THE EFFECTS OF COMPRESSION GARMENTS ON RECOVERY

VANESSA DAVIES,[1] KEVIN G. THOMPSON,[2,3] AND STEPHEN-MARK COOPER[4]

[1]Sports Council for Wales, Cardiff, United Kingdom; [2]English Institute of Sport, Gateshead, United Kingdom; [3]Northumbria University, Newcastle, United Kingdom; and [4]Cardiff School of Sport, University of Wales Institute, Cardiff, Wales, United Kingdom

ABSTRACT

Davies, V, Thompson, KG, and Cooper, SM. The effect of compression garments on recovery. *J Strength Cond Res* 23(6): 1786–1794, 2009—The purpose of this study was to investigate whether wearing lower-body compression garments attenuate indices of muscle damage and decrements in performance following drop-jump training. Seven trained female and four trained male subjects undertook blood collection for creatine kinase (CK) and lactate dehydrogenase (LDH), a mid-thigh girth measurement, and reported their perceived muscle soreness (PMS). A series of performance tests were then completed including sprints (5 m, 10 m, and 20 m), a 5-0-5 agility test, and a countermovement jump test. In a randomized cross-over experimental design, separated by 1 week, subjects completed 5 × 20 maximal drop-jumps, followed immediately after exercise by either wearing graduated compression tights (CG) or undertook passive recovery as a control (CON) for 48 hours. CK, LDH, mid-thigh girth, and PMS were retested after 24 hours and 48 hours of recovery. The performance tests were repeated after 48 hours of recovery. Analysis of variance for repeated measures indicated that for female subjects, CK values were elevated after 24-hour recovery ($p = 0.020$) and a greater PMS was observed after 48-hour recovery in the CON condition ($p = 0.002$) but not for the CG condition. For all the subjects ($n = 11$), a greater PMS was observed after 48-hour recovery in the CON condition ($p = 0.001$) but not the CG condition. Significant increases in time were reported for 10-m ($p = 0.016, 0.004$) and 20-m sprints ($p = 0.004, 0.001$) in both the CON and CG conditions and for the 5-m sprint ($p = 0.014$) in the CG condition. All other parameters were unchanged in either condition. Data indicates that CK responses and PMS might be attenuated by wearing compression tights in some participants after drop-jump training; however, no benefit in performance was observed.

KEY WORDS muscle damage, creatine kinase, lactate dehydrogenase, performance

INTRODUCTION

Severe training or competitive exercise is likely to result in a reduction in subsequent exercise performance if inadequate recovery occurs. Soreness and a reduced range of motion are typical symptoms that impact on the functional capability of the athlete. It is widely believed that in order to maximize performance, these symptoms should subside before an athlete competes or exercises severely again. This might not be possible, however, due to competitions or training sessions being programmed too close together. Exercise with a high eccentric loading is particularly associated with disruption to myofibrillar material and cytoskeleton damage (18). Plyometric or eccentric leg pressing exercises have been found to reduce jumping power (30,31) possibly due to induced muscle damage adversely affecting the number of functioning motor units. Kraemer et al. (18) speculated that this mechanical shortfall could increase the tensile load per motor unit and potentially lead to further mechanical disruption of myofibrils with subsequent exercise, resulting in Z-band streaming and further disruption throughout the sarcomere.

Recently, scientists have begun to investigate a wide range of recovery modalities that have been promoted to enhance recovery by commercial manufacturers, coaches, and athletes. Recovery modalities include, among others, massage, active recovery, contrast bathing, hyperbaric oxygen therapy, cryotherapy, nonsteroidal anti-inflammatory drugs, stretching, electromyostimulation, and compression garments, or a combination of these modalities. Evidence as to whether they enhance between-training recovery is equivocal (2). Unfortunately, research has tended to be based on studies that used untrained participants who might be more likely to exhibit greater muscle soreness and muscle damage responses than would those drawn from trained populations.

Support for compression garments as a recovery medium has come from clinical settings where they are used extensively for the treatment of chronic inflammatory disorders. The rationale for applying compression is to create

Address correspondence to Vanessa Davies, vanessa.davies@scw.org.uk.

23(6)/1786–1794

Journal of Strength and Conditioning Research

an external pressure gradient that can theoretically reduce the space available for swelling, haemorrhage and haematoma formation as well as providing mechanical support. An example is lymphoedema (swelling in the limbs due to excess fluid that accumulates when lymph nodes are removed or damaged), which is characterized by many of the inflammatory processes found following acute exercise induced soft-tissue injury (18). Recently, compression stockings have also been implemented during air travel to help prevent deep vein thrombosis. Indeed, Belcaro et al. (3) and Scurr et al. (27) have demonstrated a marked reduction in venous thromboembolism in patients who wore below-the-knee elastic stockings during long flights.

