THE INFLUENCE OF LOWER BODY COMPRESSION CLOTHING ON MARKERS OF RUNNING ECONOMY DURING SUBMAXIMAL TREADMILL RUNNING

by

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ABSTRACT

The benefit of wearing lower-body compression clothing for individuals experiencing circulatory disorders has been well documented, yet little is known about benefits of wearing such clothing during endurance exercise. This was an investigation of the influence of lower-body compression clothing (stockings and shorts) on markers of running economy. **METHODS**: Eleven endurance runners (Mean±SD: 33±7 yrs, 67.9±15.5 kg) completed treadmill tests on three separate lab visits. First, subjects performed a running test to volitional exhaustion to measure maximal oxygen uptake (VO_{2MAX}) and heart rate at lactate threshold (HR_{LT}). During the next visit, subjects ran for 90-mins at a speed that elicited 85% of HR_{LT} (Mean±SD: 6.9±0.6 miles/hr for men and 6.7±0.5 miles/hr for women) while wearing one of two lower-body clothing conditions: compression shorts and stockings or running shorts. Subjects ran 90-mins again for the last visit at the same speed wearing the second clothing condition, the order of which was counterbalanced. During the 90-min runs, measures of oxygen uptake (VO_2), heart rate (HR), left-thigh accelerometry (AC), and blood pressure (BP) were summarized at the sixth minute of each successive 10-min time interval (T1-T9). Blood lactate (LA) was measured at the end of each time interval. Blood samples were also collected pre- and 24-hrs post-test to measure blood creatine-kinase (CK), an indicator of muscle damage. Values of VO_2 and HR were also summarized as the change for each subject from their T1 values (ΔVO_2 and ΔHR, respectively). Dependent variables were evaluated using a multivariate 2-factor repeated measures ANOVA with planned contrasts for post-hoc analyses. Comparisons were performed at the 0.05 α-level. **RESULTS**: Measures of VO_2, HR, BP, ΔVO_2, ΔHR, and CK were statistically similar at each time interval between conditions ($P>0.05$). Conversely, AC was significantly lower when wearing compression clothing during all time intervals ($P<0.05$). Measures of LA were significantly higher at T6 when wearing compression clothing ($P<0.05$). **CONCLUSIONS**: While wearing compression clothing, subjects experienced less movement of the thigh musculature (i.e., less AC), but no improvements in economy (i.e., lower VO_2 or ΔVO_2) were observed. These results do not indicate any advantage to wearing lower-body compression clothing during endurance exercise.

CHAPTER ONE

INTRODUCTION

Tights are a kind of leg garment, typically covering the leg from the waist to the feet, and derive their name from the close, tight fit to the legs. The use of tights has a long history, stretching back hundreds of years. Often thought of as a women's fashion accessory, it was actually men who were the first to wear tights as a clothing option as early as the 1300s. Tights were preferred by many because they permitted free movement of the legs while still fitting closely to the body. In time, men and women both began to wear tights made of tight-knit, stretchable wool, until later when they became an exclusively feminine garment. Today, tights are typically made of nylon or cotton blended with lycra to maintain a close fit.

During the 1920s, when women's dresses became shorter and exposed more of the leg, the use of pantyhose, a very thin type of tights made primarily of nylon, became very popular among women. Women preferred the pantyhose because of the way the thin fabric covered blemishes on the legs, most notably varicose veins, and how the fabric felt. It was also noted that pantyhose could help keep legs warm in cold climates and prevent drying of the skin in arid conditions. It was rumored that women began to notice that pantyhose could help manage the pain associated with varicose veins. The external compression of the skin provided by tights and pantyhose could promote lower-body circulation and be used to treat several lower-limb conditions such as varicose veins (Liu, R, Lao, TT, Kwok, YL, Li, Y, and Tokura, H, 2010).

These observations spurred the development of newer and more specific compression garments. Compression stockings, knee-length compression socks that provide graduated compression from the ankle to the knee, were subsequently developed. External compression on the lower limbs promotes venous blood return by reducing venous distension in healthy individuals as well as in individuals with venous insufficiency. This, in turn, may increase cardiac output and cardiovascular function in both populations. This was demonstrated by Agu, Baker, and Seifalian (2004), who found that compression stockings could reduce lower-limb swelling (caused by venous pooling) by improving circulation and deep tissue oxygenation in the lower limbs. Accordingly, Bringard, Denis, Belluye, and Perrey (2006) showed that calf-muscle oxygenation was increased in healthy populations who wore compressions tights (CT) in quiet resting positions. Compression stockings now have a well-established role in the therapy of patients with venous insufficiency.

Given this information, it is not surprising that athletes eventually became interested in how to use compression garments as a means of enhancing athletic performance. Cyclists allegedly began to notice the healing effects of compression and wore women’s pantyhose during competition to reduce leg-muscle soreness in the 1970s. In the mid-1980s, researchers began to investigate the use of compression garments within athletics, most notably for recovery after exercise and competitions. As a result of the growing trend for athletes to use compression garments during and after competition, the textile company DuPont developed a product called Power Lycra in the mid-1990s.

Power Lycra was a compression garment designed for athletes that was purported to support leg-musculature and prevent muscle soreness.

More recently, compression garments have been shown to improve markers of physical performance in power sports that utilize explosive movements such as jumping in track and field (Doan et al., 2003). The compression provided by these garments (most notably compression shorts) decreased muscle oscillation (as measured by motion analysis software for a videotaped jump) during vertical jump landings, and helped to improve (i.e., increase) counter-movement jump height. Clearly these findings were relevant for all sports that employed explosive movements, but a link to endurance sport performance was not clear. With advantages provided in power sports and recovery, it is reasonable to suggest that compression garments may enhance endurance sport performance as well. However, the mechanism for how compression garments may provide an advantage to endurance athletes has not been well established.

Despite the lack of research, endurance athletes have recently been inundated with claims made by sports apparel manufacturers that compression garments, including compression stockings, compression shorts (a knee-length short), and full-length compression tights (ankle-to-hip), provide performance benefits during longer durations of exercise. The surge in sales of compression products has been so large that *Triathlete* magazine, a premier magazine within the realm of triathlon, recently published an article about the growing trend of compression stocking use during competition among elite triathletes (Kappeler, 2009).

In order to support the claim that compression garments can improve endurance performance (as these manufacturing companies have), however, there must be a measurable and significant improvement in one or more variables linked to actual performance. Of particular interest to researchers within endurance sport is movement economy, which is defined as the amount of work (energy) required to perform a specific task at a given rate. Running economy would therefore translate to the amount of energy (as defined by relative oxygen consumption, VO_2) required to run at a given velocity.

A recent study by Bringard, Perrey, and Belluye (2006) showed the that the aerobic energy cost (EC) of running at a constant pace was significantly lower when wearing full-length CTs as compared to conventional running shorts. Based on their results, the authors suggested that EC may be improved when wearing CTs by increasing proprioception and muscle coordination, which would result in a lower metabolic cost for running at a given speed. However, their investigation did not include any measurements of either of these variables to support this claim. The authors further speculated that the muscular support provided by CTs may not be evident during a short duration of exercise.

Given the speculations by Bringard et al. (2006), Bakken, Heil, Borgen, and Willis (2009) conducted a pilot study that investigated the influence of full-length compression tights (CT) on markers of running economy. Subjects (n = 5) ran at a submaximal pace for 60 minutes with or without CTs. Multiple variables, including thigh surface movement (TSM), as measured by accelerations of the thigh surface, were measured to further identify possible mechanisms for improved running economy. It was believed that the change in both HR and VO_2 (cardiovascular and aerobic drift, respectively) would better reflect the change in running economy during prolonged submaximal running than either HR or VO_2 alone. Each 60-minute running trial was divided into six 10-minute time intervals where the changes in HR and VO_2 (ΔHR and ΔVO_2, respectively) were defined as the change for each subject relative to their first time interval measurements of HR and VO_2. The change was significantly less for ΔHR and ΔVO_2 at 40 minutes of running when wearing compression tights, but not at 50 or 60 minutes of running. It was speculated, however, that the trend for decreased ΔHR and ΔVO_2 when wearing CTs would have reached statistical significance if a greater sample size had been studied. Interestingly, measures of TSM were significantly lower during the last 30 minutes of testing when wearing CTs as compared to wearing running shorts. These results may support the hypothesis that stabilization of the lower-limb musculature with CTs during running influences metabolic cost, as suggested by Bringard et al. (2006).

Based on the results of Bringard and this pilot study, there are several questions to consider for future research projects. Firstly, measurements of skin and core temperature were recorded during the pilot study, and although these measurements were similar between clothing conditions (CTs vs. running shorts), the practicality of using full-length compression tights during competition at high ambient temperatures (e.g., Hawaii Ironman Triathlon) is questionable. The use of compression shorts combined with compression stockings (as opposed to full-length tights), however, would be more appropriate for use at high ambient temperatures, since compression shorts still provide compression on the largest muscle groups of the lower-limbs while leaving part of the lower leg exposed to the air. The compression stockings would provide compression on the calf musculature. Compression shorts and stockings would therefore likely influence markers of running economy via the same mechanism as full-length compression tights.

Secondly, a challenge of the pilot study was that the first significant change in any dependent variable occurred after 30 minutes of a 60-minute running trial. Other variables did not show change until 40 minutes. Thus, exercise periods longer than 30 minutes are needed to observe differences between test conditions. Because the difference between conditions continued to grow over time, longer running trials (>60 minutes) may exacerbate differences between test conditions.

Furthermore, 60 minutes of submaximal running on a level treadmill may not elicit any significant fatigue in the lower-leg musculature. Fatigue in the lower-limbs can be caused by muscle damage (Endoh, Nakajima, Sakamoto, and Komiyama, 2005), and so a reduction in muscle damage affected by muscle stabilization or compression may be possible mechanisms that explain lower ΔHR and ΔVO_2 for runners who wear CTs. Running submaximally for a period of at least 90 minutes would be expected to elicit more fatigue (as measured by muscle damage). The link to potential muscle damage might provide a more specific mechanism as to why compression on and/or stabilization of the lower-limb musculature may be beneficial for running economy.

Research on the effects of compression tights, compression shorts, and compression stockings during endurance performance has generated many questions regarding the mechanisms of how compression garments may improve markers of running economy (VO_2, most importantly). The purpose of this study, therefore, was to measure the influence of lower-body compression clothing (compression shorts and compression stockings) on markers of running economy during extended periods (90 minutes) of submaximal treadmill running. Such markers could then be analyzed to determine if any changes in running economy could be accounted for by changes in cardiovascular drift, thigh-surface movement, lower-limb fatigue, or cardiovascular workload.

Statement of Purpose

The purpose of this study was to examine the effect of wearing lower-body compression clothing (compression shorts and compression stockings) on markers of running economy (VO_2 and ΔVO_2, namely), thigh-surface movement, and fatigue during submaximal treadmill running.

Hypothesis

The mean dependent variables related to running economy were significantly lower when wearing compression shorts and stockings when compared to wearing standard non-compression running shorts.

$$\mathbf{H_0: \mu_{RS} = \mu_{CC}}$$

$$\mathbf{H_a: \mu_{RS} > \mu_{CC}}$$

Where: μ_{RS} and μ_{CS} are population means for dependent variables directly and indirectly related to running economy, including HR, VO_2, systolic blood pressure (SBP), diastolic blood pressure (DBP), rate pressure product (RPP), left-thigh accelerometry (AC), blood lactate (LA), blood creatine-kinase (CK), ΔHR, and ΔVO_2 when wearing standard running shorts (RS) and lower-body compression clothing (CC), respectively.

Assumptions

It was assumed that participants would adhere to the guidelines of the study and the protocols regarding training prior to any lab visit set forth by the researcher. It was also assumed that the subjects were honest and accurate in the descriptions of their training status, and that their daily training activities would not influence the results of the study.

Delimitations

1. The scope of this study was delimited to competitive endurance athletes (triathletes, runners, cross-country skiers) from the Bozeman, Montana community.
2. The scope of this study was delimited to the activity of sub-maximal treadmill running.
3. The scope of this study was delimited to the Skins^{TM} brand of competition compression-style shorts and stockings.

Operational Definitions

Accelerometry:	The quantitative determination of acceleration and deceleration in the entire human body.
Compression Shorts:	Knee-length shorts providing graduated compression from the knee to the hips.
Cardiac Output:	The total blood flow from the heart during a specified period of time.
Compression Stockings:	Knee-length socks providing graduated compression from the ankle to the knee.
Compression Tights (CT):	A full-length (ankle-to-hip) tight providing graduated compression from the ankle to the hips.
Diastolic Blood Pressure (DBP):	The pressure exerted on the bloodstream by the heart during dilation (diastole).
Heart Rate:	The number of heartbeats per minute.
Lactate Threshold:	Intensity of exercise above which lactate accumulates increasingly in the blood.
Maximal Oxygen Consumption (VO_{2max}):	The maximum amount of oxygen that a person can extract from the atmosphere and then transport and use in tissues during heavy exercise.
Oxygen Consumption (VO_2):	An expression of the rate at which oxygen is used by tissues.
Rate Pressure Product (RPP):	An indicator of the oxygen requirements of the heart. Rate-pressure product is calculated as the product of heart rate and systolic blood pressure.
Running Economy:	The amount of energy (oxygen consumption) required to run at a given velocity.
Systolic Blood Pressure (SBP):	The pressure exerted on the bloodstream by the heart during contraction (systole).

