USE OF COMPRESSION GARMENTS FOR RECOVERY FROM PLYOMETRIC EXERCISE

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ABSTRACT

The purpose of this study was to evaluate the effects of compression tights and knee-high stockings on recovery from plyometric exercise. Thirty recreationally active men completed 10x10 plyometric box drop jumps to induce muscle damage. Participants were randomized into three groups: full compression tights, knee-high stockings, or passive recovery. Both compression groups wore the garments for 12 hours following exercise. Participants were assessed for muscle swelling, isokinetic strength of the ankle and knee, vertical jump height, and perceived muscle soreness before exercise, and 24, 48, and 72 hours post-exercise. All measures were compared to pretest values, and a repeated measures ANOVA was used to assess variation among groups ($p< 0.05$). A significant effect of time suggested that the protocol inflicted muscle damage. However, no significant differences occurred between groups, suggesting that the compression garments did not aid in recovery in this group of subjects.

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INTRODUCTION

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

The degree of pressure exerted by the fabric can vary among garments. Most styles use compression grading, or a variation in compressive strengths within a single garment, typically exerting more pressure at the calf and gradually decreasing toward the thigh (Troynikov, Ashiyeri, Alam, & Marteau, 2010). A study of healthy patients tested in the supine position found that both low (18-21 mmHg) and high (23-32 mmHg) grade compression stockings enhanced venous return (Lattimer, Kalodiki, Kafeza, Azam, & Geroulakos, 2013), which may help promote recovery from strenuous exercise (Chatard et al., 2004).

Manufacturers claim that their products can enhance both 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 varies in its support of these claims, especially for the use of compression during exercise. Research on runners in both sprint and endurance races did not suggest improvements in performance time from wearing graded compression stockings (Ali, Caine, & Snow, 2007; Ali, Creasy, & Edge, 2011; Faulkner, Gleadon, 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 subjects wore compression stockings between two bouts of maximal cycling. The authors suggest that the decrease in blood lactate was responsible for the maintenance of anaerobic performance (Chatard et al., 2004). Jakeman, Byrne, and Eston (2010) also found improved power maintenance when compression stockings were worn following plyometric exercise. Female subjects maintained squat jump height and isokinetic strength, and reported less muscle soreness when they wore the compression garments compared to when they did not.

However, not all studies support the use of compression for recovery. Pruscino, Halson, and Hargreaves (2013) found that compression garments did not aid in maintenance of countermovement or squat jump height following an intermittent walking, jogging, and sprinting protocol. Similar results were found by Davies, Thompson, and Cooper (2009), using plyometric box drops in a similar protocol to Jakeman and colleagues (2010). Their results conflicted with Jakeman et al., in that similar decrements in countermovement jump height were observed whether or not compression garments were worn following exercise. Interestingly, the compression group also performed significantly slower in their 20 meter sprint time compared to the control group (Davies et al., 2009). While Pruscino et al. (2013) and Davies et al. (2009) found little performance benefit, both studies reported lower muscle soreness scores when compression garments were used. Due to the mixed results of most recovery studies, more research is needed to evaluate the utility of compression garments in recovery from muscle damage.

Purpose and Significance

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. 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 realistic for athletes to follow.

Therefore, the purpose of this study is to compare the effects of knee-high compression stockings and full-length tights on recovery from plyometric box drops. Research questions to be addressed include: How will each compression garment affect an individual’s perceived muscle soreness? Will wearing compression garments help maintain vertical jump height and isokinetic strength when worn during recovery? Do compression garments affect muscle swelling in the rectus femoris and the lateral gastrocnemius? What differences in perceptual and performance variables are seen between the two styles?

Limitations

The main limitation of this study is the potential for participant bias. While a placebo garment could have been worn by the control group, individuals would quickly recognize whether or not it exerted significant pressure. In addition, preconceived ideas about the effectiveness of compression garments may also influence perceived muscle soreness scores, as well as effort exerted on the strength and power tests. To date, none of the research has reported a way to effectively minimize these biases or blind the subjects.

In addition, many other compression studies examined metabolic variables within the blood, such as blood lactate (Chatard et al., 2004) and creatine kinase (Jakeman et al., 2010; Pruscino et al., 2013). However, due to lack of specialized equipment, our study focused on performance and perceptual variables instead. Performance and perceptual variables may provide more applicable data, as they closely reflect the variables of interest for practical application.

Organization of Chapters

In the chapters that follow, the history of compression garments and their role in athletics will be discussed. Past and current research will be reviewed, with an emphasis on the use of compression garments as a recovery aid. Reliability and validity of our instrumentation will be briefly reviewed. Finally, the methodology of the proposed study will be provided, including the choice of subjects, study procedure and timeline, instrumentation, and data analysis. Results will be presented and discussed.

Definition of Terms

Compression garments: A clothing item that applies pressure to the body surface using elastic fibers (Cotter, Laing, & MacRae, 2011).

Countermovement jump: A power test where the participant squats to 90 degrees, swings their arms, and jumps as high as possible (Jakeman, Byrne, & Eston, 2010).

Ergogenic aids: "Any substance, mechanical aid, or training method that improves sport performance" (Baechle & Earle, 2008, p. 180).

Isokinetic strength: A strength test that "uses equipment that provides resistance to movement at a given speed" (Baechle & Earle, 2008, p. 531).

Visual analog scale (VAS): A visually-represented 1-10 rating system whereby the participant can score their perceived feelings (Jakeman, Byrne, & Eston, 2010).

LITERATURE REVIEW

Introduction

Ergogenic aids are substances or devices used to improve athletic performance. While ergogenic aids are most commonly thought of as nutritional supplements, they can fall into three categories including mechanical, physiological, and mental ergogenic aids (Baechle & Earle, 2008; *Segen's Medical Dictionary*, 2012). Compression garments are a common mechanical ergogenic aid that applies pressure to the skin and underlying tissues. Such garments are designed for extended wear in order to enhance athletic performance and recovery (Cotter, Laing, & MacRae, 2011). Most come in a variety of styles, including full tights, shorts, stockings, and calf sleeves, as well as upper body garments.

The elastic fibers found in compression garments are used to apply external pressure to the athlete's limbs. The pressure results from the elastic strain, or the tendency of a stretched fiber to return to its unstretched state (Dias, Yahathugoda, Fernando, & Mukhopadhyay, 2009). Most garments are available in a variety of compressive strengths and often employ compression grading, which exerts more pressure at the distal end and decreases toward the proximal. The concept of pressure grading is based on Poiseuille's Law, which states that fluid movement in a cylindrical tube is inversely proportionate to its pressure gradient (Avril, Bouten, Dupuis, Drapier, & Pouget, 2010). By this reasoning, graded compression stockings should prevent venous pooling in the lower leg. However, its practical applications in human tissues have been questioned.

Manufacturers of compression garments claim that their products can enhance venous return, increase lactate removal, reduce muscle soreness, accelerate recovery, increase muscle oxygenation, improve thermoregulation, and improve performance in strength, power, and endurance activities (SKINS Science, n.d.). However, many of these claims are made in the absence of conclusive research. In addition, a lack of homogeneity in methods and subject choice creates challenges in interpreting and generalizing the research results. Therefore, the purpose of this review is to investigate the manufacturers' claims and evaluate the growing body of research regarding compression garments as an ergogenic aid for athletic performance and recovery.

General Effects

As a non-pharmacological ergogenic aid, compression stockings are generally safe for healthy individuals, and may be effective in enhancing venous return. One proposed mechanism suggests that compressing the superficial veins causes a greater flow rate in deeper ones (Lord & Hamilton, 2004). A study by Lattimer, Kalodiki, Kafeza, Azzam, and Geroulakos (2013) examined the effects of different levels of compression on venous outflow in healthy supine subjects. Both low (18-21 mmHg) and high (23-32 mmHg) grade compression stockings were more effective at increasing venous outflow, with no significant difference between the two (Lattimer et al., 2013). While Lattimer's results sound promising, and may support the medical use of compression stockings in post-surgical patients, the findings cannot be generalized directly to an athletic population or for use with non-supine activities.

In contrast, Lord and Hamilton (2004) used duplex ultrasound to examine the effects of 20-30 mmHg compression stockings on patients in both a supine and standing position. While their results were similar to Lattimers's in supine patients, the compression garments seemed to be ineffective at reducing the diameter of both superficial and deep veins in the calf upon standing. Therefore, they concluded that graded compression stockings did not provide any benefit to wearers in an upright position (Lord & Hamilton, 2004).

Use of magnetic resonance imaging also suggests that the effectiveness of compression may be highly individualized, depending on subcutaneous fat thickness in the lower leg. Body fat is less compressive than muscle tissue, which contains most of the venules and venous blood in the lower leg. In addition, body fat may shield other tissues from external forces, leading to lower intramuscular and venous compression. Therefore, individuals with less body fat in the calf region may experience more benefit from compression garments (Avril et al., 2010).

Medical Use

By this same reasoning, use of compression therapy also has applications in preventing and treating peripheral edema. Here, the Law of Laplace suggests that the further a fabric is stretched, the less compressive force it will apply to the underlying tissues. Thus, the clinical implications of the equation suggest that using compression wraps to prevent edema may be more effective than retrospectively applying compression to a swollen limb (Basford, 2003). In accordance with Avril et al. (2010), Basford also suggests that compression garments may also be more effective at preventing peripheral edema in slender individuals.

