DOES THE USE OF UPPER LEG COMPRESSION GARMENTS AID PERFORMANCE AND REDUCE POST-RACE DELAYED ONSET MUSCLE SORENESS (DOMS)?

by

Ken Kabongo

(KBNKEN002)

SUBMITTED TO THE UNIVERSITY OF CAPE TOWN

Minor Dissertation prepared in partial fulfilment of the Master of Science in Exercise and Sports Physiotherapy Degree

Department of Human Biology

Division of Exercise Science and Sports Medicine

University of Cape Town

AHS5034W

Date of Submission: 23/06/2020

Supervisor: Associate Prof Andrew Bosch

Declaration of plagiarism

Declaration

I, Ken Mark Kabongo, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

I empower the university to reproduce for the purpose of research either the whole or a portion of the contents in any many whatsoever.

Signature: Signed by candidate

Date: 2020/06/30

Acknowledgements

I would like to thank the following people who have helped and guided me through my dissertation:

My supervisor Associate Professor Andrew Bosch, for his guidance and for his support;

The University of Cape Town, Postgraduate Physiotherapy Department, for the opportunity they gave and for their input throughout this MSc programme.

For their contributions to data collection:

The research participants for their time and effort and enthusiasm to be part of my study;

Mr Larry Trevino for his assistance in securing the equipment needed to conduct data collection;

Dr Kerry Hyland for her valuable expertise and guidance in the statistical analysis component of the study

A word of acknowledgment to the Lord Almighty for his guidance and to my dear family (Dad, Mom, Oliver, Yasmine and Kelly) who encouraged me and assisted where needed throughout the journey. My partner Lauren – I simply couldn't have done this without you, special thanks. Finally, the MSc in Sport & Exercise Physiotherapy class of 2018-2020 for the incredible journey we took.

Table of Contents

List of figures

List of tables

Abbreviations

=	equal
<	less than
%	percentage
°C	degree Celsius
g·min−1	Carbohydrate oxidation rate
ANOVA	Analysis of variance
BMI	body mass index
CG	control group
CGG	compression garment group
cm	centimetre
CK	Creatine kinase
CMJ	counter movement jump
CT	Computed tomography
DOMS	delayed onset muscle soreness
e.g.	example
EIMD	exercise-induced muscle damage
HR	heart rate
HREC	Human research ethics committee
hrs	hours
ie.	id est
IL-6	interleukin
kg	kilogram

km	kilometre
km/h	kilometre per hour
ISAK	International standards for anthropometric assessment
IQR	interquartile range
m	metres
mm	millimetre
mmHg	millimetre of mercury
min	minutes
min/km	minute per kilometre
ml	millilitre
MRI	Magnetic resonance imaging
n	number
PAR-Q	Physical activity readiness
r	reliability
RCT	randomised control trial
RPE	rating of perceived exertion
SD	standard deviation
sec	seconds
SSISA	Sport Science Institute of South Africa
UCT	University of Cape Town
VAS	Visual analogue scale
VO_2max	maximum oxygen uptake

Glossary of terms

Compression garments

This is a type of pressurised clothing (MacRae et al., 2011).

Upper leg compression garment

The upper leg compression garments are measured from the waistline to the knee (MacRae et al., 2011).

Delayed onset of muscle soreness

This refers to the sensation of muscle pain and/or discomfort and/or stiffness that occurs several hours following unaccustomed exercise (Oosthuyse & Bosch, 2017).

Eccentric exercise

Type of muscle contraction in which the muscle will lengthen while under tension (Hill et al., 2014).

Endurance running

Is a form of aerobic exercise to run prolonged distances and it utilises the aerobic energy system (Lieberman & Bramble, 2007).

Exercise-induced muscle damage

Muscle damage that occurs following unaccustomed exercise or eccentric type exercise. The signs and symptoms include decreased muscle strength, decreased power, deceased range of motion, increased swelling and oedema, increased muscle soreness and proliferation of intracellular protein found in the blood (Hill et al., 2014).

Abstract

Introduction:

Despite the lack of scientific knowledge on the physiological and biomechanical effects of wearing compression garments, there has been an increase in the use of these garments in endurance running. The purpose of this study was to compare the performance, pain and thigh circumference changes in endurance runners using upper leg compression garments while competing against runners who did not use compression garments in the same marathon race.