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

Numerous researchers have studied the physiological determinants of endurance performance, including VO_{2max}, fractional utilization of VO_{2max}, lactate threshold, and economy of movement (Hill, Long, and Lupton, 1923; Costill 1967; Coyle 1995; Pate and Branch, 1992; Sjödin and Svedenhag, 1985). Researching these determinants has improved the understanding of their relationship to overall endurance performance, as well as created opportunities for improving overall endurance performance.

Although typically evaluated in a clinical setting under resting conditions, compression garments have been shown to influence several variables also defined as determinants of endurance performance, including blood lactate accumulation, muscle oxygenation, and aerobic energy cost (Berry and McMurray, 1987; Bringard, Denis, Belluye, and Perrey, 2006; Bringard, Perrey, and Belluye, 2006; Chatard and Wilson, 2008; Lawrence and Kakkar, 1980; O'Donnell, Rosenthal, Callow, and Ledig, 1979; Sigel, Edelstein, Savitch, Hasty, and Felix, 1975). Surprisingly, there is limited research investigating how compression garments may influence performance related variables, most notably movement economy, during exercise. This lack of research prompted the current review.

Determinants of Endurance Performance

Although Hill et al. (1923) were among the very first to describe a relationship between selected physiological variables, namely maximal oxygen consumption (VO_{2max}), and endurance performance, Costill (1967) further established this relationship by associating measured VO_{2max} values, as well as other physiological characteristics, to actual performance times. In this study of well-trained cross-country runners, it was concluded that elite distance runners were typically lighter and possessed less body fat than their less-successful counterparts. In addition, when compared to slower runners, elite runners were capable of moving larger volumes of air in and out of their lungs, as measured by maximal breathing capacity per body surface area. A relationship between lower resting heart rates and superior distance running performance was also evident. Most importantly, perhaps, was the demonstration of a direct, positive relationship between VO_{2max} and distance running performance times.

A heightened interest in marathon running in the mid-1980s gave Sjödin and Svedenhag (1985) an opportunity to summarize a number of physiological determinants of marathon running performance. The authors described how marathon performances could be related to such physiological variables as VO_{2max}, oxygen cost of running at submaximal velocities (running economy), fractional utilization of VO_{2max} during running, lactate threshold (although the authors used the term “anaerobic threshold” to describe this phenomena), availability of fuels, environmental factors (such as dehydration), and the effects of regular, endurance training. Like Costill (1967), the authors suggested that elite marathon runners typically display high VO_{2max} values, and that these athletes are successful when they utilize a high percentage of their VO_{2max} at their race pace (a high fractional utilization of VO_{2max}). The authors noted, however, that a high VO_{2max} was only one determinant of a successful marathon runner. They suggested that elite marathon runners could compensate for low VO_{2max} values with good running economy (that is, spending less energy at a given submaximal treadmill speed). These three variables (VO_{2max}, fractional utilization of VO_{2max}, and running economy) combined could explain 98% of variation in marathon running performance. Furthermore, the authors noted that these three variables could also explain 93% of the variability in anaerobic threshold among marathon runners. Since these three variables explain exceptional marathon performances *and* anaerobic threshold so well, the authors concluded that anaerobic threshold was the single determinant with the highest predictive power for marathon performance.

Similarly, Pate and Branch (1992) identified three major determinants of endurance performance, namely VO_{2max}, lactate threshold, and economy of movement. The authors quantified lactate threshold as a percentage of VO_{2max}, very similar to Sjödin and Svedenhag's (1985) definition of fractional utilization of VO_{2max}. This definition, essentially, eliminated the distinction between lactate threshold and the fractional utilization of VO_{2max}. The authors described several methods of training to improve these determinants of endurance performance, and noted that an improvement in one of these three determinants would ultimately lead to a higher competitive pace (and better performance).

Similar to Pate and Branch (1992), Coyle (1995) postulated that the submaximal oxygen consumption (VO_2) at lactate threshold for an endurance athlete is the most important determinant of the energy expenditure during performance. It was noted, however, that the factor that determines how well this translates into actual athletic performance is economy of movement. Using a group of cyclists with similar VO_{2max} values, it was noted that lactate threshold could account for 90% of performance variance. When combined with economy, however, 99% of performance variance could be explained.

In summary, the majority of available literature points towards three primary determinants of endurance performance, namely VO_{2max}, lactate threshold, and economy of movement. There is some level of disagreement among researchers, however, as to which of these three determinants is the best predictor of endurance performance.

Maximal Oxygen Consumption, Lactate Threshold, and Movement Economy

Noting the importance of a high VO_{2max} for endurance athletes, Saltin and Åstrand (1967) observed VO_{2max} values for members of the Swedish National Teams in various events. Using maximal bicycle ergometer and treadmill tests, the authors noted that the highest recorded VO_{2max} values were achieved by cross-country skiers, long-distance runners, speed skaters, orienteers, and cyclists. All of these sports are typically classified as endurance sports, so the authors concluded that VO_{2max} is a primary determinant of performance in endurance events.

While recognizing the importance of high VO_{2max}, Farrell, Wilmore, Coyle, Billing, and Costill (1979) suggested that the onset of plasma lactate accumulation (OPLA), which is now more commonly referred to as the lactate threshold, is a better predictor of endurance performance than VO_{2max}. Using the running performances from various distances, a high, positive correlation was found between the treadmill velocity corresponding to the OPLA and performance at all distances.

Similarly, Powers, Dodd, Deason, Byrd, and McKnight (1983) found that ventilatory threshold could be a strong predictor of distance running performance. Although blood lactate alone does not control ventilation, Wasserman, Whipp, Koyal, and Beaver (1973) observed a correlation between ventilatory threshold and lactate threshold. The research by Powers et al. (1983), therefore, is in agreement with that of Farrell et al. (1979).

Although Hagberg and Coyle (1983) also found that the velocity at the blood lactate threshold was highly correlated to racewalking performance, the authors noted that the velocity at lactate threshold is determined by two factors, the VO_2 at lactate threshold and movement economy (the velocity that can be achieved at that VO_2). In agreement with Farrell et al. (1979), the VO_2 at lactate threshold was closely correlated to racewalking performance. There was, however, also a strong, positive correlation between the walkers’ movement economy and racewalking performance. The best performers exhibited the best movement economy (i.e., they consumed the least amount of oxygen at a given treadmill speed). The authors noted, however, that, because this was a study investigating race walking performance, the predictive power of movement economy might be more relevant for lower-intensity events (i.e., utilizing a smaller percentage of VO_{2max} during competition), as opposed to running.

Daniels (1974) observed large variations in VO_{2max} among runners with the similar running speeds. It was noted that the predicted speed of a subject with a high VO_{2max} (70 ml/kg·min) but poor economy (high oxygen (O_2) demand during submaximal running) was the same as a subject with a VO_{2max} less than 60 $ml \cdot kg^{-1} \cdot min^{-1}$. While Daniels (1974) recognized that high VO_{2max} values were often found in champion endurance athletes, he stressed the importance of markers of submaximal performance (economy) as a predictive characteristic of distance running performance. Additional researchers, including Di Prampero, Capelli, Pagliaro, Antonutto, Girardis, Zamparo, and Soule (1993) and Noakes (1988), would later reiterate this sentiment.

In addition to the strong predictive characteristic of running economy, the ability to improve running economy through means other than simply training has made running economy a remarkably notable determinant of endurance performance when compared to VO_{2max} and lactate threshold. A runner's lactate threshold can be improved through systematic training (Pate and Branch, 1992), while VO_{2max} is not easily influenced by training or technique adjustments in well-trained subjects (Basset and Howley, 2000; Pate and Branch, 1992). Running economy, alternatively, can be changed by improving running technique, adjusting step rate during running, or changing stride length, as well as systematic training (Cavanagh and Kram, 1985; Johnston, Quinn, Kertzer, and Vroman, 1997). Running economy, therefore, has been shown to be an exceptionally important physiological determinant of endurance performance. As such, improvements in running economy are likely to manifest themselves in improved endurance speeds (performance).

Cardiovascular Drift

Longer durations of steady-state submaximal exercise typically elicit a phenomenon known as cardiovascular drift, in which cardiovascular responses (heart rate, stroke volume, cardiac output, etc.) increase or decrease gradually (“drift”) during exercise as a function of time (Coyle and González-Alonso, 2001; Ekelund, 1966; Kounalakis, Nassis, Koskolou and Geladas, 2008). During prolonged submaximal exercise, blood volume is progressively redistributed to active tissues, resulting in a gradual decrease in central blood volume. As such, cardiovascular drift is typically marked by a progressive, but small, increase in heart rate (HR) as well as decreases in mean arterial pressure (MAP) and stroke volume (SV) after approximately 10 minutes of submaximal exercise (Coyle and González-Alonso, 2001). These changes can ultimately impair endurance performance (Ganio, Wingo, Carroll, Thomas, and Kureton, 2006) since the failure of the heart to maintain cardiac output (the product of HR and SV) and oxygen delivery to active muscle tissue are related to impaired skeletal muscle aerobic capacity, which precedes muscular fatigue (González-Alonso and Calbet, 2003).

Cardiovascular drift was of particular interest for the current study since HR was used as an index of running economy throughout the submaximal running trials. Several factors have been shown to influence the amount of cardiovascular drift experienced during exercise, such as hyperthermia (González-Alonso, Calbet, and Nielsen, 1998), dehydration (Montain and Coyle, 1992), and blood pooling in the periphery (Rowell, Murray, Brengelmann, and Kraning, 1969). Furthermore, it has been suggested that factors such as HR, SV, and MAP are affected by the rate of muscular contraction (Kounalakis, Keramidas, Nassis, and Geladas, 2008). Muscular fatigue (i.e., decreased muscular contraction) is related to muscle damage (Endoh, Nakajima, Sakamoto, and Komiyama, 2005), which was a dependent variable of the current study.

It was critical, therefore, to control the influence of these factors on the amount of cardiovascular drift experienced during the submaximal running trials. For the purposes of the current study, monitoring and controlling the hydration status of subjects before and during the submaximal trials was a way to accomplish this goal, since fluid ingestion helps mitigate the progressive decline of SV during prolonged exercise (Ganio et al., 2006).

Compression Garment Research:
Clinical Setting

It is well established that compression garments, including compression bandages, compression stockings, and compression tights, can influence the hemodynamics of the lower limbs (Lawrence and Kakkar, 1980; O’Donnell, Rosenthal, Callow, and Ledig, 1979; Sabri, Roberts, and Cotton, 1971; Sigel, Edelstein, Savitch, Hasty, and Felix, 1975; Spiro, Roberts, and Richards, 1970; Stanton, Freis, and Wilkins, 1949). One of the first to investigate the effects of compression, Stanton et al. (1949) reported an increase in the velocity of deep venous blood flow when external compression bandages were applied to the lower limb at rest.

Although Spiro et al. (1970) observed similar increases in the femoral vein blood flow rate of patients undergoing surgery for bilateral varicose veins at low-level external compression (<15 mmHg), it was observed that external compression >15 mmHg could actually impair femoral vein flow. There are several points from this study to consider. The first is that the subjects that participated in this study were anesthetized so that controlled respiration could be ruled out as an influence on venous flow. The results of this study, therefore, apply only to a resting state, and may not be applicable to an ambulatory patient. The second is that the compression bandaging used in this study was applied by a group of nurses who were uninformed of the purpose of the bandaging. Although a pressure transducer placed under the bandaging measured the pressure exerted on the lower leg, it is likely that the pressure applied to each patient's legs was not uniform. The authors concluded that the application of compression bandages was not practical, noting that bandages were often applied incorrectly (too tight) and that initial tension slackened regardless of proper application as the bandages worked loose.

Supporting the suggestion that too much external compression could impair venous blood flow, Sabri, Roberts, and Cotton (1971) reported that external pressure of ≥ 15 mmHg exerted on the lower limb significantly reduced femoral arterial and venous blood flow. Similar to Spiro et al. (1970), patients undergoing surgery for bilateral varicose veins were used for this study. Again, patients were anesthetized before compression was applied to their lower limbs. Only very low pressure (<5 mmHg) resulted in increased femoral arterial and venous flow. As a result, the authors advised against the use of compression bandages, in accordance with Spiro et al. (1970).

The results of Spiro et al. (1970) and Sabri et al. (1971) can likely be explained by the fact that the external compression used in their studies was applied uniformly, as opposed to a graduated pressure that increased proximal to distal, throughout the lower limbs. In response, Sigel et al. (1975) established an optimal pressure gradient for the application of external compression on the lower limbs. Using a five-chambered vinyl pneumatic sleeve, the authors found that graduating external pressure from 18 mmHg at the ankle to 8 mmHg at the midthigh resulted in an increased femoral flow velocity.

Similarly, Lawrence and Kakkar (1980) established an optimal pressure gradient of 20 mmHg at the ankle reducing to 10 mmHg at the upper thigh. This gradient increased venous flow velocities up to 75% above resting levels. Any compression greater than this, however, led to a progressive fall in subcutaneous tissue flow as well as a reduction in deep venous velocity.

