COMPRESSION GARMENTS DO NOT IMPROVE RECOVERY FROM PLYOMETRIC EXERCISE
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ABSTRACT

Purpose: To evaluate the effects of waist-high compression tights and knee-high compression stockings on recovery from plyometric exercise. Methods: Thirty recreationally active men completed 10 x 10 plyometric box drop jumps to induce muscle soreness. Participants were randomized into three groups: full compression waist-high tights (n=11), knee-high compression stockings (n=10), or passive recovery (n=9). Both compression groups wore the garments for 12 hours following exercise. Participants were assessed for muscle swelling, isokinetic strength of the plantar flexor (PF) and knee extensors (KE), vertical jump height, and perceived muscle soreness before exercise and up to 72 hours post-exercise. Results: Isokinetic peak torque decreased up to 17% KE in all groups (P<0.0001). Peak muscle soreness ratings occurred 12 hr and 24 hr post-exercise for the PF and KE, respectively (P<0.0001), however, no significant differences occurred between groups (PF P=0.762; KE P=0.137). Conclusion: Neither waist-high tights or knee-high stocking compression garments assisted in recovery from plyometric exercise.

INTRODUCTION

eccentric exercise has been closely linked with exercise-induced muscle damage, which results in muscle soreness and impaired strength and power (Miyama & Nosaka, 2004). Optimizing recovery from exercise is a significant concern for coaches, athletic trainers, and athletes themselves. Ergogenic aids that promote recovery from training or competition may allow the athlete to return to their activity faster, and with less muscle soreness or fatigue.

Compression garments are specialized clothing items used to apply pressure to the body’s surface (MacRae, Cotter, & Laing, 2011). Primarily used in medical treatment, these garments have made their way into human performance as a mechanical ergogenic aid. However, the research on compression garments is highly varied in both procedures and outcomes. As a result, many questions exist regarding proper use for the desired effects.

Manufacturers claim that their products can enhance athletic performance and recovery. Common claims include: enhanced venous return, a reduction in muscle soreness, accelerated blood lactate clearance, improved muscular strength and endurance, and increased muscle oxygenation (SKINS Science, n.d.). However, much of the research does not support claims of performance enhancement. For example, runners in sprint and endurance races did not experience an improvement in performance time from wearing graded compression garments (Ali, Caine, & Snow, 2007; Ali, Creasy, & Edge, 2011; Faulkner, Geadon, McLaren, & Jakeman, 2013; Vercruyssen et al., 2014).
The use of compression garments for recovery from exercise shows more promising results. A study of elderly cyclists showed decreased blood lactate concentrations and a smaller performance drop when participants wore compression stockings between two bouts of maximal cycling. The authors suggested that the decrease in blood lactate was responsible for the maintenance of anaerobic performance (Chatard et al., 2004). Others have found improved power maintenance when compression stockings were worn following plyometric exercise (Jakeman, Byrne, & Eston, 2010). Female participants maintained squat jump height and isokinetic strength, and reported less muscle soreness when they wore the compression garments compared to when they did not.

While all of the aforementioned studies have examined thigh-high garments or full tights, less research has been done using knee-high stockings. Knee-high stockings are more affordable, widely available, and may be more comfortable than waist- or thigh-high compression. Because proper adherence to garment protocol is necessary to experience the benefit of compression, it is important that the procedure is feasible for athletes. Therefore, the purpose of this study is to compare the effects of waist-high compression garments and knee-high compression stockings for recovery from plyometric box drops.

METHODS

Participants

A volunteer sample of healthy males (n=30) ranging from 18-25 years of age was recruited for the study. Participants were recreationally active (exercising 2-5 days per week), with no lower body plyometric training 6 months prior to the start of the study. Participants were excluded if they had musculoskeletal injuries that could be worsened by plyometric activity. Written informed consent was obtained from all individual participants included in the study. The Institutional Review Board at the Midwest university in the United States approved this study.

Garments

Waist-high tights (SKINS A400 Men’s Active Long Tights) and knee-high stockings (SKINS Unisex Active Compression Socks) were used in this study. The knee-high stockings contain 89% polyamide, 9% elastane, and 2% copper fiber. No information was available on the composition of the waist-high tights.

Experimental design

Participants were randomized into three groups: waist-high tights (n=11), knee-high stockings (n=10), and a control group (n=9) which received no garment. The sample size was chosen based on current literature using 8-11 participants per group (Chatard et al., 2004; Jakeman et al., 2010; Pruscino, Halson, & Hargreaves, 2013). A Physical Activity Readiness Questionnaire (PAR-Q) and health history questionnaire were used to screen individuals for other chronic conditions that might exclude them from the trial (AHA/ACSM, 1998). Individuals taking dietary supplements that may affect recovery were required to undergo a three-week washout period, during which they would abstain from supplementation until the study was completed.

