EFFECTS OF COMPRESSION SOCKS ON MUSCLE RECOVERY IN MASTERS RUNNERS

A Thesis submitted to the faculty of
San Francisco State University
In partial fulfillment of
the requirements for
the Degree

Master of Science

In

Kinesiology

by

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San Francisco, California

May 2017

CERTIFICATION OF APPROVAL

I certify that I have read Effects of Compression Socks on Muscle Recovery in Masters Runners by Brittany Marie Steers, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirement for the degree Master of Science in Kinesiology: Exercise Physiology at San Francisco State University.

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EFFECTS OF COMPRESSION SOCKS ON MUSCLE RECOVERY IN MASTERS RUNNERS

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Introduction: The number of Masters athletes (≥40 y.o.) is increasing yet few studies exist on this growing population. Compression socks are a popular recovery modality in endurance sports. The purpose of this study was to investigate the efficacy of compression socks on 1) perception of muscle fatigue and soreness and 2) functional recovery in Masters runners. It was hypothesized that compression socks will 1) lower perceived muscle fatigue and soreness, and 2) have no effect on functional recovery when worn for 48 hrs after exercise compared to placebo socks. ***Methods:*** 12 Masters runners with ≥18mo run training participated (age: 49.7+8.3 y.o.). During Visit 1, participants underwent ankle and calf circumferences, ankle range of motion (ROM) measures, completed fatigue/soreness surveys, and performed a timed 1-mile run. Then, participants completed a fatiguing protocol (6 sets, weighted calf raises to failure) and were assigned to wear either compression or placebo socks for 48 hrs. Visit 2 (48 hrs post-test) consisted of circumference/ROM measures, surveys, and 1-mile run. During Visits 3-4, participants completed the same protocols as Visit 1-2 and were assigned the sock type not previously given. ***Results:*** Right calf circumference decreased compared to the pre-test measurement when compression was worn, but not placebo ($p<0.05$). All other measures of functional recovery, fatigue, and soreness did not reach significance. ***Conclusions:*** There was not enough evidence to support the use of compression socks as an effective form of recovery in Masters runners.

I certify that the Abstract is a correct representation of the content of this thesis.

Chair, Thesis Committee

5-17-2017
Date

PREFACE AND/OR ACKNOWLEDGEMENTS

I would like to thank my thesis committee, James Bagley, PhD, Marialice Kern, PhD, and C. Matthew Lee, PhD for their insight, encouragement, and invaluable advice. I want to thank Nicole Bolter, PhD for walking me through my statistical analysis and inspiring my feelings of enthusiasm for working with numbers and SPSS. I want to extend a big thank you to my participants for taking time away from their jobs, families, and very busy training schedules to take part in a Master's level study. Thank you to all who helped me recruit participants, whether successfully or not, as I would not have been able to complete this study without you. Thank you to my friends and family who were there to support me through all the highs and lows of both this project and my graduate studies. I am especially indebted to the Bridge family for providing a roof over my head, food on the table, and some sense of stability while I navigated the first half of my graduate degree.

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Introduction

As the general population ages, there is an ever-increasing number of Masters athletes, which were defined in a previous study as "middle-aged and older subjects who practice substantial and well-documented types and amounts of physical activity" (Shephard et al., 1995). For the purposes of this study, Masters athletes will be specified as those who are 40 years of age or older. These athletes participate in sports such as track and field, swimming, cycling, weightlifting, and running. The participation rate of Masters athletes in endurance sports such as triathlon and running has increased dramatically in the past 25 years. With this increased participation has come increased performance, although it is unknown if Masters athletes have reached their limits in performance (Lepers et al., 2013). There is relatively little research that has been performed to study this growing athletic population, especially with regards to recovery from endurance exercise such as long distance running. It is possible that the high impact nature of running could result in a different rate of recovery than low impact sports such as swimming and cycling when compared to younger adults. Studies investigating recovery in Masters athletes have shown conflicting results, suggesting that recovery from exercise might be highly individual in older adults (Shaw, 2013).

For athletes of all ages and abilities, from recreational weekend warriors to Olympians, recovery from exercise is a priority to maximize fitness gains and minimize risk of injury. Prolonged training without proper recovery can lead to decreased performance, decreased endurance, and accumulated fatigue, all of which could lead to chronic injuries and overtraining (Welman, 2010). One of the most popular trends in endurance sports is the use of lower body compression garments (particularly socks and calf sleeves) to increase performance and maximize recovery (Del Coso et al., 2013). Sports apparel companies have specifically marketed these compression garments towards athletes, and have made superfluous claims about the various performance and recovery benefits of these garments. The theory behind the use of compression socks is twofold: 1) graduated compression around the calves will increase venous return and end-diastolic volume, thus improving cardiac output and therefore performance, and 2) they will prevent muscular vibrations, resulting in less muscular damage (Bovenschen, Te Booij, & Van der Vleuten, 2013). While the use of these garments is now commonplace, the evidence supporting the efficacy of their use for delaying fatigue and increasing the rate of recovery is inconclusive and fragmented due to the heterogeneity among studies.

Background

Masters Athletes and Recovery

Most of the research that has been conducted on Masters athletes has come from both cross-sectional and longitudinal studies (Trappe, 2001). Some of these older athletes are lifelong athletes who began training and competing in their youth and have continued an active lifestyle into their later years. Many others, however, began training and competing as middle aged and older adults (Trappe, 2001). A study by Trappe in 2001 looked at the physiological profiles of active individuals of various ages who habitually exercise. It was found that skeletal muscle has a high level of plasticity that can be maintained late into life. This plasticity means that the skeletal muscle fibers and proteins can quickly adapt to the load or lack of load placed on them. It was also found that exercise greatly influenced the expression of skeletal muscle proteins and the contraction of single muscle fibers (Trappe, 2001).

A perception among many Masters athletes is that aging negatively affects exercise tolerance, recovery, and skeletal muscle adaptations. A review by Fell & Williams (2008) looked at the many factors and variables surrounding this perception of aging in both animals and humans. The reviewers found studies that both supported and contradicted the notions that aging athletes recover differently and/or more slowly than younger athletes. The main findings of the review were that previous research investigating Masters athletes has not accounted for the natural decline in habitual physical activity that often happens as people age even though these older people might still be athletes. This causes a confounding variable when compared to younger athletes. It was also found that older athletes who trained either acutely and/or chronically throughout their lives had "significant functional benefits" and potential protection from exercise-induced skeletal muscle damage (Fell & Williams, 2008). Generally, this review found evidence to support the notion that aging skeletal muscle experiences greater fatigue and damage from exercise than younger skeletal muscle, and that aging skeletal muscle also repairs and recovers slower from this fatigue and damage. These factors overall lead to longer recovery durations (Fell & Williams, 2008).

A dissertation by Shaw in 2013 investigated the use of various recovery modalities by Masters runners following aerobic exercise. The first of the three studies included in the dissertation reviewed the practicality and effectiveness of modalities thought to decrease recovery time and increase performance following recovery, specifically in aerobic athletes. One of the modalities reviewed was compression socks, and it was found that wearing compression socks for multiple days might have some recovery benefit (Shaw, 2013). The second study in the dissertation investigated the amount of time necessary for 10 Masters runners (5 men and 5 women) to recover from an all-out 5K run. It was found that the majority of participants were able to fully recover from the 5K run after 48 hours of passive rest, although there were some individual variations present. The third study investigated the differences in recovery achieved by individual Masters runners after a maximal 5K run after 24 hours of passive recovery with vitamins C and E and protein supplementation versus using 24 hours of passive recovery with icing therapeutic recovery techniques. It was concluded that the Masters runners were fully recovered after 96 hours of passive rest, and after 24 hours of passive rest plus the use of various recovery modalities. However, the investigators found that 24 hours of passive rest plus the use of recovery modalities was not enough recovery time to increase 5K performance. The latter two parts of this dissertation did note that the results of recovery were highly individual and some participants needed less time or more time to fully recover from the maximal-effort 5K runs. More research is needed to investigate if a combination or use of other recovery modalities would be more effective for recovery after 24 hours of passive rest.

A study by Lavender & Nosaka (2007) compared indirect markers of muscle damage between young (age: 19.4 ± 0.4 years) and middle aged (48.0 ± 2.1 years) men following bouts of eccentric exercise in the elbow flexors. They hypothesized that the middle-aged men would be more susceptible to muscle damage than young men. Their findings were contrary to their hypothesis; the investigators found that changes in maximal voluntary contraction (MVC), joint ROM, upper arm circumference, plasma CK activity, and myoglobin concentration were not significantly different between the young and middle aged groups. They also found that the middle-aged participants were less likely to report having muscle soreness than the young men although the magnitude of the eccentric-induced muscle damage was the same between both groups. The investigators suggested that perception of pain might decrease as one ages, but the results of this study do not support the notion that susceptibility to soft tissue damage increases due to aging. This is in direct contradiction to the previously described review by Fell & Williams in 2008.