Compression garments are also commonly used in the medical setting for the prevention of deep vein thromboses (DVT) in post-surgical patients. Because most DVTs occur in the calf region, knee-high compression stockings are most commonly used to decrease venous stasis in the underlying blood vessels (Walker & Lamont, 2008). Based on Latimer et al.'s (2013) results, the stockings may be more effective in patients recovering in the supine position.

Cases of orthostatic intolerance present a more systemic medical use for localized compression. Orthostatic intolerance involves the inability to maintain a standing, upright posture following a change in body position, and often includes episodes of syncope or presyncope. This may be due to a decrease in stroke volume and failure of the heart rate and blood vessels to correct from the change in posture (Privett, George, Whyte, & Cable, 2010). Privett et al. (2010) links the application in medicine and athletics with their study of orthostatic intolerance in moderately- to highly-trained athletes. Following maximal cardiovascular exercise, waist-high compression garments were shown to decrease orthostatic symptoms in five out of six participants. The results are particularly important, since several pharmaceutical treatments for orthostatic intolerance are listed as banned substances for competitive athletes (Privett et al., 2010).

Endurance Performance

Trail running. Despite endorsement from elite level athletes, much of the research does not support the use of compression stockings for performance enhancement in endurance events. Trail runners experienced no difference in heart rate, blood lactate levels, completion time, or RPE when wearing compression stockings during a 15.6k time trial compared to when they did not. They also showed no change in strength or power maintenance, which suggests that the stockings did not aid in running performance or immediate recovery (Vercruyssen et al., 2014). Other authors have suggested that performance improvements may be biomechanical, citing muscle oscillations as a source of fatigue

(Kemmler et al., 2009). However, despite the uneven nature of trail running, which should seemingly increase muscle oscillations, this theory was not supported.

Distance running. Several studies have examined the use of compression garments during 10k races, or similar length time trials. Ali, Creasy, and Edge (2011) found no change in race times, heart rate, or blood lactate levels when competitive runners wore high (23-32), medium (18-21 mmHg), low (12-15 mmHg), or non-compressive stockings. However, unlike Vercruyssen et al.'s (2014) study, power was better maintained in low- or high-compression groups, suggesting a potential benefit toward sprint performance. An earlier study by Ali, Caine, and Snow (2007) supports some of these findings. Physiological markers of intensity including heart rate, blood lactate, VO_2, creatine kinase, and myoglobin remained consistent whether subjects wore high, low, or non-compressive stockings during a 40 minute time trial. However, the earlier study agrees more with Vercruyssen et al., as they did not exhibit the improved maintenance of power output as seen in the earlier runners.

Differences in the findings could be attributed to variation between the subject groups. While Ali's 2007 study used true endurance athletes—marathoners, triathletes, and ultradistance runners—the 2011 group included athletes that raced distances from 800 meters to the marathon. This observation suggests that compression garments may hold more benefit for those in shorter distance races. Further support for this idea comes from a study using different styles of compression garments on well-trained runners and triathletes. Subjects did not exhibit any differences in oxygen concentration, blood lactate levels, RPE, perceived muscle soreness, or time to exhaustion, whether they wore compression stockings, tights, a bodysuit, or non-compressive running clothes (Sperlich et al., 2010). This was one of the few studies that did not find an improvement in perceived muscle soreness with the use of compression garments. However, the authors suggested that RPE and muscle soreness ratings were not statistically significant due to the athletes' training status (Sperlich et al., 2010). Thus, the use of trained or untrained subjects may be crucial in interpreting the results.

While most other studies specified no change in heart rate, Varela-Sanz, España, Carr, Boullosa, and Esteve-Lanao (2011) found that runners wearing compression stockings achieved a lower percentage of their maximal heart rate when running at 10k pace. The authors hypothesized that the contribution of external compression to venous return could suggest less cardiac stress at a given workload (Varela-Sanz et al., 2011); however, no other studies have supported this claim. Varela-Sanz et al.'s subjects included highly trained runners with strict performance criteria. Again, this study suggests a difference in response between moderately and highly trained athletes. One possible explanation is that competitive runners tend to have low body fat percentages, which may lead to better compressive transfer to the underlying muscle and blood vessels (Avril et al., 2010; Basford, 2003)

Graded or discontinuous protocols. Kemmler et al. (2009) was one of the few studies that demonstrated performance enhancements while wearing compression garments. When moderately trained male runners were given a graded exercise test to volitional fatigue, runners achieved significantly higher speeds and total workloads when wearing below-knee compression stockings. In addition, runners achieved lactate threshold at significantly higher speeds when wearing the garments (Kemmler et al., 2009). Consistent with Ali et al., (2007) Kemmler et al. found no significant difference in heart rate, blood lactate or VO2. Unlike the others, this was the only study to use a graded exercise test as opposed to a consistent or self-paced time trial. The authors suggest that any improvement in running performance may have been biomechanical (Kemmler et al., 2009), which may have been exacerbated by the graded nature of the test.

Two other studies used discontinuous protocols to investigate endurance performance, but exhibited widely varying results. Rider, Coughlin, Hew-Butler, and Goslin's study found that male and female cross country runners exhibited lower blood lactate concentrations during a discontinuous, ramping treadmill protocol when wearing compression stockings. Interestingly, Rider et al. found that total time to exhaustion was significantly shorter when wearing the compression garments. This was one of the only studies to find a negative consequence to wearing compression garments. The authors' theory also stated that the shorter running time may have resulted in the lower blood lactate levels seen in the compression group (Rider et al., 2014). The second discontinuous protocol involved periods of both maximal and submaximal running, and found no difference in physiological or perceptual variables whether runners wore compression stockings, tights, full body garments, or non-compressive clothing (Sperlich et al., 2010). While both studies used similar grades of compression stockings, the difference in protocol may have influenced the variables. Due to the lack of homogeneity in testing protocols, comparing results between studies is often problematic.

Cycle ergometry. The investigation of compression stockings on blood lactate levels continued with Rimaud Messonnier, Castells, Devillard, and Calmels's (2010) study involving highly trained endurance athletes performing a graded cycle ergometer test. Consistent with many other studies, Rimaud and colleagues found no significant differences in heart rate, VO_2, or blood pressure in the control and compression groups. Interestingly, blood lactate levels were significantly higher immediately following exercise in the compression group. The authors hypothesized that the compressive garments may have impeded blood flow, thus limiting lactate removal (Rimaud et al., 2010). This finding directly contradicts the manufacturer's claim that compression garments can decrease blood lactate levels.

Muscular Endurance

In addition to cardiovascular endurance, the effects of compression on muscular endurance has been examined to a lesser degree. One study examined both running performance and muscular fatigue in terms of running economy. Running economy was assessed in terms of flight time, contact time, stride length, height, power output, and frequency. No significant differences were found in the mechanical variables between compression and non-compression groups, suggesting that runners experience fatigue in the same manner (Varela-Sanz, España, Carr, Boullosa, & Esteve-Lanao, 2011). Their results suggest that compression garments provide no mechanical benefit to distance runners.

Miyamoto, Hirata, Mitsukawa, Yanai, and Kawakami I (2011) investigated the effects of different grades of compression on the triceps surae (soleus and gastrocnemius) following exhaustive exercise. Subjects performed 15 sets of 10 calf raises, followed by 30 seconds of rest between sets. Peak force was compared before and after the exercise using electrical stimulation of the tibial nerve in singlet and triplet pulse patterns. Those wearing high compression stockings (30 mmHg) were found to have a smaller drop in force production when using the triplet pulse pattern, as compared to the control. The study failed to find any benefit to wearing low compression (18 mmHg) stockings during fatiguing exercise. The results are consistent with Duffield, Cannon, and King's (2010) conclusion that evoked twitch force following exhaustive exercise is not aided by compression garments, despite differences in the method of fatigue.

Sprint Performance

Compression garments are also frequently seen in shorter distance races. Faulkner, Gleadon, McLaren, and Jakeman (2013) investigated the effects of different types of compression garments on 400 meter sprint time. Regardless of garment type—full-length tights, short tights with calf sleeves, or non-compressive stockings—no differences were observed in heart rate, blood lactate, or performance time. However, subjects reported lower RPE when wearing either compression garment. This information suggests that athletes may be able to increase training intensity or volume due to lower RPE. Thus, compression stockings may indirectly aid in sprint training and performance, if only due to perceptual advantages.

Two studies investigated the effects of compression garments on a combination of sprinting and plyometric activities, which may offer more practical applications for team sports practice and competition. Duffield et al. (2010) failed to support the idea that compression garments may aid in sprint performance. Such garments did not seem to affect creatine kinase or blood lactate levels. This study also failed to find an improvement in power maintenance when wearing compression stockings, and thus does not support the idea that compression may be more useful in combined sprint and plyometric activities. However, the authors did find decreased feelings of muscle soreness in the compression group (Duffield et al., 2010).

Marcondes, Matheus Fidelis, and Nilson, (2011) also studied a combination of sprinting and plyometrics in the form of agility and volleyball-specific drills. Unlike Duffield et al. (2010), this study found increased levels of creatine kinase when players did not wear the compression stockings during practice. In addition, lactate dehydrogenase was also higher in the control group. The elevation of these enzymes in the blood suggests that more muscle damage occurred in the absence of compression garments. However, this was the only study to report these findings, and more research is needed to support these claims.

Recovery from exercise

While less of the research has viewed compression stockings as an aid to recovery, it may be a promising application. Manufacturers claim that compression products can enhance the recovery process and mitigate exercise induced muscle damage (SKINS Science, n.d.). However, the research in recovery protocols is also highly varied, and offer mixed results.