O’Donnell et al. (1979) were among the first to investigate the effects of compression tights on venous hemodynamics in the lower limbs during exercise. Despite observing no differences in venous return time when wearing compression stockings, the authors found that the peak systolic venous pressure in the foot decreased significantly when wearing compression stockings. Although the focus was purely clinical, this study had important implications for the use of compression garments as a means for improving recovery after exercise. The lowered systolic venous pressure after exercise suggested that external pressure applied to the lower limbs could make the superficial veins less compliant, reducing venous pooling and possibly improving muscle oxygenation.

Compression Garment Research:
Performance Setting

In agreement with the suggestion by O'Donnell et al. (1979), Bringard, Denis, Belluye, and Perrey (2006) observed that calf muscle oxygenation was improved and venous pooling decreased when wearing compression tights during quiet resting in both supine and standing positions. Using endurance-trained subjects, this study compared the effects of custom-made compression tights (that offered a pressure gradient of ~20 mmHg at the calf) to commercial elastic tights and a no-compression control (shorts). Patients laid supine with shorts only (control) for 5 minutes before any clothing condition measurements were made to establish a baseline. Then, wearing one of the three clothing conditions, measurements were taken during five min of supine rest, five min of sitting, and finally five min of standing. Muscle oxygenation and blood pooling were continuously measured using near-infrared spectroscopy in all of these positions. Measured by a pressure transducer at the interface between skin and clothing over the calf area, the pressures were significantly different among clothing conditions: the custom-made compression tights offered the greatest amount of pressure, followed by the commercially available elastic tights. The shorts offered no compression. Accordingly, venous pooling was significantly lower and calf-muscle oxygenation was significantly higher when wearing compression tights compared with both shorts and elastic tights in both standing and supine conditions.

Based on the results of O’Donnell et al. (1979) and Bringard et al. (2006), it is logical to speculate whether or not compression garments could have a role in improving recovery after exercise, or possibly even improving performance during exercise. Indeed, Berry and McMurray (1987) observed significantly lower post-exercise blood lactate levels when graduated compression stockings were worn during and after exercise as compared to wearing the stockings only during exercise (and not post-exercise) and wearing no stockings during or after exercise.

Doan et al. (2003) investigated the effect of wearing custom-fit compression shorts on markers of track and field performance and found that countermovement vertical jump height increased from 0.461 to 0.485 meters for the control and compression shorts condition, respectively. It was speculated that the compression shorts provided improved proprioception during the loading phase of the jump. In addition, the researchers found significantly decreased muscle oscillations (as measured by motion analysis software applied to a videotaped jump) during landing from a maximal vertical jump. Again, the researchers speculated that a reduction in oscillatory displacement of the muscle may optimize proprioception and neurotransmission at the cellular level.

Among the first to investigate the role of compression garments in endurance exercise, Bringard, Perrey, and Belluye (2006) reported that the aerobic energy cost (EC) of running at a constant pace was significantly lower when wearing full-length CTs as compared to conventional running shorts. Using trained runners, the researchers investigated the energy cost and subjective responses during different submaximal exercise intensities when wearing compression tights, classic elastic tights, or running shorts. Although there were no differences in thermal stress, clothing comfort, or sweating sensations across the three clothing conditions, the mean value of net aerobic energy cost was significantly lower at a 12 km·hr^{-1} treadmill running speed when wearing compression tights and classic elastic tights as compared to running shorts. In addition, the subjects also completed a 15 min constant running exercise at ~80% of their VO_{2max} to compare the differences in the delayed rise in the VO_2 response that occurs after 2-3 minutes of exercise onset, which is termed the slow component of VO_2. When the VO_2 slow component magnitude values, which the authors defined as the VO_2 difference between minutes two and 15, were compared across clothing conditions, running with CTs resulted in significantly lower magnitude of VO_2 slow component than both running shorts and classic elastic shorts. This suggests an improved energy cost when wearing compression tights as compared to both running shorts and classic elastic tights. Similar to Doan et al. (2003), the authors suggested that EC may be improved when wearing CTs by increasing proprioception and muscle coordination, which would result in a lower metabolic cost for running at a given speed (i.e., improved economy).

Summary

The effects of wearing compression garments during endurance exercise on markers of endurance performance remains largely uninvestigated. Running economy has been shown to be a reliable and valid predictor of endurance running performance. As such, the current study was undertaken to examine the possible influence of wearing compression clothing during prolonged running on markers of running economy, and subsequently, endurance performance.

CHAPTER THREE

METHODOLOGY

Subjects

Sixteen well-trained runners from the Bozeman, Montana community were recruited to participate in this study. In order to be eligible for participation, subjects were required to run for a duration of 90 minutes or longer at least once per week in the month leading up to their participation, as well as run a minimum total of 4 hours per week. Subject participation included three separate lab visits at the Montana State University (MSU) Movement Science/Human Performance laboratory. All subjects were actively training at the time of the study. Each subject signed an informed-consent form (Appendix A), which included a description of the testing procedures, in accordance with Montana State University's Internal Review Board. In addition, each subject completed a health-history questionnaire, which was later used for health-screening prior to participation in this study to ensure that the subjects were free of contraindications to the level of physical activity required by the protocol (Appendix B). Subjects also completed a training questionnaire to describe their training background (Appendix C). Subjects were asked to avoid any strenuous training for 48 hours prior to any lab visit. Subjects were also asked to refrain from more than 30-60 minutes of easy training and avoid alcohol or caffeine consumption 2 hours prior to any lab visit.

Research Design

This study was a repeated measures research design so that subjects would serve as their own control. This research design measured dependent variables directly related to running economy, including oxygen consumption (VO_2) and aerobic drift (ΔVO_2), as well as indirect indicators of running economy, including heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and cardiac drift (ΔHR). Rate pressure product (RPP) was calculated as the product of HR and SBP. The research design also included measures of left-thigh accelerometry (AC), blood lactate (La), and blood creatine-kinase (CK).

Procedures

Testing consisted of three treadmill tests performed over three separate lab visits. Descriptive information (age, body height and body weight) was recorded at the time of the first visit. In addition, each participant was subjected to an incremental running test to volitional exhaustion to measure maximal oxygen consumption (VO_{2max}) and heart rate at lactate threshold (HR_{LT}). The second visit included a 90-min running test at a level grade conducted at a speed that initially elicited 85% of HR_{LT} while wearing one of two clothing conditions: compression shorts and compression stockings or standard running shorts. The testing order was counterbalanced at the final visit when each subject performed another 90-min running test at the same speed wearing the alternative clothing condition. All treadmill tests were separated by at least one week. Each test was performed at approximately the same time of day (±2 hours) for each subject. The ambient laboratory conditions remained stable (21-23° C, relative humidity ~ 40-45%), while large fans were used to direct airflow over subjects while treadmill running during all lab visits.

VO_{2max} and Lactate Threshold Testing

A 15-min warm-up was required before beginning the treadmill test so that subjects could familiarize themselves with treadmill running prior to testing. The initial treadmill speed was set at 80% of the subject's estimated 5-km race pace at a level (0.0%) grade. The treadmill speed was subsequently increased by 1.0 km/hr for each additional stage. Initial stages were discontinuous, lasting four minutes with three minutes of running followed by one minute of standing rest. Each rest period was used to collect a finger stick blood sample to be used for blood lactate (LA) measurements. When measured LA values reached a level that was 1.5-2.0 mmol higher than that from the previous stage, subsequent stages were switched to a 1-minute per stage continuous protocol, increasing grade by 2.0% per stage and keeping speed constant, until the subject reached volitional exhaustion.

Heart rate at lactate threshold (HR_{LT}) was defined as the average heart rate from the stages immediately prior to and immediately following the surge in lactate accumulation. In accordance with the protocol used by Bringard et al. (2006), maximum VO_2 values were only considered a true VO_{2max} if at least two of the following criteria were met:

1. A plateau in VO_2 (change < 2.5 ml/kg·min for successive stages)
2. A respiratory exchange ratio (RER) $\geq$ 1.10 prior to end of the test
3. A heart rate ± 10 beats of the subject's age-predicted maximal heart rate

Submaximal Treadmill Tests

Prior to each 90-min treadmill test, a urine sample was collected for each subject followed by measures of body weight and resting blood pressure (taken while seated), as well as a finger-stick blood sample. To avoid the influence of dehydration on heart rate, subjects were not allowed to continue with the test unless a satisfactory urinary specific gravity (no greater than 1.03) was achieved after the first urine sample. Left-thigh accelerometry (AC), a measure of thigh surface movement, was recorded by an accelerometry-based activity monitor attached using adhesive glue and tape to the skin on the anterior surface of the thigh at the mid-point between the inguinal fold and the superior border of the patella. Depending on the clothing condition being tested, subjects then changed into either compression shorts and compression stockings or running shorts. Upper-body clothing was kept consistent for both 90-min tests. Prior to each test, subjects were asked to warm-up on the treadmill for 5-10 minutes, during which a speed that elicited 85% of HR_{LT} was established. This treadmill speed was subsequently used for both 90-min treadmill tests.

Figure 1 displays the measurement protocol used for measures of HR, LA, blood pressure (BP), and VO_2. Each 90-min test was divided into nine 10-minute time intervals successively defined as T1 through T9. For all of T1 and the first six minutes of T2, VO_2 was measured continuously. To allow the subjects to drink water and communicate with the researchers, the VO_2 measurement headgear was removed for the remaining four minutes of T2. For T3 through T9, VO_2 was measured for the first six minutes and the headgear removed for the last four minutes of each time interval. During the last four minutes of each time interval, subjects were given 75 mL of bottled water to drink, which was measured and provided by the researcher. At minute six of time interval T1, T3, T5, T7, and T9, blood pressure was measured (while subjects continued to run). At minute nine of each time interval, treadmill speed was reduced to 4 km/hr (i.e., a walking speed) to collect blood for LA measurements. A short break of three minutes was implemented after T6 to allow subjects to urinate if needed. Immediately at the end of each 90-min trial, blood pressure was recorded again. Subjects were asked to return to the lab 24 hours after the end of the test to collect a final finger-stick blood sample.

Finger-stick blood samples were used throughout the 90-min treadmill tests to determine LA levels. In addition, finger-stick blood samples were used to determine creatine-kinase levels immediately prior to and 24-hours after each 90-minute treadmill test. Creatine-kinase levels were used as a marker of the muscle damage sustained during each 90-min running trial. Urine was collected to determine the hydration status of each subject prior to and after each 90-minute treadmill test. Subjects with a urine specific gravity between 1.01 and 1.03 were considered euhydrated.

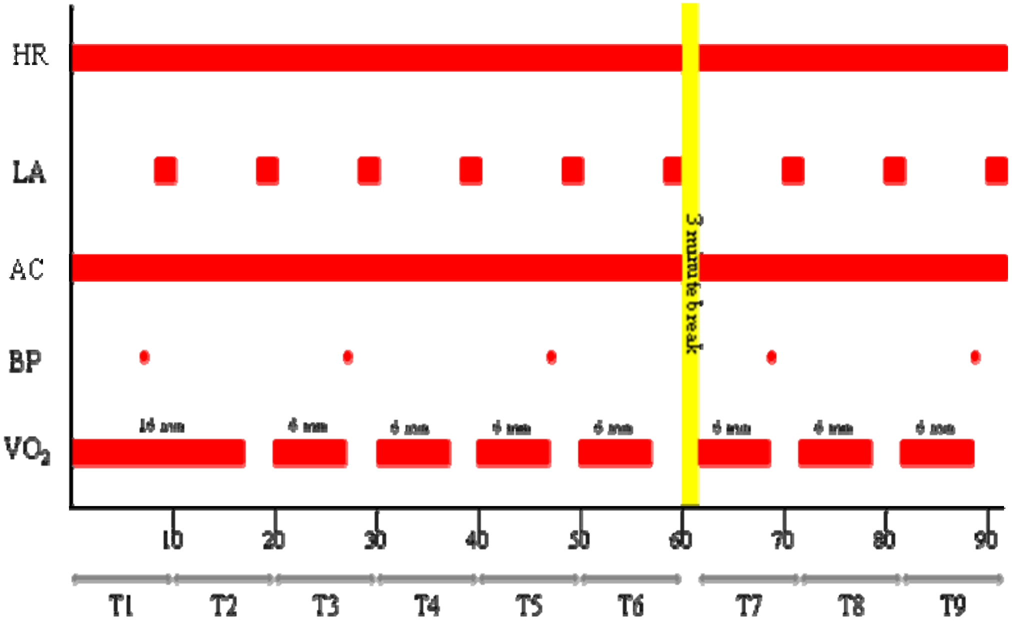

Figure 1. Measurement protocol for measures of heart rate (HR), blood lactate (LA), accelerometry (AC), blood pressure (BP), and oxygen consumption (VO_2) during each 90-min submaximal running trial. Each trial was divided into nine 10-min time intervals (T1-T9). Heart rate and AC were measured continuously throughout the test, while LA and VO_2 were measured discontinuously throughout the test. Blood pressure was measured at a single point (at 6 min) during every other time interval (T1, T3, T5, T7, and T9).