The study used a randomized pretest-posttest design. On the first visit, participants completed the following assessments: perceived muscle soreness ratings, ultrasound images of muscle thickness in the lateral gastrocnemius and rectus femoris, isokinetic strength of the knee extensors and ankle plantar flexors, and vertical jump height. Participants repeated these tests on the third, fourth, and fifth visit (24, 48, and 72 hours post-exercise).

On the second visit, participants completed 10 sets of 10 plyometric box drop jumps to induce muscle damage and soreness. Participants stepped from a 60-cm box and landed with feet shoulder width apart, lowering into a 90-degree squat. Immediately upon landing, they completed a maximal vertical jump. Up to ten seconds were allowed between drops, and one minute between sets (Jakeman et al., 2010; Miyama & Nosaka, 2004).
Immediately post-exercise, participants in the waist- and knee-high compression groups applied the garments, which were worn for the following 12 hours. The control group wore their normal clothing. Participants were instructed to remove the compression garments at the 12-hour mark post plyometric exercise and leave them off for the remainder of the study. At that time, all participants completed a Visual Analog Scale (VAS) to assess perceived muscle soreness in both the quadriceps and the calves. VAS was completed following an unweighted squat and an unweighted calf raise, respectively. All participants were instructed to maintain their normal nutrition and hydration habits, and refrain from any lower body exercise, nutritional supplements, and other recovery modalities until testing was complete.

Participants returned 24 hours after plyometric exercise to complete the first set of post-tests. The post-test included the same assessments used prior to exercise and was completed at 48 and 72 hours after exercise, using the previously described protocol.

**Testing**

*Perceived muscle soreness*

A VAS is a widely accepted, repeatable method of measuring pain perception (Rosier, Iadarola, & Coghill, 2002). Participants were instructed to mark a vertical line on 10-cm horizontal line (0 = no pain at all up to 10 = worst pain imaginable) corresponding to their perceived level of soreness felt when performing an unweighted squat to 90 degrees flexion at the knee joint (Jakeman et al., 2010) and an unweighted calf raise to their furthest range of motion of plantar flexion. Participants assessed their soreness at each testing session as well as 12, 24, 48, and 72 hours post-exercise, completing a separate VAS for both the unweighted squat and the unweighted calf raise.

*Muscle thickness*

Images of muscle thickness were obtained using a Philips ultrasound (model HD11 XE; Philips Ultrasound, Bothell, WA) ultrasound system to assess for swelling in the lateral gastrocnemius and the rectus femoris (Scott et al., 2017). Participants were supine on the examination table and relaxed the right leg. Following the midline of the limb, the linear transducer (L12-5 5mm) was placed 15 cm above the superior border of the patella to scan the rectus femoris. Images of the muscle were taken using water-based ultrasound gel, and recorded on the monitor (Bemben, 2002). The head of the transducer was traced on the skin with permanent marker for future measurements. To assess the lateral gastrocnemius, participants moved to the prone position with their foot hanging off the table. The transducer was placed over the lateral gastrocnemius, in line with the widest part of the calf (Chow et al., 2000). The head of the transducer was again traced with permanent marker for future measurements. Three images were taken of each muscle group during each data collection session to improve reliability.

To measure muscle thickness in the rectus femoris, the thickest portion of the muscle was approximated visually, and a perpendicular line was placed using the caliper tool on the ultrasound machine. From the top border of the muscle, a distance of 0.5 cm was measured to the right and the left of the thickest line, and perpendicular lines were measured from the top to the bottom of the muscle on each side. The three lines were averaged for each image, and the three images were averaged for each data collection session. To measure muscle thickness in the lateral gastrocnemius, the caliper tool was placed at the corner of the muscle, and the top border was marked at three 0.5 cm intervals. Perpendicular lines were dropped to the bottom border of the muscle at each interval, and the three lines were averaged for each image. The average of the three images were used for each data collection session. Reliability measures for the rectus femoris and lateral gastrocnemius consistently showed an inter class correlation (ICC) between 0.95-0.99.

*Vertical jump*

Vertical jump was used to assess muscular power. Participants stood beneath the Vertec (Sports Imports) with arms extended overhead, and the pole was adjusted so the lowest vane was in line with their fingertips. Participants were instructed to bend their knees and jump as high as possible, using their arm swing to assist in the motion. The highest vane the subject reached was used to calculate jump height.
(Buckthorpe, Morris, & Folland, 2012; Nuzzo, Anning, & Scharfenberg, 2011). The system was reset, and two more jumps were completed. The highest of the three jumps were used in the analysis.

