International Journal of EXERCISE SCIENCE

Original Research

The Effect of Compression Socks on Maximal Exercise Performance and Recovery in Insufficiently Active Adults

ALEXANDER H.K. MONTOYE‡[1], ALEXANDRA A. MITHEN*[1], HAVEN L. WESTRA*[1], SUMMER S. BESTEMAN*[2], BRIAN C. RIDER‡[2]

[1]Department of Integrative Physiology and Health Science, Alma College, Alma, MI, USA; [2]Department of Kinesiology, Hope College, Holland, MI, USA

*Denotes undergraduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 14(7): 1036-1051, 2021. In athletic populations, compression socks (CS) may improve exercise performance recovery. However, their potential to improve performance and/or recovery following exercise in non-athletic populations is unknown. Our study evaluated the effects of CS on exercise performance and recovery from a graded maximal treadmill test. Insufficiently active adults (n = 10, 60% female, average physical activity ~60 minutes/week) performed two graded maximal exercise tests; one while wearing below-knee CS, and the other trial with regular socks (CON). Order of trials was randomized. For both trials, heart rate, lactate, and rating of perceived exertion were measured at each stage and at one, five, and ten-minutes post-exercise. Additionally, recovery variables (soreness, tightness, annoyingness, tenderness, pulling) were measured at 24 and 48 hours post-exercise using a visual analog scale. Paired-samples t-tests were used to compare exercise and recovery variables between CS and CON trials. Heart rate, lactate, and rating of perceived exertion were not different between trials for any stage during the exercise test or immediate recovery. Most 24- and 48-hour recovery variables were significantly improved after the CS trial, with values 34.6 - 42.3% lower at 24 hours and 40.3 - 61.4% lower at 48 hours compared to CON. Compression socks provided a significant and meaningful improvement in recovery variables 24-48 hours following maximal exercise. Therefore, CS may remove a common barrier to exercise adherence and facilitate more effective training recovery for insufficiently active adults.

KEY WORDS: Ergogenic aid, compression garment, lactate, exercise performance

INTRODUCTION

Compression socks (CS) worn below the knee are a popular, low-cost strategy to improve circulation in clinical populations and, more recently, to improve athletic performance and/or recovery from exercise in athletic populations (17, 44). By placing pressure on lower leg vasculature, CS can improve venous return by supplementing the action of the skeletal muscle pump. Additionally, CS can reduce the risk of deep vein thrombosis in clinical populations and those engaging in prolonged sedentary time (e.g., plane flights) (9, 21). For exercise, there is evidence that CS may favorably affect muscle morphology, resulting in altered biomechanics, enhanced muscle fiber recruitment, and possibly improved movement economy (7, 32, 33).

Results on exercise performance are mixed, with some studies showing improved time to exhaustion and delayed lactate threshold (1, 24, 30, 41) and others demonstrating little or no effect on exercise performance assessed using race times (5, 6, 35, 42, 45, 48). However, recent reviews by Mota et al. (37) and Engel et al. (20) found evidence of reduced muscle soreness and muscle fatigue, and a study by Berry et al. (5) found faster lactate removal following exercise when using below-knee CS in athletic populations, suggesting that CS may improve athletic performance indirectly when worn in training by speeding recovery and enhancing subsequent exercise performance.

While CS appear to have recovery benefit in athletes, there is a dearth of research examining the effects of CS for exercise performance or recovery in non-athletic individuals. Exercise programs for non-athletic individuals typically have poor adherence (i.e., < 50%), limiting their potential effects on long-term health (22, 43, 47). Frequently cited reasons for dropout include lack of enjoyment, burnout, and soreness/injury (13). To combat dropout, intervention strategies for improving enjoyment, reducing perceived effort, and/or enhancing recovery may help to improve exercise program adherence in non-athletic populations. Given the purported effects of CS when used among athletic populations, their potential for improving exercise performance and/or recovery in non-athletic populations warrants further study.

Athletes and non-athletic populations differ markedly in physical performance abilities in ways that may make CS more effective when used by non-athletes during and after exercise. For example, athletes are able to exercise at a higher intensity than non-athletes before reaching lactate threshold, due in part to better blood delivery to, and/or better shuttling of lactate away from active skeletal muscle (4, 19, 25). If CS can enhance venous return from the lower extremities and thereby assist with increased stroke volume and improved lactate shuttling, they may be particularly helpful in non-athletic populations to extend endurance exercise performance and increase maximal endurance performance. Additionally, muscular fatigue often contributes to limiting exercise performance (18, 26), and non-athletes frequently experience higher muscle pain and longer recovery following exercise than athletes (12, 14). Thus, CS may be especially beneficial in reducing fatigue, muscle soreness, and improving recovery in non-athletic populations, as other types of compression garments have demonstrated (27). While intriguing, these possibilities are yet unexplored in current research to date. Therefore, our study's purpose was to determine the effects of below-knee CS on performance on a graded, maximal exercise test as well as in recovery indicators for up to 48 hours following the maximal exercise test. We hypothesized that blood lactate levels would be lower at near-maximal exercise and immediate recovery when wearing CS (compared to control) and that 24- and 48-hour markers of recovery would be improved with CS.

METHODS

Participants

Ten apparently healthy participants (six female, four male) were recruited for this study. Participants were 22-39 years of age (29 ± 7 [mean ± standard deviation]) and were "insufficiently active," defined as failing to reach the current aerobic guidelines for physical activity (150 min/week moderate-intensity exercise or 75 min/week of vigorous-intensity

exercise or equivalent combination) (39). All participants completed a health history form to confirm that it was safe to participate in vigorous-intensity exercise. Prior to testing, participants provided written consent which was approved by the institution's Human Subjects Review Board. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (38) and the Declaration of Helsinki. Participant demographics and physical activity levels are shown in Table 1.