Short-term recovery. Two maximal cycling studies took a narrow look at the recovery process. Chatard et al. (2004) investigated the effects of wearing compression stockings between two 5-minute bouts of maximal cycling using elderly trained cyclists. Driller and Halson (2013) used younger athletes in a similar setup, with a longer time trial. Both studies resulted in a significantly smaller drop in power output in the post-recovery time trial when subjects wore compression stockings during the 60- (Driller & Halson, 2013) to -80-minute (Chatard et al., 2004) recovery period. Blood lactate was also lower during recovery for both groups, suggesting improved lactate clearance (Chatard et al., 2004; Driller & Halson, 2013).

While long-term recovery research may hold more practical application for endurance events, the two short-term studies may be beneficial for intermittent athletes. Multi-stage events such as cycling competitions, track meets, and team sports tournaments may require an athlete to recover quickly between bouts of exercise. The results of Driller and Halson (2013) and Chatard et al. (2004) suggest that compression garments show promising results for maintaining power output and decreasing blood lactate in individuals participating in maximal exercise with minimal recovery time.

Long-term recovery. The use of compression for long-term recovery may be of particular interest to coaches and athletes who do not engage in repeated bouts of exercise within a single day. DeGlanville and Hamlin (2012) found that such garments improved power maintenance in cyclists performing a 40k time trial. When subjects wore waist-high compression tights for 24 hours following the first trial, they experienced a 3.3% increase in average power output during the second trial. The authors proposed that the external compression may have aided in glycogen resynthesis during recovery, which would account for the decreased VO_2 values they observed in the second time trial (DeGlanville & Hamlin, 2012).

Further support for the use of compression in long-term recovery comes from a study of marathon runners. Subjects showed an increase in time to exhaustion during a graded treadmill test when below-knee compression stockings were worn for 48 hours post-marathon. Interestingly, this was the only study to use below-knee stockings instead of full tights or thigh-high garments. The authors cited compliance reasons for their choice of garments (Armstrong, Till, Maloney, & Harris, 2015).

Researchers have attempted to study the effects of compression following simulated team sports practices with varying results. One study of trained hockey players used an intermittent running protocol, designed to simulate the intermittent nature of practice and competition. Subjects wore either loose pants or compression tights for 24 hours after exercise, then completed a series of power tests. The authors found no significant difference in vertical or squat jump height between compression and passive recovery groups, suggesting that compression garments had not aided in power maintenance (Pruscino, Halson, & Hargreaves, 2013). However, this study differed from many, in that the exercise used to induce muscle damage was greatly different from the performance variable. This observation speaks for the heterogeneity of the compression research available.

Team sports practices often include a plyometric component, which has been widely shown to induce muscle soreness. Thus, the use of compression garments has been of particular interest for recovery from plyometric activity. Davies, Thompson, and Cooper (2009) investigated the effects of compression garments on biochemical and performance variables following plyometric box drops. Eleven trained subjects stepped from a 60 centimeter plyometric box, and completed a maximal vertical jump upon landing. However, the authors failed to demonstrate many positive effects. Post-recovery values for performance tests, as well as creatine kinase and lactate dehydrogenase levels remained unchanged whether or not subjects wore compression garments during recovery. The only difference included decreased feelings of muscle soreness in the compression trials (Davies, Thompson, & Cooper, 2009). The small sample size and the researchers' choice of trained subjects may have affected their results.

Conflicting results were found by Jakeman, Byrne, and Eston (2010), who used a similar protocol of plyometric box drops to induce muscle damage. Their results showed improved maintenance of squat jump height and isokinetic strength, as well as decreased feelings of muscle soreness for subjects in the compression group. However, the authors used recreationally active females (Jakeman et al., 2010) rather than a trained, mixed-gender group. While it might be inferred that trained individuals may have less body fat, and thus experience more deep venous compression due to the garments (Avril et al., 2010), the results are not congruent with this theory. A more likely explanation is that the box drops did not provide a strong enough stimulus to induce muscle damage in the trained individuals.

Measurements and Reliability

Ultrasound images. While magnetic resonance imaging (MRI) remains the gold standard for measuring muscle size, issues with cost and accessibility pose significant concerns. Ultrasound imaging offers a more practical and affordable alternative. A study of 12 recreationally active men suggested that ultrasound imaging is both a reliable and valid method of assessing linear muscle measurements when compared to MRI. Linear measures ranged in ICC from 0.84-0.94, with no significant different difference between the two modes (Worsley, Kitsell, Samuel, & Stokes, 2014).

The use of ultrasound has also been validated by computerized tomography (CT). One study of 20 adults with coronary artery disease reported an ICC of .92 when comparing ultrasound images to CT scans (Thomaes, Thomis, Onkelinx, Coudyzer, Cornelissen, & Vanhees, 2012), which surpassed the accepted threshold of .90 as an acceptable value for diagnostic testing (Worsley et al., 2014). Thomaes et al. (2014) also examined test-retest reliability using a single experienced ultrasound operator. Differences in measurements were not significant, with an ICC of 0.97 and an error percentage of 4.2%. Together, these results suggest that ultrasound is both reliable and valid when compared to criterion measures.

While the literature suggests that ultrasound may be a reliable measurement of muscle diameter, each of the aforementioned studies has used experienced technicians. One study using images of the rectus femoris examined the reliability between novice and experienced ultrasound operators. The ICC was reported as 0.787, suggesting a relatively high reliability despite differences in experience level. However, an ICC of 0.99 was seen between two experienced ultrasound operators, suggesting that additional experience may be beneficial. The authors cited transducer placement, pressure, and measurement errors as possible explanations for the variability between operators (Hammond, Mampilly, Laghi, Goyal, Collins, McBurney, et al., 2014).

Vertec. While laboratory force plates are considered the "gold standard" of muscular power measurements, they are not always practical in sport or exercise settings. Alternative measurement systems include portable force plates, contact mats, belt mats, and the Vertec Vertical Jump Meter (Buckthorpe, Morris, & Folland, 2012; Nuzzo, Anning, & Scharfenberg, 2011).

The Vertec consists of an adjustable metal pole with horizontal plastic vanes to indicate jump height to the nearest half inch. The pole is adjusted to the subject's reach height prior to jumping. At the apex of the jump, subject extends the shoulder to tap the highest reachable vane to indicate the height of the jump (Buckthorpe, Morris, & Folland, 2012, Nuzzo, Anning, & Scharfenberg, 2011). Two research studies sought to quantify the reliability of the Vertec when compared to criterion measures. A 2012 study found that vertical jump scores from the Vertec system are significantly correlated to those measured by the laboratory force plate. However, scores measured by the Vertec were significantly lower than criterion measures. The authors suggested this may be due to the skill involved with timing the arm swing at the apex of the jump (Buckthorpe, Morris, & Folland, 2012).

Similar results were reported by Leard et al., when comparing the Vertec and the Just Jump contact mat to the former criterion measure of three-camera motion analysis. The Vertec reported significantly lower jump heights compared to other measures. The authors suggested that shoulder flexibility and human error in setting and reading the Vertec system may have accounted for some of the difference (Leard et al., 2007).

Nuzzo, Anning, and Scharfenberg (2011) investigated inter- and intrasession reliability of the Vertec, as well as the Just Jump contact mat and the Myotest accelerometer-based vertical jump system. The Vertec demonstrated the lowest inter- and intrasession reliability among 79 recreationally active men and women, with the Myotest showing the best reliability. Based on these findings, the authors suggest a familiarization session when measuring vertical jump with the Vertec, and a minimum of three attempts to achieve maximum height (Nuzzo, Anning, & Scharfenberg, 2011).

Conclusion

Perceived muscle soreness and power maintenance following muscle-damaging exercise is of particular interest to athletes and researchers, as many manufacturers claim that their products can decrease the effects of exercise-induced muscle damage (SKINS Science). Several studies have suggested that compression garments may be effective in improving feelings of soreness (Jakeman et al., 2010; Davies et al., 2009) and perceived recovery (Pruscino et al., 2013). However, each of these studies have used waist-high compression tights, as opposed to shorter, knee-high stockings.

Knee-high stockings are widely available, comfortable to wear, and more affordable than full-length tights. The only recovery study using knee-high stockings demonstrated positive effects on recovery from distance running (Armstrong et al., 2015). However it is unclear whether those benefits would extend toward power maintenance and muscle soreness. The choice to use untrained subjects comes from the conflicting results found by two studies using a similar protocol. The study using recreationally active subjects found more benefit (Jakeman et al., 2010) than the study using trained individuals (Davies et al., 2009). Therefore, the purpose of this study is to investigate the difference between full-length tights and knee-high stockings following plyometric box drops in recreationally active individuals.

METHODS

Research has indicated that compression garments may be helpful in reducing muscle soreness (Jakeman et al., 2013; Davies et al., 2010; Pruscino et al., 2010) and improving power output (Chatard et al., 2004; Jakeman et al., 2010) when worn after muscle-damaging exercise. This may be helpful for athletes who train intensely, with little recovery between workouts. While most of the research has focused on thigh-high garments or full-length tights, it is unclear whether the same benefits would extend to the more popular knee-high style. Therefore, the purpose of this study was to evaluate the difference between knee-high and waist-high compression garments to aid in recovery from plyometric exercise. Subjects were assessed for perceived muscle soreness, swelling, vertical jump height, and isokinetic strength, in order to evaluate the difference between garment styles. A randomized, pretest-posttest design was used and compared to a control group; however, no placebo garment was introduced due to the obvious compressive qualities of the garments being studied.