Skeletal Muscle Damage

Muscle tissue may be damaged following intense prolonged exercise relative to the level to which the individual was previously adapted (Brancaccio et al., 2010). This can be due to metabolic factors resulting in increases in creatine kinase (CK), lactate dehydrogenase (LDH), aspartate aminotransferase (AST), alanine aminotransferase

(ALT), which are evidence of both tissue damage and cellular necrosis (Nie et al., 2010). Myoglobin, troponin, and carbonic anhydrase (CAIII) are also very useful blood serum markers of damage (Brancaccio et al., 2010). Mechanical factors that induce skeletal muscle injury include, but are not limited to, direct hits, strenuous exercise, intense manual labor, crush injury, and electrical injury (Brancaccio et al., 2010).

Endurance exercise can lead to oxidative stress-induced injury and inflammation (Sugama et al., 2015). This occurs due to increased oxygen utilization, ischemia-reperfusion, and leukocyte activation, which leads to the creation of damaging reactive oxygen species (ROS). The increased use of oxygen in aerobic exercise also leads to the consumption of resident antioxidants. When the balance of ROS outweighs the number of antioxidants, oxidative-stress and therefore, cellular tissue damage, takes place (Sugama et al., 2015).

It is not unusual for athletes to experience muscle pain, swelling, aches, and pain following prolonged physical activity (Branccacio et al., 2010). Symptoms can also include decreased muscle strength and range of motion (ROM) (Lavender & Nosaka, 2007). These symptoms can be a result of the muscle producing more force than it is currently adapted to produce or can result from actual tissue damage. The muscle tissue damage occurs as the sarcomere degenerates due to the Z-disc fragmenting (Branccacio et al., 2010). The architecture of muscle cells is designed to minimize the amount of stress placed on the plasma membrane by transmitting forces from the extracellular matrix to the cytoskeleton through various protein structures. When tissue damage occurs from the membrane failing, there is an influx of extracellular ions and an efflux of cytoplasmic components. To prevent cell death, various membrane proteins, including SNARE proteins, are involved in fusing endomembrane vesicles on the membrane of the damaged site via exocytosis (Branccacio et al., 2010). These microscopic tears in the sarcomeres cause the muscle pain and soreness that athletes experience.

During endurance exercise, eccentric muscle contractions are well known to cause the greatest amount of muscle damage. Eccentric contractions occur when muscle fibers are lengthening as force is generated. This creates high amounts of tension in the muscle fibers and increases the likelihood of muscle damage (Yanagisawa et al., 2015). Yanagisawa et al. (2015) found that repetitive eccentric muscle contractions in the triceps surae resulted in increased "muscle hardness", but did not correlate with the usual markers of muscle damage including edema, soreness, and decreased joint ROM.

Plantar Flexion

The triceps surae muscles in the calf, which include the gastrocnemius and soleus muscles, are responsible for 80% of plantar flexion force. The triceps surae attaches to the Achilles tendon, which is the strongest tendon in the human body (Sman et al., 2014). The triceps surae stabilizes the foot while it is bearing weight, and the plantar flexion it generates is essential for forward momentum during running and walking. Thus, plantar flexion strength and endurance is essential for not only basic walking mobility, but also continuous running (Sman et al., 2014). When the plantar flexors do not fire properly, instability will be present during walking and running, resulting in increased energy expenditure and decreased safety (Lunsford & Perry, 1995). In terms of running and similar endurance sports, this causes metabolic inefficiencies and increases the chance of injury.

The heel rise test is commonly used by physical therapists to assess the strength and endurance of the plantar flexors (Sman et al., 2014). Classically, this test is performed with the participant rising as high onto the balls of their feet as possible, while only using a single finger for balance (Lunsford & Perry, 1995). The ankles of the participants are hooked up to an electric goniometer to measure the degree of plantar flexion. Other variations of this test include standing and rising on one leg at a time or while hooked up to various devices (Sman et al., 2014). While standards of how to interpret the results of this test have been proposed, there is no standardized heel rise device (Sman et al., 2014). The standard for "Normal" plantar flexion strength and endurance is 25 heel rises for both men and women (Lunsford & Perry, 1995). This standard however, is for physical therapists, and therefore a clinical population. It does not reflect how many heel rises would be necessary for athletic performance of a runner.

Compression in the Clinical Setting

In the clinical setting, the use of compression garments has long been a method to help with venous return and decrease peripheral swelling, both in vascular patients with conditions like deep vein thrombosis (DVT) and in healthy adults traveling on long airplane flights (Sajid et al., 2006). Graduated elastic compression stockings are often prescribed to patients with DVT to prevent post-thrombotic syndrome (PTS), a chronic result of DVT, or to alleviate leg pain and swelling (Kahn et al., 2002).

Sajid et al. (2006) performed a systematic review of the literature to investigate whether knee length or thigh high socks are more effective in reducing the risk of developing DVT in vascular patients in hospital settings and healthy participants on very long airplane flights. This review looked at both healthy and high risk travelers, and concluded that despite a possible "tourniquet effect", Class I and Class II compression socks with ankle pressures of 14-30 mmHg helped prevent DVT. It was found that the knee length socks were as effective as thigh length compression socks in preventing DVT in these populations.

In 2011, Mosti and Partsch looked at the effects of using progressive graduated compression stockings on walking. These socks had higher pressures over the calf than the ankle area, which is the opposite of most compression socks. They found that the external compression increased the pressure on the veins during muscle contraction. The investigators concluded that there was greater efficacy in increasing the venous ejection fraction from the leg when using these progressive graduated compression stockings compared to stockings that had greater pressure in the ankle than the calf.

Kahn et al. (2002) studied the effects of using compression socks during exercise on a treadmill in participants who had been diagnosed with unilateral DVT and/or PTS at least one year before the study. Since exercise capacity is severely diminished in these populations, the objective was to investigate if the use of these socks could increase exercise capacity and decrease acute signs and symptoms of DVT. The participants wore knee-high custom-fitted socks with 30 mmHg of pressure on the affected leg during exercise. The study found no measureable benefit at the acute level on exercise induced changes in leg volume, flexibility, or venous symptoms. This applied to all participants whether PTS was present or not. Overall, the study found inconclusive results as to if the use of compression socks could increase exercise capacity in those with DVT.

Compression and Hemodynamic Variables

The relationship between the use of compression socks and hemodynamic variables in endurance athletes and recreationally active athletes has been examined with varying results. Vercruyssen et al. (2012) found no significant difference in hemodynamic variables, including blood lactate concentration and heart rate values, in trained trail runners wearing compression socks versus runners wearing normal socks during a 15.6 km run at race effort. This study also found no increase in performance when comparing the times of the participants when they wore compression socks versus their usual running socks, which is similar to the findings of other studies. In contrast to other studies, Vercruyssen et al. did not find any changes in near-infrared spectroscopy measurements, though this could be because these measurements were taken in the vastus lateralis while the compression was applied around the calves and ankles, suggesting that muscular blood flow and other circulatory responses occur locally.

Another study by Sperlich et al. (2011) looked at the effects of increasing levels of compression socks on metabolic and cardiorespiratory parameters in endurance trained young men during a submaximal ramp test. The socks were knee-high and had five levels of compression: 0, 10, 20, 30, and 40 mmHg as measured at the widest circumference of the calf. Each subject performed the submaximal ramp test protocol six times, including an initial VO_{2max} test, therefore serving as their own controls. The researchers found no effects on cardiac output, stroke volume, arteriovenous difference, heart rate, and blood lactate concentration (Sperlich et al., 2011).

When recreationally active females ran for 30min and then performed a 400m sprint while wearing compression pants, Venckunas et al. (2014) found a trend toward increased venous emptying rate in the 3-10 minute period after exercise that increased to statistical significance 30 minutes after exercise. They also found an increase in skin temperature directly underneath the compression garment when compared to the skin under the loose-fitting clothing. This study found no other significant physiological or running performance effects when the participants wore compression breeches compared to the loose-fitting breeches. However, the participants perceived that they did experience major changes when they were asked to rate various subjective measurements.

Compression and Endurance Sports Performance

Many studies have been conducted to examine the relationship between endurance sports performance and the use of compression garments, but the findings of these studies have been very mixed depending on the variables measured. A study by Menetrier et al. (2011) aimed to determine the effects of wearing knee high compression socks on running performance and calf muscle oxygen saturation before exercise and during a recovery period in moderately trained male endurance athletes. They followed a treadmill protocol that included periods of rest and various intensities of work, either with or without compression socks. The study found a significant increase in oxygen saturation to the calf muscle tissue with compression socks both before exercise and during a prolonged recovery 30 minutes after maximal running. This was possibly due to changes in skin blood flow via temperature and pressure and an increase in perfusion rate. The study found no evidence of improvement in running performance.

In 2010, Ali et al. looked at the physiological effects of well-trained runners wearing different grades of graduated compression stockings during and after treadmill running. This study was one of the few that included a placebo sock. There were three grades of compression used in this study: none (0 mmHg at calf and ankle), low (12 mmHg at knee and 15 mmHg at ankle), and high (23 mmHg at knee and 32 mmHg at ankle) compression. Each visit, the participants were given one of the three grades of compression socks to wear during their treadmill protocol. They wore normal running socks over the compression socks. Blood samples were collected and the counter movement jump test was performed each trial. Each participant was assigned one of the three levels of compression socks at each trial, and wore each grade once. Only four participants reported muscle soreness during recovery from running. There were no differences in muscle function, and therefore performance, between trials. The study found evidence that runners who wore graded compression socks did not experience any physiological benefits during or following treadmill running. It is worth noting however, that the participants felt more comfortable wearing low grade than high grade compression while running.