Table 1. Demographic characteristics of sample.

	Females (n = 6)	Males (n = 4)
Physical activity level (min/week)	55.0 ± 41.8	68.8 ± 44.4
Height (cm)	164.7 ± 6.3	181.3 ± 5.5
Weight (kg)	80.3 ± 30.9	85.2 ± 12.8
Body mass index (kg/m^2)	29.5 ± 11.0	25.8 ± 2.3

Protocol

A flowchart of the protocol can be seen in Figure 1. For the protocol, participants reported to the laboratory for three exercise trials and were asked to dress comfortably for exercise. The laboratory was temperature- and humidity-controlled to ensure similar environmental conditions across all trials. Prior to each trial, participants were instructed to refrain from strenuous exercise for at least 48 hours and from caffeine for at least twelve hours. Additionally, they were instructed to eat the same types of foods at the same times of day prior to each trial. In Trial 1, baseline measures (resting heart rate, blood pressure, height, and weight) and typical physical activity levels were obtained (2001 Behavioral Risk Factor Surveillance System Survey Questionnaire) (46). Then, participants completed a familiarization protocol. The protocol started at 3.5 miles/hour and 0% grade, with the speed staying constant throughout but the incline increasing by 2% grade every two minutes until participants reached 80% of their age predicted maximal heart rate or verbally expressed a desire to stop. This was done in an effort to expose the participants to the protocol they would be completing during Trials 2 and 3. Many of the participants were unaccustomed to walking on a treadmill and, thus, we felt this was necessary to minimize any possible learning effect for the control and experimental trials, while minimizing the risk of muscle soreness prior to the start of Trial 2.

For Trial 2, which occurred at least 48 hours following Trial 1, weight and resting blood pressure were measured. Next, participants were fitted with a Polar A360 heart rate monitor (Polar Electro Oy, Kempele, Finland), which was fastened securely to the posterior side of the non-dominant wrist. The A360 has been previously validated for exercise heart rate assessment (40). If completing the compression sock (CS) trial, participants were then fitted with new Sigvaris below-knee CS (Athletic Recovery Graduated Compression Stockings; Sigvaris Inc., Peachtree City, GA, USA). These CS were comprised of 67% dri-release polyester, 26% nylon, and 7% spandex. Each CS was manufactured to provide a minimum of 20mm Hg pressure (ankle) to 15 mm Hg pressure (calf) when properly fitted according to each participant's shoe size. Researchers ensured proper fit and wear of the CS before participants put their shoes on. If completing the control (CON) trial, participants wore their normal socks. Following equipment fitting, participants performed a graded, maximal exercise test on a treadmill using the same

protocol as in Trial 1, except they kept going until volitional exhaustion. In the last ten seconds of each stage and in the recovery period one, five, and ten minutes following the test, heart rate, blood lactate (finger stick; Lactate Plus Analyzer [Nova Biomedical, Walthman MA, USA]), and rating of perceived exertion (RPE, Borg 6-20 scale) (8) were measured. Following the treadmill test, participants were seated for a 10-minute passive recovery period. If in the CS trial, following the ten-minute recovery measure the CS were removed. Then, participants were allowed to leave the laboratory and go about their normal daily activities with no restrictions.

At 24 and 48-hours following Trial 2, participants received a reminder text message to complete five body-weight calf raises and five body-weight squats and then rate their level of "soreness", "tightness", "tenderness", "annoyingness", and "pulling" in their legs using a set of visual analog scales (VAS). Each VAS was a 100mm horizontal line which was anchored with "not at all" and "extremely." Cleather and Guthrie (15) reported these terms to be the most commonly cited descriptors of delayed onset muscle soreness. The VAS attempted to measure attitudes that range across a continuum of values and are not easily measured by direct methods. Participants mailed back the VAS after completion.

For Trial 3, which occurred approximately seven days after Trial 2 and at a similar time of day, the same procedure occurred as in Trial 2, except the participants would be in the opposite study group (CS or CON). They also completed the VAS assessments at 24 and 48-hours following Trial 3.

The order of participation in CS or CON was randomized using a balanced Latin square design. Additionally, in an effort to reduce potential bias, participants were not informed of any possible effects the CS were purported to have on performance or perceptual responses to exercise.