**Isokinetic Strength**

The Biodex System 4 Isokinetic Dynamometer (Biodex Medical Systems, Shirley, NY) was used to measure isokinetic strength of the knee extensors (KE) and the plantar flexors (PF). To evaluate the KE strength, participants were seated upright in the Biodex and secured with lap- and shoulder-belts. The dynamometer’s axis of rotation was placed at the center of the knee, with the ankle held securely to the attachment. Participants performed ten warmup repetitions, followed by a 60-second break. They then performed three repetitions at maximal effort at 60 degrees per second, using a 75-degree range of motion. Strong verbal encouragement was given throughout the test, and participants could view their results on a computer monitor. The highest peak torque value during knee extension was used for analysis. (Jakeman et al., 2010).

To evaluate PF strength, participants were in the reclined position, with hip and knee flexed, and the shin parallel to the ground. The foot was securely attached to foot plate. Testing range of motion was set by subtracting five degrees from the participants’ maximal active plantar- and dorsiflexion range of motion. Following ten warmup repetitions and a 60-second break, participants performed five repetitions at maximal effort at 30 degrees per second. Again, participants were given strong verbal encouragement and could view their results on the computer monitor. The highest peak torque value during plantarflexion was used for analysis.

**Statistics**

A one-way ANOVA was used to compare subject demographics. A repeated measures ANOVA was used to analyze muscle thickness, performance, and pain perception variables among groups. Post-hoc analysis using Bonferroni’s adjustments identified significant interactions. A Levene’s test was used to assess equal variance among groups and Bonferroni pairwise comparisons were made using variables that showed significant interactions. Significance value was set at $p < 0.05$ for each test. All statistical analysis was performed in SPSS (v 23.0, Armonk, NY).

**RESULTS**

A total of 30 males participated in the study and their characteristics can be found in Table 1. No significant difference was seen in age ($p = 0.667$), height ($p = 0.452$), body mass ($p = 0.230$), or body composition ($p = 0.781$) between groups (Table 1).

**Recovery**

Results from the repeated measures analysis showed that both treatment and control groups experienced similar changes in all indices of recovery, but none were significantly different ($p > 0.05$). There were no significant group x time interactions between recovery and the following variables: VAS PF ($p = 0.762$), VAS KE ($p = 0.118$), rectus femoris thickness ($p = 0.607$), lateral gastrocnemius thickness ($p = 0.391$), vertical jump ($p = 0.760$), KE strength ($p = 0.137$) or PF strength ($p = 0.174$).

Because no significant interactions were observed among treatment and control groups across time the main effects of time were examined. A significant time effect occurred with four of the variables showing pooled effects of plyometric exercise across time regardless of treatment: VAS (KE: $p < 0.001$; PF: $p < 0.001$), vertical jump ($p = 0.001$) and KE isokinetic strength (KE: $p < 0.001$).

**Perceived muscle soreness**

Participants significantly increased ($p < 0.001$) in perceived muscle soreness over time in both the PF (Figure 1) and KE (Figure 2) muscles. Post-hoc analysis examined differences contributed by time using pairwise comparisons with Bonferroni adjustment (Figure 1).

**Muscle thickness and vertical jump**

There were no significant differences in muscle thickness for the rectus femoris or the lateral gastrocnemius over time (Table 2). The pairwise comparisons using Bonferroni’s adjustment indicated a
significant decrease \((p = 0.001)\) in vertical jump height from pre-exercise to 24 hours post exercise (Table 2).

**Isokinetic strength**

Isokinetic strength in the KE significantly declined compared to pre-exercise values \((p < 0.001)\) (Figure 3). PF strength did not significantly change \((p = 0.331)\) (Figure 4). For the KE, the significant differences occurred when comparing a post-exercise measure to the pre-exercise measure.