Subjects

After IRB approval, a convenience sample of 30 healthy males aged 18-25 was recruited for participation. The sample size was chosen based on current literature using 8-11 subjects per group (Chatard et al., 2004; Jakeman et al., 2010; Pruscino et al.,2013). Subjects were located by a recruiting email will be sent out through the student Listserv. Activity criteria stated that subjects must be recreationally active (exercising 2-5 days per week), with no lower body plyometric training within the past 6 months. Other exclusion criteria included musculoskeletal injuries that could be worsened by plyometric activity (Jakeman, Byrne, & Eston, 2010). A Physical Activity Readiness Questionnaire (PAR-Q) was used to screen individuals for other chronic conditions that might exclude them from the trial (American College of Sports Medicine, 1998). Checking “Yes” on any item was grounds for exclusion. A health history questionnaire was also administered. 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 they had completed the study.

This study was approved by the university’s Institutional Review Board. Informed consent was obtained in writing after a thorough explanation of the study’s benefits, risks, and procedures. The study contained no more than minimal risk, other than mild cardiovascular and muscular fatigue during exercise, and the potential for delayed onset muscle soreness following plyometrics. Subjects were compensated $100 for their time—$40 after their third visit, and $60 upon completion of the study.

Instrumentation

Participant descriptive. Descriptive measurements were taken on all subjects, including age, height, weight, and body composition estimates using bioelectrical impedance analysis.

Perceived muscle soreness. A visual analog scale (VAS) was used to assess for perceived muscle soreness, as it is a widely accepted, repeatable method of measuring pain perception (Rosier, Iadarola, & Coghill, 2002). The VAS is a 10-cm horizontal line marked 0-10, with 0 being no pain at all, and 10 being the worst pain imaginable. Subjects were instructed to mark a vertical line on the area that corresponded to their perceived level of soreness felt when performing a body-weight squat to 90 degrees (Jakeman et al., 2010) and a body-weight calf raise. Subjects assessed their soreness five times over the course of the study, completing a separate VAS for both the thigh and the calf.

Muscle swelling. Images of muscle size were obtained using a Philips HD11 XE (Bothell, WA) ultrasound system to assess for swelling in the right lateral gastrocnemius and the rectus femoris. Subjects were instructed to lay supine on the examination table and relax the right leg. Following the midline of the limb, the 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 a permanent marker for future measurements, and the subject was instructed not to wash it off.

To assess the lateral gastrocnemius, subjects rested in 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, Medri, Martin, Leekam, Agur, & Mckee, 2000). The head of the transducer was again traced with permanent marker for future measurements.

Vertical jump height. Vertical jump was used to assess muscular strength and power. Subjects stood beneath the Vertec Vertical Jump Meter (Sports Imports) with arms overhead, and the pole was adjusted so the bottom bar was in line with their fingertips. Subjects were instructed to bend their knees and jump as high as possible, using their arm swing to assist in the motion. The highest rung the subject touched was used to determine 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 was used for analysis (Jakeman et. al, 2010; Nuzzo, Anning, & Scharfenberg, 2011).

Isokinetic strength. The Biodex System4 Isokinetic Dynamometer (Shirley, NY) was used to measure isokinetic strength of the knee extensors and the calf plantarflexors. Dynamometer settings for both positions were recorded for each subject for use in future measurements. To evaluate the knee extensor strength, subjects were seated upright in the Biodex and secured with lap- and shoulder-belts. The axis of rotation of the dynamometer was placed at the center of the knee, with the ankle held securely to the attachment. Subjects were given ten warmup reps, followed by a one-minute break. They were then instructed to exert maximal force throughout three repetitions at 60 degrees per second, using a 75-degree range of motion. Strong verbal encouragement was given throughout the test, and subjects were allowed to view their results on a computer monitor. The strongest contraction during extension was used for analysis (Jakeman et al., 2010), as well as the time to peak torque.

To evaluate calf strength, subjects were placed in the reclined position, with hip and knee flexed, and the shin parallel to the ground. The foot was securely attached to foot plate. Range of motion was set by the participant by subtracting five degrees from their maximal plantar- and dorsiflexion. Following ten warmup reps and a one-minute break, subjects were instructed to exert maximal force throughout five repetitions at 30 degrees per second. Again, subjects were given strong verbal encouragement and were allowed to view their results on the computer monitor. The strongest contraction during plantarflexion was used for analysis, as well as time to peak torque.

Treatment

Pretesting. All testing took place during the spring semester of 2016. Potential subjects attended a recruiting meeting, in which they were presented with the nature of the study, risks, and benefits. Informed consent was obtained in writing, as well as a PAR-Q and health history questionnaire to screen for exclusion criteria. Individuals meeting all necessary qualifications were then scheduled for subsequent visits.

Subjects completed initial testing on their first visit, including perceived muscle soreness ratings, ultrasound images of the lateral gastrocnemius and rectus femoris, isokinetic strength, and vertical jump height. Subjects were randomized into three groups: Full-length tights, knee-high stockings, and a passive recovery group who received no compression garment.

Exercise protocol. Plyometric exercise took place the on the second visit. Subjects were instructed on proper technique, and all exercise was monitored to minimize risk of injury. Each subject completed 10 sets of 10 plyometric box drop jumps. Subjects stepped from a 60 cm box and landed with feet together, lowering into a 90 degree squat. Immediately upon landing, they completed a maximal vertical jump. Up to ten seconds was allowed between drops, and one minute between sets (Jakeman et al., 2010).

Compression garments were donned by both compression groups immediately following exercise, and subjects wore the garments for the next 12 hours. Those in the passive recovery group were instructed to wear their normal clothing. Subjects were instructed to maintain their normal nutrition and hydration habits, and refrain from lower body exercise, nutritional supplements, and other recovery modalities until testing was complete. At the 12-hour mark, subjects in the compression groups were instructed to remove the garments, and not to put them on again for the remainder of the study. All subjects completed a VAS for perceived muscle soreness in the quadriceps and the calves at that time.

Post-testing. Subjects returned 24 hours after exercise to complete the first set of post-tests. The post-test included the same assessments used prior to exercise: a VAS to assess for perceived muscle soreness, ultrasound images, isokinetic strength, and vertical jump height, in that order. Post-testing was also completed at 48 and 72 hours after exercise, using the same protocol as previously described.

Analysis

A repeated measures ANOVA was used to analyze muscle size, power, peak torque, time to peak torque, and pain perception among groups (SPSS 23.0, Armonk, NY). Significance value was set at $p \leq$

0.05. A Levene’s test was used to assess for equal variance among groups, and pairwise comparisons were made using variables that showed significance.

ARTICLE

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 (Cotter, Laing, & MacRae, 2011). Once used primarily in medical treatment, such garments have made their way into the world of athletics as a mechanical ergogenic aid. However, the research on compression garments is highly varied in both procedures and outcomes. As a result, many questions still exist regarding proper use for the desired effects.

Manufacturers claim that their products can enhance both 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. Runners in both 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, Gleadon, 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 subjects wore compression stockings between two bouts of maximal cycling. The authors suggest that the decrease in blood lactate was responsible for the maintenance of anaerobic performance (Chatard et al., 2004). Jakeman, Byrne, and Eston (2010) also found improved power maintenance when compression stockings were worn following plyometric exercise. Female subjects 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 realistic for athletes to follow. Therefore, the purpose of this study is to compare the effects of knee-high compression stockings and waist-high garments for recovery from plyometric box drops. Subjective measurements of muscle soreness and objective measurements of muscle swellings (via muscle thickness), strength, and power were used to assess recovery in recreationally active males.

Methods

Participants. Thirty healthy males aged 18-25 was recruited for participation (mean ± SD: height 1.81 ± 0.078 m; body mass 79.28 ± 12.59 kg; age 21.40 ± 2.28) years). The sample size was chosen based on current literature using 8-11 subjects per group (Chatard et al., 2004; Jakeman et al., 2010; Pruscino et al.,2013). Subjects were randomized into three groups: full-length tights (n=11), knee-high stockings (n=10), and a control group (n=9) which received no garment. Activity criteria stated that subjects must be recreationally active (exercising 2-5 days per week), with no lower body plyometric training within the past 6 months. Other exclusion criteria included musculoskeletal injuries that could be worsened by plyometric activity (Jakeman, Byrne, & Eston, 2010). 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 (American College of Sports Medicine, 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.

Garments. The garments used in the study were the SKINS A400 Men's Active Long Tights and the SKINS Unisex Active Compression Socks. The compression socks contain 89% polyamide, 9% elastane, and 2% copper fiber. No information was available on the composition of the full tights.

Study design. The study used a randomized pretest-posttest design. Subjects completed initial testing on their first visit, including perceived muscle soreness ratings, ultrasound images of muscle thickness in the lateral gastrocnemius and rectus femoris, isokinetic strength of the knee extensors and ankle plantarflexors, and vertical jump height. This same set of tests was repeated on the third, fourth, and fifth visit (24, 48, and 72 hours post-exercise).

Plyometric exercise took place the on the second visit. Each subject completed 10 sets of 10 plyometric box drop jumps. Subjects stepped from a 60 cm box and landed with feet together, 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).

Compression garments were donned by the waist-high and knee-high compression groups immediately following plyometric exercise, and subjects wore the garments for the next 12 hours. The control group received no garment and wore their normal clothing. All subjects were instructed to remove the compression garments at the 12-hour mark if applicable, and leave them off for the remainder of the study. They also completed a visual analog scale (VAS) to assess for perceived muscle soreness in both the quadriceps and the calves, when completing a body weight squat and a body weight calf raise respectively. All subjects 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.