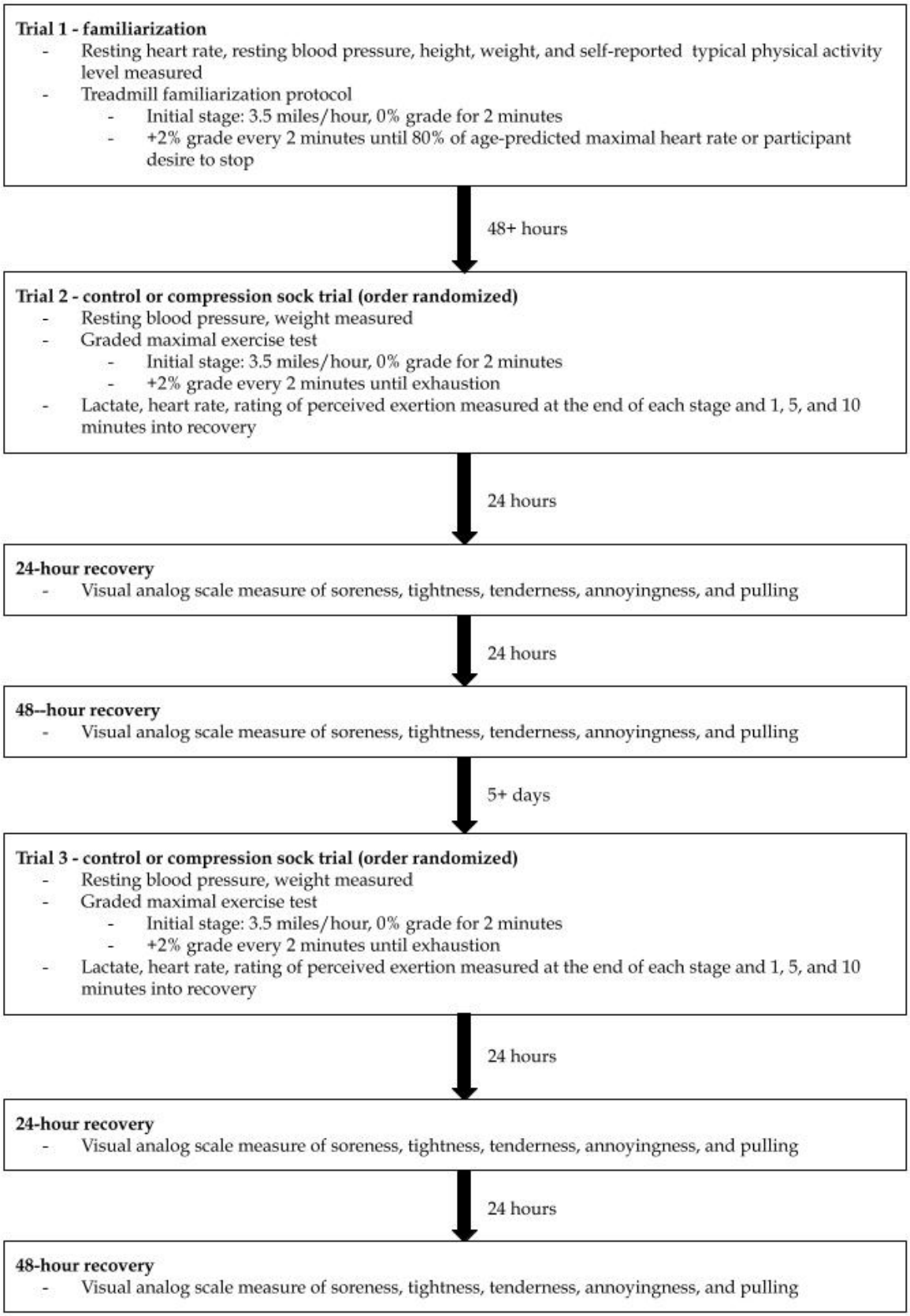

Figure 1. Flowchart describing participant involvement in study.

Statistical Analysis

Heart rate, lactate, and RPE were compared at each treadmill stage and in immediate recovery between CS and CON conditions using paired-samples t-tests. VAS scores for soreness, tightness, annoyingness, tenderness, and pulling were also compared between CS and CON at both 24 and 48 hours post-test using paired-samples t-tests. Differences between groups were considered statistically significant at a p-value of $p < 0.05$. Additionally, to better understand the magnitude of differences between groups, effect sizes (ES) were calculated and were evaluated as ES < 0.20 = trivial, 0.20 ≤ ES < 0.50 = small, 0.50 ≤ ES < 0.80 = Medium, 0.80 ≤ ES < 1.30 = Large, and ES > 1.30 = very large (16). A necessary sample size of $n = 10$ was determined using the G*Power analysis software (version 3.0.10; Kiel, Germany) with an alpha of 0.05, a desired power of 0.75, and a desired effect size of 0.8 for detecting large effect sizes. Finally, as has been done with other ergogenic aids studies, a smallest worthwhile change analysis was conducted, where a meaningful change was determined as a difference between groups of greater than 0.6*standard deviation of the measures during the CS trial (11, 34). Analyses were conducted in SPSS version 24.0 (IBM Corp., Armonk NY) and Microsoft Excel 2016 (Microsoft Corp., Redmond WA).

RESULTS

Participants completed an average of 10.1 ± 2.5 stages in the CON trial and 10.2 ± 2.6 stages in the CS trial (range 6-13 stages), with one participant completing an extra stage in the CS trial and the remaining nine participants completing the same number of stages. Heart rate, lactate, and RPE during exercise and during immediate recovery are shown in Figures 2, 3, and 4, respectively. There were no significant differences in heart rate, lactate, or RPE between trials at any stage or in immediate recovery. Analyses were re-run across the last four stages of each participant's data (to account for the fact that participants completed different numbers of stages), but there were also no significant differences for heart rate, lactate, or RPE in this analysis.

