S, et al. Measurement of lower leg compression in vivo: Recommendations for the performance of measurements of interface pressure and stiffness. *Dermatol Surg* 2006;32:224–233.
15. Brophy-Williams N, Driller MW, Halson SL, et al. Evaluating the Kikuhime pressure monitor for use with sports compression clothing. *Sports Eng* 2014;17:55–60.
16. Lawrence D, Kakkar VV. (1980). Graduated, static, external compression of the lower limb: a physiological assessment. *Br J Surg* 1980;67:119–121

17. Dascombe BJ, Hoare TK, Sear JA, et al. The effects of wearing undersized lower-body compression garments on endurance running performance. *Int J Sports Physiol Perform* 2011;6:160–173.
18. Watanuki S, Murata H. Effects of wearing compression stockings on cardiovascular responses. *Ann Physiol Anthropol* 1994;13:121–127.
19. Sperlich B, Haegele M, Krüger M, et al. Cardio-respiratory and metabolic responses to different levels of compression during submaximal exercise. *Phlebology* 2011;26:102-106.
20. Sperlich B, Born D P, Swarén M, et al. Is leg compression beneficial for alpine skiers? *Sports Sci Med Rehabil* 2013;*5*(18): 1-12.
21. French DN, Thompson KG, Garland, SW, et al. The effects of contrast bathing and compression therapy on muscular performance. *Med Sci Sports Exerc* 2008;40:1297–1306.
22. Davies V, Thompson KG, Cooper SM. The effects of compression garments on recovery. *J Strength Cond Res* 2009;23:1786–1794
23. Bringard A, Perrey S, Belluye N. Aerobic energy cost and sensation responses during submaxmal running exercise – positive effects of wearing compression tights. *Int J Sports Med* 2006;27:373–378.
24. Duffield R, Edge J, Merrells R, et al. The effects of compression garments on intermittent exercise performance and recovery on consecutive days. *Int J Sports Physiol Perf* 2008;3:454–468.
25. Higgins T, Naughton GA, Burgess D. Effects of wearing compression garments on physiological and performance measures in a simulated game-specific circuit for netball. *J Sci Med Sport* 2009;12:223–226.
26. Hill JA, Howatson G, van Someren K, et al. The variation in pressures exerted by commercially available compression garments. *Sports Eng* 2015;18:115–121.
27. Jakeman JR, Byrne C, Eston RG. Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. *Eur J Appl Physiol* 2010;109:1137–1144.
28. Kraemer WJ, French DN, Spiering BA. Compression in the treatment of acute muscle injuries in sport: review article. *Int Sport Med J* 2004;5:200–208.

## FIGURE LEGENDS

**Figure 1.** Perceived ratings of global lower limb soreness (A) and quadriceps soreness (B) for the LOW, HI and SHAM treatment groups. Values are presented as mean ± SD. No significant differences were observed between treatment groups. ɫ denotes significant time effect compared to baseline.

**Figure 2.** Percentage change in MVC for the LOW, HI and SHAM treatment groups. The HI compression group was significantly different from the SHAM treatment group. Values are presented as mean ± SD, data was recorded in newtons and converted to a percentage change. * denotes a significant difference from the HI group. ɫ denotes significant time effect compared to baseline.

**Figure 3.** Percentage change in CMJ for the LOW, HI and SHAM treatment groups. The HI compression group was significantly different from the LOW compression group at 24 h post exercise. Values are presented as mean ± SD. * denotes a significant difference from HI group. ɫ denotes significant time effect compared to baseline. α denotes significant interaction between HI and LOW compression groups.

**Table 1**. Participant characteristics for the low compression pressure group (LOW), high compression pressure group (HI) and sham ultrasound treatment group (SHAM). Values are presented as mean ± SD.

**Table 2.** Effect sizes ± 90% CI of the application of treatment on markers of exercise-induced muscle damage.

**Table 3.** Plasma markers of CK, MB and CRP for the LOW, HI and SHAM treatment groups. No significant differences were observed between treatment groups. Values are presented as mean ± SD. * denotes significant time effect was observed.