Subjects 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: a VAS to assess for perceived muscle soreness, ultrasound images of muscle thickness, isokinetic strength, and vertical jump height. Post-testing was also completed at 48 and 72 hours after exercise, using the same protocol as previously described.

Perceived muscle soreness. A VAS was used to assess for perceived muscle soreness, as it is a widely accepted, repeatable method of measuring pain perception (Rosier, Iadarola, & Coghill, 2002). The VAS is a 10-cm horizontal line marked 0-10, with 0 being no pain at all, and 10 being the worst pain imaginable. Subjects were instructed to mark a vertical line on the area that corresponds to their perceived level of soreness felt when performing a body-weight squat to 90 degrees (Jakeman et al.,

2010) and a body-weight calf raise. Subjects assessed their soreness at each testing session as well as 12 hours post-exercise, completing a separate VAS for both the thigh and the calf.

Ultrasound images. Images of muscle thickness were obtained using a Philips HD11 XE (Bothell, WA) ultrasound system to assess for swelling in the lateral gastrocnemius and the rectus femoris. Subjects were instructed to lay supine on the examination table and relax the right leg. Following the midline of the limb, the 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, subjects rested in 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, Medri, Martin, Leekam, Agur, & Mckee, 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 size 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 botttom 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. Reliability measures for the rectus femoris consistently showed an ICC between 0.95-0.99.

To assess 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.

Vertical jump. Vertical jump was used to assess muscular power. Subjects 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. Subjects 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 System4 Isokinetic Dynamometer (Shirley, NY) was used to measure isokinetic strength of the knee extensors and the plantarflexors of the calf. Dynamometer settings for both positions were recorded for each subject for use in future measurements. To evaluate the knee extensor strength, subjects 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. Subjects were given ten warmup repetitions, followed by a 60-second break. They were then instructed to exert maximal force throughout three repetitions at 60 degrees per second, using a 75-degree range of motion. Strong verbal encouragement was given throughout the test, and subjects were allowed to view their results on a computer monitor. The highest peak torque value during knee extension was used for analysis, as well as time to peak torque (Jakeman et al., 2010).

To evaluate plantarflexor strength, subjects were placed 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 the participant by subtracting five degrees from their maximal active plantar- and dorsiflexion range of motion. Following ten warmup repetitions and a 60-second break, subjects were instructed to exert maximal force throughout five repetitions at 30 degrees per second. Again, subjects were given strong verbal encouragement and were allowed to view their results on the computer monitor. The highest peak torque value during plantarflexion was used for analysis, as well as time to peak torque.

Statistical analysis. A one-way ANOVA was used for subject descriptives. A repeated measures ANOVA was used to analyze muscle thickness, performance, and pain perception variables among groups (SPSS 23.0, Armonk, NY). Significance value was set at $p \leq 0.05$ for each test. A

Levene's test was used to assess for equal variance among groups, and Bonferroni pairwise comparisons were made using variables that showed significant interactions.

Results

Descriptive statistics were calculated for each of the treatment and control groups. A one-way ANOVA was used, and no significant difference was seen in age (p = 0.667), height (p = 0.452), weight, or body composition between groups (Table 1).

A repeated measures ANOVA was used to assess for differences in each variable, with a Levene's test to assess for variance between groups. The Levene's test showed equal variance among all three groups. Results from the multivariate analysis showed that both treatment and control groups experienced similar changes in all measures of recovery. The results of the multivariate analysis were not significant (Table 2). Means and SD can be found in the Appendix. Because no significant interactions were observed among treatment and control groups across time, the groups were combined and the main effects of time were examined. A significant time main effect occurred with six of the variables showing pooled effects of plyometric exercise across time regardless of treatment ($p < 0.05$) (Table 3).

Table 1

Descriptive statistics

Group	Descriptive	Mean	Standard Deviation
Control (n = 9)	Age (years)	21.56	2.55
	Height (m)	1.83	0.07
	Weight (kg)	85.23	15.83
	Body Fat (%)	17.01	5.35
Short Stockings (n = 10)	Age (years)	21.80	2.53
	Height (m)	1.80	0.08
	Weight (kg)	75.75	9.46
	Body Fat (%)	15.55	3.92
Full Tights (n = 11)	Age (years)	20.91	1.92
	Height (m)	1.79	0.08
	Weight (kg)	77.62	11.46
	Body Fat (%)	16.36	4.29

The post-hoc analysis examined differences contributed by time using pairwise comparisons with Bonferroni adjustment were done for muscle soreness ratings (Table 4) as well as strength, power, and swelling (Table 5). For both the lateral gastrocnemius (LG) and the rectus femoris (RF), the majority of significant differences occurred when comparing a post-exercise measure to the pre-exercise measure. The rectus femoris also showed several significant differences between the 72-hour post-exercise measurement and earlier measures.

Table 2

Time-group interaction

Variable	Wilks' Lambda	F	Hypothesis DF	Error DF	Significance	Partial η²
VAS Calves (mm)	0.727	1.035	8	48	0.424	0.147
VAS Quads (mm)	0.687	1.238	8	48	0.298	0.171
Vertical Jump (cm)	0.808	0.937	6	50	0.477	0.101
KE Peak Torque (n·m)	0.637	2.109	6	50	0.069	0.202
PF Peak Torque (n·m)	0.699	1.635	6	50	0.157	0.126
KE TTPT (ms)	0.971	0.123	6	50	0.993	0.015
PF TTPT (ms)	0.827	0.831	6	50	0.522	0.091
RFUS (cm)	0.875	0.552	6	48	0.766	0.065
LGUS (cm)	0.840	0.699	6	46	0.652	0.084

VAS = Visual analog scale (perceived muscle soreness), KE = Knee extensors, PF = Plantar flexors, TTPT = Time to peak torque, RFUS = Rectus femoris ultrasound (muscle thickness), LGUS = Lateral gastrocnemius ultrasound (muscle thickness)

Table 3

Time effect

Variable	Wilks' Lambda	F	Hypothesis DF	Error DF	Significance	Partial η²
VAS Calves (mm)	0.370	10.207	4	24	<0.001*	0.630
VAS Quads (mm)	0.152	33.472	4	24	<0.001*	0.848
Vertical Jump (cm)	0.525	7.550	3	25	0.001*	0.475
KE Peak Torque (n·m)	0.487	8.762	3	25	<0.001*	0.513
PF Peak Torque (n·m)	0.874	1.196	3	25	0.331	0.164
KE TTPT (ms)	0.385	13.294	3	25	<0.001*	0.615
PF TTPT (ms)	0.560	6.545	3	25	0.002*	0.440
RFUS (cm)	0.794	2.081	3	24	0.129	0.206
LGUS (cm)	0.876	1.083	3	23	0.376	0.124

VAS = Visual analog scale (perceived muscle soreness), KE = Knee extensors, PF = Plantar flexors, TTPT = Time to peak torque, RFUS = Rectus femoris ultrasound (muscle size), LGUS = Lateral gastrocnemius ultrasound (muscle size)

* $p<0.05$

Table 4

Pairwise comparisons for perceived muscle soreness by time

	0-12 hours	0-24 hours	0-48 hours	0-72 hours	12-24 hours	12-48 hours	12-72 hours	24-48 hours	24-72 hours	48-72 hours
PF	<0.001*	0.002*	0.016*	0.177	1.000	0.841	0.011*	1.000	0.062	0.117
KE	<0.001*	<0.001*	<0.001*	<0.001*	1.000	1.000	0.015*	0.633	<0.001*	<0.001*

PF = Plantar flexors

KE = Knee extensors

* $p<0.05$

Similarly, all of the significant differences for the strength, power, and swelling comparisons were found when comparing a pre-exercise measure to a post-exercise measure (Table 5). Time to peak torque (TTPT) for the ankle and the knee showed the greatest number of significant relationships, with each of the three pre-to-post comparisons being significant at $p < 0.05$.

Table 5

Pairwise comparisons for power, strength, and swelling by time

	0-24	0-48	0-72	24-48	24-72	48-72
Vertical Jump	0.006*	0.290	1.000	0.981	0.055	0.354
KE Peak Torque	0.000*	0.007*	0.011*	1.000	0.970	1.000
PF Peak Torque	1.000	1.000	0.624	1.000	0.983	0.759
KE TTPT	0.018*	0.000*	0.000*	0.494	0.339	1.000
PF TTPT	0.002*	0.001*	0.007*	1.000	1.000	1.000
RFUS	0.777	0.145	1.000	1.000	1.000	0.447
LGUS	1.000	0.577	0.634	0.803	1.000	1.000

VAS = Visual analog scale (perceived muscle soreness), KE = Knee extensors, PF = Plantar flexors, TTPT = Time to peak torque, RFUS = Rectus femoris ultrasound (muscle thickness), LGUS = Lateral gastrocnemius ultrasound (muscle thickness)

* $p<0.05$

Discussion

The purpose of this study was to evaluate the effects of compression garments on muscular strength, size, power, and soreness following plyometric exercise. Thirty healthy, recreationally active males were monitored for 72 hours following a plyometric box drop protocol. Perceptual measures of muscle soreness were collected using a VAS, as well as objective measures of vertical jump height, isokinetic strength, and muscle swelling via ultrasound. Together, these tests were used to assess subjects’ recovery.