Within the field of sports science, it has been suggested that compression garments might confer additional benefits in aiding an athlete's recovery following training and competition. One such benefit is an increase in venous return, from the compression of superficial veins and an improved capillary filtration resulting in a greater blood volume being shunted through deep veins (23). This increase in blood flow is hypothesised to aid the removal of waste products and allow blood gases to return to normal, thereby working on a similar principle to active recovery. Compression garments are also being used by conditioners to shorten the recovery period between competitive races or strenuous training periods and to allow more frequent bouts of heavy work to be completed due to an improved pre-exercise physical performance capacity (32).

To date, however, the limited research that has been published has produced conflicting results regarding the potential benefits of wearing compression garments during exercise and recovery (4,16). Studies that have reported responses within a few hours of prior exercise have shown equivocal results. Compression garments worn during and after exercise (30 minutes) in well-conditioned college participants (4) and after exercise in elderly participants (80 minutes) (6) have been found to attenuate blood lactate concentrations following 3–5 minutes of strenuous cycling exercise. In the latter study, however, participants also elevated their legs during the 80 minutes recovery period. Berry and McMurray (4) attributed the reduced lactate response to the muscular bed retaining lactate rather than a greater lactate removal as no plasma volume shifts were observed. Finally, Berry et al. (5) reported no differences when elastic tights were worn during exercise and recovery, during recovery alone or not at all, in terms of postexercise blood lactate, heart rate, or oxygen uptake responses. It is arguable, however, if these measurements are relevant as markers of between training recovery given that cardiorespiratory parameters and muscle and blood lactate concentrations would return to normal in most cases before the next training session would take place (>90 minutes later) and muscle and blood pH would recover even more quickly (2,28).

A few studies have investigated the effect of compression garments over a number of days postexercise, following resistance exercise-induced muscle damage. Chleboun et al. (7) observed that nonstrength trained women demonstrated attenuated increases in appendage circumference and stiffness following a one-off bout of eccentric elbow flexion, compared to a control condition, when they completed intermittent pneumatic compression therapy for 20 minutes each day for 5 days. This was most obvious on days 2 and 3 postexercise. These findings were supported by Kramer et al. (16) who found that nonstrength trained males who completed two sets of 50 repetitions with a maximal eccentric contraction every fourth repetition, then wore a compression sleeve for 5 days afterwards, demonstrated an attenuation of the creatine kinase response, loss of elbow extension, swelling, and perception of muscle soreness compared to a matched-pairs control group. These data coincided with a greater recovery of force production compared to the control condition. Finally, Trenell et al. (29) observed that following 30 minutes of downhill walking, a compression stocking worn on one of the legs (the other leg being the control) appeared to elevate skeletal muscle phosphodiester 1 hour after exercise. It was suggested that this potentially indicated an alteration of the repair processes which might allow for faster cellular repair. However, no differences in perceived muscle soreness, muscle pH, phosphomonoester, phosphocreatine, phosphate, or magnesium ions were detected between the compression and control conditions in the Trenell et al. (29) study.

Commercial promotion and anecdotal reports have led to lay acceptance and the widespread use of compression garments by athletes because they appear to be a cost-effective and safe way of attenuating strength loss, removing markers of muscle damage, and lowering subjective measures of discomfort (18). As there is some evidence from experimental research to support these assumptions, at least in untrained participants, we were interested in determining if such benefits might occur in chronically trained athletes. Consequently, we undertook a study to investigate whether wearing compression tights for 48 hours following plyometric exercise would lead to attenuation in the appearance of muscle damage markers and muscle soreness, and whether any decrement in sprinting and jumping performance would occur.

Methods

Experimental Approach to the Problem

In the present study, a crossover randomized experimental design was used. Subjects were required to undertake exercise trials 1 week apart, followed by a different recovery modality (compression tights or passive recovery). Biochemical, anthropometric, and performance changes were monitored pre-exercise and postrecovery.

Subjects

Subjects were members of a British university women's netball academy ($n = 7$, age $= 19.7 \pm 0.5$ years, stature $= 1.669 \pm 0.047$ m, body mass $= 66.7 \pm 8.9$ kg) and men's basketball team (n = 4, age = 26.3 ± 5.1 years, stature = 1.892 ± 0.139 m, body mass = 88.4 ± 13.1 kg). Ethical approval was given by the ethics committee of the university at which the subjects were studying. Before testing, subjects were informed of the protocol and the purpose of testing, and each subject gave written informed consent to take part in the study. Subjects were asked not to undertake any vigorous training the day before testing, to maintain their normal dietary habits, and not to consume any alcohol 24 hours before the tests began or during the testing period. Subjects were also asked to refrain from taking any medication that might adversely influence the experimental results (e.g., anti-inflammatory medicines) and to limit water temperature and duration when bathing (16).