Instrumentation

Cardiorespiratory Measures

Oxygen consumption was measured using a TrueMax 2400 metabolic system (Parvo Medics, Sandy, UT, USA). Subjects breathed room air through a mouthpiece fitted with one-way valves, which directed expired air into the analyzer module via a standard length of tubing. The oxygen and carbon dioxide analyzers were calibrated prior to each test using a certified gas mixture. The accuracy of the system's ventilation measurements were evaluated using a calibrated 3-L syringe (Hans Rudolph, Kansas City, MO, USA). The sample interval for computed VO_2 values was 20 s during the

VO_{2max} tests and 60 s during the 90-min tests. Heart rate was summarized with 60-s averages using a telemetry-based Polar Accurex Plus heart rate monitor (Polar Electro, Inc, Lake Success, NY, USA). Blood lactate levels were measured at minute nine of every time interval using a LactatePro portable blood lactate analyzer (Arkray Factory, Inc., Shiga, Japan). Blood pressure measurements, including systolic blood pressure (SBP), diastolic blood pressure (DBP) were recorded using the auscultatory technique with a standard anaroid sphygmomanometer (Prestige Medical, Los Angeles, CA, USA).

Muscle Movement, Muscle Damage, and Hydration Status

Left-thigh accelerometry (AC) was recorded as counts per minute using the accelerometry-based Actical activity monitor (Respironics Co., Bend, OR, USA). Blood creatine-kinase levels were measured using a Vitros II reflectance photometer (Johnson & Johnson Clinical Diagnostics, Inc., Rochester, NY). Urine specific gravity was measured using a Master-SUR/NM refractometer (Atago Co., LTD., Tokyo, Japan).

Data Analyses

Measures of AC, HR, and VO_2 between minutes 4-6 were summarized as average values for each time interval (T1-T9). Blood pressure variables (SBP, DBP, and RPP) were summarized as point values at minute 6 for T1, T3, T5, T7, and T9. Values of VO_2 and HR were also summarized as the change for each subject from their first time interval values (ΔVO_2 and ΔHR, respectively). Blood creatine-kinase levels and urine specific gravity levels were summarized as point values at the time of their measurement. All dependent variables differences were evaluated for statistical significance using a multivariate 2-factor repeated measures ANOVA with planned contrasts for post-hoc analyses. All comparisons were performed at the 0.05 alpha-level.

CHAPTER FOUR

RESULTS

This study was conducted to investigate the influence of lower body compression clothing on markers of running economy during longer (90 minutes) bouts of submaximal exercise. All dependent variables differences were evaluated for statistical significance using a multivariate 2-factor repeated measures ANOVA with planned contrasts for post-hoc analyses. All comparisons were performed at the 0.05 alpha-level.

Sixteen subjects were recruited to participate in this study. Of these original sixteen subjects, one subject dropped out of the study due to personal conflicts and an additional two subjects dropped out due to discomfort and/or issues with the measurement instrumentation. An additional two subjects were dropped from the data set after completing all testing due to faulty data collection and/or unexplainable trends in the data. Table 1 provides a summary of the subject demographics for the remaining eleven subjects (5 males and 6 females) that completed the three trials of treadmill testing. Table 2 provides a summary of the results from the maximal treadmill test. Additionally, each subject was required to fill out a training questionnaire to describe the nature of his or her training (i.e., runner, triathlete, cross-country skier, etc.). Of the 11 subjects that were included in the data set, six described themselves as runners, two described themselves as triathletes, and three described themselves as both runners and triathletes. Eight of the 11 subjects had participated in some form of endurance competition in the previous six months.

Tables 3, 4, and 5 summarize the results from the two submaximal treadmill tests. Several variables showed significant main effects between the variable and one of the two factors (time or condition). There was a statistically significant time effect for heart rate (HR) to increase over time regardless of clothing condition ($p < 0.001$). Additionally, there was also a time effect for systolic blood pressure (SBP): SBP was significantly lower for the first time interval (T1) than for all other time intervals (T2-T9) ($p < 0.001$). There was a tendency for little or no change in SBP after increasing to 130-133 mmHg. Concordantly, there was a time effect for rate pressure product (RPP): the RPP values were significantly lower for T1 than for T2-T9 ($p < 0.001$). There was a condition effect for measures of left-thigh accelerometry (AC) over all time intervals ($p = 0.029$). The AC values, which were measures of acceleration changes (counts/min) by the activity monitor attached to the left thigh, were significantly lower when wearing compression clothing for all time intervals when compared to wearing running shorts (Mean Main Effects; 10779 counts/min when wearing compression clothing versus 11465 counts/min when wearing running shorts). The mean treadmill running speed (±SD) for the submaximal trials was 6.9±0.6 mph for men and 6.7±0.5 mph for women.

Measures of blood lactate (LA) showed an interaction effect between time and condition at time interval T6. Lactate values (Mean±SE) were significantly higher when wearing compression clothing as compared to standard running shorts at this time interval (2.1±0.5 mmol versus 1.3±0.1 mmol). This, however, was the result of abnormally high lactate values (>4.0 mmol) for two subjects at that time interval and was not consistent for the majority of subjects. Measures of submaximal oxygen consumption (VO_2), HR, SBP, diastolic blood pressure (DBP), and RPP remained statistically similar for each of the two clothing conditions (i.e., the main effects for condition were not significant) at each time interval.

Table 1. Summary statistics for demographic data, including age, body height, body mass, and body mass index (BMI) for all subjects prior to maximal treadmill running test (n=11). All values expressed as Mean ± SD.

	Sample Size	**Age (yrs)**	**Body Height (cms)**	**Body Mass (kgs)**	**BMI ($kg \cdot m^{-2}$)**
Men	5	36 ± 9	178.6 ± 10.8	78.3 ± 17.0	24.2 ± 2.7
Women	6	31 ± 6	165.0 ± 5.3	59.2 ± 6.9	21.7 ± 1.2
All Subjects	11	33 ± 7	171.2 ± 10.5	67.9 ± 15.5	22.9 ± 2.4

Table 2. Summary statistics for maximal aerobic capacity (VO_{2MAX}) and heart rate at lactate threshold (HR_{LT}) measured during maximal treadmill running for all subjects (n=11). All values expressed as Mean ± SD.

	Sample Size	**VO_{2MAX} ($ml \cdot kg^{-1} \cdot min^{-1}$)**	**VO_{2MAX} ($l \cdot min^{-1}$)**	**HR_{LT} ($bts \cdot min^{-1}$)**
Men	5	58.4 ± 7.2	4.5 ± 0.7	166 ± 7
Women	6	51.3 ± 4.3	3.0 ± 0.4	178 ± 6
All Subjects	11	54.5 ± 6.6	3.7 ± 0.9	172 ± 8

Table 3. Summary statistics for relative oxygen consumption (VO_2; $ml \cdot kg^{-1} \cdot min^{-1}$), and absolute oxygen consumption ($l \cdot min^{-1}$) during 90 minutes of constant speed treadmill running while wearing lower-body compression clothing (Experimental) and non-compression shorts (Control) (n = 11).

All variables were assessed at nine successive time periods (T1-T9) corresponding to 6, 16, 26, 36, 46, 56, 69, 79, and 89 minutes into each running trial. All values expressed as Mean ± SE.

Time Period	Condition	VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	VO_2 ($l \cdot min^{-1}$)
T1	Control Experimental	35.1 ± 0.9 36.0 ± 1.1	2.38 ± 0.17 2.44 ± 0.17
T2	Control Experimental	35.7 ± 1.0 36.1 ± 1.2	2.42 ± 0.17 2.44 ± 0.17
T3	Control Experimental	35.5 ± 1.1 36.3 ± 1.1	2.40 ± 0.17 2.47 ± 0.19
T4	Control Experimental	36.1 ± 1.1 35.8 ± 1.0	2.44 ± 0.17 2.43 ± 0.18
T5	Control Experimental	36.0 ± 1.2 36.5 ± 1.2	2.44 ± 0.19 2.47 ± 0.18
T6	Control Experimental	36.3 ± 1.2 35.6 ± 1.2	2.46 ± 0.19 2.41 ± 0.18
T7	Control Experimental	35.6 ± 1.1 35.9 ± 1.1	2.42 ± 0.20 2.44 ± 0.18
T8	Control Experimental	36.1 ± 1.2 35.4 ± 1.1	2.45 ± 0.18 2.41 ± 0.19
T9	Control Experimental	36.2 ± 1.1 36.2 ± 1.1	2.46 ± 0.19 2.47 ± 0.19

Table 4. Summary statistics for heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and rate pressure product (RPP) during 90 minutes of constant speed treadmill running while wearing lower-body compression clothing (Experimental) and non-compression shorts (Control) (n = 11 for HR, n = 9 for SBP, DBP, and RPP). Measures of HR were assessed at nine successive time periods (T1-T9) corresponding to 6, 16, 26, 36, 46, 56, 69, 79, and 89 minutes into each running trial. Measures of SBP and DBP were measured at alternating time periods (T1, T3, T5, T7, T9) corresponding to 6, 26, 46, 69, and 89 minutes. All values expressed as Mean ± SE.

Time Period	**Condition**	**HR ($bts \cdot min^{-1}$)**	**SBP (mmHg)**	**DBP (mmHg)**	**RPP (units)**
T1	Control	143 ± 4	126.9 ± 2.4*	70.6 ± 2.4	18.5 ± 0.6*
	Experimental	144 ± 3	125.3 ± 2.1*	71.0 ± 1.5	18.0 ± 0.4*
T2	Control	147 ± 4			
	Experimental	147 ± 3			
T3	Control	148 ± 4	130.1 ± 2.2	67.1 ± 2.4	19.2 ± 0.5
	Experimental	149 ± 3	131.1 ± 2.6	71.1 ± 2.6	19.7 ± 0.5
T4	Control	149 ± 4			
	Experimental	150 ± 3			
T5	Control	150 ± 4	132.1 ± 2.8	70.0 ± 1.7	19.8 ± 0.7
	Experimental	150 ± 4	134.0 ± 2.7	69.5 ± 1.7	20.3 ± 0.4
T6	Control	150 ± 4			
	Experimental	150 ± 3			
T7	Control	149 ± 4	127.9 ± 3.1	68.1 ± 2.1	19.1 ± 0.7
	Experimental	150 ± 4	131.3 ± 3.1	71.1 ± 2.0	19.5 ± 0.4
T8	Control	152 ± 3			
	Experimental	151 ± 4			
T9	Control	153 ± 4	132.1 ± 3.2	68.9 ± 2.3	20.2 ± 0.7
	Experimental	153 ± 4	131.8 ± 1.6	71.0 ± 1.8	20.2 ± 0.5

*Mean time effect for BP and RPP at T1 significantly lower ($p<0.05$) than for other time periods.

Table 5. Summary statistics for left-thigh accelerometry (AC) and blood lactate (LA) during 90 minutes of constant speed treadmill running while wearing lower-body compression clothing (Experimental) and non-compression shorts (Control) (n = 11). Measures of AC and LA were assessed at nine successive time periods (T1-T9) corresponding to 6, 16, 26, 36, 46, 56, 69, 79, and 89 minutes into each running trial. All values expressed as Mean ± SE.

Time Period	**Condition**	**AC (counts·min^{-1})**	**LA (mmol˙L^{-1})**
T1	Control Experimental	11739 ± 387 10891 ± 300*	1.7 ± 0.1 1.7 ± 0.2
T2	Control Experimental	11686 ± 443 10792 ± 314*	1.6 ± 0.2 1.5 ± 0.1
T3	Control Experimental	11584 ± 410 10837 ± 298*	1.8 ± 0.2 1.4 ± 0.1
T4	Control Experimental	11520 ± 405 10712 ± 288*	1.5 ± 0.1 1.4 ± 0.1
T5	Control Experimental	11565 ± 405 10807 ± 306*	1.5 ± 0.2 1.3 ± 0.1
T6	Control Experimental	11464 ± 373 10672 ± 302*	1.3 ± 0.1 2.1 ± 0.5**
T7	Control Experimental	11556 ± 353 10750 ± 290*	1.2 ± 0.1 1.5 ± 0.2
T8	Control Experimental	11548 ± 367 10673 ± 303*	1.3 ± 0.1 1.5 ± 0.1
T9	Control Experimental	11577 ± 367 10880 ± 274*	1.5 ± 0.1 1.7 ± 0.2

*Mean value of AC for experimental condition significantly lower (p<0.05) than mean value for control condition.

**Mean value of LA for experimental condition significantly higher (p<0.05) than mean value for control condition

Note: Accelerometer variable derived using Actical accelerometer mounted to frontal surface of left thigh.

Measures of the amount of change (pre-test to 24 hours post-test) in blood creatine-kinase (CK) remained statistically similar between the two clothing conditions (Mean ± SE; 153.75±43.20 IU/L for running shorts versus 130.58±65.65 IU/L for compression clothing; $p = 0.75$). Over the course of three weeks, two unsuccessful attempts were made to measure values of CK before CK values were successfully measured during a third attempt. During this time, the blood samples were thawed and re-frozen once. When one extreme outlier was removed from the data set, the difference in mean values for the change in CK approached statistical significance (Mean ± SE; 145.27±46.40 IU/L for running shorts versus 65.91±12.36 IU/L for compression clothing, p=0.13).