Del Coso et al. (2013) examined the effects of compression stockings on performance during an Ironman 70.3 (half-Ironman) triathlon. Performance was defined as improved finishing time compared to previous 70.3 triathlons, and as improved muscle function as measured by varying blood parameters. Half of the participants wore graduated compression socks during the race while the other participants served as controls. The main finding was that overall finishing time was not affected, and there was no increase in swim, bike or run velocities in those who wore compression during the race. Both groups experienced similar post-race myoglobin and CK levels, and had similar decreases in lower body maximal strength and power. The researchers concluded that while the stockings had no effects on maintaining muscle performance or delaying fatigue during the triathlon, they could possibly enhance the recovery of muscle strength and power (Del Coso et al., 2013). Overall, it appears that compression socks do not provide a significant increase in performance in endurance sports.

Compression and Exercise Recovery

An influential study by Chatard et al. (2004) looked at the effects of elastic compression stockings on recovery in elderly male cyclists (63 ± 3 years). Trained elderly male cyclists performed two different 5-minute maximal exercises on a cycle ergometer separated by an 80-minute recovery period twice a week for two weeks with a two-day rest period. The investigators found that wearing the stockings during an 80-minute passive recovery period with the legs elevated significantly decreased blood lactate concentration and hematocrit, and increased the participants' performance in subsequent exercise bouts. It was also found that wearing the compression socks was associated with reduced leg pain, but this sensation was not correlated with increased performance (Chatard et al., 2004).

A frequently cited review by Macrae et al. in 2012 states that while the use of compression garments is well accepted by coaches and athletes of all levels, the evidence supporting their ergogenic use is fragmented due to the heterogeneity among studies including training status among participants, duration and type of garment used, and variables used to measure performance and/or recovery. This review also found that ratings of post-exercise delayed onset muscle soreness (DOMS) are almost uniformly more favorable when compression socks are worn, suggesting a placebo effect. The investigators also found that compression socks have mixed effects on measures of recovery and subsequent performance, such as post-exercise limb swelling, clearance of muscle cell proteins and metabolites, and blood plasma concentrations.

Born et al. (2013) performed a systematic review of the literature regarding the effects of applying compression for sports performance and recovery purposes. The researchers found minimal effect sizes on sports performance when compression was applied during exercise. They found small to moderate effect sizes in the recovery of maximal strength and power when compression was applied after exercise, especially when participants performed a vertical jump test. The review also found increases in blood lactate removal and body temperature, and decreases in perceived muscle soreness and muscle swelling (Born et al., 2013).

Like Born et al., Bottaro et al. (2011) performed a review of literature to investigate how compression garments can influence the neuromuscular effects of strength and recovery. The review states that more evidence has been found to support and enhance the performance of sports that are more neuromuscular-based rather than solely reliant on cardiovascular endurance, such as volleyball, basketball, and tennis. The investigators found that compression garments might improve the rate of lactate removal from the blood after exercise and might improve aerobic performance, but the results are mixed and controversial. This review also found varying results when reviewing the literature regarding neuromuscular adaptations, with the most consistent finding being that DOMS was decreased after 24 hours.

Two studies found that wearing compression garments in the recovery from eccentric exercise may alter the inflammatory response and increase the rate of muscle repair, though the exact mechanism and necessary application time is still elusive. One of these studies, by Perrey et al. (2008), found that graduated compression socks might decrease soreness associated with DOMS, but may not be beneficial in preventing strength and functional declines. In this study, each participant served as their own control, with one leg wearing a compression sock and the other leg serving as an untreated control. The researchers concluded that the triceps surae of the leg wearing compression had levels of maximal voluntary torque and muscle force capacity that recovered significantly within 24 hours, which was not the case in the leg not wearing compression.

The other study previously mentioned, by Trenell et al. (2006), looked at young recreationally active males who walked downhill on a treadmill for 30 minutes, who then wore compression socks on one leg while the other leg served as an untreated control. They found that wearing compression could alter the inflammatory response to eccentric exercise as measured by muscle pH levels and cellular metabolic processes, and could possibly accelerate the repair process within the muscle.

A dissertation by Welman in 2011 looked at the use of compression socks as a recovery modality in long and ultra-distance runners. The first part of the study in the dissertation aimed to compare the use of graduated compression socks and a placebo sock during a 56 km (34.8 mile) ultra-distance event. It was found that wearing the compression socks during the race and during a subsequent 72 hour recovery period had a beneficial effect on recovery time over the first 48 hours when compared to those participants not wearing compression socks. The next part of the investigation sought to determine if it is more effective to wear graduated compression socks during or after exercise. This was done by measuring skeletal myoglobin, serum CK, c-reactive protein, swelling in the legs, perceived muscle soreness, a viability questionnaire, and a countermovement jump test. The results from this part of the investigation suggested that wearing compression socks during exercise will reduce muscle damage more so than wearing the compression socks only after exercise. The investigator also found evidence that wearing compression during the recovery period might contribute to less swelling and less additional disruption to the soft tissue, meaning that compression could be a valuable recovery option.

Driller and Halson (2012) found significant improvement in recovery, as measured by leg girth and blood lactate concentration, between two bouts of exercise when highly-trained cyclists who wore lower body compression garments were compared to controls wearing loose fitting clothing. The participants wore the compression for 60 minutes of passive recovery between 30 minute exercise bouts. The proposed mechanisms for this increase in recovery is that the compression aided in metabolic clearance of blood lactate and/or the compression weakened the inflammatory response, therefore decreasing the perception of DOMS. No definite mechanism was determined in this study, and no placebo was used. Unlike other studies, the investigators also found an increase in aerobic performance in those who wore the compression.

A study by Armstrong et al. (2014) looked at whether wearing compression socks for 48 hours after a marathon would influence functional recovery, which was measured as a graded and timed treadmill test to exhaustion 14 days after the marathon. Those who were in the compression group increased their average time to exhaustion by 2.6%, while those in the placebo group decreased their average time to exhaustion by a significant 3.4%. This shows a significant effect on functional recovery when runners wore compression socks for 48 hours after a marathon were compared to a placebo group (Armstrong et al., 2014). No blood markers were taken in this test, and the only other physiological measurements taken were maximal and average heart rates.

Like Armstrong et al., Hill et al. (2014) looked at the use of compression garments for accelerating recovery after a marathon. The participants were recreationally active marathon runners. The compression group wore lower limb compression tights for 72 hours after a marathon run. The sham group was treated to 15 minutes of sham ultrasound following the marathon run. Perceived muscle soreness, maximal voluntary isometric contraction (MVIC), CK, and c-reactive protein were assessed before, immediately after, and 24, 48, and 72 hours post-marathon run. The only significant finding in this study was that those in the compression group experienced less muscle soreness 24 hours post-marathon compared to the sham group. It is possible that the compression tights served a placebo effect since none there were no significant differences between groups for MVIC, CK, and c-reactive protein. There was however, a trend for decreased recovery time of MVIC, CK, and c-reactive protein in the compression group.

In conclusion, the relationship between the use of compression socks and muscle recovery from various forms of exercise is inconclusive, but does seem to have some promise. More homogeneity between studies, compression garments, and study participants is needed before definite conclusions can be reached. These studies also need to include sham-garments (placebos) to compensate for the possibility of a placebo effect from wearing compression garments. Different populations including older runners need to be examined as well since limited only limited conclusions can be drawn from young or elite athletes.

Based on this comprehensive review of the literature, we were lead to ask the question do compression socks increase the rate of muscle recovery in experienced Masters runners? The purpose of this study was to investigate the efficacy of compression socks on 1) the perception of muscle fatigue and soreness and 2) functional recovery in Masters runners. It was hypothesized that compression socks would 1) lower perceived muscle fatigue and soreness, and 2) have no effect on functional recovery (as measured by a performance test, joint range of motion, and swelling) when worn for 48 hours after exhaustive eccentric exercise compared to placebo socks.

Methods

Participants

To conduct this randomized trial study, the investigator recruited 15 Masters runners (13 men, 2 women) who had been running consistently for ≥18 months. Three participants dropped out of the study. One did not follow the post-test instructions. Another was asked to drop out by their physician due to concerns about fluctuating blood pressure. The third drop out did not want to continue to the third visit. This left a total of 12 participants: 10 men and 2 women (age 49.7±8.3 years) (Table 1a). Both women were post-menopausal, and therefore there was no need to control for fluctuating hormone levels that might or might not affect recovery. Ten of the participants had participated in triathlons or other multisport events (aquathlon, duathlon, etc.), 6 participated in running races or ultramarathons, 4 participated in ball sports (tennis, soccer, etc.), and 4 participated in other sports (scuba, rock climbing, etc.). On average, the participants exercised 5.4± 0.9 days per week for 1.7±1.0 hours per day, typically at a moderate intensity level (Table 1b.)

