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Compression Stockings and Aerobic Exercise: A Meta-Analysis

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Abstract The aim of this study was to conduct a meta-analysis to determine if wearing compression clothing affects athletic performance by increasing endurance and aerobic capacity as measured by improvements in both VO_2 max and heart rate. Studies were found by using the search engines Google and Galileo, and by using search terms such as "compression garments and their effect on performance." Only studies that examined compression clothing and its effect on endurance and aerobic capacity were used. Of the four studies, only one study concluded that compression clothing does improve performance ($P<0.05$), whereas the other three found that compression clothing were highly effective with reducing delayed on-set muscle soreness ($P=0.05$) and/or leg edema when wearing compression stockings (effect sizes = 0.00-0.65). All studies were performed on recreational to well-trained athletes. In conclusion, compression clothing may be more physiological than physical for improving endurance.

Keywords Compression Socks, Compression Garments, VO_2, Aerobic Capacity, Heart Rate

1. Introduction

Due to the competitive nature of sports athletes are always seeking to gain an advantage. It is a belief that the desire to win is what drives athletes to find an edge over competitors. Athletes may turn to coaches who have in depth knowledge of their sports and the most efficient training techniques to improve their performance. Athletes could also turn towards using equipment or training aids to gain a competitive advantage [1]. One piece of sports equipment that is becoming more popular among athletes today is compression clothing [2-4]. Athletes who compete in sporting events that require them to maintain physical activity for extended periods of time such as long distance runners have begun wearing compression garments because they feel that these garments improve their endurance [4].

Ali [6] examined the effect that compression stockings had on continuous exercise. Their research was on 14 males who competed in a sport that was based on running; such as rugby, soccer, tennis, and/or were considered recreational runners (performed at least two training runs while running at a moderate intensity which lasted 30-60 minutes per session per week). Before the main trials, subjects ran a 10km route that was used to determine the pace that each individual would run during the two randomized main trials. In the experimental trials participants wore compression stockings underneath ankle length socks while running the 10km route. The control participants only wore the ankle length socks. In order to ensure that participants maintained a pace that was similar to the pace that they ran during the initial run test, a confederate rode along beside the participant while they ran and provided time checks at regular intervals to ensure the pace was consistent with the test run. The results found that there was no difference in exercise performance between the two conditions, and there was no difference in heart rate between the two conditions.

Creasy [7] also conducted a study with compression stockings and continuous exercise. He used 12 well-trained runners who performed five trials of 10km runs in order to measure the effect that varying grades of compression socks had on a 10km performance. Before the experimental trials began, participants completed a test to determine their VO_2 max and their lactate threshold. Participants then ran an initial 10km run on a 400m track to determine the pace that would be used during the experimental trials. Then participants completed four trials of 10km at using four different grades of graduated compression socks with six days between each trial. Participants completed four trials of 10km runs wearing either a sock with no compression (0 mmHg), a low compression sock (12-15 mmHg), a medium compression sock (18-21 mmHg), or a high compression sock (23-32 mmHg). Before beginning the trials participants donned a downloadable heart monitor that recorded heart rate every five seconds during the run. After completing the trials other measures such as rating of perceived exertion, level of blood lactate, and perceptual measures were taken. It was found that there were no significant differences in performance times across trials, and that there were no significant differences between heart rate across trials, thus no significance was found with varying uses

of compression socks.

A study by Sperlich [7] also examined the effects that various levels of compression had on long distance running. Fifteen well trained male runners were instructed to complete a ramp test to determine their individual maximal oxygen uptakes and to determine the speed they would run during the experimental trials. Each participant performed five-45 minute runs at the same intensity (approximately 70% of each participant's peak oxygen uptake (VO_2 max) with different levels of compression in a randomized order with four days between trials. Participants completed the experimental trials wearing compression socks with a mean calf pressure of 0 mmHg, 10mmHg, 20mmHg, 30mmHg, and/or 40 mmHg. During all trials, including the controls both oxygen uptake (VO_2) and heart rate were measured. Results found that there were no significant differences across $VO_2$and heart rate trials and compression socks had no effect on performance.

In contrast to the results of Ali [6]; Creasy [7] and Sperlich [8] manufacturers of compression garments promote their products by listing the benefits of wearing them during exercise. Zootsports.com [9] claims that wearing Zoot Sports compression socks will boost performance for long distance runners. Another brand of compression clothing, Bio Skin [10] claims that their compression shorts improve athletic performance and endurance. No citations were given on the websites to justify their claims. Empirical evidence that has been researched has found compression clothing to be questionable when it comes to improving athletic performance for long distance runners.