Experimental Design

A crossover randomised experimental design was used in this study, in which the 11 subjects were randomly assigned to one of two groups. One group completed the control condition first, followed by the experimental condition 1 week later. The other group completed the experimental first followed by the control condition 1 week later. Under both conditions, subjects were required to complete two exercise trials separated 1 week apart. Both exercise trials required subjects to complete a plyometric drop-jump protocol consisting of 5 sets of 20 drop jumps from a platform 60 cm high followed immediately by a maximal upward jump, with a 2-minute rest period between sets (22). After one of these plyometric drop-jump trials, subjects wore compression tights during a 48-hour recovery period while, after the other trial, in order to act as a control, they did not wear the compression tights. According to the manufacturers (Linebreak), the compression tights applied a graduated pressure of approximately 15 mmHg from the lower to the upper legs. One week before the completion of the first plyometric drop-jump protocol, subjects completed a series of performance tests (pre-exercise condition) including a) timed sprints (Brower timing systems, Speed trap 2, 2002, Draper, UT 84020) over 5 m, 10 m and 20 m, expressed in seconds (12); b) a timed 5-0-5 agility test also expressed in seconds (11), and; c) a countermovement jump test (1) expressed in centimeters (Just Jump system, Probotics, Huntsville, AL, USA). These performance tests were selected because they are already an integral part of the netball and basketball testing protocols. The performance tests were repeated again 48 hours after the completion of the plyometric drop-jump protocol (postexercise condition).

Immediately before performing the plyometric drop-jump protocol, subjects sat quietly for 10 minutes while a baseline capillary blood sample was taken from a finger and spun down (100-μL tube, Micro Haematocrit Mk IV Centrifuge, Hawksley & Sons, United Kingdom) for the determination of serum creatine kinase (CK) and lactate dehydrogenase (LDH) using dry chemistry analysers (Vitros DT60, DTSC II, DTE II chemistry analysers, Axis-Shield Diagnostics, United Kingdom). We followed the physiological convention of transforming measurements of CK into natural logarithms. Lactate dehydrogenase was expressed in absolute units ($U \cdot L^{-1}$). Mid-thigh girth was also measured at baseline according to the ISAK criteria at the mid-trochaterion-tibiale-laterale site (15) and expressed in centimeters. Finally, subjects reported a baseline rating of their perceived muscle soreness (PMS) using an adapted Graphic Ratings Scale (20). These measurements were repeated again at 24 hours and at 48 hours after the completion of the plyometric drop-jump protocol.

Statistical Analyses

Because the 7 female subjects in this study constituted a sample drawn from a specific population of games players (i.e., netball), we decided to analyze these data and report the outcomes separately from those for all 11 subjects. Notwithstanding these small sample sizes, the null hypothesis (H_0): $\bar{x}_B = \bar{x}_{24} = \bar{x}_{48}$(where $\bar{x}$= the sample mean, B = measures made at baseline, 24 = measures made at 24-hour recovery and 48 = measures made at 48-hour recovery) was tested for CK, LDH, mid-thigh girth, and PMS under both the control condition and the condition when subjects' wore the compression tights using the analysis of variance for repeated measures (ANOVA-RM). We considered it appropriate to use the ANOVA-RM because all these variables were recorded on a ratio scale (except for PMS) and the residuals, saved when running the ANOVA-RM, were confirmed as being normally distributed via the Anderson-Darling test of normality. Even though PMS was measured on an ordinal scale, ANOVA-RM was also used to test the H_0 for this variable because, once again, saved residuals were confirmed as normally distributed. In order to identify between which means the significant differences identified by the ANOVA-RM test lay, post-hoc analyses included reporting the results of the 95% confidence intervals for the means based on their pooled standard deviation. Additionally, the H_0: $\bar{x}_{PRE} = \bar{x}_{POST}$ was tested for all the performance test variables as a result of both the pre-plyometric measurement and the postplyometric measurement conditions using the dependent t-test. This t-test was also used because all of these variables were measured on a ratio scale and their residuals were confirmed as being normally distributed. In this case, however, residuals were recorded as the differences between the post-plyometric and the preplyometric scores (post–pre). Confidence intervals (95%) were constructed about relevant means.

Because we were concerned about the effects of making multiple comparisons, we adjusted our original level of alpha by which an outcome would be deemed statistically significant ($p \leq 0.05$) using the Dunn-Sidák method. Consequently, alpha was set at $p \leq 0.020$ for significance throughout the data analyses. Finally, although we were concerned about the statistical significance of these hypothesis tests, we were also concerned about the practical significance of the outcomes. For this reason, we also computed post-hoc the effect size statistics (ES) for all the statistically significant F-ratios and

Table 1. Comparison of responses under both experimental conditions for all subjects ($n = 11$) following the plyometric training protocol.*