**Table 1** Age, height, body mass, and body composition in the control \((n = 9)\), knee-high stockings \((n = 10)\), and waist-high tights \((n = 11)\) groups

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Knee-High Stockings</th>
<th>Waist-high Tights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.56 ± 2.55</td>
<td>21.80 ± 2.53</td>
<td>20.91 ± 1.92</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>183 ± 0.70</td>
<td>180 ± 0.80</td>
<td>179 ± 0.80</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>85.23 ± 15.83</td>
<td>75.75 ± 9.46</td>
<td>77.62 ± 11.46</td>
</tr>
<tr>
<td>Body composition</td>
<td>17.01 ± 5.35</td>
<td>15.55 ± 3.92</td>
<td>16.36 ± 4.29</td>
</tr>
<tr>
<td>(%BF)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2** Muscle thickness and vertical jump over time

<table>
<thead>
<tr>
<th></th>
<th>Rectus femoris</th>
<th>Lateral gastrocnemius</th>
<th>Vertical jump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre exercise (cm)</td>
<td>1.67 ±0.35</td>
<td>0.74 ± 0.16</td>
<td>53.76 ± 8.84</td>
</tr>
<tr>
<td>24 hours post</td>
<td>1.71 ± 0.36</td>
<td>0.75 ± 0.16</td>
<td>50.63 ±10.53*</td>
</tr>
<tr>
<td>48 hours post</td>
<td>1.74 ± 0.36</td>
<td>0.78 ± 0.14</td>
<td>51.55 ± 12.03</td>
</tr>
<tr>
<td>72 hours post</td>
<td>1.71 ± 0.36</td>
<td>0.77 ± 0.15</td>
<td>52.58 ± 11.75</td>
</tr>
</tbody>
</table>

Data are mean ± SD

Rectus femoris \(p = 0.129\); Lateral gastrocnemius \(p = 0.376\) compared to pre-exercise; Vertical jump \(*p = 0.001\) compared to pre-exercise
Figure 1 Perceived muscle soreness for KE following plyometrics. Mean ± standard deviation (SD). *p < 0.001 vs. pre-exercise; # p < 0.05 vs. 72 hours post-exercise.

Figure 2 Perceived muscle soreness for PF following plyometrics. Mean ± standard deviation (SD). *p < 0.001 vs. pre-exercise; # p < 0.05 vs. 72 hrs post-exercise.
Figure 3 Isokinetic strength in KE following plyometric exercise. Mean ± standard deviation (SD). *p < 0.001 vs. pre-exercise

Figure 4 Isokinetic strength in PF following plyometric exercise. Mean ± standard deviation (SD).

DISCUSSION
The main findings of this investigation were that although the plyometric exercise protocol did induce: 1) muscle soreness, 2) a decline in vertical jump height, and 3) a decrease in isokinetic KE torque, the compression garments did not minimize these indices or have an effect on recovery. Further, although we attempted to determine if compression garments influenced the degree of muscle swelling of rectus femoris and lateral gastrocnemius using ultrasound following plyometric exercise, there were no significant elevations at 24, 48 or 72 hours post exercise in any of the groups.

**Perceived muscle soreness.** According to our results, perceived muscle soreness in KE and PF did not vary significantly among the treatment and control groups. This contradicts previous studies, which found increased muscle soreness in those that did not wear compression garments (Davies, Thompson, & Cooper, 2009; Jakeman et al., 2010). While our results did not reach statistical significance between groups, an interesting pattern in the KE emerged. Muscle soreness in the control group peaked at 12 hours post-exercise, while the waist-high tights group peaked at 24, and the knee-high stockings group at 48. This finding warrants further investigation, and may necessitate a larger sample size to see statistical significance (group by time interaction effect size: \( \eta^2_p = 0.121 \text{ KE}; 0.035 \text{ PF} \)). Interestingly, muscle soreness in PF did not follow the same pattern. Muscle soreness peaked at 12 hours for both the control and knee-high stockings group, and 24 hours for the waist-high tights. Combined data from all three groups showed that perceived muscle soreness at 12, 24, and 48 hours post-exercise significantly increased from baseline values for both muscle groups. By 72 hours post-exercise, the KE still showed significantly elevated soreness compared to baseline levels, though the PF seemed to have recovered.

Our results are most comparable to the findings of Davies et al. (2009). While this study used trained men and women in a similar jump protocol, their results showed that differences in muscle soreness were only significant at 48 hours post-exercise. The authors suggested that the plyometric stimulus may not have been strong enough to induce muscle damage in trained participants (Davies et al., 2009). This finding leads us to believe that participants’ training status is vital in this line of research, and may affect muscle soreness and recovery. Similarly, the heterogeneity of our subject group may have influenced their responses to muscle-damaging exercise. While our activity criteria specified that participants should be “recreationally active” with no prior jump training, we received participants from a variety of backgrounds. Several individuals reported playing recreational sports that required some exposure to jumping, though they engaged in no formal jump training program. Thus, these individuals may have experienced less muscle damage than those who engage in no jumping activities at all. Future studies may wish to control more closely for exposure to plyometric activities by disqualifying individuals who play basketball, volleyball, or other sports that require a large amount of jumping.