CHARACTERISTICS (Mean±SD)	
Sex	2 Females 10 Males
Age (years)	49.7±8.3
Height (cm)	176.0±12.3
Weight (kg)	79.9±15.1
Body Fat (%)	22.1±4.5
Resting Heart Rate (bpm)	61.8±10.0
Systolic Blood Pressure (mmHg)	124.8±10.7
Diastolic Blood Pressure (mmHg)	79.7±7.0

Table 1a. *Participant characteristics (mean±SD).*

TRAINING HISTORY

Exercise (days/week)	5.4± 0.9
Exercise (hours/day)	1.7±1.0
Typical Exercise Intensity (Light/moderate/hard)	Moderate
Major Events/Sports	• 10 triathlons and other multisport • 6 running and ultramarathons • 4 Ball sports (soccer, tennis) • 4 Other sports (rock climbing, scuba)

Table 1b. *Participants' training history (mean±SD). All participants ran regularly, but participated in a wide variety of athletic events.*

Participants were recruited from various running and triathlon clubs and groups in the San Francisco Bay Area of California. Emails inviting athletes to participate were sent to the presidents, managers and owners of local running stores, clubs, and groups so that they could forward the invitation to their members. There were also flyers posted throughout Silicon Valley and San Francisco. Those who responded to the recruitment emails and flyers were sent the ACSM Risk Stratification Screening Questionnaire to determine cardiovascular disease risk. There were no participants who scored >2 on the questionnaire, and therefore no participant needed a physician's note to participate in the study.

Any athlete who fit one or more of the exclusion criteria was not included in the study. Exclusion criteria included those who were on medications that affect exercise heart rate and blood pressure, had a history of cardiovascular or pulmonary diseases or blood clots, had any lower limb orthopedic disorders, or those who had an ACSM risk score ≥2 and were unable or unwilling to obtain a physician's note.

Experimental Procedure

The experimental procedure consisted of four visits to the Exercise Physiology Laboratory in GYM 111 at San Francisco State University. Participants were instructed to not complete any races or prolonged race-effort workouts the week before performing their first visit. Furthermore, the participants were instructed not to exercise, consume alcohol, or take any non-steroidal anti-inflammatory drugs (NSAIDs) for at least 24 hours before the experimental procedure, not to consume caffeine for 3 hours before the experiment, to eat a normal breakfast and lunch, and drink at least 1L of water on the day of experiment (Bushra & Aslam, 2010).

Each participant served as their own control and underwent the experimental procedure two times. During the first visit, the investigator measured ankle and calf circumference using a gulick measuring tape, height, weight, resting heart rate (HR), blood pressure (BP), and body fat percentage via bioelectrical impedance using a Fitbit Aria Scale in normal mode. Participants were also asked to fill out an Exercise History Questionnaire (Appendix 1). A goniometer (Medigauge, Electronic Digital Goniometer) was used to measure ankle plantar flexion and dorsiflexion ROM. Participants were instructed to move their ankle only as far as they could go without increasing any sensations of pain, soreness or stiffness that might or might not already be present. This will be referred to hereon as "pain-free ROM". All measurements and tests were conducted by the principal investigator.

The participants completed a pre-printed journal each visit. The journal included 3 diagrams for muscle soreness, stiffness, and pain (Appendix 2; Southerst et al., 2013), and a questionnaire (Appendix 3) that included questions about their hydration, diet, sleep, medication used, and experience with the use of compression garments.

After undergoing the measurements and filling out the journal, participants ran one mile for time on a treadmill in their normal running shoes and socks. Before the time trial began, the warm up consisted of walking or jogging on the treadmill at a comfortable self-selected speed until the participant felt "warmed up". During the warm up and time trial, the incline was set to 0.5%. The participant then ran one mile on the treadmill for time at a self-selected speed pace, and could adjust the speed up or down as necessary. To normalize the procedure, each participant ran each of the four time trials on the same treadmill and began each time trial at the same speed. After they completed the time trial, they could run or walk for as long as they wanted to "cool down".

The fatiguing exercise procedure consisted of the participants performing eccentric calf raises on a raised platform while holding a kettlebell in one hand and lightly holding onto a pole for balance with the other hand. The participant initially chose the weight of the kettlebell, and then used the same weight during both fatiguing exercise procedures in the study. Both female participants and 7 male participants used the 16kg kettlebell, and the other 3 male participants chose the 24kg kettlebell. They performed 6 sets of calf raises until they reached fatigue in each set (Jamurtas et al., 2000). The participants performed a mean of 26.72 $\pm$11.70 reps per set. The participants switched the hand holding the kettlebell each set. They were instructed to move with control during both the concentric and eccentric movements of the calf raise to cause as much muscle soreness as possible.

Immediately after the fatiguing protocol, participants were assigned either knee-high compression socks (Mojo Athletic, Compression Socks Knee Length - Medium Support 15-20mmHg) or knee-high placebo socks (Mizuno Performance Sock G2). The first participant of the study was asked if they "wanted a black sock or a white sock", with black being the placebo sock and white being the compression sock. Each subsequent participant was assigned the opposite sock type of the participant before them. Each participant wore the assigned socks on both legs for 48 hours starting from when they were assigned the sock type. The socks could only be removed for the purposes of bathing or washing.

The post-test guidelines were as follows. No recovery mechanisms or procedures were permitted. This included, but was not limited to, massage therapy, foam rolling, stretching, myofascial release, ice baths, heat therapy, yoga, etc. Shower/bath temperature and duration had to be within reason. No exercise was permitted until after the follow up visit to prevent any effects that might come from "active recovery". No NSAIDs or other anti-inflammatory drugs were permitted.

Twenty-four hours after the fatiguing protocol, the participants received emails with electronic versions of the diagrams and questionnaire to fill out and return to the investigator by the end of that day. Forty-eight hours after the exercise protocol, each participant returned to GYM 111 to fill out their journal, have circumferences and ankle joint ROM measured, and perform the one-mile time trial.

Two weeks later, the participants returned to the lab for their third visit to perform the exercise protocol a second time. They filled out their journal, had ankle and calf circumferences and ankle joint ROM measured, warmed up, and then ran the one-mile time trial. After finishing the fatiguing protocol of calf raises with a kettlebell, the participants received the sock type that they were not assigned after the first visit.

As before, the participants were contacted via email 24 hours' post-test to fill out the journal. They returned to GYM 111 48 hours after the third visit, and performed the same measurements and tests as previously described. Each participant received compensation consisting of goodie bags filled with Power Bars, Clif Bars, Peet's Coffee, coconut water, and other products that the investigator obtained through generous donations.

Statistical Analysis

2x2 ANOVAs were used to analyze differences between sock type and measures of functional recovery: ankle circumference, calf circumference, plantarflexion ROM, dorsiflexion ROM, and the one-mile time trial. Correlations were run among the functional recovery variables. There were high correlations between left and right legs in terms of circumference and ROM, so MANOVA was not used to analyze this data. 2x3

ANOVAs were used to analyze differences between sock type and measures of perceived soreness and muscle fatigue. A nonparametric test, Cochran's Q, was used to analyze differences between distributions of calf pain, stiffness, and soreness between the three different visits. Results are reported as mean ± standard deviation (SD). SPSS Windows version 24.0 was used for statistical analyses. The significance level was set at $p<0.05$.

Results

Perceived Soreness and Fatigue

Based on the daily questionnaire, participants self-rated their level of leg fatigue (Figure 1) on a scale from 1 (least) to 10 (most) at baseline, 24 hours after, and 48 hours after the fatiguing protocol. There were no significant differences found between leg fatigue and sock types, but there was a trend towards less leg fatigue 48 hours after the fatiguing protocol in the compression group compared to the placebo group.

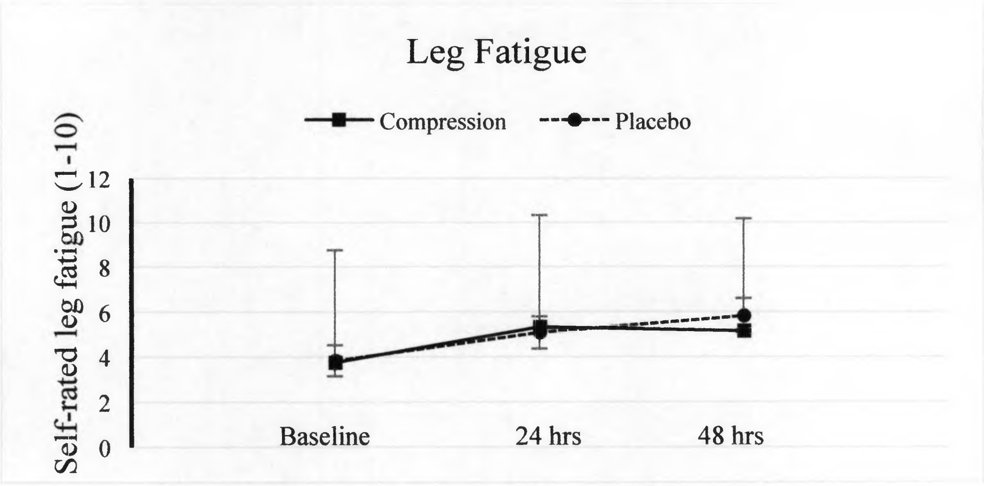

Figure 1. *Self-rated leg fatigue (mean±SE) as rated on a scale from 1 (least) to 10 (most) before, 24 hours after, and 48 hours after the fatiguing protocol.*

For each of the three diagrams included in the questionnaire, the number of participants who indicated the presence of pain, soreness or stiffness in at least one of their calves was counted. There were significant differences between counts at baseline and 24 hours, between counts at baseline and 48 hours, but no differences between counts at 24 and 48 hours in all diagrams. Those wearing the placebo were more likely to report the presence of calf pain at 24 and 48 hours after the fatiguing protocol (Figure 2). Participants wearing the placebo socks were much more likely to report soreness in their calves 24 and 48 hours after the fatiguing protocol than those wearing compression socks (Figure 3). There were no differences between sock types when participants were asked to rate stiffness in their calves (Figure 4). None of the differences between sock types reached significance.