Experimental variables (units)	Control condition			Compression tights worn		
	Baseline	24 hours	48 hours	Baseline	24 hours	48 hours
Creatine kinase	4.7 ± 0.8 (4.2–5.2)	5.0 ± 0.6 (1.8–8.2)	4.8 ± 0.7 (4.3–5.3)	4.7 ± 0.9 (4.1–5.3)	5.1 ± 0.7 (1.9–8.3)	4.8 ± 0.7 (4.3–5.3)
Lactate dehydrogenase ($U \cdot L^{-1}$)	459.0 ± 69.1 (412.6–505.4)	471.2 ± 68.6 (425.1–517.3)	454.6 ± 58.9 (415.0–494.2)	459.7 ± 70.3 (412.5–506.9)	459.0 ± 90.1 (398.5–519.3)	483.1 ± 96.9 (418.0–548.2)
Mid-thigh girth (cm)	55.1 ± 4.2 (52.3–57.9)	55.0 ± 4.2 (52.2–57.8)	54.9 ± 4.3 (52.0–57.8)	4.7 ± 4.6 (51.6–57.8)	54.7 ± 4.8 (51.5–57.9)	54.6 ± 4.9 (51.3–57.9)
Perceived muscle soreness	1.3 ± 0.7† (0.9–1.7)	2.0 ± 1.1 (1.4–2.6)	2.6 ± 1.3† (1.9–3.7)	1.6 ± 0.8 (1.1–2.1)	2.2 ± 1.0 (1.5–2.9)	2.2 ± 1.1 (1.5–2.9)
5-m sprint time (s)	1.16 ± 0.18 (1.04–1.27)		1.20 ± 0.11 (1.13–1.28)	1.16 ± 0.18† (1.04–1.27)		1.26 ± 0.11† (1.18–2.23)
10-m sprint time (s)	1.94 ± 0.21* (1.80–2.08)		2.05 ± 0.16* (1.94–2.16)	1.94 ± 0.21* (1.80–2.08)		2.10 ± 0.19* (1.97–2.23)
20-m sprint time (s)	3.41 ± 0.31† (3.20–3.61)		3.56 ± 0.29† (3.36–3.75)	3.41 ± 0.31† (3.20–3.61)		3.61 ± 0.30† (3.41–3.82)
Countermovement jump (cm)	43.1 ± 10.4 (36.1–50.1)		43.4 ± 10.9 (36.1–50.7)	43.1 ± 10.4 (36.1–50.1)		43.8 ± 10.0 (37.1–50.5)
5-0-5 agility test time (s)	2.54 ± 0.17 (2.43–2.66)		2.61 ± 0.10 (2.53–2.68)	2.54 ± 0.17 (2.43–2.66)		2.57 ± 0.18 (2.45–2.69)

*Data are mean ± *SD* (95% CI). CK data shown in the table summarizes the logged values.
†Significantly different ($p \le 0.020$).

Table 2. Comparison of responses under both experimental conditions for female subjects only ($n = 7$) following the plyometric training protocol.

Experimental variables (units)	Control condition			Compression tights worn		
	Baseline	24 hours	48 hours	Baseline	24 hours	48 hours
Creatine kinase	4.2 ± 0.5† (3.7–4.7)	4.8 ± 0.4† (4.4–5.2)	4.6 ± 0.5 (4.1–5.1)	4.5 ± 0.9 (3.7–5.3)	4.9 ± 0.8 (4.2–5.6)	4.6 ± 0.6 (4.1–5.2)
Lactate dehydrogenase ($U \cdot L^{-1}$)	425.4 ± 28.6 (399.0–451.9)	466.9 ± 56.3 (414.8–519.0)	423.6 ± 19.8 (405.3–441.9)	435.7 ± 51.7 (387.9–483.5)	443.4 ± 35.1 (410.9–475.9)	444.0 ± 27.7 (418.4–469.6)
Mid-thigh girth (cm)	54.2 ± 5.2 (49.4–59.0)	54.1 ± 5.2 (49.3–58.9)	54.0 ± 5.2 (49.2–58.8)	53.8 ± 5.6 (48.6–59.0)	53.8 ± 5.9 (48.3–59.3)	53.6 ± 5.9 (48.1–59.1)
Perceived muscle soreness	1.3 ± 0.8† (0.6–2.0)	1.7 ± 1.1 (0.7–2.7)	2.1 ± 0.9† (1.3–2.9)	1.7 ± 1.0 (0.8–2.6)	2.0 ± 0.8 (1.3–2.7)	2.1 ± 1.1 (1.1–3.1)
5-m sprint time (s)	1.26 ± 0.14 (1.13–1.38)		1.26 ± 0.07 (1.20–1.33)	1.26 ± 0.14 (1.13–1.38)		1.32 ± 0.04 (1.28–1.36)
10-m sprint time (s)	2.06 ± 0.14 (1.93–2.20)		2.14 ± 0.10 (2.05–2.23)	2.06 ± 0.14 (1.93–2.20)		2.21 ± 0.08 (2.14–2.29)
20-m sprint time (s)	3.61 ± 0.15 (3.47–3.75)		3.74 ± 0.16 (3.59–3.89)	3.61 ± 0.15 (3.47–3.75)		3.81 ± 0.11 (3.71–3.91)
Countermovement jump (cm)	36.2 ± 4.2 (32.4–40.1)		35.9 ± 3.6 (32.6–39.2)	36.2 ± 4.2 (32.4–40.1)		37.1 ± 3.9 (33.5–40.8)
5-0-5 agility test time (s)	2.63 ± 0.12 (2.52–2.74)		2.64 ± 0.08 (2.57–2.71)	2.63 ± 0.12 (2.52–2.74)		2.6 1± 0.11 (2.51–2.71)

*Data are mean ± *SD* (95% CI). CK data shown in the table summarizes the logged values.
†Significantly different ($p \leq 0.020$).

t-ratios identified. Knowing the ES also enabled us to estimate the power (10) of each significant analysis and subsequently to comment upon the confidence (%), we placed in rejection of the H_0 in the population from which the study participants were drawn (i.e., H_0: $\mu_B = \mu_{24} = \mu_{48}$ and H_0: $\mu_{PRE} = \mu_{POST}$, where μ = the population mean and the subscripts are as reported above).