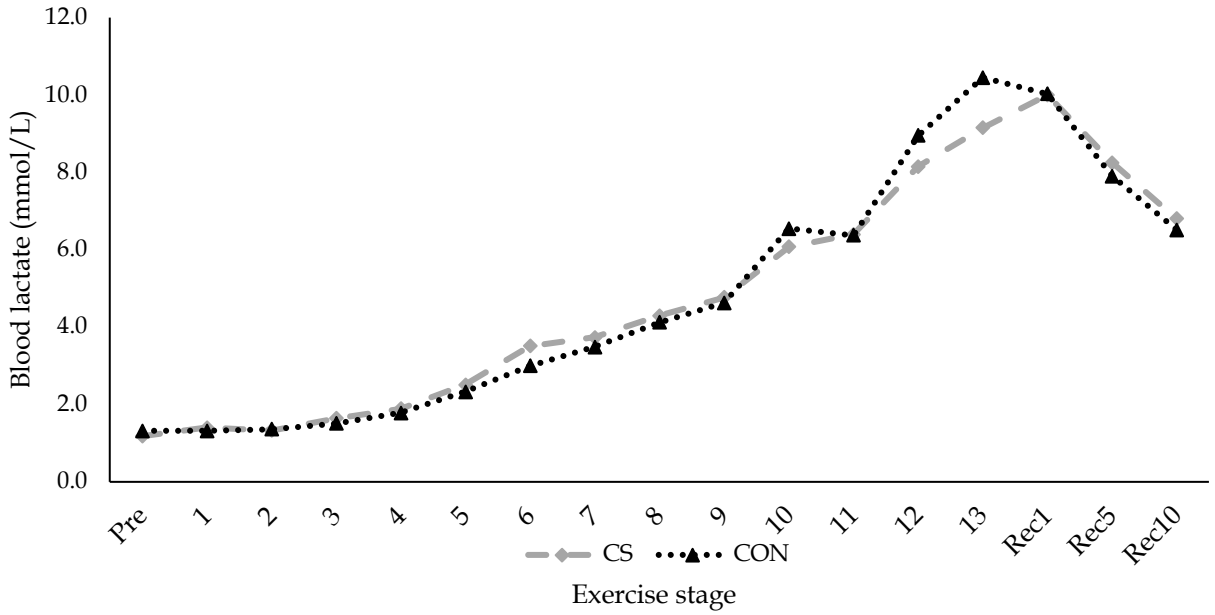

Figure 2. Stage-by-stage lactate measures during compression sock and control trials. Pre: measure taken before starting exercise test, Rec1: 1 minute following completion of exercise test, Rec5: 5 minutes following completion of exercise test, Rec10: 10 minutes following completion of exercise test, CS: compression sock trial, CON: control trial.

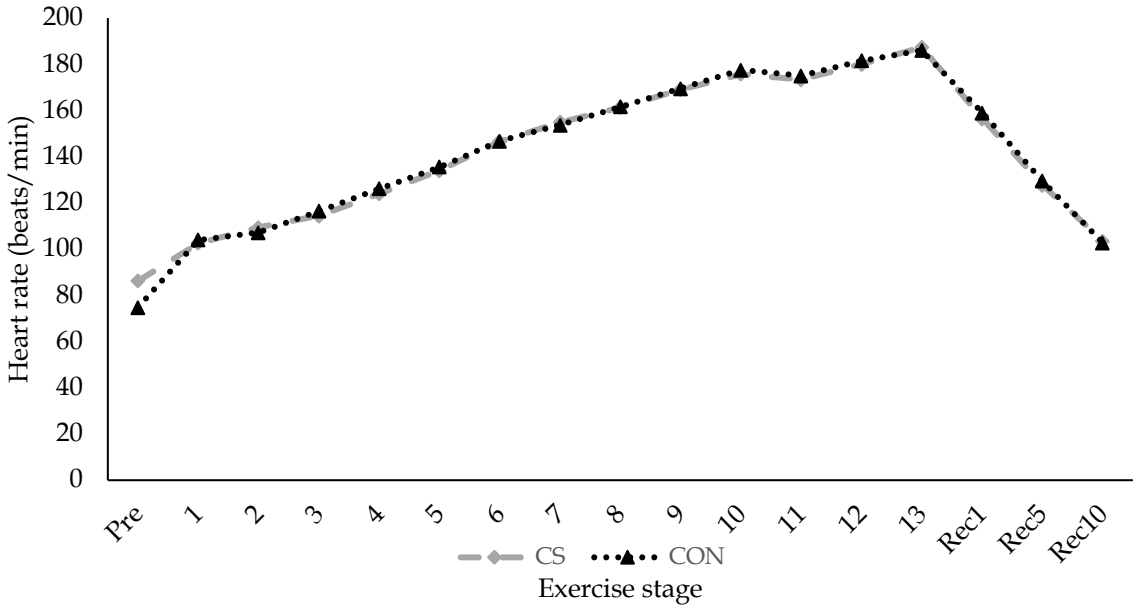

Figure 3. Stage-by-stage heart rate measures during compression sock and control trials.

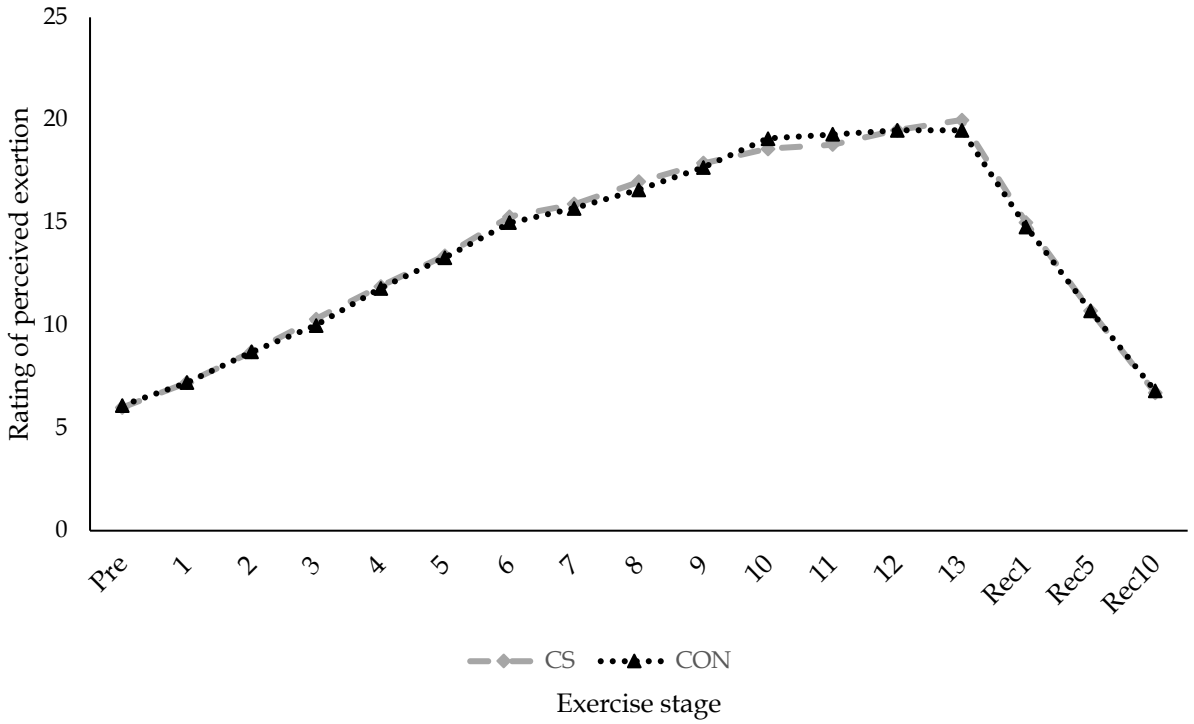

Figure 4. Stage-by-stage rating of perceived exertion measures during compression sock and control trials.