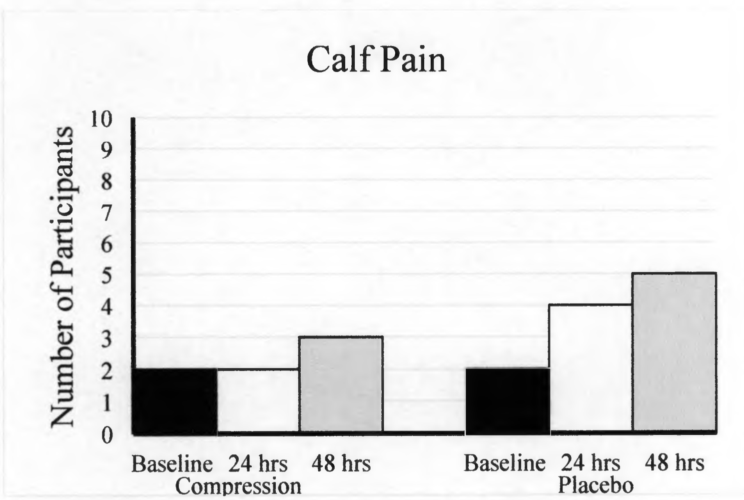

Figure 2. *Number of participants that indicated they were experiencing pain in one or both of their calves before, 24 hours after, and 48 hours after the fatiguing protocol while wearing either compression or placebo socks.*

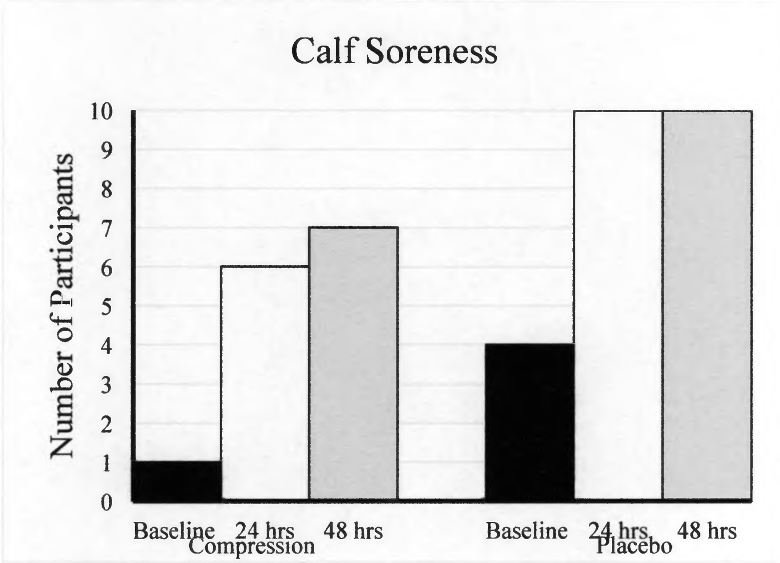

Figure. 3. *Number of participants that indicated they were experiencing soreness in one or both of their calves before, 24 hours after, and 48 hours after the fatiguing protocol while wearing either compression or placebo socks.*

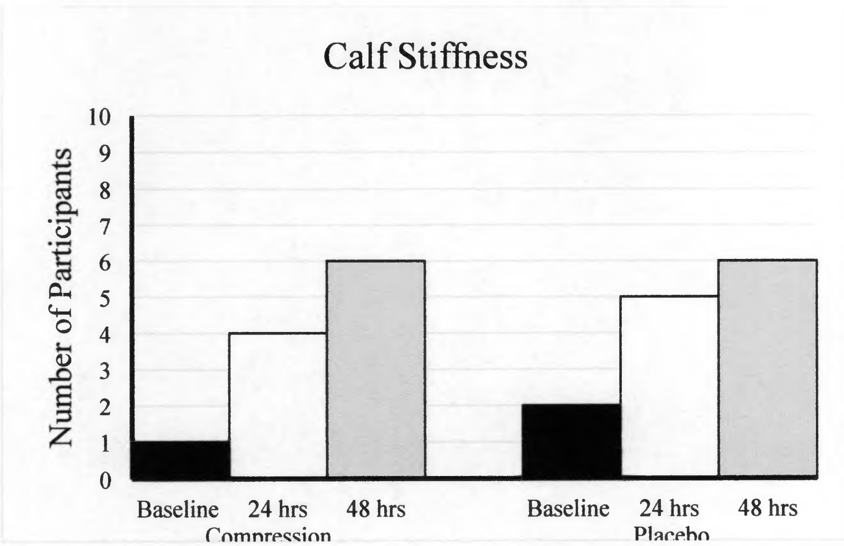

Figure 4. *Number of participants that indicated they were experiencing stiffness in one or both of their calves before, 24 hours after, and 48 hours after the fatiguing protocol while wearing either compression or placebo socks.*

In the daily questionnaire, participants rated their level of overall soreness (Fig. 5), as opposed to just soreness in the legs. There were no differences between groups, and both the placebo and compression groups followed the same trend of steadily increased soreness throughout the 48 hours following the fatiguing protocol.

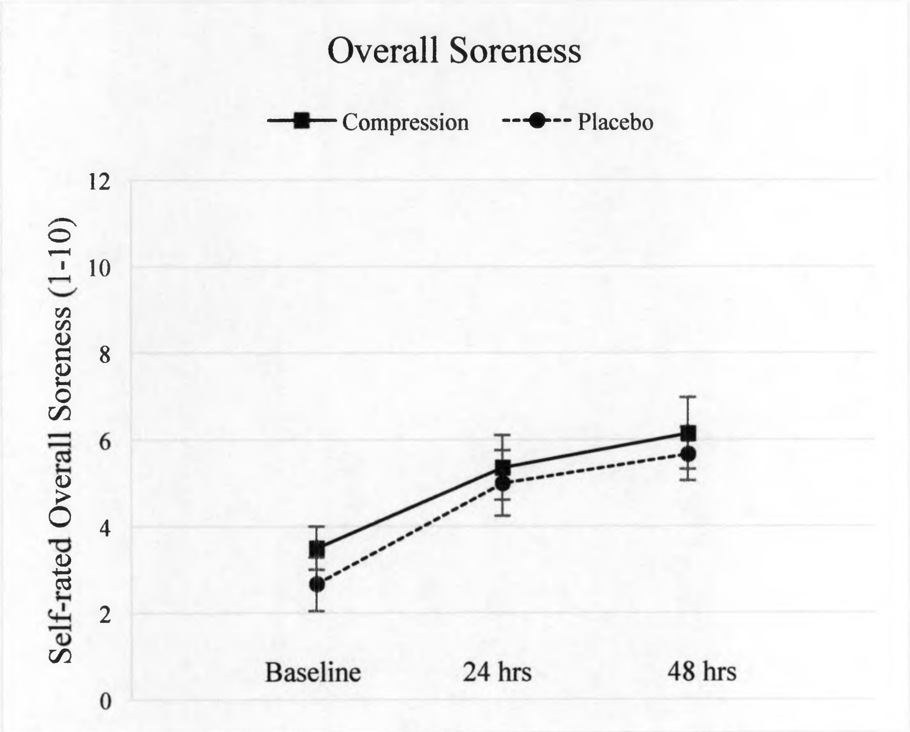

Figure 5. *Self-rated overall soreness (mean±SE) as rated on a scale from 1 (least) to 10 (most) before, 24 hours after, and 48 hours after the fatiguing protocol while wearing either compression or placebo socks.*

Functional Recovery

No statistically significant differences were found between sock types in either left or right ankle circumference (Figure 6). Measurements were taken before and 48 hours after the fatiguing protocol.