Results

The results section is split into two parts. The first section details analysis outcomes for all 11 subjects (Table 1), whereas the second section details analysis outcomes for the 7 female subjects (Table 2).

All Subjects

When subjects used compression tights as a recovery modality, no significant differences were found between means for measurements made at baseline and at 24 hours and 48 hours after exercise for CK, LDH, mid-thigh girth, and PMS ($p \geq 0.020$). Similar results were forthcoming for CK, LDH, and mid-thigh girth under the control condition ($p \geq 0.020$). A significant increase between the mean measure at baseline and that at 48 hours postexercise was found, however, for PMS ($F_{2,20} = 9.25$, $p = 0.001$; ES = 0.63, power = 87.7%).

When the compression tights were worn, results for the performance measures showed significant increases in time between pre- and post-exercise means for the 5-m sprint times ($\bar{x}_{DIFF} \pm S_{DIFF} = 0.10 \pm 0.11$ s; $T_{10} = 2.95$, $p = 0.014$; ES = 0.91, power = 66.4%), 10-m sprint times ($\bar{x}_{DIFF} \pm S_{DIFF} = 0.16 \pm 0.15$ s; $T_{10} = 3.65$, $p = 0.004$; ES = 1.07, power = 78.2%) and 20-m sprint times ($\bar{x}_{DIFF} \pm S_{DIFF} = 0.21 \pm 0.15$ s; $T_{10} = 4.55$, $p = 0.001$; ES = 1.33, power = 91.2%). No significant differences were found, however, between pre- and postexercise means for the 5-0-5 agility test and the counter movement jump test under this condition ($p \geq 0.020$). Under the control condition, significant increases in time were observed between pre- and post-exercise means for the 10-m sprint times ($\bar{x}_{DIFF} \pm S_{DIFF} = 0.11 \pm 0.13$; $T_{10} = 2.90$, $p = 0.016$; ES = 0.85, power = 60.4%) and the 20-m sprint times ($\bar{x}_{DIFF} \pm S_{DIFF} = 0.15 \pm 0.14$; $T_{10} = 3.69$, $p = 0.004$; ES = 1.07, power = 78.2%). No significant differences were observed between pre- and post-exercise means for the 5-m sprint times, the 5-0-5 agility test times, and the counter movement jump test under the control condition ($p \geq 0.020$).

Female Subjects

When the female subjects used the compression tights, no significant differences were reported between means for measurements made at baseline and at 24 hours and 48 hours after exercise for CK, LDH, mid-thigh girth, and PMS ($p \geq 0.020$). Under the control condition, however, a significant increase was reported between the mean at baseline and that at 24 hours after exercise for CK ($F_{2,12} = 5.56$, $p = 0.020$; ES = 0.57, power = 57.2%) and between the mean at baseline and that at 48 hours after exercise for PMS ($F_{2,12} = 10.80$, $p = 0.002$; ES = 0.74, power = 80.4%). No significant differences were observed between means at baseline and at 24 hours and 48 hours after exercise for LDH and mid-thigh girth under the control condition ($p \geq 0.020$). When the performance measures were analyzed, no significant differences were found between the pre- and post-exercise means for any of the variables measured under either of the experimental conditions ($p \geq 0.020$).

Figure 1.

Discussion

Physical exercise potentially induces muscle damage; the purpose of this study was therefore to investigate whether wearing compression tights shortens the recovery process following exercise. Creatine kinase and LDH have been shown to be released from damaged muscle tissue into the bloodstream and as such can be used as markers of muscle damage (16). The results from this study showed that for the female subjects, there was a statistically significant increase in CK when measured at baseline and at 24 hours after plyometric exercise under the control condition. This was not the case, however, when the females wore compression tights during recovery. No significant differences were found between means measured at baseline and at 24 hours and 48 hours during the recovery period for CK when the data for all the subjects was analyzed under either of the experimental conditions.

This significant increase in CK under the control condition, coupled with the fact that there were no significant differences observed when the tights were worn during recovery, might suggest that wearing the tights shortens the recovery period. Other researchers investigating compression garments as a recovery modality have also found significant increases in CK under control conditions, but in these studies it appears that the exercise modalities used caused greater muscle damage when compared to that identified in the present study. For example, Kraemer et al. (16) found significant differences for CK in both control and experimental groups and only after 2 days were there significant differences between means under the two conditions. Kraemer et al. (17) observed significant differences in CK values when compared to those at baseline after three days of recovery, and at this time there was also a significant difference between the two conditions. Kraemer et al. (18) suggested two possible mechanisms as to why compression garments might reduce the concentration of CK in the bloodstream: a) the release of damage markers is attenuated as a result of compression treatment, and b) compression aids the clearance and removal of myofibrillar proteins.