A non-significant trend was noted for measures of oxygen uptake drift (ΔVO_2; Figure 3), while measures of cardiac drift (ΔHR; Figure 2) showed no trend over the course of 90 minutes. Both ΔHR and ΔVO_2 values were computed as the difference between measures at the first time interval (T1) and other time points (T2-T9) for each subject. The non-significant trend displayed in Figure 3 suggests that the observed changes in ΔVO_2 over 90 minutes of running may have been smaller when the subjects were wearing compression clothing as compared to wearing running shorts.

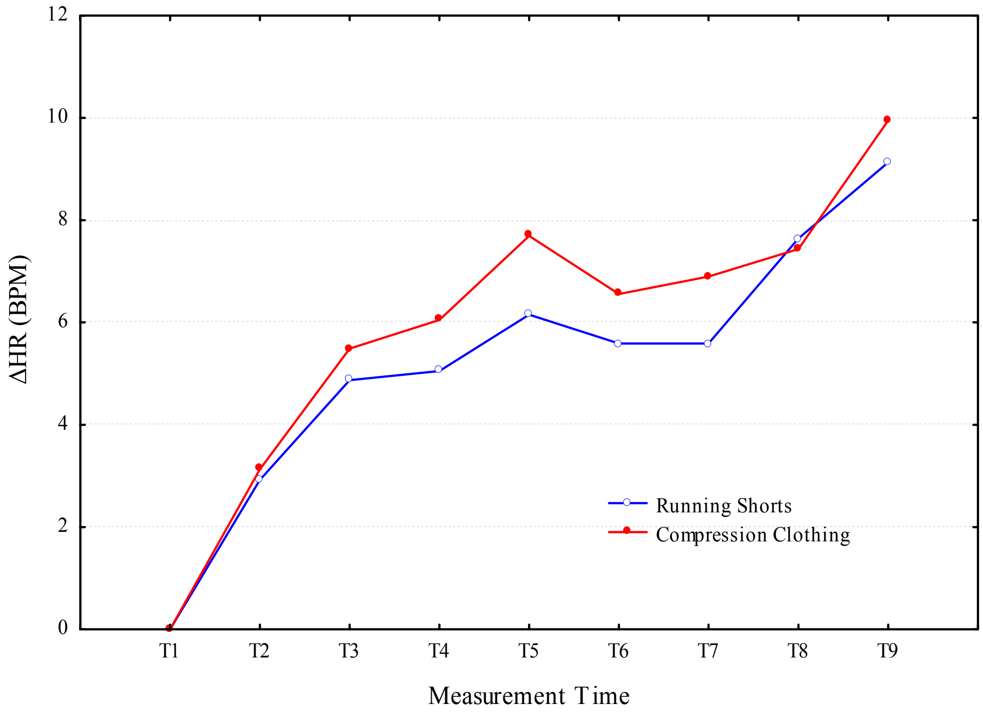

Figure 2. Mean values of cardiac drift (ΔHR) during 90 minutes of constant speed treadmill running while wearing lower-body compression clothing (Experimental) and non-compression shorts (Control) (n = 11). Values of ΔHR were computed at nine successive measurement time periods (T1-T9) corresponding to 6, 16, 26, 36, 46, 56, 69, 79, and 89 minutes into each running trial. Values of ΔHR computed as the difference between measures at T1 and other time points (T2-T9) for each subject.

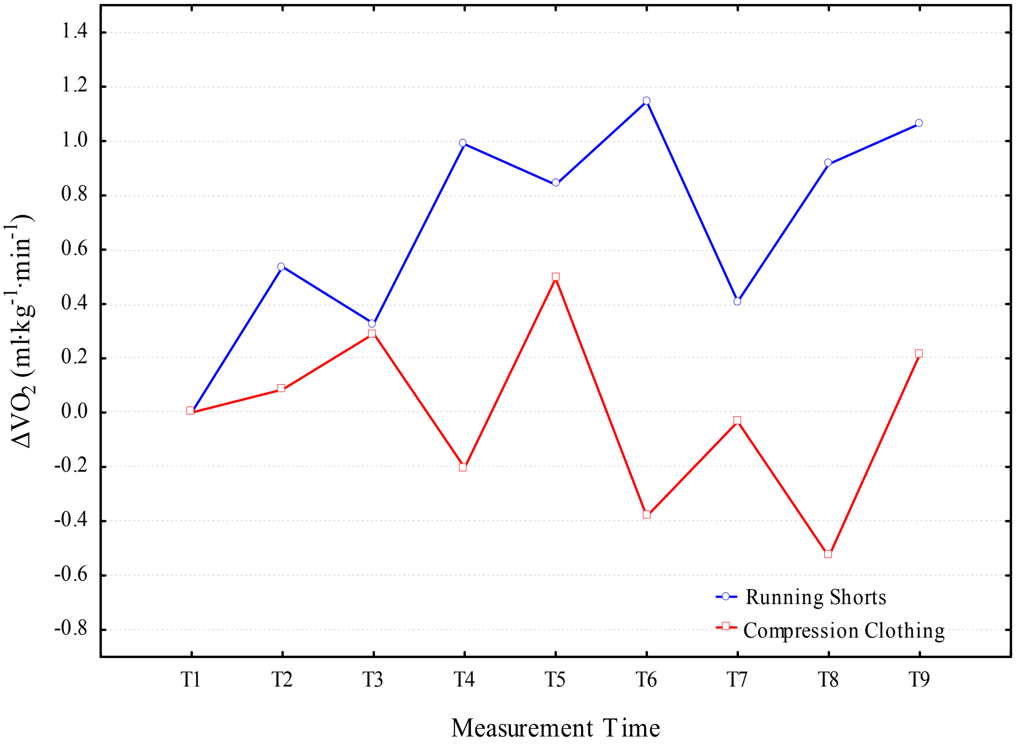

Figure 3. Mean values of oxygen uptake drift (ΔVO_2) during 90 minutes of constant speed treadmill running while wearing lower-body compression clothing (Experimental) and non-compression shorts (Control) (n = 11). Values of ΔVO_2 were computed at nine successive measurement time periods (T1-T9) corresponding to 6, 16, 26, 36, 46, 56, 69, 79, and 89 minutes into each running trial. Values of ΔVO_2 computed as the difference between measures at T1 and other time points (T2-T9) for each subject.

Finally, the amount of variability in the mean responses of ΔVO_2 and ΔHR between each successive time interval prompted a post-hoc analysis of the summed values of each variable (ΔVO_2 and ΔHR). Measures of ΔVO_2 and ΔHR were summed across all time intervals for each condition, providing a single value to describe the trend of oxygen uptake and heart rate drift across the entire submaximal trial. A paired *t*-test was used to evaluate these summed values at the 0.05 alpha level. The results of this analysis showed a non-significant trend toward a difference between the two clothing conditions ($p = 0.10$). The observed change in oxygen uptake drift was smaller when subjects were wearing compression clothing as compared to standard running shorts (Mean±SE; 6.24±2.32 $ml \cdot kg^{-1} \cdot min^{-1}$ when wearing running shorts versus -0.07±2.53 $ml \cdot kg^{-1} \cdot min^{-1}$ when wearing compression clothing). A similar analysis of the summed ΔHR values (Mean±SE) did not show a trend toward a difference between the clothing conditions (53±9 bpm when wearing running shorts versus 49±10 bpm when wearing compression clothing). Effect sizes (ES) were also calculated for both summed ΔHR and summed ΔVO_2, and were determined by the formula: $[mean_1 - mean_2]$/pooled SD for the differences in each variable between clothing conditions (Hopkins, 2003). Effect sizes were considered very small (0.0-0.2), small (0.2-0.6), moderate (0.6-1.2), or large (>1.2). The effect size for summed ΔVO_2 was moderate (ES=0.79), while the effect size for summed ΔHR was very small (ES=0.12). Figures 4 and 5 graphically display the mean of the summed values of ΔVO_2 and ΔHR for each clothing condition.

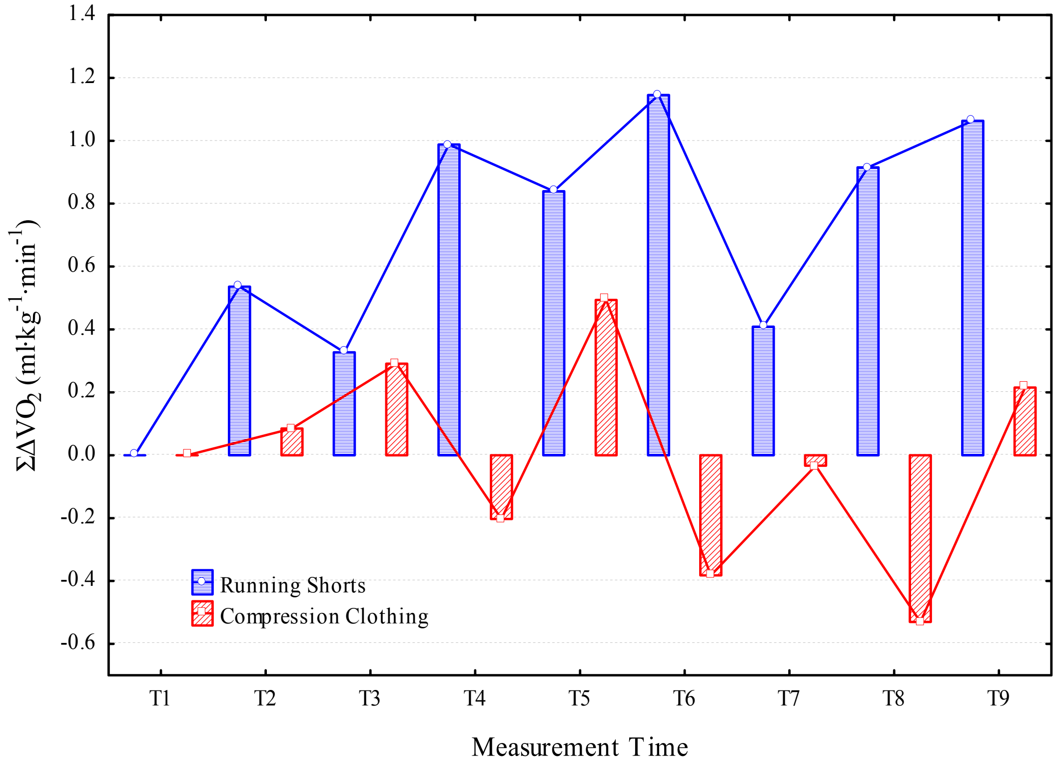

Figure 4. Graphic representation of the mean summed values of oxygen uptake drift ($\sum\Delta VO_2$) for all subjects (n=11). Final $\sum\Delta VO_2$ value computed as the sum of all ΔVO_2 values for all measurement times (T1-T9) for both conditions (running shorts and compression clothing).

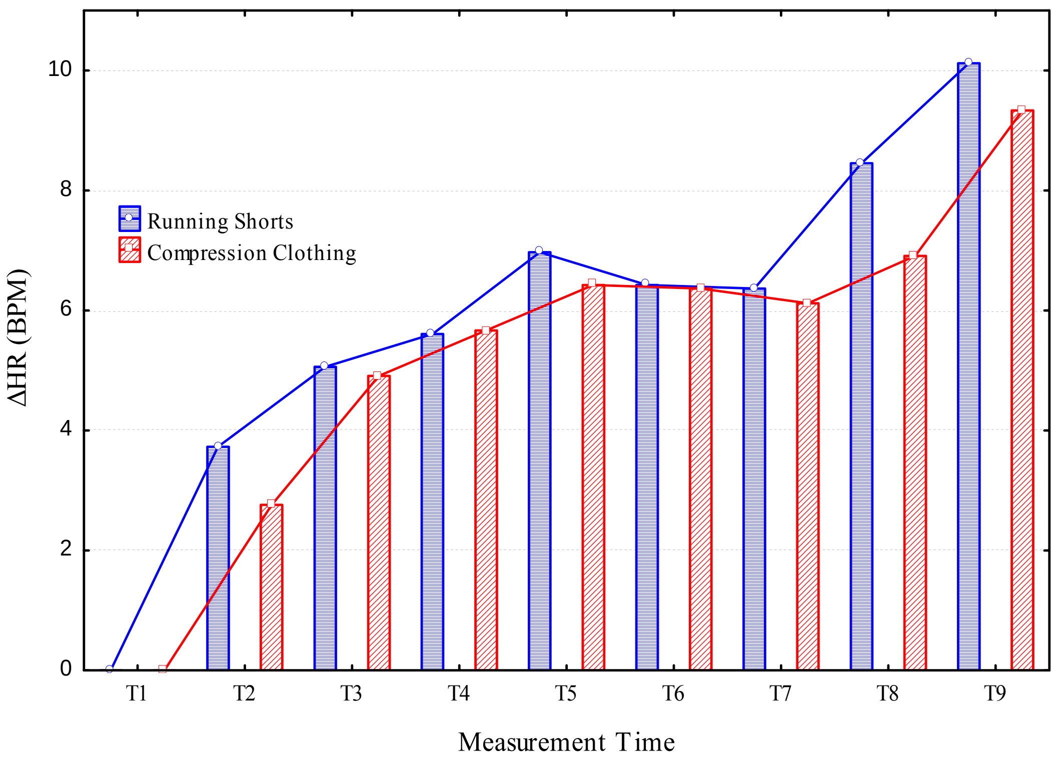

Figure 5. Graphic representation of the mean summed values of cardiac drift (∑ΔHR) for all subjects (n=11). Final ∑ΔHR value computed as the sum of all ΔHR values for all measurement times (T1-T9) for both conditions (running shorts and compression clothing).