**Table 1**. Participant characteristics for the low compression pressure group (LOW), high compression pressure group (HI) and sham ultrasound treatment group (SHAM). Values are presented as mean ± SD.

| | **Age (yrs)** | **Height (cm)** | **Weight (kg)** |
|---|---|---|---|
| **LOW** | 29.2±4.7 | 173.6±11.7 | 73.3±17 |
| **HI** | 32.7±7.8 | 175±7.4 | 71.7±7.2 |
| **SHAM** | 28.3±4.1 | 174.1±9.4 | 71.7±10.2 |

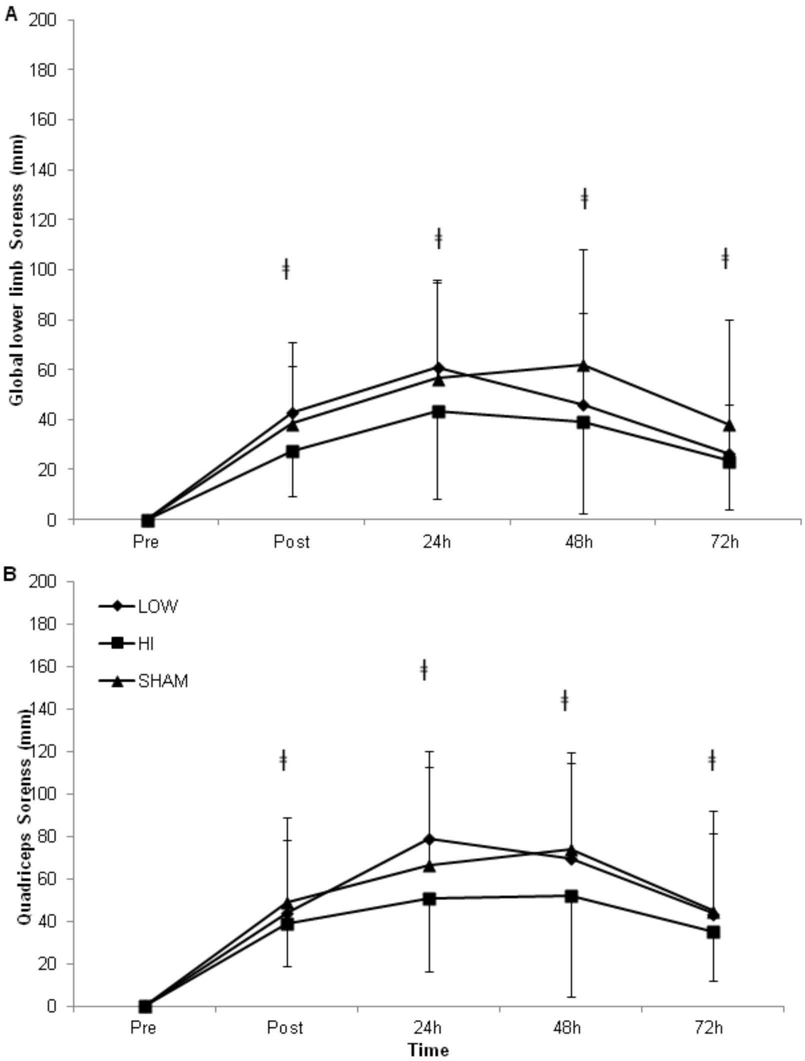
**Table 2.** Effect sizes ± 90% CI of the application of treatment on markers of exercise-induced muscle damage.