An explanation for the small changes observed in the mean CK response in the present study compared with that reported in other pertinent research (16,17) could be due to the training status of our subjects. For sedentary individuals, a single episode of exercise involving eccentric muscular contractions might produce significant muscle soreness and damage (24). There is, however, evidence that plyometric training offers protection against delayed-onset muscle soreness, which has been termed the "repeated bout effect" (9). Indeed, it has been suggested that a single session of plyometric training has a protective effect lasting up to 3 weeks (25). This might be why well-trained athletes, who perform eccentric muscle actions, do not usually show large increases in plasma CK, although they still experience soreness, possibly as a result of damage and inflammation of connective tissue structures in muscle (21). A recent study by Gill et al. (14) showed that familiar exercise mediums might induce muscle damage, with CK levels being significantly elevated following a professional rugby match. It should be noted, however, that the duration of a rugby match is 80 minutes; that is more than double the time of the exercise protocol used in our study. Rugby is also a contact sport in which little protective equipment is worn, and subsequently muscle trauma might have significantly contributed to the elevation in CK reported in the Gill et al. (14) study. Additionally, Gill et al. (14) measured CK in forearm exudate samples, a method which has yet to be validated (2). Nonetheless, they did observe a lower CK response in the group that wore compression tights for 12 hours compared to a matched group that did not. This is supportive of our findings.

Lactate dehydrogenase is not as widely reported as CK as a marker of muscle damage. Kraemer et al. (16) and Friden et al. (13) have, however, reported similar observations to those identified in the present study in that there were no significant differences in mean LDH responses during the recovery period. Schwane et al. (26) also reported no change in pre-exercise LDH values and those following flat and downhill running. Differences in LDH and CK responses following exercise induced muscle damage might be due to their location in structurally different areas. This would mean that responses might depend upon where the primary site of muscle damage occurred (16).

Edema is associated with the inflammatory response that occurs as a result of muscle damage. In our study, mid-thigh girth was used as a simple and indirect method of assessing swelling of the quadriceps and hamstrings. We found no significant differences in mean mid-thigh girth in either the female sample or the total group of subjects under either of the experimental conditions. A review by Clarkson et al. (8), however, found that peak swelling occurred 5 days post-exercise. In the present study, mid-thigh girth was only measured for a 48-hour postexercise period, so it is possible that swelling might have occurred after our measurements had been completed. A more likely explanation, however, is that due to the repeated bout effect, muscle damage was not severe enough to result in a pronounced edema in our well-conditioned subjects. The absence of a repeated bout effect might explain why our data do not support those of Kraemer et al. (16) who reported a significant increase in mean upper arm circumference from measures taken pre-exercise until the fifth day of recovery in an untrained controlled group, whereas an untrained experimental group experienced no significant change in mean arm circumference. Kraemer et al. (17) also found mean biceps circumference to be significantly greater during recovery days 1 and 2 when compared to the mean baseline measures in their control group.

Despite our suspicion that the exercise protocol in our study did not elicit severe muscle damage, when the data for all the subjects was analyzed it was still sufficient to cause performance decrements. This would suggest a substantial effect of fatigue and possibly muscle damage. Additionally, significantly slower mean times were recorded for all the sprint tests when compression tights were worn, whereas significantly slower mean times were only observed for the 10-m and the 20-m sprint tests under the control condition. Interestingly, the significant elevation in mean CK for females under the control condition did not correspond to any significant performance decrements. There were also nonsignificant differences in mean performance measures under the tights condition for the females. These results conflict with those of Kraemer et al. (17) and Kraemer et al. (16), who observed significant differences between their untrained control and experimental groups for measures of peak torque and power.

Our findings do not support the notion that wearing compression tights as an aid to recovery has a beneficial effect on performance. We did find evidence, however, that they might attenuate the perception of muscle soreness. Significant increases in PMS were reported under the control condition at 48 hours postexercise for all subjects and when the female only data was considered. This was not the case however, when the compression tights were worn during recovery. It would seem therefore that the subjects perceived more comfort and less pain while wearing the tights. It should be noted, however, that no significant differences were reported at any point between the two experimental conditions. Participants in the control and compression garment groups in the Kraemer et al. (17) and Kraemer et al. (16) studies reported similar perceived pain scores up until day 3 of recovery. After day 3, however, the experimental group reported less pain. There is supporting evidence, therefore, from both these studies that compression garments might attenuate the perception of muscle soreness following eccentrically enhanced exercise induced muscle damage. Caution has to be exercised with this data, however, due to the subjectivity of these measurements.