CHAPTER FIVE

DISCUSSION

This study was conducted to investigate the influence of lower body compression clothing on different markers of running economy during prolonged (90 minutes) submaximal treadmill running. Running economy (RE), which is defined as the energy cost to run at a particular speed, has been identified as one of several physiological factors that influence distance running performance by Di Prampero, Capelli, Pagliaro, Antonutto, Girardis, Zamparo, and Soule (1993). In fact, Noakes (1988) established that RE was a critical determinant of success in distance running, which supports the claim by Daniels (1974) that markers of submaximal performance (economy) are of more importance than other physiological determinants (e.g., maximal aerobic capacity and lactate threshold).

In the current study, there were no significant differences in the dependent variables directly associated with RE (oxygen uptake and oxygen uptake drift) when wearing compression clothing, nor were there any differences between clothing conditions for indirect measures of RE (heart rate, blood pressure, and rate pressure product). Measures of accelerometry, on the contrary, were significantly lower when wearing compression clothing as compared to standard running shorts. Additionally, blood lactate was significantly higher at 60 minutes of running when wearing compression clothing, but remained statistically similar for both clothing conditions at all other measurement time periods.

Physiological Determinants of Running Performance

When compared with other physiological determinants of running performance (maximal aerobic capacity and lactate threshold, namely), RE is unique in that it is a factor that can be changed or improved by means other than simply training. These means can include improving running technique, adjusting step rate during running, and increasing or decreasing stride length, all of which can produce a lower energy cost when running at a given speed (Cavanagh and Kram, 1985; Johnston et al., 1997). This improved running economy, ultimately, can result in improved running performance. Maximal aerobic capacity (VO_{2max}), conversely, is a factor that is not easily influenced by training or technique adjustments in well-trained subjects (Basset and Howley, 2000; Pate and Branch, 1992). While a runner's lactate threshold can be improved (driving the threshold closer to the runner's VO_{2max}) through systematic training (Pate and Branch, 1992), it seems that running economy is a factor more easily influenced by external means (Cavanagh and Kram, 1985).

In recent years, it has been proposed that the trend of wearing lower body compression clothing, including full-length compression tights, half-length compression tights, and compression stockings, during endurance events may provide an external means of influencing running economy (Bakken et al., 2008; Bringard et al., 2006). Compression clothing already has a well-established role in the therapy of patients with venous insufficiency (Lawrence and Kakkar, 1980), and compression clothing has also successfully been worn as a means of improving recovery after exercise (Bringard et al., 2006; Berry and McMurray, 1987). It is believed, therefore, that wearing compression clothing can also influence endurance performance, most notably through improving running economy.

Testing Models for Previous Studies of Compression Clothing

The goal of this study was to investigate how endurance running performance might be influenced by wearing lower-body compression clothing. More specifically, running economy and various markers associated with running economy were the aspects of running performance that were of interest for the current study. Several of these markers, including oxygen uptake (VO_2) and oxygen uptake drift (ΔVO_2), were direct measures of running economy (Fletcher, JR, Esau, SP, MacIntosh, BR, 2009), while other observed variables provided indirect indicators of running economy (i.e., heart rate, blood pressure, and rate pressure product). As such, an appropriate testing model for observing potential differences between clothing conditions (i.e., running shorts versus compression clothing) was needed. A variety of compression clothing testing models have been developed to observe differences in markers of athletic performance (Ali, Caine, and Snow, 2007; Berry and McMurray, 1987; Bringard et al., 2006; Doan et al., 2003; Scanlan, Dascombe, Reaburn, and Osbourne, 2008; Sperlich, Haegele, Achtzehn, Linville, Holmberg, Mester, 2010). The testing models used in these studies were designed to maximize the potential effects of compression clothing on the dependent variables of interest.

Berry and McMurray (1987) were among the first to examine the role of compression clothing on athletic performance and recovery. Their testing model, which was designed with the observation of blood lactate in mind, involved running healthy college students through several bouts of running and cycle ergometer exercise while wearing compression stockings in one trial and no compression stockings in another trial. Blood lactate measurements were taken immediately after each maximal bout of exercise while the subjects were at rest in the seated and supine positions. While the authors noted no difference in the time to exhaustion between the two clothing conditions, they reported lower post-exercise blood lactate values when subjects wore the compression stockings.

In the study conducted by Doan et al. (2003), 20 members of a university track and field team were recruited to participate in a series of tests while wearing either half-length compression tights or loose-fitting track shorts. The testing model was one that focused on explosive movements (the tests involved 60-m sprints and repeated counter-movement vertical jumps), and so only members that specialized in sprinting and jumping events from the track team were recruited to participate. The authors reported improvements in counter-movement jump height, as well as decreased muscle oscillation, while wearing the half-length compression tights.

Only a few testing models have been created with the goal of investigating the role of compression clothing in improving endurance performance. Scanlan et al. (2008) was one such study that used a 1-hr cycling time-trial as a testing model to examine potential improvements in performance and observed improved muscle oxygenation economy (defined as the mean power output divided by the percentage of mean muscle oxygenation) when wearing compression garments, although no associated improvements in performance were noted.

The remaining test models have examined endurance running performance while wearing compression clothing. Ali et al. (2007) conducted a field-based trial to examine differences in performance for 14 recreational runners wearing compression clothing, but found 10-km run time to be similar when wearing compression clothing as compared to standard running shorts. Bringard et al. (2006) conducted their endurance running research in a laboratory setting, and the testing model used 6 trained runners that ran for 3 minutes at several standardized speeds (10, 12, 14, and 16 $km \cdot hr^{-1}$), and again at 80% of VO_{2max} for 15 minutes in a subsequent test. The authors reported a lower aerobic energy cost when the runners ran at 12 $km \cdot hr^{-1}$ while wearing full-length compression tights. Similarly, Sperlich et al. (2010) evaluated the effects of compression clothing on a 15-min bout of running at 70% of ventilatory threshold, followed by a time to exhaustion run at a velocity associated with VO_{2max}, but found no significant differences in VO_2 or heart rate (HR) between the clothing conditions (compression clothing versus standard running shorts).

The testing model used in the current study was one similar to that of Bringard et al. (2006) in that it utilized submaximal treadmill running to observe differences in endurance running performance while wearing compression clothing. The testing model for the current study, however, also attempted to exploit fatigue in a fundamentally different way, namely by employing a submaximal running test that was considerably longer (90 minutes) than that used by Bringard et al. (2006).

Testing Model for Current Study

The model used by the current study was prompted by a pilot study of lower body compression clothing conducted by Bakken, Heil, Borgen, and Willis in 2008. The investigators observed a notable trend towards a difference between the two conditions (full-length compression tights versus standard running shorts). The results of the pilot study indicated that wearing compression tights could reduce the amount of cardiovascular drift over the course of 60 minutes of submaximal treadmill running, as well as the amount of oxygen uptake drift, when compared to wearing standard running shorts. The differences between the conditions were statistically significant at 40 minutes of running. The sample size of the pilot study was quite small (n=5), however, and so the differences failed to reach statistical significance at subsequent measurement time periods.

Noting the apparent trends in this pilot study, the same testing model was used for the current study. By increasing the subject sample size (from 5 to 13, 11 of which were included in the final data set) and increasing the duration of submaximal exercise (from 60 to 90 minutes), it was assumed that the trends observed in the pilot study would reach statistical significance and continue to increase over 90 minutes. In addition, the pilot study investigators speculated that the mechanism responsible for the trends was cardiovascular in nature, so measures of blood pressure were included in the current study to assess the workload by the heart.

Given the time effect for several different variables, including HR, systolic blood pressure (SBP), and rate pressure product (RPP), it is clear that the model was appropriate for observing changes in several variables over the course of 90 minutes of submaximal treadmill running. These expected changes are in agreement with a similar model used in a study by Goh et al. (2010) that investigated the effects of compression garments on 20-min submaximal running performance at two different temperatures.

There were, however, no statistically significant results from the current study to support the conclusions by Bakken et al. (2008). The amount of heart rate drift (ΔHR) remained statistically similar for each time interval between clothing conditions over 90 minutes of running. Additionally, measures of HR, SBP, diastolic blood pressure (DBP), and RPP remained similar between conditions for each successive time interval. It should be noted, however, that measures of SBP, DBP, and RPP are based on a smaller sample size (n=9), as two additional subjects were dropped for these variables as a result of numerous missing data points. Blood lactate remained statistically similar between conditions for each time interval, with the exception of an interaction effect between time and condition at 60 minutes (T6). This interaction effect can be explained by high outlier values for two subjects at T6 while wearing compression clothing.

Interestingly, the amount of oxygen uptake drift (ΔVO_2) remained statistically similar between clothing conditions, although the data showed a trend toward a lower ΔVO_2 when wearing compression clothing as compared to running shorts. The amount of variability in the mean responses of ΔVO_2 and ΔHR between each successive time interval prompted a post-hoc analysis of the summed values of each variable (ΔVO_2 and ΔHR). Measures of ΔVO_2 and ΔHR were summed across all time intervals for each condition, providing a single value to describe the trend of oxygen uptake and heart rate drift across the entire submaximal trial for each subject. The results of this post-hoc analysis showed a non-significant trend for a smaller amount of change in ΔVO_2 (i.e., the summed values of ΔVO_2) when wearing compression clothing (Mean±SE; 6.24±2.32 $ml \cdot kg^{-1} \cdot min^{-1}$ when wearing running shorts versus -0.07±2.53 $ml \cdot kg^{-1} \cdot min^{-1}$ when wearing compression clothing). Additionally, there was a moderate statistical effect size for the summed values of ΔVO_2 ($\sum \Delta VO_2$), which supports the idea that there was a practical difference in $\sum \Delta VO_2$ between the two clothing conditions. The trends in ΔVO_2 and $\sum \Delta VO_2$ are, however, the only variables that support the findings of the pilot study by Bakken et al. (2008). Nevertheless, these trends are also consistent with the findings by Bringard et al. (2006), which indicate improved aerobic cost when running at submaximal speeds while wearing compression clothing.

Aside from ΔVO_2 and $\sum \Delta VO_2$, the data from the current study showed no other trends that were similar to the trends observed by Bakken et al. (2008) and Bringard et al. (2006). This suggests that, if compression clothing did indeed improve running performance, running economy may not have been the appropriate question of interest for this study. The testing model used for the current study was appropriate for observing differences in running economy between clothing conditions, as several variables associated with running economy were shown to increase with time. The difference in the brand of compression clothing (Skins^{TM} was the brand used for the study as opposed to Zoot^{TM} used in the pilot study), however, may have changed the nature of the compression provided by the clothing, and therefore the nature of the question of interest. When compared to another study that investigated the influence of Skins^{TM} brand compression clothing on similar markers of running economy with a relatively similar testing model (Goh et al., 2010), the results of the current study are the same (i.e., no changes in VO_2 or HR were observed in either study).

Zoot Sports maintains that the graduated compression (by as much as 30 mmHg) provided by their model of tights helps facilitate blood flow back to the heart, which in turn reduces workload by the heart. While Skins^{TM} also claims that their products provide graduated compression, they argue that the compression of the clothing helps to stabilize musculature and prevent muscle damage, which is in agreement with the suggestions made by Bringard et al. (2006) and Doan et al. (2003). The significant trend of the thigh musculature to move less when wearing the Skins compression clothing during the 90-min trials supports the claim that the musculature is stabilized, and the non-significant observation for lower creatine kinase (CK) values when wearing compression clothing (Mean ± SE; 145.27±46.40 IU/L for running shorts versus 65.91±12.36 IU/L for compression clothing, $p = 0.13$) supports the idea that muscle stabilization may prevent muscle damage. It is possible, therefore, that the model used for testing Skins brand compression clothing should focus more on measuring markers of muscle stabilization and muscle damage to confirm the results of Bringard et al. (2006) and Doan et al. (2003).

Explanation of Results

The lack of observed significant differences in the current study can likely be explained by one of four different scenarios: 1) the testing model used for this study was not the best model, 2) uncontrolled confounding variables influenced the study results, 3) the sample size (n=11) was not large enough to observe potential differences, or 4) compression shorts and socks do not have any significant impact on running economy.

There was a large amount of variability present in several of the measured variables across 90 minutes of steady-state running. The nature of the testing model used for the current study may explain this variability. Firstly, the submaximal trials consisted of 90 minutes of running on a treadmill. During this time, subjects were required to breathe through a mouthpiece to measure VO_2. Several subjects noted that this became very uncomfortable over the course of 90 minutes. One subject dropped out of the study as a result of the discomfort experienced by the mouthpiece. It is possible, therefore, that the subjects adapted a style of breathing through the mouthpiece that allowed for greater comfort but less accuracy of VO_2 measurement (i.e., leakage of air from the system). This could explain for the seemingly erratic VO_2 and ΔVO_2 responses over the course of 90 minutes of running for several subjects (since these values were expected to increase gradually for each time interval). Despite this explanation, the data for two subjects were dropped from the final data set as a result of high, unexplainable variability in several dependent variables. This presents a clear advantage to the shorter durations of exercise in the testing models used by Bringard et al. (2006) and Sperlich et al. (2010).