Perceived muscle soreness. According to our results, perceived muscle soreness in the quadriceps ($p = 0.298$) and the calves ($p = 0.424$) did not vary significantly among the treatment and control groups. This contradicts many former studies, which found increased muscle soreness in those that did not wear compression garments (Davies et al., 2009; Jakeman et al., 2010). While our results did not reach statistical significance between groups, an interesting pattern in the quadriceps emerged:

Muscle soreness in the control group peaked at 12 hours post-exercise, while the full tights group peaked at 24, and the short stockings group at 48. This finding warrants further investigation, and may necessitate a larger sample size in order to see statistical significance. Interestingly, muscle soreness in the calves did not follow the same pattern. Muscle soreness peaked at 12 hours for both the control and short stockings group, and 24 hours for the full tights.

Combined data from all three groups showed that perceived muscle soreness at 12 (calves $p < 0.001$, quadriceps $p < 0.001$), 24 (calves $p = 0.002$, quadriceps $p < 0.001$), and 48 (calves $p = 0.016$, quadriceps $p < 0.001$) hours post-exercise significantly increased from baseline values for both muscle groups. By 72 hours post-exercise, the quadriceps still showed significantly elevated soreness compared to baseline levels ($p = 0.000$), though the calves seemed to have recovered ($p = 0.177$).

Our results can be compared most closely to Davies, Thompson, and Cooper (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 subjects (Davies et al., 2009). This finding leads us to believe that subjects' 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 subjects should be "recreationally active" with no prior jump training, we received subjects 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. As a result, 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.

Finally, the VAS may have caused some confusion among participants. The control group, the first subjects to begin their trials, reported a pre-exercise VAS score of 9.33 ± 11.36 for the quadriceps, and 3.78 ± 6.96 for the calves. While the differences weren't significant, they were noticeably higher than each of the treatment groups, which completed their trials at a later date. Thus, it is possible that the researchers' ability to explain the VAS improved over time, and that earlier VAS scores reflected joint discomfort or other pain sensations as opposed to true muscle soreness.

Muscle swelling. Jakeman, Byrne, and Eston (2010) suggested that future compression research investigate the garments' effects on edema. Based on our findings, subjects in the compression groups did not experience less muscle swelling in the rectus femoris (p = 0.129) or the lateral gastrocnemius (p = 0.376) compared to the control group. The subjects' daily activities over the course of the trial may have influenced the garments' effectiveness. Our subjects were young, active college students, and many reported commuting by bike or on foot even though they refrained from structured exercise. One study suggested that compression garments were effective in increasing venous outflow in supine patients, though the effects were not present in the upright position (Lord & Hamilton, 2004). Our subjects were instructed to attend class and work as they normally do, and most likely remained upright for much of their 12-hour wear time. As a result, our subjects' posture and daily activities may have influenced the garments' effects on swelling.

However, several studies have suggested that compression garments may be effective in reducing "evening edema," or volume differences in the lower leg following a typical workday (Partsch & Winiger, 2004). In a study of patients with chronic venous disease, knee-high compression stockings were shown to reduce evening edema when worn for nine hours during subjects' normal daily activities (Carvalho, Lopes Pinto, Guerreiro Godoy, & Pereira de Godoy, 2015). A similar study using both healthy individuals and those with varicose veins and venous edema showed similar results. Over a 7-hour workday, knee-high compression stockings were shown to reduce evening edema by around 50% (Partsch & Winiger, 2004). These findings, particularly in relation to healthy individuals, suggest that our subjects should have experienced similar results. The fact that they did not suggests fundamental differences in the subjects or the garments used.

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 (Carvalho, Lopes Pinto, Guerreiro Godoy, & Pereira de Godoy, 2015; Lord & Hamilton, 2004), whereas

Partsch and Winiger (2004) examined gradings from 8-20 mmHg, and found garments over 10mmHg 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, Carvalho and colleagues (2015) measured edema immediately upon removal of the garment. It is possible that our subjects 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 were chosen for analysis for their ease of visibility on the ultrasound images. However, it is possible that other muscles in the quadriceps group or the calves may have experienced swelling to a 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 both the knee and the ankle to assess the quadriceps and the calves respectively. Differences between control and compression groups were not significant for either muscle group (knee $p = 0.069$, ankle $p = 0.157$). However, a significant effect of time was present in the knee, with the 24, 48, and 72 hour post-exercise measurements being significantly lower than baseline values ($p < 0.05$). This suggests that muscle damage occurred as a result of the plyometric protocol, resulting in mild loss of function at the quadriceps. 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 plyometric protocol found that isokinetic strength at the knee was significantly higher in the compression groups in the four days following muscle damaging exercise (Jakeman, Byrne, & Eston, 2010). Our results failed to support these findings. However, our data suggest 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 did not reach statistical significance. While the authors 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, as well as the use of female subjects, 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 ankle. Examination of group data suggests inconsistent performance among subjects. For the control and full tights group, peak torque values for 72 hours post-exercise were higher than baseline values, suggesting that practice may have influenced subjects' performance. Many subjects casually mentioned that the setup felt "awkward" or "unnatural." This 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. Vertical jump height was used as a measure of muscular power. Changes in vertical jump height among treatment and control groups were not statistically significant ($p = 0.477$), suggesting that neither knee-high stockings nor full compression tights aided in power maintenance when worn during recovery. Likewise, Davies, Thompson, and Cooper (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, Byrne, & Eston, 2010). Our results failed to 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 ($p = 0.006$). The similarity between our results and those of Davies, Thompson, and Cooper (2009) suggests that our subject pool may share more characteristics with their trained athletes than the untrained females used by Jakeman, Byrne, and Eston (2010).

Conclusions

The purpose of this study was to compare the effects of two different styles of compression garments on recovery from plyometric exercise. Our results suggest that muscle damage occurred, though no significant differences in perceptual or performance variables were seen among groups wearing full-length 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.

SUMMARY AND CONCLUSIONS

Compression garments are a widely used mechanical ergogenic aid that have become popular in athletics in recent years. The purpose of this study was to evaluate the effects of knee-high compression garments and full-length tights on recovery from muscle damaging exercise. This study used a randomized pretest-posttest design, in which thirty healthy, recreationally active college-aged males were randomly allocated into control, short stockings, or full tights groups. Subjects participated in a plyometric box drop protocol designed to induce muscle damage, and wore the compression garments for 12 hours post-exercise, if applicable. Tests of muscle strength, power, swelling, and perceived soreness were applied at 24, 48, and 72 hours following the muscle damaging protocol.

Our first research question sought to answer how each compression garment would affect perceived muscle soreness. Subjects evaluated two muscle groups—the quadriceps and the calves—using a visual analog scale to represent perceptions of muscle pain. Our overall model for the ANOVA stated that differences between both compression and control groups were not statistically significant ($p = 0.477$), suggesting that neither compression garment had helped decrease feelings of muscle soreness. Only a significant effect of time was found. When groups were combined, muscle soreness was significantly higher than baseline at 12, 24, 48, and 72 hours for the quadriceps, and 12, 24, and 48 hours for the calves ($p < 0.05$).

Our second question addressed whether wearing compression would help subjects maintain their muscular power and strength, measured by vertical jump height and isokinetic dynamometry. Isokinetic strength was measured at both the knee and the ankle to assess the quadriceps and calves respectively. Again, the overall ANOVA model suggests that no significant differences were seen between groups for either measure. Combined data suggests a significant time effect, with vertical jump being significantly lower at the 24 hour post-exercise measure ($p = 0.006$). For isokinetic strength, only the quadriceps showed a significant time effect when the groups were combined. Peak torque was significantly lower than baseline at 24 ($p = 0.00$), 48 ($p = 0.007$) and 72 ($p = 0.011$) hours post-exercise.

Our third question examined whether compression garments would affect muscle swelling in the rectus femoris and the lateral gastrocnemius. Ultrasound images were taken for each muscle group, and muscle thickness was assessed using the caliper tool. Our results showed no differences between treatment and control groups, as well as no significant effect of time. Reliability measures ranged from 0.952-0.999, meeting the threshold of acceptability of 0.90 for diagnostic imaging (Worsley et al., 2014). These results were similar to those seen by Thomaes et al. (2014), who reported an ICC of 0.97 when using an experienced ultrasound technician.

Our final question addressed what differences were seen in perceptual and performance variables between the two models of compression garments. The non-significance of our ANOVA suggests that no differences occurred among the full tights, short stockings, and the control group. However, a significant effect of time was present for six of the variables measured. Based on our results, we can conclude that compression garments did not help attenuate muscle soreness, swelling, or decrements in strength and power. While no subjects reported experiencing undue pain, discomfort, or other negative effects of wearing the garments, our study suggests that such garments offer no performance benefit to any of the variables we tested.

However, our research was not without its limitations. Most notably, our subjects showed great variation in their definition of "recreationally active." We received individuals from a variety of backgrounds, including current and former team sports athletes, endurance athletes, and recreational exercisers. As a result, individuals may have experienced varying degrees of muscle damage depending on their typical exposure to jumping activities. Future researchers may wish to clarify their participants' activity requirements beyond "recreationally active" and "exercising 2-5 days per week." From a psychological standpoint, individuals may have differed in their concepts maximal effort during the jump protocol, vertical jump test, and isokinetic strength measures. Submaximal effort during the jump protocol may have resulted in less muscle damage than might be expected. Similarly, during strength and power testing, exerting submaximal effort would result in lower peak torque and vertical jump height values.

The effects of practice may also have influenced our results. For recreational athletes and exercisers alike, the isokinetic strength tests were unfamiliar, as most individuals do not use an isokinetic dynamometer on a regular basis. Those with no sports background may have also been unfamiliar with vertical jump testing. To achieve more reliable results, future researchers should consider implementing a familiarization session prior to testing, in which individuals can practice with the equipment.