A potential limitation of commercially manufactured compression tights, such as those used in the present study, is whether they can exert enough pressure to be effective. Indeed, it is doubtful whether standard sizes of compression tights would be effective given the widespread differences in leg dimensions and tissue structure within a given population. It would seem logical, therefore, to suggest that tights would need to be made specifically for an individual. The compression tights used during the present study were provided by Linebreak (Figure 1) and were allocated to participants based upon United Kingdom waist sizes for the males and United Kingdom dress sizes for the females. These compression tights were composed of 20% lycra and 80% nylon and the structure of the material was such that it was cross-knit into a four dimensional weave. According to the manufacturer's information (Linebreak), this design ensures that the same pressure (approximately 15 mmHg) is applied across the surface of the muscle and that the pressure is graduated from the lower towards the upper leg. Due to the sizing issue, however, it is possible that 15 mmHg is not always the pressure applied. For example, the female sizes used were 8/10 or 10/12 and the males sizes used were 32- or 34-inch waists. The actual pressures applied by these tights to each of the subjects were not measured during this study, so the values cannot be reported. Lawerence and Kakkar (19) suggest that the pressure exerted should be graduated with a minimum pressure of 18 mmHg at the ankle and 8 mmHg at the level of the mid-thigh. Kraemer et al. (16) and Kraemer et al. (17) applied a pressure of 10 mmHg for an arm compression sleeve and they did not opt for the graduated effect; however, they still found positive effects during recovery. Gill et al. (14) did not report a pressure for the compression tights they used in their study either. The results from the studies of Kraemer et al. (16) and Kraemer et al. (17) might suggest, however, that the pressure of 15 mmHg reportedly applied by the Linebreak tights we used in this study would be sufficient.

To conclude, our findings did not provide evidence that wearing compression tights during 48 hours of recovery after plyometric exercise has a beneficial effect upon significantly reducing bloodborne markers of muscle damage or improving sprint, agility, or jumping performance. It is important, however, to note that our subjects reported more comfort and less pain while wearing the compression tights. In fact, a number of the subjects involved in the study have subsequently begun to use compression garments as a recovery modality. For future research to be more meaningful, we believe that study methodologies need to be more unified in order to produce reliable and valid results, and there needs to be more research conducted with well-conditioned and athletically trained subjects.

Practical Applications

It is debatable whether elite athletes undertaking their usual training programs require compression garments in order to aid recovery because the muscle damage experienced might not be that great. Compression garments might, however, be of benefit to younger athletes when being introduced to plyometric training, or when experiencing a significant increase in training intensity and volume. Compression garments might also be of benefit to recovery in athletes who are involved with in contact sports. Additionally, it has been suggested by Gill et al. (14) that compression garments could provide an effective recovery modality, particularly when teams are playing away from home. As well as the ease of use, compression garments appear to be a safe recovery modality. Appropriate protocols need to be put in place with regard to the length of time that the garments are worn, however. The subjects in our study reported that the compression tights were uncomfortable to wear during the night, and they further suggested that the tights caused an increase in body temperature, thereby disturbing our subjects' patterns of sleep.

Acknowledgments

We thank Linebreak for the loan of the compression garments used in this study. We also thank John McFall and Joe Hewitt for their time and assistance. The research was conducted at the Sports Science Laboratory based at the Sports Council for Wales, Sophia Gardens, Cardiff, Wales, United Kingdom.

References

1. Arteaga, R, Dorado, C, Chavarren, J, and Calbet, JAL. Reliability of jumping performance in active men and women under different stretch loading conditions. *J Sports Med Phys Fitness* 40: 26–34, 2000.
2. Barnett, A. Using recovery modalities between training sessions in elite athletes: does it help? *Sports Med* 36: 781–796, 2006.