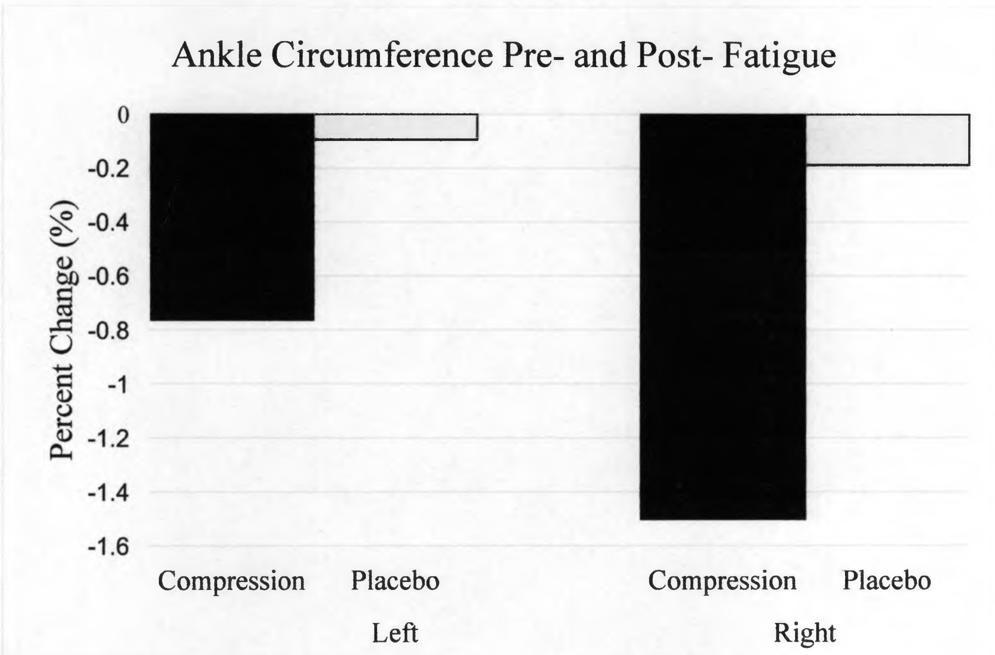

Figure 6. *Percent change in measurements of left and right ankle circumference taken before and 48 hours after the fatiguing exercise protocol. There were no differences between sock types on either leg.*

No statistically significant differences were found between sock types in left calf circumference (Figure 7). There was a statistically significant difference between right calf circumference and sock types (p=0.036). Like the left calf, the circumference of the right calf did not change significantly from pre- to post-test when the placebo was applied. However, when the compression socks were worn for 48 hours, the circumference of the right calf decreased significantly when compared to the pre-test measurement.

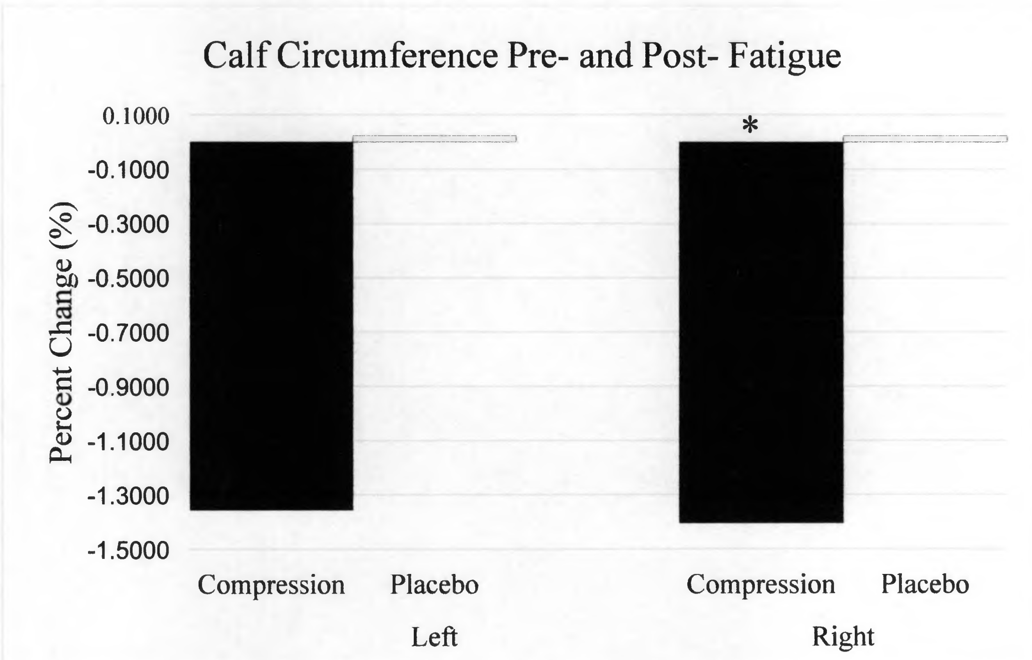

Figure 7. *Percent change in calf circumference taken before and 48 hours after the fatiguing exercise protocol when the participant wore either compression or placebo socks. (*) indicates p<0.05 between sock types.*

No significant differences were found between sock types and ankle dorsiflexion pain-free ROM in the left ankle or the right ankle (Figure 8). Unexpectedly, there was less of a decrease in dorsiflexion in the placebo group than in the compression group in the right ankle, although the opposite was true in the left ankle.

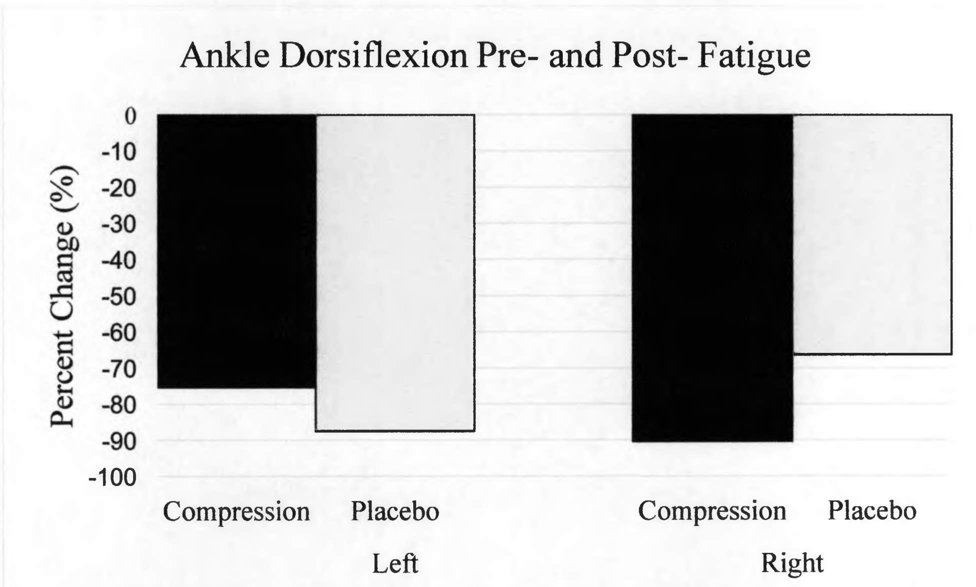

Figure 8. *Percent change in measurements of ankle dorsiflexion taken before and 48 hours after the fatiguing exercise protocol when the participant wore either compression or placebo socks. There were no significant differences between sock types.*

There was no significant difference found in plantar flexion pain-free ROM in either ankle (Figure 9). In general, there was a decrease in ROM from pre-test to post-test in both sock types and on both ankles. Unexpectedly however, there was an increase in right ankle ROM when wearing the placebo sock, which approached significance ($p<0.062$).

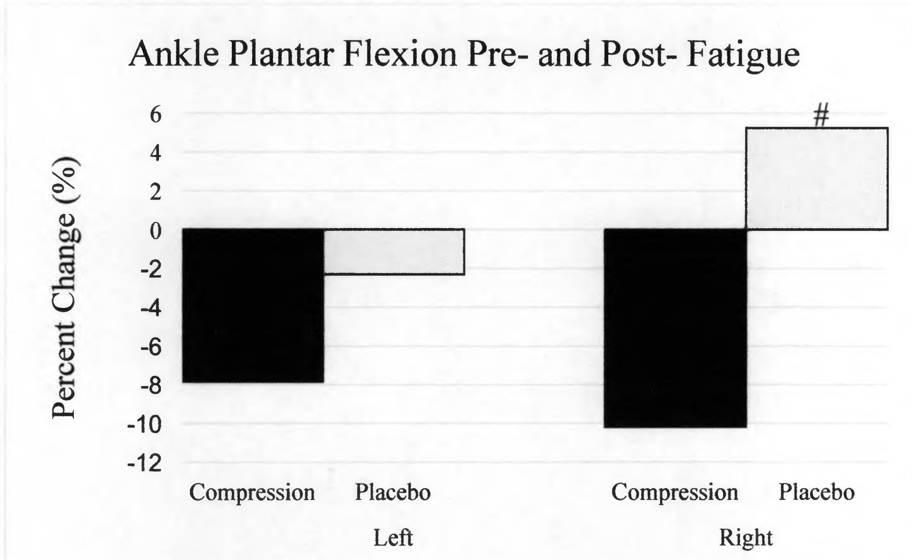

Figure 9. *Percent change in measurements of ankle plantar flexion taken before and 48 hours after the fatiguing exercise protocol when the participant wore either compression or placebo socks. While there were no statistically significant differences found in either leg, (#) denotes p<0.1 difference between sock types.*

There were no significant differences between mile times between sock types (Figure 10). There was a trend towards faster mile times 48 hours after the fatiguing protocol in the compression group, while the placebo group's mile times generally got slower.