Although good reliability was achieved in measuring muscle thickness on the ultrasound images (ICC > 0.95), the images' validity could be questioned. Ultrasound images are highly sensitive to the transducer location, angle, and pressure used (Hammond et al., 2014). Although the location of the transducer was traced on the skin to reduce error, some variation still occurred. Use of an experienced ultrasound technician would be highly recommended for future studies, and may help pick up subtle differences in muscle swelling. Alternatively, magnetic resonance imaging could be used if the equipment and funding was available.

Finally, the garments themselves may have contributed some variation to the treatment effects. Unlike medical grade compression garments, the products we used did not specify how much pressure was exerted by the garments. A representative from the company mentioned an overall rating of 19-33 mmHg for their entire product line, but no further information was given on the products used in our study. The full length tights were sized by height and weight, and the stockings were sized by calf circumference. Each size served a broad range of individuals, which suggests that compressive force may have been different for each person. Future studies using these products should consider quantifying the amount of compression exerted by the product on each subject.

REFERENCES

AHA/ACSM Joint position statement: Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. (1998). *Medicine & Science in Sports & Exercise, 30*(6), 1009-1018. Retrieved March 4, 2015, from http://journals.lww.com/acsm-msse/Fulltext/1998/06000/AHA_ACSM_Joint_Position_Statement__Recommendations.34.aspx

Ali, A., Caine, M.P., & Snow, B.G. (2007). Graduated compression stockings: Physiological and perceptual responses during and after exercise. *Journal of Sports Sciences, 25*(4), 413-419.

Ali, H. A., Creasy, A. R., & Edge, A. J. (2011). The effect of graduated compression stockings on running performance. *Journal of Strength and Conditioning Research, 25*(5), 1385-1392.

Armstrong, S., Till, E., Maloney, S., & Harris, G. (2015). Compression socks and functional recovery following marathon running. *Journal of Strength and Conditioning Research,29*(2), 528-533.

Avril, S., Bouten, L., Dubuis, L., Drapier, S., & Pouget, J.-F. (2010). Mixed experimental and numerical approach for characterizing the biomechanical response of the human leg under elastic compression. *Journal of Biomechanical Engineering, 132*(3), 031006-031006.

Baechle, T.R. & Earle, R.W. (2008). *Essentials of strength training and conditioning.* Champaign, IL: Human Kinetics.

Basford, J. (2003). The law of Laplace and its relevance to contemporary medicine and rehabilitation. *Archives of Physical Medicine and Rehabilitation, 83*(8), 1165-1170.

Bemben, M. (2002). Use of diagnostic ultrasound for assessing muscle size. *Journal of Strength and Conditioning Research, 16*(1), 103-108

Buckthorpe, M., Morris, J., & Folland, J. P. (2012). Validity of vertical jump measurement devices. *Journal of Sports Sciences, 30*(1), 63-69. Retrieved March 3, 2016.

Chatard, J. C., Atlaoui, D., Farjanel, J., Louisy, F., Rastel, D., & Guézennec, C. Y. (2004). Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. *Eur J Appl Physiol, 93*(3), 347-352.

Chow, R., Medri, M., Martin, D., Leekam, R., Agur, A., & Mckee, N. (2000). Sonographic studies of human soleus and gastrocnemius muscle architecture: Gender variability.*European Journal of Applied Physiology, 82*, 236-244.

Cotter, J. D., Laing, R. M., & MacRae, B. A. (2011). Compression garments and exercise: garment considerations, physiology and performance. *Sports Medicine*, *41*(10), 815+. Retrieved from http://go.galegroup.com.ezproxy.lib.ndsu.nodak.edu/ps/i.do?id=GALE%7CA268651414&v=2.1&u=ndacad_58105ztrn&it=r&p=EAIM&sw=w&asid=ed53975292c2087038cc5b62d13ef310

Davies, G. V., Thompson, G. K., & Cooper, G. S.-M. (2009). The effects of compression garments on recovery. *Journal of Strength and Conditioning Research, 23*(6), 1786-1794.

De Glanville, M. K., & Hamlin, J. M. (2012). Positive effect of lower body compression garments on subsequent 40-kM cycling time trial performance. *Journal of Strength and Conditioning Research, 26*(2), 480-486.

Dias, T., Yahathugoda, D., Fernando, A., & Mukhopadhyay, S. (2009). Modelling the interface pressure applied by knitted structures designed for medical-textile applications. *Journal of the Textile Institute,94*(3-4), 77-86.

Driller, M., & Halson, S. (2013). The effects of lower-body compression garments on recovery between exercise bouts in highly-trained cyclists. *Journal Of Science And Cycling, 2*(1), 45-50. Retrieved from http://www.jsc-journal.com/ojs/index.php?journal=JSC&page=article&op=view&path%5B%5D=30

Duffield, R., Cannon, J., & King, M. (2010). The effects of compression garments on recovery of muscle performance following high-intensity sprint and plyometric exercise. *Journal of Science and Medicine in Sport, 13*(1), 136-140.

Ergogenic aid. (n.d.) *Segen's Medical Dictionary*. (2011). Retrieved February 10 2015 from http://medical-dictionary.thefreedictionary.com/ergogenic+aid

Faulkner, A. J., Gleadon, R. D., McLaren, R. J., & Jakeman, R. J. (2013). Effect of lower-limb compression clothing on 400-m sprint performance. *Journal of Strength and Conditioning Research, 27*(3), 669-676.

Hammond, K., Mampilly, J., Laghi, F. A., Goyal, A., Collins, E. G., Mcburney, C., . . . Tobin, M. J. (2014). Validity and reliability of rectus femoris ultrasound measurements: Comparison of curved-array and linear-array transducers. *Journal of Rehabilitation Research and Development J Rehabil Res Dev, 51*(7), 1155-1164. Retrieved March 2, 2016.

Jakeman, J., Byrne, C., & Eston, R. (2010). Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. *Eur J Appl Physiol, 109*(6), 1137-1144.

Kemmler, V. W., Stengel, V. S., Köckritz, V. C., Mayhew, V. J., Wassermann, V. A., & Zapf, V. J. (2009). Effect of compression stockings on running performance in men runners. *Journal of Strength and Conditioning Research, 23*(1), 101-105.

Lattimer, C. R., Kalodiki, E., Kafeza, M., Azzam, M., & Geroulakos, G. (2013). Quantifying the degree graduated elastic compression stockings enhance venous emptying. *European Journal of Vascular & Endovascular Surgery, 47*(1), 75-80.

Leard, J. S., Cirillo, M. A., Katsnelson, E., Kimiatek, D. A., Miller, T. W., Trebincevic, K., & Garbalosa, J. C. (2007). Validity of Two Alternative Systems for Measuring Vertical Jump Height. *J Strength Cond Res The Journal of Strength and Conditioning Research, 21*(4), 1296-1299. Retrieved March 3, 2016.

Lord, R. S., & Hamilton, D. (2004). Graduated compression stockings (20−30 mmHG) do not compress leg veins in the standing position. *ANZ Journal Of Surgery*, *74*(7), 581-585. doi:10.1111/j.1445-2197.2004.02994.x

Marcondes, F., Matheus Fidélis, F., & Nilson, P.-S. (2011). Efeito do uso de meia elástica sobre os níveis dos biomarcadores de lesão muscular em atletas de voleibol após atividade física Effect of elastic stockings on biomarkers levels of muscle soreness in volleyball players after exercise. *Jornal Vascular Brasileiro, 10*(4), 289.

Miyama, M, Nosaka, K. Muscle Damage and Soreness Following Repeated Bouts of Consecutive Drop Jumps. *Advanced Exercise and Sports Physiology*. 2004;10(3):63–69.

Miyamoto, N., Hirata, K., Mitsukawa, N., Yanai, T., & Kawakami, Y. (2011). Effect of pressure intensity of graduated elastic compression stocking on muscle fatigue following calf-raise exercise.*Journal of Electromyography and Kinesiology, 21*(2), 249-254.

Nuzzo, J. L., Anning, J. H., & Scharfenberg, J. M. (2011). The Reliability of Three Devices Used for Measuring Vertical Jump Height. *Journal of Strength and Conditioning Research, 25*(9), 2580-2590. Retrieved March 5, 2016.

Partsch, H., Winiger, J., & Lun, B. (2004). Compression Stockings Reduce Occupational Leg Swelling. *Dermatologic Surgery Dermatol Surg, 30*(5), 737-743. Retrieved March 30, 2016.

Privett, S., George, K., Whyte, G., & Cable, N. (2010). The effectiveness of compression garments and lower limb exercise on post-exercise blood pressure regulation in orthostatically intolerant athletes. *Clinical Journal of Sport Medicine, 20*(5), 362-367.

Pruscino, C., Halson, S., & Hargreaves, M. (2013). Effects of compression garments on recovery following intermittent exercise. *European Journal of Applied Physiology, 113*(6), 1585-1596. Retrieved February 23, 2015, from http://link.springer.com.ezproxy.lib.ndsu.nodak.edu/article/10.1007/s00421-012-2576-5#

Rider, C. B., Coughlin, M. A., Hew-Butler, D. T., & Goslin, R. B. (2014). Effect of compression stockings on physiological responses and running performance in division III collegiate cross-country runners during a maximal treadmill test. *Journal of Strength and Conditioning Research, 28*(6), 1732-1738.