Self-reported recovery data using the VAS are shown in Figure 5. At 24 hours post-test, feelings of soreness (CS: 16.6 ± 15.2 vs. CON: 26.5 ± 18.1) and pulling (CS: 14.7 ± 15.4 vs. CON: 25.5 ± 21.6) suggested quicker recovery for the CS trial compared to the CON trial. Similarly, at 48 hours post-test, tightness (CS: 13.7 ± 18.3 vs. CON: 35.4 ± 29.4), annoyingness (CS: 12.3 ± 17.6 vs. CON: 27.2 ± 29.1), and pulling (CS: 13.7 ± 18.7 vs. CON: 31.3 ± 28.0) all favored quicker recovery for the CS trial compared to the CON trial. Additionally, point estimates at 48 hours were higher than at 24 hours in four of the five variables in the CON trial but none of the variables in the CS trial, suggesting prolonged recovery following CON compared to CS.

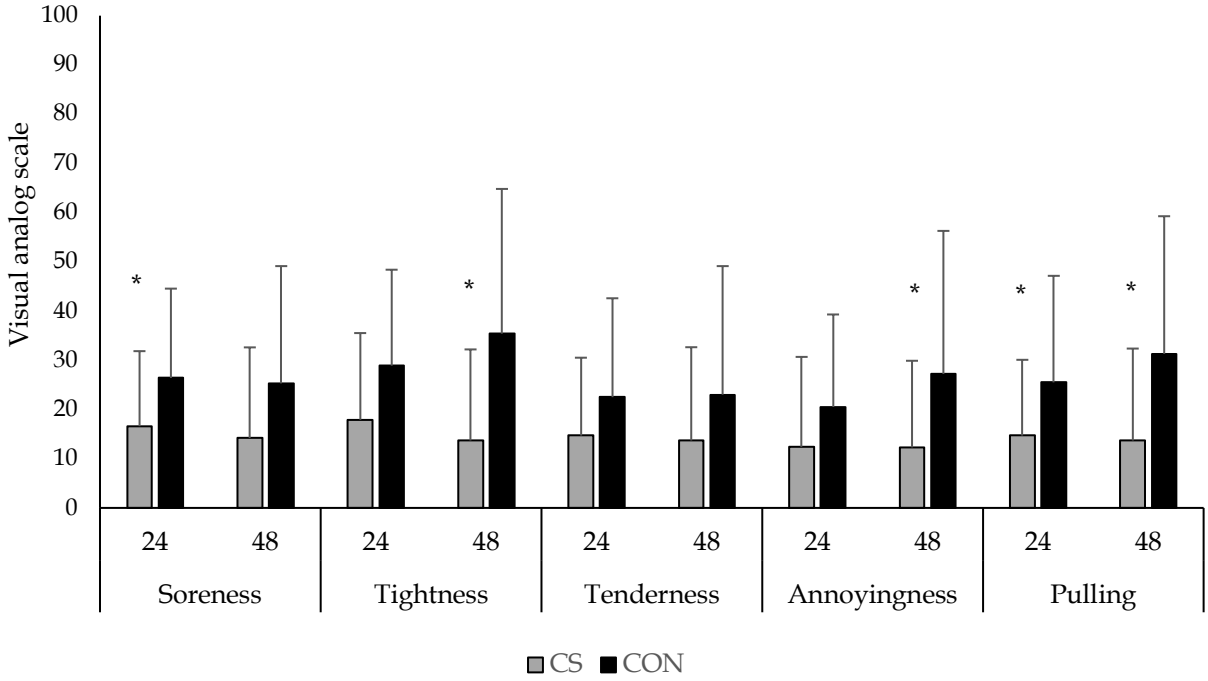

Figure 5. Comparison of visual analog scale measures for recovery 24 and 48-hours following exercise test for compression sock and control trials. 24: 24 hours following exercise test, 48: 48 hours following exercise test. *Indicates significant difference ($p < 0.05$) from CON trial.

Tables 2 and 3 show effect sizes for the differences between trials for exercise and recovery variables, respectively. During exercise, there was a medium effect size favoring lower lactate in the CS trial for Stage 12, a very large effect size favoring lower lactate in the CS trial for Stage 13, and a medium effect size favoring lower RPE in the CON trial at Stage 13. All other effect sizes were small or trivial. For the recovery variables, there were medium or large effect sizes favoring CS at 24 hours, 48 hours, or both for all variables except annoyingness, which had small effect sizes at both time points.

Table 2. Effect sizes for lactate, heart rate, and rating of perceived exertion between compression sock and control trials.

Stage	Lactate (mmol/L)	Heart rate (beats/min)	Rating of perceived exertion
Pre	0.27	0.66*	0.45
1	0.18	0.07	0.00
2	0.06	0.11	0.00
3	0.21	0.11	0.15
4	0.10	0.10	0.04
5	0.13	0.08	0.04
6	0.22	0.01	0.12
7	0.11	0.06	0.09
8	0.08	0.02	0.20
9	0.09	0.02	0.08
10	0.22	0.14	0.39
11	0.03	0.30	0.42
12	0.73*	0.20	0.00
13	1.67+	0.27	1.00+
Rec1	0.02	0.24	0.09
Rec5	0.17	0.15	0.00
Rec10	0.14	0.10	0.10

* indicates medium effect sizes. + indicates large or greater effect sizes.