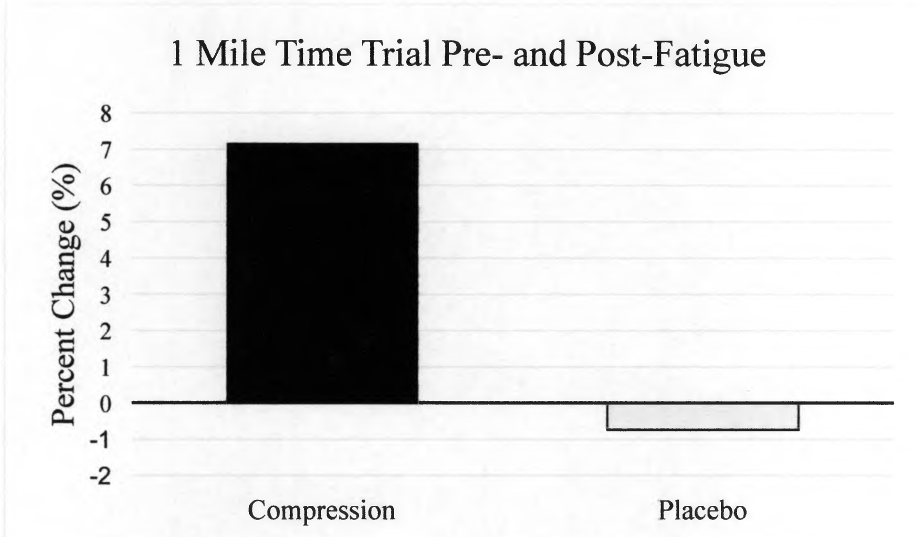

Fig. 10. *Percent difference in mile times before and 48 hours after the fatiguing exercise protocol. There were no significant differences between sock types.*

Discussion

The purpose of this study was to investigate the efficacy of compression socks on 1) the perception of muscle fatigue and soreness and 2) functional recovery in Masters runners. It was hypothesized that compression socks would 1) lower perceived muscle fatigue and soreness, and 2) have no effect on functional recovery when worn for 48 hours after exhaustive eccentric exercise compared to placebo socks. In this study, it appears that participants did experience less leg fatigue, calf pain, and calf soreness while wearing compression than when wearing a knee-high placebo sock, but none of the findings were statistically significant. Compression socks did not conclusively help with measures of functional recovery except for the decrease of swelling in the right (typically dominant) calf. The degree to which the compression socks aided recovery from the fatiguing exercise protocol was highly individual.

No significant differences in ankle circumference were observed between sock types pre-test and 48 hours' post-test. This means that there was no edema or pooling of blood present in the ankles despite the strenuous nature of the calf raises. There was a significant difference ($p<0.05$) in right calf circumference 48 hours' post-test in those wearing the compression socks. The left calf circumference in those wearing compression followed a similar trend as the right side, but did not reach significance. Since this result was only significant in the right leg, the investigator contacted the participants and asked them what leg they considered to be their dominant leg (what leg did they use to unclip from cycling peddles, kick a ball, etc). Except for one participant, all participants considered themselves to be right leg dominant. It is possible that the participants were subconsciously favoring their dominant sides during the time trial and fatiguing exercise, causing more muscle damage and a greater inflammatory response and therefore greater clearance of fluid by the sock. Some degree of inter-limb asymmetry is normal during exercise. The extent of inter-limb asymmetries varies depending on the type of exercise and the speed and intensity in which that exercise is performed, with the dominant leg typically activating more than the non-dominant leg (Boyd & Villa, 2012; Carpes et al., 2010).

This possible prevention of edema in the calf is consistent with other studies. Kraemer et al. (2001) noted that the compression garments act as an "external mechanical support" to the muscle, which results in more rapid recovery of force production and an increase in circulation. The reduction in swelling after eccentric exercise by use of compression is noted to be a clinical therapeutic intervention to manage soft tissue injury (Kraemer et al., 2001). The decrease in swelling, and possible soft tissue injury prevention, might be enough reason for older athletes to wear compression socks. Future research should focus on a longitudinal study looking at the relationship between compression socks and soft tissue injury prevention in older athletes.

Ankle pain-free ROM did not differ significantly between sock types in dorsiflexion, though there was a trend towards significance in the increase of right ankle plantar flexion ROM in the placebo group ($p=0.062$). Decreased ankle ROM is an indirect indicator of muscle damage (Yanagisawa et al., 2015), which suggests that those wearing the placebo did not cause as much muscle damage to their right triceps surae as when wearing the compression sock. It is also possible that the participants who had already gone through the protocol one time purposely did not go into plantar flexion as far during their baseline measurement so that they could "increase" their ROM during the following visit. It is important to note that many of the participants were triathletes and have some degree of a swimming background. This resulted in some of the participants having a somewhat greater plantar flexion ROM than the average population. The overall mean between groups when measured pre-test was 52.81°±1.45°. The overall mean of dorsiflexion when measured pre-test was 5.52°±0.55°. The normal ROM for dorsiflexion is 0-20° and normal ROM for plantar flexion is 0-50° (Keene, 2016). The normal ROM of plantar flexion in swimmers is approximately 65°, although some literature suggests that the physiological norm for women (both swim trained and non-swim trained) is also ~65° (Radlinska & Berwecki, 2015). Runners often exhibit more limited range of motion, with dorsiflexion being especially limited, but no standards of what constitutes limited dorsiflexion currently exist (Maggs, 2013).

When training for races such as triathlons or marathons, it is highly likely that athletes will be training, at least occasionally, with sore and fatigued legs. In many training plans, hard training days are separated by at least one day of easy training or complete recovery. The purpose of the 1 mile time trial pre- and 48 hours post-fatigue was to assess the degree to which compression socks contribute to an athlete's acute recovery time and ability to perform at a high level of effort. There were no statistically significant differences between run times and sock types. This result is consistent with other compression sock studies measuring performance. One meta-analysis found that the largest recovery benefits of wearing compression garments came from wearing compression immediately following resistance training and enhanced next day cycling performance, but not running performance (Brown et al., 2017).

Compression sock manufacturers often claim that their products will help reduce exercised-induced leg fatigue. While it was found in this study that those who wore compression reported as having less leg fatigue 48 hours after the calf raises compared to those wearing the placebo, the difference was not significant. This could be because the compression socks used in this study had graduated compression with 20 mmHg at the ankle and 15 mmHg at the calf, which was denoted as "medium support" by the manufacturer, but is often denoted as "light compression" in the literature (Miyamoto & Kawakami, 2014). Many sport-specific compression socks are modeled after medical-grade compression garments, thus following the graduated compression model with higher pressure at the ankles and lower pressure at the calves (Miyamoto & Kawakami, 2014). It has been shown though, that graduated compression is not a necessary feature to prevent muscle fatigue in the gastrocnemius, and that the most important feature to decrease fatigue is adequate pressure such as 30 mmHg at the ankle and 21 mmHg at the muscle belly of the gastrocnemius (Miyamoto & Kawakami, 2014). It is highly likely however, that runners would be willing to wear high grade compression for long periods of time due to discomfort. It is likely that the sock pressure used in this study was not high enough to produce statistically significant results, although many participants did complain about discomfort when wearing the compression sock.

There were no statistically significant differences between sock types and the number of participants who indicated they were experiencing pain, stiffness, and soreness in their calves, or in self-rated amount of overall soreness. Those wearing placebo, however, were more likely to report calf soreness at 24 and 48 hours post-test than those wearing compression. A review by Beliard et al. (2015) looked at the effects on performance and recovery of many different combinations of compression garment pressure, time applied, use during or after exercise, and in conjunction with resistance or endurance exercise. This review found that when worn for recovery only, DOMS was often attenuated regardless of the amount of pressure applied (Beliard et al., 2015). It is possible that with a larger sample size, the differences in leg pain, stiffness, and soreness, and overall soreness would have been significant. This study, like most compression garment studies, had a small population size and therefore any conclusions drawn from this study and others like it must be done with caution (Beliard et al., 2015). The results of this study contrast with a meta-analysis by Hill et al. (2013), which found after looking at the results of 12 studies that wearing compression garments after strenuous exercise and competition reduces the severity of DOMS and accelerates the recovery of muscle function. The mean age of these studies however was 22.3±2.3 years, which does not account for the differences that might be seen in the older population of the current study.

Limitations

There were several limitations to this study. One limitation was that no objective measures of muscle damage were assessed (i.e., blood or muscle biopsy markers), which means recovery rate could not be assessed. Another limitation is that the participants could guess as to whether they were assigned compression socks or placebo socks. While the sock type was not revealed until the study was completed, it is possible that some of their questionnaire answers were based on their assumption about the sock type they were wearing.

Another limitation of this study was the training effect from the first session of eccentric exercise. Even with a two-week break, none of the participants experienced the same level of pain, stiffness, and soreness after repeating the fatiguing exercise protocol a second time compared to their first time. This is called the "Repeated Bout Effect" (RBE). RBE refers to the adaptation where a single bout of eccentric exercise protects against muscle damage from subsequent exercise bouts (McHugh, 2003). This adaptation is characterized by significantly faster recovery of strength and less soreness when the eccentric exercise is repeated within 1 week and up to 6 months after the initial bout (Janecki et al., 2011). Several theories about the specific mechanism for RBE exist, although some researchers propose that several mechanisms working either independently or simultaneously might be responsible, such as cellular protein remodeling (McHugh, 2003, Janecki et al., 2011). Janecki et al. found that adaptations in the biceps brachii after the first bout of eccentric exercise resulted in a smaller increase in passive muscle stiffness and soreness as well as faster isometric torque recovery. Lavender et al. (2006) found that RBE occured to a much lesser degree in older men compared to younger men, and that trainability/adaptability to exercise decreases as one ages. This likely explains why the participants still experienced pain, stiffness, and soreness during their second bout of eccentric exercise, and highlights the need for more research on the aging athlete population. This limitation could have been avoided by doing a randomized control trial with two large groups who only performed the experimental protocol once with only one sock type. It was chosen not to do this because it was suspected that recruitment from this population would be very challenging.