3. Belcaro, G, Geroulakos, G, Nicolaides, AN, Myers, KA, and Winford, M. Venous thromboembolism from air travel: the LONFLIT study. *Ahgiology* 52: 369–374, 2001.
4. Berry, MJ and Mcmurray, RG. Effects of graduated compression stockings on blood lactate following an exhaustive bout of exercise. *Am J Phys Med* 61: 121–132, 1987.
5. Berry, MJ, Bailey, SP, Simpkins, LS, and Tewinkle, JA. The effects of elastic tights on post-exercise response. *Can J Sports Sci* 15: 244–248, 1990.
6. Chartard, JC, Atlaoui, D, Farjanel, J, Louisy, F, Rastel, D, and Guezennec, CY. Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. *Eur J Appl Physiol* 93: 347–352, 2004.
7. Chleboun, GS, Howell, JN, Baker, HL, Ballard, TN, Graham, JL, Hallman, HL, Perkins, LE, Schauss, JH, and Conatser, RR. Intermittent pneumatic compression effect on eccentric exercise-induced swelling, stiffness, and strength loss. *Arch Phys Med Rehabil* 76: 744–749, 1995.
8. Clarkson, PM, Nosaka, K, and Braun, B. Muscle function after exercise-induced muscle damage and rapid adaptation. *Med Sci Sports Exer* 24: 512–520, 1992.
9. Cleak, MJ and Eston, RG. Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise. *Br J Sports Med* 26: 267–272, 1992.
10. Cohen, J. *Statistical Power Analysis* (2nd ed.). New York: Lawrence Erlbaum Associates, 1988.
11. Draper, JA and Lancaster, MG. The 505 test for agility in the horizontal plane. *Aust J Sci Med* 17: 15–18, 1985.
12. Ellis, L, Gastin, P, Lawerence, S, Savage, B, Buckendge, A, Staff, A, Tumilty, D, Quinn, A, Wollford, S, and Young, W. Protocols for the assessment of team sport players. In: *Physiological Tests for Elite Athletes.* Australian Sports Commission: Human Kinetics, 2000. pp. 128–144.
13. Friden, J, Sfakianos, PN, and Hargens, AR. Blood indices of muscle injury associated with eccentric muscle contractions. *J Orthopaedic Res.* 7: 142–145, 1989.
14. Gill, ND, Beaven, CM, and Cook, C. Effectiveness of post-match recovery strategies in rugby players. *Br J Sports Med.* 40: 260–263, 2006.
15. The International Society for the Advancement of Kinanthropometry (ISAK). International standards for anthropometric assessment. 2001.
16. Kraemer, WJ, Bush, JA, Wickham, RB, Denegar, CR, Gomez, AL, Gotshalk, LA, Duncan, ND, Volek, JS, Putukian, M, and Sebastianelli, WJ. Influence of compression therapy on symptoms following soft tissue injury from maximal eccentric exercise. *J Orthop Sports Phys Ther* 31: 282–290, 2001.
17. Kraemer, WJ, Bush, JA, Wickham, RB, Denegar, CR, Gomez, AL, Gotshalk, LA, Duncan, ND, Volek, JS, Newton, RU, Putukian, M, and Sebastianelli, WJ. Continuous compression as an effective therapeutic intervention in treating eccentric-exercise-induced muscle soreness. *J Sports Rehab* 10: 11–23, 2001.
18. Kraemer, WJ, French, DN, and Spiering, BA. Compression in the treatment of acute muscle injuries in sport. *Int J Sports Med.* 5: 200–208, 2004.
19. Lawerence, D and Kakkar, VV. Graduated, static, external compression of the lower limb: a physiological assessment. *Br J Surg* 67: 119–121, 1980.
20. Mattacola, CG, Perrin, DH, Gansneder, SM, Allen, JD, and Mickey, CA. A comparison of visual analog and graphic rating scales for assessing pain following delayed onset muscle soreness. *J Sport Rehab* 6: 38–46, 1997.
21. Maughan, R and Gleeson, M. *The Biochemical Basis of Sports Performance.* Oxford: Oxford University Press, 2004.
22. Motoyoshi, M and Kazunori, N. Influence of surface on muscle damage and soreness induced by consecutive drop jumps. *J Strength Cond Res* 18: 206–211, 2004.
23. O'donnell, TF, Rosenthal, DA, Callow, AD, and Ledig, BL. Effect of elastic compression on venous hemodynamics in postphlebitic limbs. *Jama* 242: 2766–2768, 1979.
24. Pyne, DB. Regulation of neutrophil function during exercise. *Sports Med* 17: 245–258, 1994.
25. Reilly, T and Ekblom, B. The use of recovery methods post-exercise. *J Sports Sci* 23: 619–627, 2005.
26. Schwane, JA, Johnson, SR, Vandenakker, CB, and Armstrong, RB. Delayed-onset muscular soreness and plasma CPK and LDH activities after downhill running. *Med Sci Sports Exer* 15: 51–56, 1983.
27. Scurr, JH, Machin, SJ, and Bailey-King, S. Frequency and prevention of symptomless deep-vein thrombosis in long-haul flights: a randomised trial. *Lancet* 357: 1485–1489, 2001.
28. Thompson, KG, Harrison, A, Dietzig, B, and Cosgrove, M. Physiological responses to bouts of high intensity exercise two hours apart. *J Human Movement Stud* 51: 77–88, 2006.
29. Trennel, MI, Rooney, KB, Sue, CM, and Thompson, CH. Compression garments and recovery from eccentric exercise: a 31P-MRS study. *J Sports Sci Med* 5: 106–114, 2006.
30. Vaille, J and Gill, ND. The effect of recovery strategy on symptoms of delayed onset of muscle soreness (DOMS). Hamilton, New Zealand: Waikato Institute of Technology, 2003.
31. Viitasalo, JT, Niemela, K, Kaappola, R, Korjus, T, Levola, M, Mononen, HV, Rusko, HK, and Takala, TE. Warm underwater water-jet massage improves recovery from intense physical exercise. *Eur J Appl Physiol Occup Physiol* 71: 431–438, 1995.
32. Wigernaes, I, Hostmark, AT, Kierulf, P, and Stromme, SB. Active recovery reduces the decrease in circulating white blood cells after exercise. *Int J Sports Med* 21: 608–612, 2000.