The only study found where research was conducted using compression socks and found that they did improve performance in long distance running was by Kemmler [11]. Participants were asked to perform two stepwise speed-incremented treadmill tests (performed to voluntary maximum termination): one while wearing compression socks and one without compression socks. The initial speed was set at 9 to 11km/hr based on the athlete's known performance capabilities and was increased 1 km/hr every 5 mins. During the trials oxygen uptake (VO_2) and heart rate were both measured. Because the experimental trial runs were done until voluntary completion running performance was determined by time under load (mins) and total work (kJ). It was found that running performance was significantly higher and that maximum run speed was also significantly higher while running with compression socks. However compression socks did not significantly affect both VO_2 and heart rate max. In order to provide a more comprehensive understanding of the effects that compression clothing has on the performance of continuous exercise and to provide support to or refute the claims made by manufacturers, a meta-analysis was conducted. The aim of the present study was to examine the results of several studies that tested the effects that compression clothing had on the athletic performance of subjects that participated in continuous exercise.

2. Materials and Methods

2.1. Inclusion and Exclusion Criteria

It was determined that in order to promote homogeneity that only studies which examined continuous running should be used. Compression clothing has been studied in previous research using many other types of physical activities [4, 5, 12-14] however it was found that studies that did not include continuous exercise had too much variability in either the design of the study, the types of physical activities that were used to measure athletic performance, or how athletic performance was measured to conduct a meta-analysis.

Previous literature that examined compression clothing and the effect that it had on athletic performance is quite varied in the type of athletic activities that were used during experimental trials. This variability in the activities used to assess the effectiveness of compression clothing and the impact that it has on athletic performance makes it difficult to really understand their effects. Previous studies asked participants to perform sprints [6, 13], jumps [15, 16], and long distance runs/cycling [5-8, 11].

For example a study conducted by Doan [17] instructed participants to perform maximal countermovement jumps vertical jumps, and only used the highest jump recorded for each participant in their results which concluded that maximal vertical jump height increase when participants wore compression shorts. A similar study conducted by Kraemer [16] also had participants perform maximal height countermovement jumps but instead of conducting just one trial of countermovement jumps as found in Doan [17] subjects performed three sets of 10 countermovement jumps with only 10 minutes of rest between the three conditions. This difference in the total number of jumps performed may have impacted maximal jump heights between conditions as the results found that wearing compression shorts had no significant effect on maximal force or power of the highest jump but mean force over the 10 jumps was significantly higher when the compression shorts were worn. Another difference between Doan [17] Kraemer [16] was the types of compression garments that were worn during the experimental countermovement jump trials. In Doan [17] the participants either wore compression shorts or loose fitting gym shorts in all trials, and in Kraemer [16] participants wore compression shorts, undersized compression shorts, or loose fitting gym shorts. It is difficult to compare the results of these two studies when the types of compression garments used were not identical, and when the experimental procedures were different. Because of these differences this makes it challenging to generalize the effect that compression clothing has on jump height even though both studies found that in at least one condition jump height and jump power were improved when compression shorts were worn.

In order to objectively study the effects of compression clothing and the impact that it has on athletic performance it

was decided that only data from studies that examined the effects that compression clothing had on one type of physical activity would be considered for use in the meta- analysis. The present study examines the effect that compression stockings had on long distance running. It was thought that compression stockings should be the only type of compression garments selected for this meta-analysis in order to create homogeneity between studies and because it would be very difficult to generalize the results of other types of compression clothing across studies without conducted additional research.

Once it was decided that only studies that examined the effects that compression stockings had on athletic performance it was then necessary to determine what type of physical activities should be examined and which studies should be included in the meta-analysis. Again because of the inconsistency between the types of physical activity found in previous research that examined compression meta-analysis clothing it was decided that in order to measure the effects compression stockings had on athletic performance that only one type of athletic activity should be used in the meta-analysis. Because of the growing popularity of the use of compression stockings as a performance aid for long distance runners [2, 3, 8, 11] studies that used long distance running events were the only type of studies used in the meta-analysis. The study of compression stocking's effect on long distance running is critical because it may reveal the supposed benefits of wearing the stockings which would be of great value to runners.