Another limitation of this study was sample size and recruiting participants. Many potential participants were either unable or unwilling to come to San Francisco State University for four visits. Many potential participants indirectly cited the lack of monetary compensation as the reason they were unwilling to participate. Recruitment efforts were ongoing throughout the duration of the study, but all the participants were known to the primary investigator. No participants were recruited through posting flyers, reaching out to running and sports goods stores, or through Bay Area running and triathlon teams that the primary investigator was not associated with. It is recommended that future studies targeting this population have a sufficient budget to provide monetary compensation to attract and retain participants.

Though there were many limitations and difficulties due to the design of this study, it is important to note that this study on runners over 40 is a novel population in the ever-increasing body of work regarding compression garments and their effects on performance and recovery in all types of physical activities. Most studies target younger and elite athlete participants, which have been previously shown to recover and adapt to exercise differently than older athletes (Fell & William, 2008, Lavender & Nosaka, 2006). Due to the difficulty of recruiting from the target population, and lack of knowledge of the repeated bout effect, the investigator chose to have each participant serve as their own control so that not as many participants would need to be recruited. Although the placebo might not have completely fooled each participant, its use is important as many of the findings of this study suggest that, in addition to possibly being more comfortable and economical for the wearer, an inexpensive pair of soccer socks might be just as effective for some measures of recovery as an expensive pair of knee-high compression socks.

Conclusions

In summary, this data does not provide enough evidence to support the use of compression socks as an effective form of recovery in runners over 40 years of age, although the effects seem to be highly individual. Based on the data, it appears that compression socks will help attenuate swelling in the dominant leg when worn after intense exercise, which might be enough of an effect to convince athletes to use such a product since a decrease in swelling could prevent future soft tissue injury. It is recommended that compression socks be used as part of a multi-faceted recovery strategy and not just as a standalone recovery method. Future research should focus on the efficacy of compression in conjunction with other recovery modalities and the long-term rate of injury prevention in this older athlete population.

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Appendices

Appendix 1

EXERCISE HISTORY QUESTIONNAIRE

Effects of Compression Socks on Muscle Recovery in Masters Runners

The following questions are designed to obtain information regarding physical activity and exercise history. Please answer all questions and provide as much information as you possibly can. This questionnaire, as well as any other family medical information you provide, will be kept confidential and will not be shared with any unauthorized person or organization unless you specifically request us to do so.

Name: ____

Date Completed: ___________________________________

Date of Birth: __________ Age: _____

mm-dd-yy

Sex: M _____ F _____

Major Events/Sports:

____

Major Awards/Best Performances:

____

Exercise History Age 40-50

Describe the exercise(s) that you usually participated in (e.g., running, cycling, swimming, skiing, weight lifting). Include the type of training (e.g., long duration, interval training, etc…)

____

____

____

How often did you exercise (days/week)?

____

At what intensity did you typically exercise? Light _____ Moderate _____ Hard _____

OR

Pace______________________________

On days that you did exercise, how long did you usually exercise (hours)?

____

Did you participate in competitive sports? Yes _____ No _____

If yes, what sports did you participate in?

____

If the sport was a team sport, what position did you play?

____

If the sport was an individual sport, what event(s) did you participate in?

____

What was your best time or performance?

____

Did you win any awards? Yes _____ No ______

If yes, what awards did you win?

____

Did you participate in weight lifting? Yes ______ No ______

If yes, how many times per week? ______________________________

How long was each session? __________________________________

Describe a typical weight lifting session (what exercises, how many sets, how many repetitions, how intense?)

____

____

____

Did you have any significant time off from your exercise program?

Yes ______ No _______

If yes, why (planned, injury, other circumstances)?

____

____

____

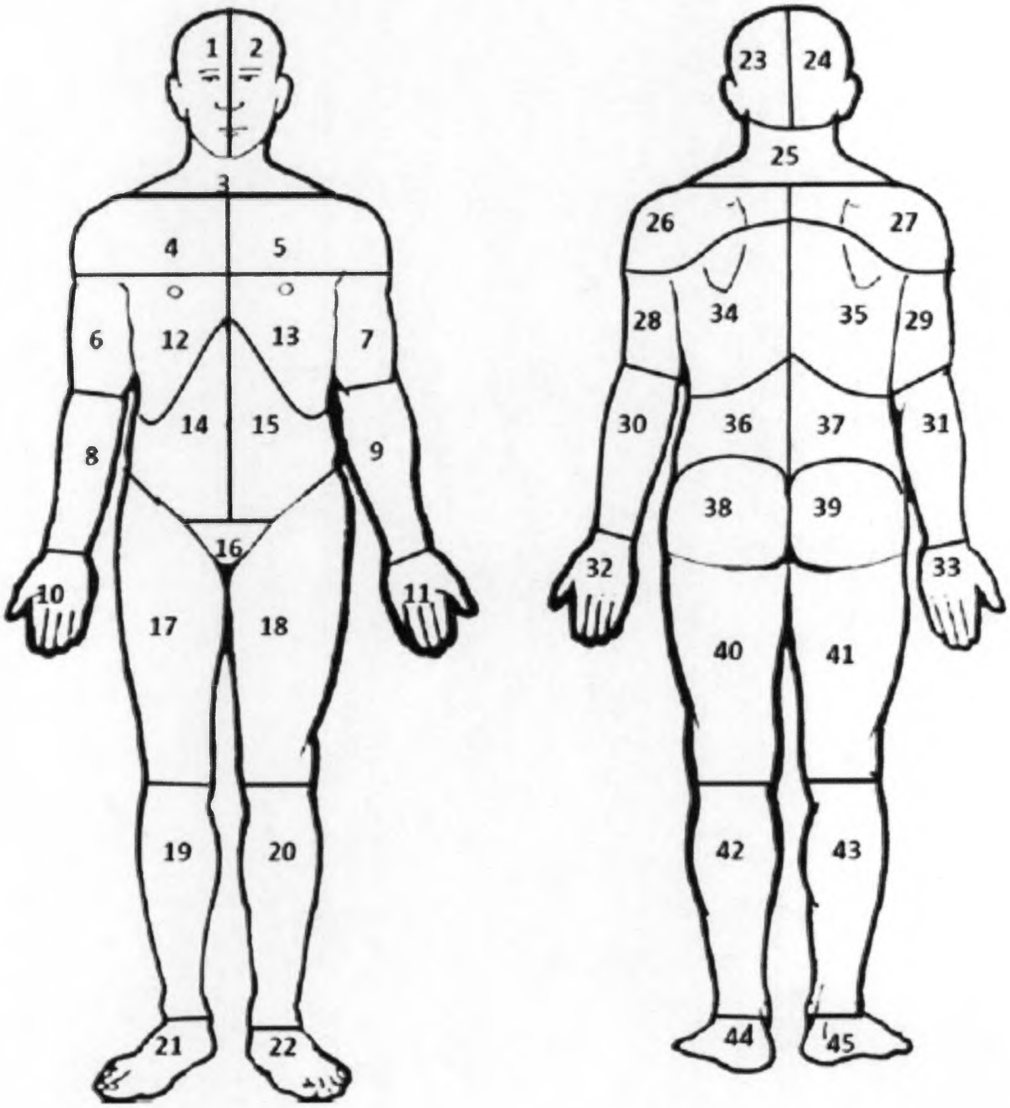
How long did you have time off?

____

Did you participate in any physical activity outside of your training (work, transportation, recreational, etc…)? If yes, please describe.

____

Appendix 2



Southerst et al., 2013

Appendix 3

Questionnaire—Visit 1

1. Have you ever worn compression socks or calf sleeves before? Yes or No (circle)
    a. If yes, what brand of compression did you wear?
    b. If yes, did you wear them for training or racing?
    c. If yes, did you wear them for performance or recovery?
2. Have you had caffeine today? Yes or No (circle)
    a. How much in cups?
3. Have you taken drugs today? Yes or No (circle)
    a. What have you taken?
4. Have you maintained normal dietary habits?
   1 2 3 4 5 6 7 8 9 10 (Circle)
   (Least) (Most)
5. Have you maintained your normal hydration status?
   1 2 3 4 5 6 7 8 9 10 (Circle)
   (Least) (Most)
6. How was your sleep quality last night?
   1 2 3 4 5 6 7 8 9 10 (Circle)
   (Worst) (Best)
7. Compared to a normal day of training/running, how fatigued do your legs feel?
   1 2 3 4 5 6 7 8 9 10 (Circle)
   (Least) (Most)
8. Overall, how sore do you feel?
   1 2 3 4 5 6 7 8 9 10 (Circle)
   (Least) (Worst)