Table 3. Effect sizes for differences recovery variables at 24 & 48-hours following compression sock and control trials.

Time post-test	Soreness	Tightness	Annoyingness	Tenderness	Pulling
24 hours	0.57*	0.55*	0.38	0.39	0.49
48 hours	0.61*	1.08+	0.44	0.69*	0.77*

* indicates medium effect sizes. + indicates large or greater effect sizes.

Tables 4 and 5 present the smallest worthwhile change analysis for the differences between trials for exercise and recovery variables, respectively. During exercise, the differences between trials exceeded the smallest worthwhile change threshold for all variables at Stage 13 and for lactate at Stage 12. For the recovery variables, all but annoyingness and tenderness were meaningfully improved at 24 hours for the CS compared to the CON trials, and at 48 hours for all variables, except tenderness were meaningfully improved for the CS compared to the CON trials.

Table 4. Smallest worthwhile change analysis for differences in exercise variables between compression sock and control trials.

	Lactate (mmol/L)		Heart rate (beats/min)		Rating of perceived exertion	
Stage	SWC	Mean difference CON - CS	SWC	Mean difference CON - CS	SWC	Mean difference CON - CS
Pre	0.35	0.14	11.27	11.40#	0.00	0.10#
Stage 1	0.28	-0.08	12.63	1.30	0.62	0.00
Stage 2	0.38	0.03	11.67	-2.10	1.27	0.00
Stage 3	0.48	-0.13	12.20	2.00	1.36	-0.30
Stage 4	0.77	-0.11	13.53	2.20	1.40	-0.10
Stage 5	1.01	-0.18	13.07	1.60	1.36	-0.10
Stage 6	1.71	-0.51	14.08	0.20	1.52	-0.30
Stage 7	1.52	-0.24	13.51	-1.22	1.48	-0.22
Stage 8	1.53	-0.18	12.45	0.38	1.20	-0.38
Stage 9	0.95	-0.14	10.28	0.29	1.12	-0.14
Stage 10	1.38	0.47	8.00	1.71	0.91	0.57
Stage 11	0.55	-0.03	1.79	1.75	0.57	0.50
Stage 12	0.71	0.80#	3.46	1.50	0.35	0.00
Stage 13	0.21	1.30#	0.85	-1.00#	0.00	-0.50#
Rec1	1.04	0.03	5.62	2.40	1.44	-0.20
Rec5	1.33	-0.35	6.52	1.70	1.36	0.00
Rec10	1.51	-0.29	4.53	-0.90	0.64	0.10

SWC: smallest worthwhile change. # indicates that difference between trials exceeded the smallest worthwhile change.

Table 5. Smallest worthwhile change analysis for differences in recovery variables between compression sock and control trials.

	24 hours post-test		48 hours post-test	
VAS	SWC	Mean difference CON - CS	SWC	Mean difference CON - CS
Soreness	9.15	9.80#	11.05	11.11#
Tightness	10.57	11.01#	11.10	21.74#
Annoyingness	10.97	8.17	10.56	14.97#
Tenderness	9.49	7.79	11.37	9.26
Pulling	9.23	10.78#	11.20	17.58#

# indicates that difference between trials exceeded the smallest worthwhile change.

DISCUSSION

Our study found that CS worn during and in the ten minutes following maximal exercise did not improve physiological variables including heart rate, lactate, and RPE during a graded exercise test or during immediate recovery. Despite the theoretical mechanism of enhancing lactate removal from muscles by enhancing venous return from the legs, most findings in athletes suggest little or no effect of CS on lactate levels during exercise (2, 3, 10). Our results seem to indicate similar findings in non-athletes, although larger sample sizes are needed to

allow for conducting sub-analyses by variables such as sex and fitness level to see if such factors influence the effect of CS on lactate clearance. The lack of significant differences in heart rate or RPE additionally reveals that CS did not lower physiologic or perceived effort during exercise, suggesting minimal effect of CS on a single bout of maximal exercise in non-athletes. Despite no improvement in acute exercise performance, our study participants reported reduced symptoms of soreness and generally improved recovery at both 24 and 48 hours following the CS trial compared to the CON trial. This finding is in agreement with a 2016 review by Engel et al. (20), which found consistent evidence of reduced symptoms of muscle pain, delayed onset muscle soreness, and inflammation when wearing CS following exercise in mainly athletic populations. Over 90% (29 out of 32) of the studies included in this review were in athletic populations and the remaining three were in healthy adult populations, only one of which examined recovery and found positive effects of CS in males (36). Our study extends previous findings by including inactive individuals and female participants. Additionally, while many previous studies had participants wear compression socks for an extended period (often hours or days) after exercise, our participants wore them only during and for ten minutes following the exercise test. The fact that CS positively impacted recovery when worn during and immediately after exercise further supports the practicality of their use in improving recovery in the days following heavy exercise.

Pain and soreness following exercise is a frequently cited reason for poor adherence to, and high dropout after starting, exercise programs (13). This is especially true in individuals who suffer from chronic pain (e.g., low back pain, arthritis), who often fear their pain being worsened by exercise (23). Although we did not study a chronic pain population, our findings of improved recovery in insufficiently active individuals offer an important first step in suggesting that use of CS may lessen one barrier for the adoption of a physically active lifestyle in previously insufficiently active adult populations. Reduction of pain, especially when starting an exercise program, may thereby enhance exercise adherence (28). We also did not study individuals who may wear CS for medical reasons (e.g., individuals with deep vein thrombosis, diabetes, heart disease), but such individuals often wear CS for their noted benefits in lessening blood pooling and edema in the lower leg (49). Since individuals with such conditions may already own CS, they could use their CS not only for everyday activities but also during exercise to assist with recovery. Given the known effectiveness of exercise in managing chronic pain and preventing/managing many chronic diseases (23, 31), the exciting possibility that CS might lessen pain and/or improve exercise adherence in these or other adult populations should be studied further.