It was also decided that in order to determine if compression stockings improved athletic performance that physiological measure(s) would need to be considered. VO_2 max and heart rate have traditionally been used as variables to examine performance in long distance running [18-21]. VO_2 max is defined as the maximum volume of oxygen that the body can consume during intense whole-body exercise [11, 18]. VO_2 max is a variable that can be used to determine an athlete's aerobic capacity which is linked to peak performance [19] and is thought to be the best predictor of athletic performance for long distance running events [20]. Heart Rate is also a measure that has been used to assess athletic performance in long distance running and endurance exercise and it is defined as the number of heartbeats per a given unit of time and it is typically measured in minutes [21]. If a runner has a lower heart rate compared to a competitor their heart is working more efficiently to pump blood throughout the body which leads to improvements in performance [21]. This means that heart rate and $V0_2$ max are related and that improvements in both can lead to improvements in athletic performance [21]. In the studies used to conduct this meta-analysis all studies used measured either VO_2 max, heart rate, or both as measures of performance.

Studies were found using the online search engine Google, and by using the database Academic Search Complete. Search terns used were "compression socks long distance running" and "compression socks athletic performance." All studies that were found that met the inclusion criteria of using long distance running events during the experimental trials and measuring VO_2 max and heart rate changes while wearing compression stockings. Other variables included in previous research that studied compression clothing such as perceived fit of compression garment [6] were not considered in this meta-analysis. Only studies that were published in peer-reviewed journals were considered.

Since there were only four studies that met the inclusionary criteria, a coding system was not deemed useful. Using a coding system would severely limit the amount of remaining studies that could be included in the analysis. By not creating a coding system we know this may leave room for selection bias. However, if a coding system had been used we would not be able to conduct this meta-analysis.

Three of the studies used in the meta-analysis had subjects perform 10-km runs so we thought it would be easier to create a higher level of homogeneity to include studies that used similar distances or running events that had participants run for roughly the same amount of time that 10km competitors usually run. Even though two of the studies did not have participants run for 10km, we felt they were close enough within measure to use. Kemmler [11] had participants perform a stepwise speed-incremented treadmill test performed to voluntary maximum termination in which speed was increased 1 km/hr every 5 mins. Initial speed of the treadmill test was set at 9 to 11km/hr. Subjects terminated the test after around 35 to 40 mins in both the control and experimental conditions. Upon further investigation the average time for both men and women running 10km in the U.S. in 2013 was found to be 56:05 mins for men and 1:04:49 for women [22]. Because participants began the test running at a speed of 9 to 11km/hr this means that they were running at a pace that was similar to the average 10km pace for both men and women [22]. Even though participants did not run for the same amount of time as the average 10km run for both men and women, we felt that the results of Kemmler [11] should still be included in the meta-analysis because participants ran at a pace that was similar to the pace for a 10km and as the testing continued this pace was increased and reached a maximum speed of around 16 km/hr in both the control and experimental conditions. Kemmler [11] did not provide the average total distance that each participant covered in all trials, but they may have been near 10km because of the top speeds that were reached in the 35 to 40 min.

The other study included in the meta-analysis that did not have participants run for exactly 10km was Sperlich et al. 2011 [8]. Sperlich [8] had participants perform five separate runs at the same intensity (approximately 70% of their peak oxygen uptake) for 45 mins in order assess the effect that five different levels of compression socks had on various metabolic and cardio-respiratory measures such as VO_2 max and heart rate. Again even though the participants did not run 10km we still felt that the inclusion of this study would allow for a high level of homogeneity because participants ran at a moderate pace for an extended amount of time as found in [5-7].

3. Results

In conducting the meta-analysis that examined the effect that compression stockings had on athletic performance as measured by VO_2 max and heart rate a total of four randomized studies were declared eligible for the meta-analysis [6-8, 11]. Details of the search are shown in Appendix A, while details of included studies are shown in Table 1.

4. Discussion

After completing the meta-analysis, we found that compression socks may not have any effect on athletic performance in long distance running events, though there might be physiological effects as found with Zoot [9] and Bioskin [10] reports and with Kemmler [11]. It was also found that compression socks did not have any effect on VO_2 or heart rates among each of the studies.

Kemmler [11] found that compression socks significantly improved running performance at different metabolic thresholds by an underlying mechanism which was only partially explained by a slightly higher aerobic capacity in moderately trained runners. Kemmler [11] also found a significant increase in running performance as measured in time under load, work, and speed but no significant effect on VO_2 max was found, hence making one believe that there might be more psychological reasoning behind the improvement than physical. Kemmler [11] argued that wearing compression socks provide an increased biomechanical support for muscle tissue and muscle-tendons. This support for muscle tissue and muscle-tendons may result in less metabolic costs at given workloads, meaning that the socks provide support so that the physiological pathways involved in supplying oxygen to the muscles during exercise allows for less oxygen to be needed to maintain exercise. Kemmler [11] also mentions that there is some uncertainty in generalizing these results to runners of all levels since his participants were moderately trained runners. It is thought that if these results could be generalized to even advanced or elite runners than the implications would be astounding as even small increases in performance at advanced and elite levels of competition may be seen as a competitive advantage.