A more likely explanation of the VO_2 variability, however, is the presence of multiple small holes that were discovered in several of the air collection tubes that were used after all the data was collected for the study. It is unknown to what extent these holes affected the VO_2 measurements, but it is impossible to discount this discovery as a major source of error for VO_2 measurement accuracy.

Furthermore, the testing model used for the current study allowed for a 3-minute break at 60-minutes of running. Because subjects were given 75 mL of water to drink during each time interval (675 mL total), the subjects were given the opportunity to urinate during this break if needed. The break, however, also seemed to create a gap in the continuity of measurement of several variables. The gradual increase in several variables (as expected during prolonged submaximal running) was disrupted by this 3-min break, and may have interfered with possible differences between clothing conditions.

There are several other uncontrolled confounding variables that may help explain the lack of observed significant differences between the two clothing conditions. It is also possible that the variability in the running backgrounds of the participants may have created subsequent variability in responses of VO_2 and ΔVO_2. All of the participants in the current study were self-described endurance runners and needed to fulfill several criteria in order to be eligible for participation. Despite these criteria, the training backgrounds of the participants varied considerably. Several of the participants were actively training for ultra-marathons (distances of 50+ miles), some were training for triathlon competitions, while still others trained on a recreational basis. As such, the subjects likely entered the study with varying degrees of running experience. The variability in the running experience of the subjects may have created large disparities in the fitness level of each subject prior to each testing session.

Comparatively, the subjects of the pilot study by Bakken et al. (2008) all had relatively homogenous training backgrounds (all of the subjects were actively training for cross-country skiing), and the investigators noted consistently increasing responses in ΔVO_2 over 60 minutes of treadmill running. Likewise, the populations used for Bringard et al. (2006) and Sperlich et al. (2010) were homogenous groups of well-trained athletes. Although the subjects used in the study by Ali et al. (2007) were recreational runners, the subject pool nevertheless remained homogenous. This may indicate, therefore, that the population recruited for the current study was not appropriate (i.e., too heterogeneous) for the testing model used. As noted earlier, this would have been further exacerbated by the different brand of compression clothing used for the current study. Furthermore, when the number of dropped data sets is taken into consideration (only 11 were included in the final analysis), heterogeneity of a relatively small sample size becomes an especially critical confounder.

The fact that several subjects experienced ΔVO_2 that fell below their established baseline may be explained by a lack of familiarity with treadmill running. Although the initial maximal treadmill test was supposed to serve as an opportunity for subjects to familiarize themselves with treadmill running, the subjects may have experienced a certain amount of anxiety or anticipation to treadmill running. Perhaps far more important than other explanations, there was no standardized warm-up period prior to any of the tests. This may have created high initial values for VO_2 for subjects who opted for minimal amounts of warm-up, which would then create a false baseline for subsequent VO_2 measurements. This is evidenced by the fact that several subjects experienced ΔVO_2

values that fell below their established base-line well into the submaximal tests (i.e., these subjects were working at an aerobic rate lower than what they initially started at after prolonged periods of running). This presents a significant confounding variable to the study.

Finally, it is important to note that several subjects experienced fluctuations in the treadmill belt speed, which varied in frequency and severity. Although attempts were made to record the belt speed fluctuations when they occurred, it is not known to what extent these fluctuations may have affected the data. Although one subject dropped out of the study as a result of these fluctuations in belt speed, the fluctuations were not considered sufficient to eliminate data from the final data set.

Despite the variability present in several of the dependent variables (namely VO_2 and ΔVO_2), there were also several consistent and non-significant responses, including the HR and ΔHR responses. Of the main effects present in the data, there was a time effect for HR, indicating that HR increased consistently for each time interval, but the amount of change in HR (the cardiovascular drift) was not significantly different between the clothing conditions. Considering the consistent HR responses between each clothing condition, it is possible that the variability in the VO_2 and ΔVO_2 responses could be explained by the percent error in the measurement equipment, since the fluctuations in VO_2 responses only varied by 1.0 $ml \cdot kg^{-1} \cdot min^{-1}$ at most. This calls the idea of practical versus statistical significance into question (i.e., although some variables may have approached statistical significance, the amount of difference may have been too small to be considered practically significant). It is interesting to note that if the VO_2 and ΔVO_2

variables were excluded from the analysis entirely, the only variables that approached statistical significance were measures of CK (*p* = 0.13, when an extreme outlier was removed from the data set) and AC (*p* = 0.03), with the exception of LA, which showed an interaction effect at T6. This could suggest that the experimental model used for this study was not appropriate for the brand of compression clothing used. Running economy may not, therefore, be the question of interest when considering Skins^{TM} brand compression clothing. As such, a different testing model, like the model used by Doan et al. (2003), should be used for future research of Skins^{TM} brand compression clothing.

Regardless of the testing model used, however, it is impossible to discount the fact that uncontrolled confounding factors may have influenced the study results. These confounding variables were likely large contributors to the lack of observed significant differences between the clothing conditions. Considering the moderate statistical effect size observed in the $\sum\Delta VO_2$ data, it seems likely that statistical significance could have been achieved (even if practical significance remains questionable) for dependent variables associated with VO_2 had the confounding variables been controlled. When this explanation is coupled with the fact that only 11 data sets were included in the final analysis, the confounding variables become too influential to discount as potential contributors to the overall variability of several of the dependent variables. Future studies, therefore, need to account for these confounding variables and use a larger sample size in order to observe potential differences.

CHAPTER SIX

CONCLUSION

With no significant differences in variables directly associated with running economy (oxygen uptake and oxygen uptake drift), the preliminary findings indicate that running economy is not improved when wearing lower-body compression clothing during longer durations of submaximal treadmill running. Likewise, there were no differences in the variables that were indirect markers of running economy (heart rate, blood pressure, and rate pressure product). The findings from this study, therefore, do not support the initial hypothesis that the mean dependent variables related to running economy would be significantly lower when wearing lower-body compression clothing when compared to wearing standard non-compression running shorts.

There were, however, notable trends for a decrease in the variables directly associated with running economy when wearing compression clothing, most notably in oxygen uptake drift. There was a moderate statistical effect size associated with this trend, suggesting that this trend may have reached statistical significance with a greater sample size, although it is unknown as to the amount of influence the uncontrolled cofounding variables had on these results.

It is interesting to note that measures of accelerometry were significantly lower when wearing compression clothing as opposed to standard running shorts. It is possible that there is a relationship between lower accelerometry values (decreased thigh musculature movement) and a trend for lower oxygen uptake drift, although this is purely speculation without further investigation.

Ultimately the question that needs to be addressed is who stands to gain from wearing lower-body compression clothing during prolonged submaximal exercise? The trend for a decrease in oxygen uptake drift is minimal (at most a decrease in a few milliliters of oxygen for each kilogram of body weight per minute), and so it is arguable whether or not wearing lower-body compression clothing could create a notable change in the outcome of an endurance running performance. For the elite endurance runner, the potential for improvement may well be worth the investment in lower-body compression clothing. For the recreational endurance runner, however, committing more time to training may be far more beneficial than investing in lower-body compression clothing.

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APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM

FOR PARTICIPATION IN HUMAN RESEARCH

MONTANA STATE UNIVERSITY

Project Title:	Influence of Lower Body Compression Clothing on Markers of Running Economy During Submaximal Treadmill Running
Principle Investigator:	Bjørn Bakken Graduate Student, Exercise Physiology Department of Health and Human Development Movement Science Laboratory Health & Physical Education Complex, Montana State University Bozeman, MT 59717-3540 (218) 340-5934 bjorn.bakken@montana.edu
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Purpose of the study:

You are being asked to participate in a study that will compare the effects of running continuously on a treadmill for 90 minutes while wearing compression shorts and compression socks as opposed to non-compression shorts and socks (i.e., standard running shorts and socks). Compression clothing garments (including compression shorts and compression socks) are designed to provide external compression on your limbs. It is hypothesized that this external compression can provide muscle stabilization as well as aide blood flow back to your heart. Data will be collected over the course of three laboratory visits, and will subsequently be used to determine what differences in running economy, if any, exist between the two testing conditions (wearing compression shorts and compression socks vs. wearing standard running shorts and running socks). You were selected as a subject for this study based on your experience as an endurance athlete and, more specifically, your weekly routine of running a minimum of 4 hours per week and your ability to run continuously for 90 minutes comfortably.

Prior to any testing, each subject is required to read and sign a Subject Consent Form. Medical clearance will be obtained using the Health Status Questionnaire. The medical questionnaires will be used for identification and exclusion of subjects with medical contraindications to the level of exercise required by the protocol. All testing and screening procedures are in accordance with those outlined for testing "low risk" adults by the American College of Sports Medicine[1]. You will also be asked to fill out a running history questionnaire prior to any testing.

Testing Procedures:

If you agree to participate in this study, you will be required to make three visits to the Movement Science / Human Performance Lab in the basement of the Romney gymnasium on the Montana State University campus. You should expect to spend approximately 1 - 1½ hours during the first lab visit, and approximately two hours during each of the final two lab visits. You will need to follow up each of the final two tests with a short (5 minutes) visit to the lab 24 hours after each test. Each test will be scheduled at least 48 hours AFTER your last hard workout. Please prepare for each lab visit as you would before a race so you are ready for strenuous exercise. Please avoid ingesting any medications, including caffeine and/or aspirin, for at least 2 hours before arriving at the lab. You should inform the lab personnel of any medications that were taken prior to the visit (including cold or allergy medicine) BEFORE any testing so that we can reschedule your visit. *If you use an inhaler to treat asthma, please bring the inhaler with you each time you visit the lab.* We ask participants to arrive at the lab ready

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[1] American College of Sports Medicine (2006). *ACSM's Guidelines for Exercise Testing and Prescription* (6th edition). Williams & Wilkins, Philadelphia, Pa.

to engage in exercise, which means you should arrive dressing in appropriate athletic clothing (i.e., running shoes, ankle-length running socks, shorts, short-sleeved top, etc.), properly hydrated and nourished.

Each visit to the lab is described as follows:

First lab Visit

During the initial visit to the Movement Science / Human Performance Lab and after all necessary forms are completed, anthropometric and demographic data such as age, height, weight, and gender will be collected. You will then be asked to participate in a running VO_{2max} test on the treadmill, which will be used to assess your aerobic capacity. You will be asked to warm up for a period of 10 minutes to make sure you are accustomed with treadmill running. After the warm up, you will be asked about your typical 5km race time. The initial speed of the treadmill will be established based on your response. When this pace has been established, you will be fitted with a mouthpiece connected to a gas collection tube that runs to the metabolic measurement system so that the amount of oxygen you are using can be measured. The mouthpiece is designed to fit inside of your mouth like a snorkel. You will also be fitted with a heart rate monitor strap around your chest to measure your heart rate during the test.

You will begin the test by running on the treadmill for a total of 3 minutes at 80% of your selected race pace at a level grade, followed by one minute of standing rest (for a total of 4 minutes per stage). During the rest periods, the lab technicians will draw a fingertip blood sample from your left hand. This involves poking the end of a finger with a sterile lancet until a small droplet of blood forms on the end of the finger. This blood is then absorbed into a blood lactate measurement strip. The technician will clean and bandage your finger before the start of the next stage.

Subsequent stages will increase gradually in speed using the same protocol (3 minutes of running followed by 1 minute of standing rest). When the lab technicians see a spike in your blood lactate measurements, indicating that you have surpassed your lactate threshold, stages will become continuous (i.e., no rest between stages) and will only last one minute. At this point, speed will be kept constant, and the grade of the treadmill will increase gradually between stages. You will continue with this protocol until you are unable to continue with the test (volitional exhaustion). *The goal of this test is for you to last as long as you possible can into the protocol before you reach the point where you must stop.*

Second and Third Lab Visits

During the second and third lab visits, you will run on the treadmill for a total of 90 minutes each visit. During one test you will wear the compression shorts and compression socks provided by the lab, while you wear non-compression clothing (e.g. running shorts and ankle-length running socks) during the other visit.

Once arriving at the lab, a measurement of resting blood pressure will be taken. At the same time, you will be fitted with a special measurement device prior to warming up. To measure the difference in how much your thigh musculature moves with the ground impact forces of running, a small accelerometer (roughly the size of a small wristwatch) will be bandaged to the front of your left thigh, midway between the hip and knee. It is possible that the compression shorts will cause the musculature to move around less when running. The accelerometer, therefore, should be able to tell the investigators if this has occurred or not. At the end of each running trial, the accelerometer is removed and the collected data is downloaded to a computer.