In addition to potentially improving exercise adherence, less soreness following exercise may enhance subsequent exercise performance. We are aware of only two studies examining CS use and subsequent exercise performance; in the studies, trained runners saw improved five kilometer run performance one hour following a preliminary five kilometer run when wearing CS compared to a control condition (9, 10). If these results can be confirmed in the days following exercise and in insufficiently active populations, increased performance during subsequent training could serve as a motivating factor to continue an exercise program. Improved recovery may also allow individuals to progress more quickly during an exercise training program, potentially enhancing the benefits seen from exercise training (29). Such possibilities should be explored in future work.

Several study limitations should be considered alongside our results. Our study lacked metabolic analyses, and we were therefore unable to determine potential changes in maximal oxygen consumption or running economy with CS. Additionally, our study was not blinded to treatment, and use of a placebo (e.g., below-knee dress socks with minimal compression) could have helped eliminate potential bias that may have been present in the study. Finally, the sample size was too small to conduct sub-analyses by fitness level or sex. Future research with a larger sample should be conducted to confirm our findings and stratify analyses to determine if different subgroups of insufficiently active individuals have different responses to CS during and after exercise.

In conclusion, our study found little difference in physiologic responses or performance when using CS in an insufficiently active population during a graded exercise test. However, recovery variables 24 - 48 hours post-exercise suggest significantly improved recovery when wearing CS during exercise as compared to a control condition. Thus, the use of CS appears to aid in exercise recovery, with the potential to remove a frequently cited barrier to exercise in inactive populations.

ACKNOWLEDGEMENTS

The authors would like to thank participants for their contribution to the study. There are no funding sources to report, and the authors declare no conflicts of interest.

REFERENCES

1. Ali A, Caine MP, Snow BG. Graduated compression stockings: Physiological and perceptual responses during and after exercise. J Sports Sci 25(4): 413-419, 2007.

2. Ali A, Creasy RH, Edge JA. The effect of graduated compression stockings on running performance. J Strength Cond Res 25(5): 1385-1392, 2011.

3. Areces F, Salinero JJ, Abian-Vicen J, Gonzalez-Millan C, Ruiz-Vicente D, Lara B, Lledo M, Del Coso J. The use of compression stockings during a marathon competition to reduce exercise-induced muscle damage: Are they really useful? J Orthop Sports Phys Ther 45(6): 462-470, 2015.

4. Beneke R, Leithauser RM, Ochentel O. Blood lactate diagnostics in exercise testing and training. Int J Sports Physiol Perform 6(1): 8-24, 2011.

5. Berry MJ, McMurray RG. Effects of graduated compression stockings on blood lactate following an exhaustive bout of exercise. Am J Phys Med 66(3): 121-132, 1987.

6. Bieuzen F, Brisswalter J, Easthope C, Vercruyssen F, Bernard T, Hausswirth C. Effect of wearing compression stockings on recovery after mild exercise-induced muscle damage. Int J Sports Physiol Perform 9(2): 256-264, 2014.

7. Birmingham TB, Kramer JF, Inglis JT, Mooney CA, Murray LJ, Fowler PJ, Kirkley S. Effect of a neoprene sleeve on knee joint position sense during sitting open kinetic chain and supine closed kinetic chain tests. Am J Sports Med 26(4): 562-566, 1998.

8. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14(5): 377-381, 1982.

9. Brophy-Williams N, Driller MW, Kitic CM, Fell JW, Halson SL. Effect of compression socks worn between repeated maximal running bouts. Int J Sports Physiol Perform 12(5): 621-627, 2017.

10. Brophy-Williams N, Driller MW, Kitic CM, Fell JW, Halson SL. Wearing compression socks during exercise aids subsequent performance. J Sci Med Sport 22(1): 123-127, 2019.

11. Buchheit M. The numbers will love you back in return-I promise. Int J Sports Physiol Perform 11(4): 551-554, 2016.

12. Byrnes WC, Clarkson PM. Delayed onset muscle soreness and training. Clin Sports Med 5(3): 605-614, 1986.

13. Canadian Fitness and Research Institute. Progress in prevention. Fitness and Lifestyle Institute; 2015.

14. Cheung K, Hume P, Maxwell L. Delayed onset muscle soreness: Treatment strategies and performance factors. Sports Med 33(2): 145-164, 2003.

15. Cleather DJ, Guthrie SR. Quantifying delayed-onset muscle soreness: A comparison of unidimensional and multidimensional instrumentation. J Sports Sci 25(8): 845-850, 2007.

16. Cohen S. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.

17. da Silva CA, Helal L, da Silva RP, Belli KC, Umpierre D, Stein R. Association of lower limb compression garments during high-intensity exercise with performance and physiological responses: A systematic review and meta-analysis. Sports Med 48(8): 1859-1873, 2018.

18. Davis MP, Walsh D. Mechanisms of fatigue. J Support Oncol 8(4): 164-174, 2010.

19. Donovan CM, Brooks GA. Endurance training affects lactate clearance, not lactate production. Am J Physiol 244(1): E83-92, 1983.

20. Engel FA, Holmberg HC, Sperlich B. Is there evidence that runners can benefit from wearing compression clothing? Sports Med 46(12): 1939-1952, 2016.

21. Fletcher L, Raab S, Sanderson S, Vargo L. Efficacy of compression socks to enhance recovery in distance athletes. Sport and Art 2(2): 15-18, 2014.