Contrary to the idea proposed in Kemmler [11] no studies have been found that stated that wearing any type of compression garment increased local or systemic blood flow during dynamic exercise at intensities reflected in training and competition [3]. The suggested mechanism by which compression alters variables such as venous blood velocity and venous pooling is by reducing total cross sectional area of the veins [3]. In people without vascular disorders, various compression stockings with applied pressures ranging from 20-50 mmHg (higher than typical sporting CGs) were found not to reduce the diameter of the long saphenous, popliteal and common femoral veins, and not to increase peak venous velocity when in upright positions [3]. Data directly demonstrating influences on venous return, cardiac output or stroke volume appear to be sparse, and none were identified for people engaged in exercise [3].

When conducting the meta-analysis several studies listed confounds that may have impacted results. One of the most obvious confounds that is relevant towards conducting research involving compression socks, and other types of compression clothing, is that there is not a definitive method which allows both researchers and participants to be blinded. In the four studies used for this meta-analysis, no attempt was made to keep neither the participants nor the researchers blind as to which condition was being tested. However an inherent problem arises from studying compression clothing because even if an attempt was made to keep participants blind, participants would more than likely be able to feel when compression garments are being worn due to the tighter compression feeling to the body compared to a control garment. Participants may also know the difference in the effort it takes to put a compression garment verses a non-compression garment. It is also difficult to keep researchers blinded as researchers examine participants to ensure that the compression garments are fitted and/or worn properly.

Another possible confound within conducting compression clothing research could be a placebo effect. If participants are told that they will perform better while wearing a compression garment then they may believe these claims and work harder and hence perform better. MacCrae et al. 2011 [3] conducted a study where participants performed a fatigue inducing exercise to determine if such a placebo effect could occur. Participants completed ten countermovement jumps while wearing either a pair of compression shorts or a pair of loose fitting gym shorts (that exerted no compression). After completing the jumps participants were then asked to rate on a scale from 1-10 approximately how much the garment had affected their jumping ability. The participants rated the compression shorts as having a moderate to big difference (from 3 to 5 on the scale used) compared to the loose fitting gym shorts which received a low rating of 0. The large perceptual difference in how the participants felt the shorts assisted them may have been a result of the placebo effect.

In conclusion, without any of the studies used for this meta-analysis being able to truly blind participants or the researchers, one may conclude that there may be more of a placebo effect during exercise and participants believed the compression socks aided in their running performance. No current study showed any significant improvements in performance or measures of performance when measuring heart rate or VO_2 max. Within all current searches, we did find that lower extremity compression can be very effective for reducing edema after exercise, hence, wearing the compression socks during or after exercise may reduce exercise induced edema (23, 24)

Table 1. Rticles Included in the Meta-Analysis

Name of Author	Type of Compression Clothing	Control	Study Design	Number of Participants (n)	Type of Exercise	Number of Trials	Fitness Level of Participants	Results
Kemmler et al. (2007)	Compression Stockings (24 mmHg)	Conventional Running Socks	Random Cross Over Design	21 males (39 ± 10.9 y)	Speed Incremented Treadmill Test	2 (1 experimental, 1 control)	Moderate	Significant improvement in running performance when wearing compression socks however compression socks did not affect VO_2 or maximum heart rate.
Ali et al. (2007)	Compression Stockings (18-22 mmHg)	Sport Socks	Randomized Counterbalanced Design	14 males (23.05 ±0.5y)	10 Km runs	2 (1 experimental, 1 control)	Moderate	No difference in 10km run times, no significant differences in heart rate.
Creasy (2008)	Compression Stockings	Placebo Garment with No Compression	Counter Balanced Design	9 males and 1 female (36 ±10y)	10 Km runs	5 trials of 10 km runs at 5 varying levels of compression	Well Trained	No performance time difference, no differences in VO_2 (oxygen uptake), no differences in heart rate
Sperlich et al. (2011)	Compression Stockings	Athletic sock with no compression	Randomized	15 males (22.2 ± 1.3y)	Running on a treadmill at approximately 70% of their peak oxygen uptake for 45 mins	5 trials running on a treadmill at approximately 70% of their peak oxygen uptake for 45 mins	Well Trained	No significant difference in VO_2 or heart rate between conditions.

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