After the accelerometer is properly attached to your thigh, you will be allowed to warm up on the treadmill for 5-15 minutes. Prior to your first 90 minute running trial, you will need to determine a running pace that corresponds to 85% of the heart rate corresponding to your lactate threshold (which is determined from the VO_{2max} test results during your first visit). A heart rate of 170 beats per minute at lactate threshold, for example, would yield a target heart rate of 144 beats per minute for the running trials (0.85x170=144). The running speed that corresponds with this target heart rate, as determined during the warm-up for the first 90 minute running trial, will be your running speed for the entire 90 minutes for both trials.

Prior to the test, a lab technician will draw a blood sample from your fingertip using the same procedure described for the VO_{2max} test. This blood will be used to measure the amount of creatine-kinase in the blood, which is an indicator of muscle damage. Once the running trial begins, both heart rate and oxygen consumption will be measured using the same equipment described for the VO_{2max} test. In addition, blood lactate will be measured every ten minutes during the test for a total of 10 measures (times 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 mins). Again, the procedure for drawing a fingertip blood sample will be the same as that used in the VO_{2max} testing.

Prior to the test, you will also be asked to provide a urine sample, which will be measured for specific gravity to ensure that you are properly hydrated before the test. In the event that you are not properly hydrated, we will gladly reschedule your visit. In order to ensure proper hydration throughout the test, you will be given a small amount of water (75 mL) to drink every ten minutes (times 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 mins). It is imperative that you drink the full amount at each collection time to ensure consistency in hydration. At the same time you are given water to drink, a lab technician will take a measurement of your exercising blood pressure. After 60 minutes of running, you will be allowed a one-minute break to provide another urine sample for the investigators. A final urine sample will be collected at the completion of the test. These samples will be measured for specific gravity to ensure that hydration was properly maintained throughout the test.

<u>NOTE</u>: Ideally, you should wear the same shoes for both of these 90-min running trials. This will help to control variations in energy expenditure (oxygen consumption) that may result from wearing different shoes between trials.

Potential Risks:

A VO_{2max} test can cause extreme fatigue immediately after the test as well the next day. Because VO_{2max} testing involves such high intensity exercise, there is a chance of precipitating a cardiac event (such as abnormal heart rhythms) or even death during the test. The possibility, however, of such an occurrence is very slight (less than 1 in 10,000) because of you are in good physical condition with no known symptoms of heart disease. Additionally, the test will be administered by trained personnel (American Red Cross CPR certified) who are familiar with the lab's emergency action plan. *These risks are certainly no greater than those experienced by trained athletes in actual race competition.*

During the three lab visits, you will be required to wear headgear with an attached mouthpiece for a portion of each test. As a result, you may experience some degree of discomfort during each test. The headgear and mouthpiece support the gas collection tube during exercise and, despite being uncomfortable, are required to accurately assess your aerobic capacity. Provisions will be made to ensure each subject is as comfortable as possible during all procedures in the testing sessions.

In addition to wearing the gas-collection headgear, samples of blood will be drawn via a finger stick periodically throughout each of the three tests for blood lactate and blood creatine-kinase measurements. Although the amount of blood drawn per sample is minimal (5-10 drops), each sample is vital to assess the amount of muscle damage sustained (as determined by blood creatine-kinase) as well as the intensity of exercise (as determined by blood lactate) during the testing procedure. You may experience some degree of discomfort during this process, and some minor bruising at the site of the finger stick may occur after the testing is done. The risk of local infection is less than 1 in 1,000. Provisions will be made to ensure that this procedure is as safe, efficient, and painless as possible.

Subject Compensation:

Upon completion of all aspects of this study, you be allowed to keep the compression garments that you used, all of which are provided by Skins (a combined retail value of $130). A summary of the results from your VO_{2max} test will also be provided to you at no charge—the open market value of which is approximately $250.

Benefits:

There are no direct benefits to you as a volunteer for this project. The principle investigator, however, is willing to discuss the interpretation of your own test results, as well as those for the study upon completion. You may contact the principle investigator, Bjørn Bakken, by phone at (218) 340-5934 or by email at bjorn_bakken@hotmail.com to discuss this option further.

Confidentiality:

The data and personal information obtained from this study will be regarded as privileged and confidential. They will not be released except upon your written request/consent. Your right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each subject's data.

Freedom of Consent:

You may withdraw consent for participation in writing, by telephone or in person without prejudice or loss of benefits (as described above). *Participation in this project is completely voluntary.*

In the UNLIKELY event that your participation in the project results in physical injury to you, the Project Director will advise and assist you in receiving medical treatment. No compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of your participation in this project. Additionally, no compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of traveling to and from your appointments at the Movement Science / Human Performance Laboratory. *Further information regarding medical treatment may be obtained by calling the Project Director, Bjørn Bakken, at 218-340-5934.* You are encouraged to express any questions, doubts or concerns regarding this project. The Project Director will attempt to answer all questions to the best of their ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety and comfort in mind. *Additional* *questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-5721.*

PROJECT TITLE: *Influence of Lower Body Compression Clothing on Markers of Running Economy During Submaximal Treadmill Running*

STATEMENT OF AUTHORIZATION

I, *the participant*, have read the Informed Consent Document and understand the discomforts, inconvenience, risks, and benefits of this project. I, ______________________________________ *(print your name)*, agree to participate in the project described in the preceding pages. I understand that I may later refuse to participate, and that I may withdrawn from the study at any time. I have received a copy of this consent form for my own records.

Signed:____ Age _______
Date_____________

Subject's Signature

APPENDIX B

HEALTH HISTORY QUESTIONNAIRE

Health Status Questionnaire (HSQ) - Montana State University

Movement Science / Human Performance Laboratory

INSTRUCTIONS

Complete each of the following questions as accurately as possible by filling in the blanks or checking the most appropriate box. All information provided is confidential and no information will be released without your written consent.

Today's Date _______________

GENERAL INFORMATION

Mr. ○ *Ms.* ○ *Miss* ○ *Mrs.* ○ *Dr.* ○

Last Name ______________________________ *First Name* ______________________

Mailing Address

____

____

Home Phone __________________________ *Office Phone* _______________________

Occupation ____

Employer ____

Person to Contact in Emergency: *Name* ___________________________________

Relationship ______________________________

Phone ______________________________

▪ *Descriptive information:*

Gender: *Male* ○ *Female* ○ *Body Weight* _____________

Age _______ *Date of Birth* ___________ *Body Height* _____________

▪ *Why are you filling out this questionnaire?*

○ *Your have volunteered for a research study or project.*

○ *You are being screened for fitness testing in the Movement Science Lab.*

○ *Other reason...*____

MEDICAL HISTORY

Name of your physician

____

(Address/phone?)

____

- *Family History:*

Did your father, or other first degree male relative (like a brother) die before the age of 55?

No ○ *Yes* ○ *If Yes, cause?* ____________________

Age at death? ____________________

Which relative? ____________________

Did your mother, or other first degree female relative (like a sister) die before the age of 65?

No ○ *Yes* ○ *If Yes, cause?* ____________________

Age at death? ____________________

Which relative? ____________________

- *List any food or drug allergies:*

____

____

▪ *List any medication you are currently taking (non-prescription and prescription, including oral contraceptives). Please comment on the reason for each medication.*

▪ *Please describe any recent illnesses, hospitalizations, or surgical procedures:*

▪ *Any of these health symptoms that occurs frequently (ranked as either a 4 or 5 below), <u>either at rest or during physical exertion</u>, is the basis for a prompt medical evaluation. Circle the number indicating how often you have each of the following:*

0 *= Never*
1 *= Practically never*
2 *= Infrequently*
3 *= Sometimes*
4 *= Fairly often*
5 *= Very often*

a. Coughing up blood.	*0*	*1*	*2*	*3*	*4*	*5*
b. Abdominal pain.	*0*	*1*	*2*	*3*	*4*	*5*
c. Low-back pain.	*0*	*1*	*2*	*3*	*4*	*5*
d. Chest pain.	*0*	*1*	*2*	*3*	*4*	*5*
e. Neck, jaw, arm, or shoulder pain.	*0*	*1*	*2*	*3*	*4*	*5*
f. Leg pain.	*0*	*1*	*2*	*3*	*4*	*5*
g. Swollen joints, especially the ankles.	*0*	*1*	*2*	*3*	*4*	*5*
h. Feel faint.	*0*	*1*	*2*	*3*	*4*	*5*
i. Feeling of dizziness.	*0*	*1*	*2*	*3*	*4*	*5*
j. Breathless with slight exertion.	*0*	*1*	*2*	*3*	*4*	*5*
k. Palpitation or fast heart rate.	*0*	*1*	*2*	*3*	*4*	*5*
l. Unusual fatigue with normal activity.	*0*	*1*	*2*	*3*	*4*	*5*
m. Abnormal/labored breathing at night.	*0*	*1*	*2*	*3*	*4*	*5*

For any score of “4" or higher, use the space below to explain the frequency and the conditions under which you experience that particular symptom:

· *Please indicate which of the following for which* ***you have been diagnosed or treated*** *by a physician or health professional. Please be as complete as possible.*

Check if "Yes" *If "Yes", please comment further...*

○ *Alcoholism*

○ *Anemia, sickle cell*

○ *Anemia, other*

○ *Asthma*

○ *Back strain*

○ *Blood pressure -* *High?*

Low?

○ *Bronchitis*

○ *Cancer*

○ *Cirrhosis, liver*

○ *Cholesterol -* *High?*

○ *Concussion*

○ *Congenital defect*

○ *Diabetes* *Type?*

○ *Emphysema*

○ *Epilepsy*

○ *Eye problems*

○ *Gout*

○ *Hearing loss* ________________________________

○ *Heart problems* ________________________________

○ *Hypoglycemia* ________________________________

○ *Hyperlipidemia* ________________________________

○ *Infectious mononucleosis* ________________________________

○ *Kidney problems* ________________________________

○ *Menstrual irregularities* ________________________________

○ *Mental illness* ________________________________

○ *Neck stain* ________________________________

○ *Obesity* ________________________________

○ *Phlebitis* ________________________________

○ *Rheumatoid arthritis*________________________________

○ *Stroke* ________________________________

○ *Thyroid problems* ________________________________

○ *Ulcer* ________________________________

○ *Other* ________________________________

____

____

BLOOD CHEMISTRY PROFILE

▪ *Have you ever had a fasting blood sample analyzed for cholesterol?* ○ *Yes* ○ *No*

If "Yes", when was last time your blood was analyzed? ___________________

If "Yes", please provide as much detail as possible with regard to the specific blood components requested below (<u>most recent test results only</u>). Ideally, we would like both the numerical value of the test result AND the units of the measurement (the units are typically reported along with the numerical value of the test result).

· *Total serum cholesterol*	_________	*units?* __________
· *HDL (high density lipoprotein)*	_________	*units?* __________
· *LDL (low density lipoprotein)*	_________	*units?* __________
· *VLDL (very low density lipoprotein)*	_________	*units?* __________
· *Triglycerides*	_________	*units?* __________
· *Blood glucose*	_________	*units?* __________
· *Hemoglobin*	_________	*units?* __________
· *Hematocrit*	_________	*units?* __________
· *Iron*	_________	*units?* __________

HEALTH-RELATED BEHAVIORS

- *Do you now smoke?* ❍ *Yes* ❍ *Infrequently* ❍ *No*

If "Yes" or "Infrequently", indicate the number smoked per day (on average):

Cigarettes: *40 or more* *20-39* *10-19* *1-9*

*Cigars/pipes - describe:*____

- *Have you recently quit smoking?* ❍ *Yes* ❍ *No*

If "Yes", how long ago did you quit? ________ *years* _________ *months*

- *Do you currently work in an environment where smoking is allowed?*

❍ *Yes* ❍ *No*

If "Yes", where do you work AND how frequently do you work in this environment?

- *Do you drink alcoholic beverages on a regular basis?* ○ *Yes* ○ *No*

(ie. at least once/week)

If "Yes", please answer the following:

1) How frequently do you drink?

2) What alcoholic beverages do you typically consume?

- *Have you* ***exercised*** *regularly in the past 4 weeks?* ○ *Yes* ○ *No*

If "Yes", describe in terms of frequency, duration, intensity, and type of exercise:

- *Do you consider yourself* **physically active** *due to work-related demands, home or farm chores, etc.?*

○ *Yes* ○ *No*

If "Yes", describe in terms of frequency, duration, intensity, and type of exercise:

▪ *Please describe anything not already described on this questionnaire that might cause you problems during exercise (use the space below).*

▪ *Are there any other health-related problems or concerns NOT addressed on this questionnaire that we should know about?*

○ *Yes* ○ *No*

If "Yes", please describe:

APPENDIX C

TRAINING AND EXPERIENCE QUESTIONNAIRE

Training and Experience Questionnaire

Name: Age:

Please include an address if you would like a copy of your test results.

How do you classify yourself as an athlete (e.g. runner, cross-country skier, triathlete etc.)?

How many months out of the year do you train/race consistently? Please specify the time period for each year.

How many hours of general training did you complete in the last month? In the last week?

What percentage of your overall training is made up of running?

How many miles/hours per week do you run?

What is your current 5k run time?

Please describe the type and frequency of your racing in the past two months.

How many years have you been training/racing competitively?

Have you had any recent injuries that may adversely affect your performance? If so, please describe.

Please list any medications, supplements, or ergogenic aids that you are currently using.