22. Fogelholm M, Kukkonen-Harjula K. Does physical activity prevent weight gain - A systematic review. Obes Rev 1(2): 95-111, 2000.

23. Geneen LJ, Moore RA, Clarke C, Martin D, Colvin LA, Smith BH. Physical activity and exercise for chronic pain in adults: An overview of Cochrane reviews. Cochrane Database Syst Rev 4: CD011279, 2017.

24. Gimenes SV, Marocolo M, Pavin LN, Spigolon LMP, Barbosa Neto O, da Silva BVC, Duffield R, da Mota GR. Compression stockings used during two soccer matches improve perceived muscle soreness and high-intensity performance. J Strength Cond Res 35(7): 2010-2017, 2021.

25. Gliemann L, Vestergaard Hansen C, Rytter N, Hellsten Y. Regulation of skeletal muscle blood flow during exercise. Curr Opin Phys 10: 146-155, 2019.

26. Hawley JA, Myburgh KH, Noakes TD, Dennis SC. Training techniques to improve fatigue resistance and enhance endurance performance. J Sports Sci 15(3): 325-333, 1997.

27. Hill J, Howatson G, van Someren K, Leeder J, Pedlar C. Compression garments and recovery from exercise-induced muscle damage: A meta-analysis. Br J Sports Med 48(18): 1340-1346, 2014.

28. Howatson G, van Someren KA. The prevention and treatment of exercise-induced muscle damage. Sports Med 38(6): 483-503, 2008.

29. Jones AM, Carter H. The effect of endurance training on parameters of aerobic fitness. Sports Med 29(6): 373-386, 2000.

30. Kemmler W, von Stengel S, Kockritz C, Mayhew J, Wassermann A, Zapf J. Effect of compression stockings on running performance in men runners. J Strength Cond Res 23(1): 101-105, 2009.

31. Kirwan JP, Sacks J, Nieuwoudt S. The essential role of exercise in the management of type 2 diabetes. Cleve Clin J Med 84(7 Suppl 1): S15-S21, 2017.

32. Kraemer WJ, Bush JA, Newton RU, Duncan ND, Volek JS, Denegar CR, Canavan P, Johnston J, Putukian M, Sebastianelli WJ. Influence of a compression garment on repetitive power output production before and after different types of muscle fatigue. Sports Med Train Rehabil 8(2): 163-184, 1998.

33. MacRae BA, Cotter JD, Laing RM. Compression garments and exercise: Garment considerations, physiology and performance. Sports Med 41(10): 815-843, 2011.

34. Marocolo M, Simim MAM, Bernardino A, Monteiro IR, Patterson SD, da Mota GR. Ischemic preconditioning and exercise performance: Shedding light through smallest worthwhile change. Eur J Appl Physiol 119(10): 2123-2149, 2019.

35. Menetrier A, Mourot L, Bouhaddi M, Regnard J, Tordi N. Compression sleeves increase tissue oxygen saturation but not running performance. Int J Sports Med 32(11): 864-868, 2011.

36. Miyamoto N, Kawakami Y. No graduated pressure profile in compression stockings still reduces muscle fatigue. Int J Sports Med 36(3): 220-225, 2015.

37. Mota GR, Simim MAM, Dos Santos IA, Sasaki JE, Marocolo M. Effects of wearing compression stockings on exercise performance and associated indicators: A systematic review. Open Access J Sports Med 11: 29-42, 2020.

38. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

39. Piercy KL, Troiano RP. Physical activity guidelines for Americans from the US Department of Health and Human Services. Circ Cardiovasc Qual Outcomes 11(11): e005263, 2018.

40. Rider BC, Conger SA, Ditzenberger GL, Besteman SS, Bouret CM, Coughlin AM. Examining the accuracy of the Polar A360 monitor. J Strength Cond Res Epub doi: 10.1519/JSC.0000000000003136, 2019.

41. Rider BC, Coughlin AM, Hew-Butler TD, Goslin BR. Effect of compression stockings on physiological responses and running performance in Division III collegiate cross-country runners during a maximal treadmill test. J Strength Cond Res 28(6): 1732-1738, 2014.

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

43. Rivera-Torres S, Fahey TD, Rivera MA. Adherence to exercise programs in older adults: Informative report. Gerontol Geriatr Med 5: 2333721418823604, 2019.

44. Sigel B, Edelstein AL, Savitch L, Hasty JH, Felix WR, Jr. Type of compression for reducing venous stasis. A study of lower extremities during inactive recumbency. Arch Surg 110(2): 171-175, 1975.

45. Treseler C, Bixby WR, Nepocatych S. The effect of compression stockings on physiological and psychological responses after 5-km performance in recreationally active females. J Strength Cond Res 30(7): 1985-1991, 2016.

46. U.S. Department of Health and Human Services. Behavioral Risk Factor Surveillance System survey questionnaire. Atlanta, GA: Centers for Disease Control and Prevention; 2001.

47. van Heuvelen MJ, Hochstenbach JB, Brouwer WH, de Greef MH, Scherder E. Psychological and physical activity training for older persons: Who does not attend? Gerontology 52(6): 366-375, 2006.

48. Varela-Sanz A, Espana J, Carr N, Boullosa DA, Esteve-Lanao J. Effects of gradual-elastic compression stockings on running economy, kinematics, and performance in runners. J Strength Cond Res 25(10): 2902-2910, 2011.

49. Wu SC, Crews RT, Skratsky M, Overstreet J, Yalla SV, Winder M, Ortiz J, Andersen CA. Control of lower extremity edema in patients with diabetes: Double blind randomized controlled trial assessing the efficacy of mild compression diabetic socks. Diabetes Res Clin Pract 127: 35-43, 2017.