**Muscle thickness.** Jakeman et al. (2010) suggested that future compression research investigate the garments’ effects on edema. While previous reports have used circumference measurements (Carling, Francis, & Lorish, 1995; Davies et al., 2009) to monitor edema, to our knowledge we are the first to systematically explore individual muscles using panoramic ultrasonography (Scott et al., 2017). Based on our findings, participants in the compression garment groups did not experience reduced muscle swelling in the rectus femoris or the lateral gastrocnemius compared to the control group.

The degree of compression exerted by each garment may have greatly influenced the muscle swelling. Two of the aforementioned studies used garments that provided 20-30 mmHg of compression (Carvalhal, Lopes Pinto, Guerreiro Godoy, & Pereira de Godoy, 2015; Lord (Hamilton, 2004), whereas Partsch, Winiger, and Lun (2004) examined gradings from 8-20 mmHg, and found garments over 10 mmHg to be helpful in reducing edema. However, the garments used in our study were not medical-grade compression garments. While the company provided an overall compression rating of 19-33 mmHg for their entire product line, we were unable to find an exact value for the products we used. Thus, it is possible that our garments provided insufficient compression to obtain the desired effects on edema. In addition, Carvalhal and colleagues (2015) measured edema immediately upon removal of the garment. It is possible that our participants would have shown similar results if ultrasound images were
taken at the 12-hour garment removal mark. Future research may wish to use medical-grade garments or quantify their compression rating, and assess for edema as soon as the garments are removed. Finally, the rectus femoris and the lateral gastrocnemius muscle were individually chosen for analysis for their ease of visibility on the diagnostic ultrasound. However, it is possible that other muscles in the knee extensor or plantar flexor group or the group as a collective may have experienced swelling to a measurable greater degree. In future studies, researchers may consider evaluating additional muscles in these two muscle groups for a broader look at muscle swelling overall.

**Isokinetic strength.** Isokinetic strength was measured at KE and PF with non-significant differences between control and compression groups seen (group by time interaction effect size: $\eta^2_p = 0.115$ KE; $0.106$ PF). However, a significant effect of time was present in KE, with the 24, 48, and 72-hour post-exercise measurements being significantly lower than baseline values. This suggests that the plyometric protocol resulted in exercise induced muscle damage evidenced by mild loss of function at the KE. Based on our results, it appears that compression garments did not aid in the maintenance of isokinetic strength for either muscle group.

Previous research using a similar exercise protocol found that isokinetic strength at the knee was significantly higher in the compression groups in the four days following exercise (Jakeman et al., 2010). Our results failed to support these findings. However, our data suggested that the groups experienced the largest strength losses at different points during recovery. While the control group showed the largest decrement at the 24-hour post-test, both the short stockings and full tights groups achieved their lowest strength values at 48 hours post-exercise. However, these findings were not significant. While Jakeman and colleagues reported using the same brand of compression garments used in the present study, the model was not reported. Thus, potential differences in the compressive strength of the garments may be responsible for the varied response in isokinetic strength.

To our knowledge, this is the first compression study to evaluate the isokinetic strength of the PF. Examination of group data suggests inconsistent performance among participants. For the control and waist-high tights group, peak torque values for 72 hours post-exercise were higher than baseline values, suggesting that practice may have influenced participants’ performance. Many participants casually mentioned that the setup felt “awkward” or “unnatural” which may account for the lack of significance by either group or time variables. To control for the effects of practice, future studies should consider implementing a familiarization session prior to testing.

**Vertical jump.** Changes in vertical jump height among treatment and control groups were not statistically significant, suggesting that neither knee-high stockings nor waist-high tights aided in power maintenance when worn during recovery (group by time interaction effect size: $\eta^2_p = 0.031$). Likewise, Davies et al. (2009) found no differences in pre- and post-exercise measures of vertical jump when a similar protocol was used on a mixed gender group of basketball athletes.

Prior research using untrained females showed that vertical jump height was only statistically significant between treatment and control groups at 48 hours post-exercise (Jakeman et al., 2010). Our results did not support these findings. Even when all three groups were combined to examine the significant time effect, vertical jump height was only significantly lower at 24 hours post-exercise compared to baseline. The similarity between our results and those of Davies et al. (2009) suggests that our subject pool may share more characteristics with their trained athletes than the untrained females used by Jakeman et al. (2010).

**CONCLUSION**

In conclusion, our results suggest that while muscle soreness occurred, no significant differences in perceptual or performance variables were seen among groups wearing waist-high compression tights, knee-high stockings, and the control group wearing no compression garment. While our results do not
support the use of compression as a recovery from plyometric exercise, additional research should be done to determine whether differences in subject characteristics or garments may yield different results.

REFERENCES


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