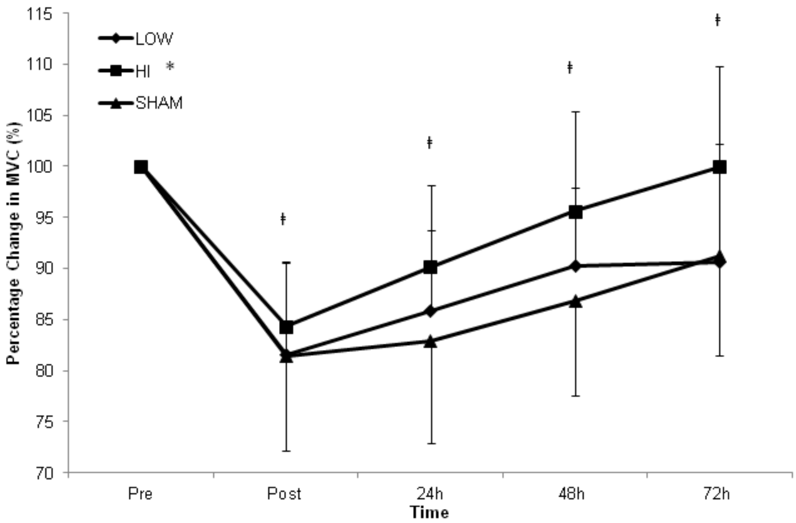
| | **Post** | **24 h** | **48 h** | **72 h** |
|---|---|---|---|---|
| **Change from baseline** | | | | |
| **Global soreness** | | | | |
| LOW v SHAM | -0.12±15.7 | -0.12±15.9 | 0.35±18.8[a] | 0.31±14.3[a] |
| HI v SHAM | 0.41±10.9[a] | 0.36±15.1[a] | 0.55±17.2[b] | 0.45±12.8[a] |
| LOW v HI | -0.47±13.6 [a] | -0.48±15.2[a] | -0.17±16.9 | -0.11±11.9 |
| **Quadriceps soreness** | | | | |
| LOW v SHAM | 0.14±15.2 | -0.28±18.0[a] | 0.09±18.6 | 0.03±16.3 |
| HI v SHAM | 0.32±13.0[a] | 0.39±16.7[a] | 0.47±19.2[a] | 0.26±15.6[a] |
| LOW v HI | -0.18±11.5 | -0.74±15.6[b] | -0.38±19.1[a] | -0.27±14.9[a] |
| **MVC** | | | | |
| LOW v SHAM | -0.02±3.8 | -0.33±3.7[a] | -0.40±3.5[a] | 0.06±4.4 |
| HI v SHAM | -0.36±3.3[a] | -0.80±3.7[c] | -0.92±3.9[c] | -0.88±4.0[c] |
| LOW v HI | 0.35±3.2[a] | 0.53±3.3[b] | 0.61±3.6[b] | 0.86±4.4[c] |
| **CMJ** | | | | |
| LOW v SHAM | 0.25±4.2[a] | 0.60±4.2[b] | 0.86±4.0[c] | 0.62±3.3[b] |
| HI v SHAM | 0.10±3.5 | -0.93±3.6[c] | -0.01±4.2 | -0.38±3.2[a] |
| LOW v HI | -0.17±4.0 | -1.30±4.5[c] | -0.99±3.4[c] | -1.09±3.0[c] |
| **CK** | | | | |
| LOW v SHAM | -0.46±173.7[a] | -0.51±99.0[b] | -0.18±64.8 | -0.79±75.0[b] |
| HI v SHAM | -0.73±85.4[b] | -0.27±119.2[a] | -0.14±125.4 | 0.12±153.6 |
| LOW v HI | -0.09±190.7 | -0.13±145.8 | 0.05±122.6 | 0.50±155.1[b] |
| **Mb** | | | | |
| LOW v SHAM | 0.22±75.7[a] | -0.47±96.0[a] | -0.03±113.2 | -0.73±93.1[b] |
| HI v SHAM | -0.08±92.6 | -0.26±111.2[a] | 0.01±140.6 | -0.64±108.5[b] |
| LOW v HI | 0.08±84.3 | -0.15±101.1 | -0.03±111.8 | 0.01±113.0 |
| **CRP** | | | | |
| LOW v SHAM | 0.06±0.5 | 0.23±0.5 | 0.14±0.5 | 0.10±0.5 |
| HI v SHAM | -0.13±0.5 | 0.36±0.5 | 0.11±0.4 | 0.02±0.5 |
| LOW v HI | 0.22±0.4 | -0.09±0.5 | 0.04±0.5 | 0.07±0.5 |

Mean effect refers to the first names group minus the second named group, [a] indicates a small effect size, [b] indicates a medium effect size, [c] indicates a large effect size.