Rimaud, D., Messonnier, L., Castells, J., Devillard, X., & Calmels, P. (2010). Effects of compression stockings during exercise and recovery on blood lactate kinetics. *Eur J Appl Physiol, 110*(2), 425-433.

Rosier, E., Iadarola, M., & Coghill, R. (2002). Reproducibility of pain measurement and pain perception. *Pain, 98*(1), 205-216.

SKINS Science. (n.d.). Retrieved November 21, 2014, from http://www.skins.net/usa/

Sperlich, B., Haegele, M., Achtzehn, S., Linville, J., Holmberg, H.-c., & Mester, J. (2010). Different types of compression clothing do not increase sub-maximal and maximal endurance performance in well-trained athletes. *Journal of Sports Sciences, 28*(6), 609-614.

Thomaes, T., Thomis, M., Onkelinx, S., Coudyzer, W., Cornelissen, V., & Vanhees, L. (2012). Reliability and validity of the ultrasound technique to measure the rectus femoris muscle diameter in older CAD-patients. *BMC Medical Imaging BMC Med Imaging, 12*(1), 7. Retrieved March 2, 2016.

Troynikov, O., Ashayeri, E., M., B., A., S., Alam, F., & Marteau, S. (2010). Factors influencing the effectiveness of compression garments used in sports. *Procedia Engineering, 2*(2), 2823-2829. Retrieved February 11, 2015, from http://www.sciencedirect.com/science/article/pii/S1877705810003279#

Varela-Sanz, A. A., España, A. J., Carr, A. N., Boullosa, A. D., & Esteve-Lanao, A. J. (2011). Effects of gradual-elastic compression stockings on running economy, kinematics, and performance in runners. *Journal of Strength and Conditioning Research, 25*(10), 2902-2910.

Vercruyssen, F., Easthope, C., Bernard, T., Hausswirth, C., Bieuzen, F., Gruet, M., et al. (2014). The influence of wearing compression stockings on performance indicators and physiological responses following a prolonged trail running exercise. *European Journal of Sport Science, 14*(2), 144-150.

Walker, L., & Lamont, S. (2008). Graduated compression stockings to prevent deep vein thrombosis.*Nursing Standard, 22*(40), 35-38.

Worsley, P. R., Kitsell, F., Samuel, D., & Stokes, M. (2014). Validity of measuring distal vastus medialis muscle using rehabilitative ultrasound imaging versus magnetic resonance imaging. *Manual Therapy, 19*(3), 259-263. Retrieved March 2, 2016.

APPENDIX. DATA BY TREATMENT GROUP

Table A1

Vertical jump height

Group	Pre-Exercise (cm)	24 Hours Post-Exercise (cm)	48 Hours Post-Exercise (cm)	72 Hours Post-Exercise (cm)
Control	59.41 ± 5.64	55.03 ± 6.29	57.71 ± 4.50	58.28 ± 5.62
Short Stockings	50.17 ± 8.76	47.88 ± 11.63	47.50 ± 14.53	48.51 ± 13.29
Full Tights	52.42 ± 9.40	49.53 ± 11.91	49.88 ± 12.65	51.61 ± 13.01
Pooled Data	53.76 ± 8.84	50.63 ± 10.53*	51.44 ± 12.03	52.58 ± 11.75

*Significantly different compared to baseline; $p < 0.05$

Table A2

Perceived muscle soreness – quadriceps

Group	Pre-Exercise (mm)	12 Hours Post-Exercise (mm)	24 Hours Post-Exercise (mm)	48 Hours Post-Exercise (mm)	72 Hours Post-Exercise (mm)
Control	9.33 ± 11.36	52.33 ± 26.77	48.89 ± 22.88	39.44 ± 22.34	27.67 ± 19.49
Short Stockings	3.33 ± 6.67	27.30 ± 20.08	32.20 ± 15.75	35.40 ± 16.60	23.70 ± 15.06
Full Tights	2.64 ± 4.06	39.00 ± 21.12	47.64 ± 22.12	39.73 ± 21.78	25.55 ± 15.71
Pooled Data	4.87 ± 8.00	39.10 ± 24.06*	42.87 ± 21.19*	38.20 ± 19.77*	25.57 ± 16.21*

*Significantly different compared to baseline; $p < 0.05$

Table A3

Perceived muscle soreness – calves

Group	Pre-Exercise (mm)	12 Hours Post-Exercise (mm)	24 Hours Post-Exercise (mm)	48 Hours Post-Exercise (mm)	72 Hours Post-Exercise (mm)
Control	3.78 ± 6.96	18.89 ± 15.57	12.33 ± 12.48	9.67 ± 10.23	8.33 ± 10.61
Short Stockings	3.33 ± 6.67	18.30 ± 18.09	17.10 ± 18.19	14.20 ± 14.44	7.30 ± 9.27
Full Tights	3.09 ± 4.59	15.09 ± 16.80	16.18 ± 20.13	13.55 ± 20.39	4.09 ± 5.43
Pooled Data	3.37 ± 5.88	17.30 ± 16.39*	15.33 ± 17.02*	12.60 ± 15.52*	6.43 ± 8.45

*Significantly different compared to baseline; $p < 0.05$

Table A4

Isokinetic strength - knee

Group	Pre-Exercise (n·m)	24 Hours Post-Exercise (n·m)	48 Hours Post-Exercise (n·m)	72 Hours Post-Exercise (n·m)
Control	236.72 ± 53.41	189.70 ± 65.16	208.23 ± 63.98	192.1 ± 63.67
Short Stockings	173.54 ± 66.77	158.69 ± 63.22	156.41 ± 71.51	160.43 ± 77.43
Full Tights	212.88 ± 58.25	167.59 ± 52.12	167.56 ± 40.32	191.42 ± 46.99
Pooled Data	206.92 ± 63.35	171.25 ± 59.28*	176.05 ± 61.30*	181.29 ± 63.11*

*Significantly different compared to baseline; $p < 0.05$

Table A5

Isokinetic strength - ankle

Group	Pre-Exercise (n·m)	24 Hours Post-Exercise (n·m)	48 Hours Post-Exercise (n·m)	72 Hours Post-Exercise (n·m)
Control	99.88 ± 16.00	116.99 ± 22.18	104.79 ± 43.49	124.43 ± 30.70
Short Stockings	86.53 ± 25.06	79.18 ± 22.32	82.23 ± 26.53	81.47 ± 27.51
Full Tights	95.36 ± 22.85	94.85 ± 21.05	94.78 ± 21.91	99.63 ± 31.74
Pooled Data	93.77 ± 21.82	96.27 ± 26.03	93.60 ±31.46	101.01 ± 33.84

Table A6

Time to peak torque - knee

Group	Pre-Exercise (ms)	24 Hours Post-Exercise (ms)	48 Hours Post-Exercise (ms)	72 Hours Post-Exercise (ms)
Control	421.11 ± 103.13	382.22 ± 106.63	331.11 ± 55.55	312.22 ± 108.14
Short Stockings	501.00 ± 80.89	432.00 ± 114.29	398.00 ± 89.79	395.00 ± 107.11
Full Tights	451.82 ± 89.42	378.18 ± 96.42	351.82 ± 70.12	347.27 ± 62.46
Pooled Data	459.00 ± 93.78	397.33 ± 104.98*	361.00 ± 76.35*	352.67 ± 96.27*

*Significantly different compared to baseline; $p < 0.05$

Table A7

Time to peak torque – ankle

Group	Pre-Exercise (ms)	24 Hours Post-Exercise (ms)	48 Hours Post-Exercise (ms)	72 Hours Post-Exercise (ms)
Control	500.00 ± 164.47	360.00 ± 89.16	345.56 ± 79.23	338.89 ± 94.00
Short Stockings	542.00 ± 165.18	475.00 ± 124.03	452.00 ± 115.84	493.00 ± 166.47
Full Tights	413.64 ± 70.32	364.55 ± 86.18	359.09 ± 78.54	346.15 ± 101.64
Pooled Data	482.33 ± 144.05	400.00 ± 111.54*	386.00 ± 101.53*	392.92 ± 140.67*

*Significantly different compared to baseline; $p < 0.05$

Table A8

Muscle size – rectus femoris

Group	Pre-Exercise (cm)	24 Hours Post-Exercise (cm)	48 Hours Post-Exercise (cm)	72 Hours Post-Exercise (cm)
Control	1.52 ± 0.26	1.62 ± 0.30	1.64 ± 0.33	1.62 ± 0.34
Short Stockings	1.72 ± 0.37	1.72 ± 0.45	1.75 ± 0.40	1.73 ± 0.46
Full Tights	1.74 ± 0.39	1.78 ± 0.33	1.82 ± 0.31	1.77 ± 0.29
Pooled Data	1.67 ± 0.35	1.71 ± 0.36	1.74 ± 0.36	1.71 ± 0.36

Table A9

Muscle size – lateral gastrocnemius

Group	Pre-Exercise (cm)	24 Hours Post-Exercise (cm)	48 Hours Post-Exercise (cm)	72 Hours Post-Exercise (cm)
Control	0.69 ± 0.17	0.73 ± 0.15	0.77 ± 0.12	0.75 ± 0.17
Short Stockings	0.72 ± 0.11	0.70 ± 0.11	0.76 ± 0.10	0.73 ± 0.12
Full Tights	0.80 ± 0.18	0.81 ± 0.20	0.81 ± 0.19	0.81 ± 0.17
Pooled Data	0.74 ± 0.16	0.75 ± 0.16	0.78 ± 0.14	0.77 ± 0.15