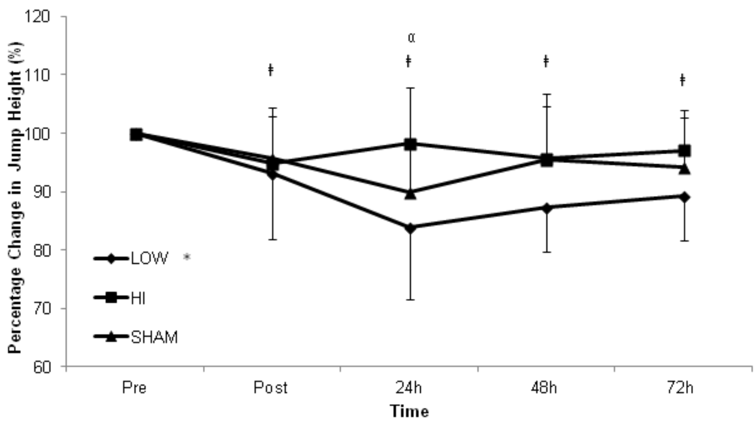
**Table 3.** Plasma markers of CK, MB and CRP for the LOW, HI and SHAM treatment groups. Values are presented as mean ± SD.

| | **Pre** | **Post** | **24 h** | **48 h** | **72 h** |
|---|---|---|---|---|---|
| **CK (IU.L$^{-1}$)** | | | | | |
| LOW | 184.3±152.3 | 418.9±722.3 | 368±440.7 | 280±259.8 | 168.5±82.5 |
| HI | 207.7±218.6 | 401.6±333.4 | 345.7±371.4 | 318.8±355.3 | 380.9±438.4 |
| SHAM | 217±298.5 | 258.2±332.9 | 277.3±326.4 | 284.9±355.4 | 345.1±579.7 |
| **Mb (ng.ml$^{-1}$)** | | | | | |
| LOW | 434.3±107.0 | 489.8±186.1 | 534.1±204.8 | 439.5±155.3 | 504.1±194.7 |
| HI | 458±182.2 | 571.5±155.7 | 519.7±145.7 | 454.8±261.9 | 566.7±159 |
| SHAM | 490.4±88.5 | 585.8±180 | 480±170.2 | 487.7±158.8 | 429.7±128.3 |
| **CRP (pg.mL$^{-1}$)** | | | | | |
| LOW | 2.5±0.7 | 2.3±0.8 | 2.4±1.0 | 2.2±1.0 | 2.3±0.9 |
| HI | 2.6±0.7 | 2.5±0.9 | 2.3±0.6 | 2.3±0.9 | 2.4±1.1 |
| SHAM | 2.3±0.5 | 2.2±0.8 | 2.5±0.9 | 2.1±1.0 | 2.3±1.0 |


A
Global lower limb Sorenss (mm)
200
180
160
140
120
100
80
60
40
20
0
‡
Pre
Post
24h
48h
72h
B
LOW
HI
SHAM
Quadriceps Sorenss (mm)
Time



LOW
HI *
SHAM
Percentage Change in MVC (%)
115
110
105
100
95
90
85
80
75
70
Pre
Post
24h
48h
72h
Time



Percentage Change in Jump Height (%)
120
110
100
90
80
70
60
α
‡
LOW *
HI
SHAM
Pre
Post
24h
48h
72h
Time