Methods:

A randomised controlled intervention study was conducted in endurance runners (n=18) participating in the 2019 Winelands Marathon (42.2km). The compression garment group (n=10) participated in the race wearing upper leg compression garments while the control group (n=8) did not. Participants in the compression garment group only wore the compression garments during the marathon. Various outcome measures of perceived exercise-induced muscle damage (EIMD) and running performance were assessed three days before, immediately post-race and two days post-race. Three days prior to the race, mid-thigh circumference measurements were performed. Immediately post-race, mid-thigh circumference measurements, Visual Analogue Scale (VAS) pain ratings and Likert scale for determination of muscle soreness were assessed and race performance times were recorded. Two days post-race, mid-thigh circumference measurements, VAS pain rating and Likert scale for determination of muscle soreness were repeated.

Results:

VAS pain ratings for hamstring (compression garment 2.50 vs control group 4.00) (p=0.04), knee flexion (compression garment 2.50 vs control group 5.00) (p=0.02) and hip extension (compression garment 2.50 vs control group 4.00) (p=0.04) had a statistically significant difference between the compression garment and control group immediately post-race. VAS pain ratings for hamstring (compression garment 0.00 vs control group 1.00) (p=0.04), knee flexion (compression garment 1.00 vs control group 2.00) (p=0.02) and hip extension (compression garment 1.00 vs control group 2.50) (p=0.04) had a statistically significant difference between the compression garment and control group two days post-race. There were no statistically significant differences in any other outcome measures

(i.e. Likert scale for determination of muscle soreness, mid-thigh circumference and race performance) between the compression garment and control group.

Conclusion:

The use of upper leg compression garments is a recovery ergogenic aid which improves VAS pain ratings post-race. The results suggest that upper leg compression garments have a protective effect on the hamstring muscle in runners in the recovery phase. However, since a runner would be in a recovery phase after a marathon, a minor difference would be of little practical advantage since, importantly, there was no statistically significant differences in race performance and thigh circumference measures.

Chapter 1: Introduction and scope of the dissertation

1.1 Introduction

Endurance running has become more competitive worldwide and has become increasingly popular in recent years as a result of its easy accessibility, popularity of iconic races and the associated health benefits (Schattke et al., 2014; van Gent et al., 2007). For example, the number of marathon finishers in the South Africa for the Comrades Marathon increased from 640 in 1970 to 16482 in 2018 (Comrades marathon association, 2020). Participants of endurance running races ranges from recreational to elite runners.

Endurance running race course profiles contain a variety of different uphill, downhill and flat sections. The downhill sections have the greatest effect on the lower extremity, as it induces a high proportion of eccentric muscle action on the quadricep muscles of the upper leg (Eston et al., 1995). Unaccustomed eccentric muscle action results in negative symptoms associated with exercise-induced muscle damage (EIMD). During an eccentric muscle action, the muscle lengthens while under tension, resulting in mechanical damage to the sarcomeres. This mechanical damage leads to an inflammatory response, which is proposed to exacerbate the degree of damage (Hill et al., 2014). The muscle damage and inflammatory responses are indicated by increased levels of Creatinine Kinase (CK), interleukin 6 (IL-6), and post subsequent exercise, by higher myoglobin levels post exercise than prior to the eccentric damage (Armstrong et al., 2015; Clarkson & Hubal, 2002; Gleeson et al., 1998). The signs and symptoms of EIMD include temporary reductions in muscle strength, decreased rate of force development (power), reduced range of motion, swelling, increased feelings of soreness and the appearance of intracellular proteins in the blood (Hill et al., 2014). It is widely believed that to maximize adaptation, EIMD symptoms should subside before an athlete competes or exercises severely again. Oosthuyse and Bosch (2017) studied the effect of gender and menstrual phase on CK activity and muscle soreness following downhill running. The study found that the CK and delayed onset muscle soreness (DOMS) response to downhill running is gender--specific and that recovery occurs more rapidly in women than men. The CK and DOMS response occur in concert in men but not in women. The DOMS response in women is prolonged and may be influenced by menstrual phase.

In recent years strategies to reduce symptoms of EIMD and recovery processes have been investigated and implemented to improve performance of endurance athletes (Barnett, 2006). Several post exercise recovery strategies have been used and researched including massage, stretching, cryotherapy, foam rolling, electrotherapy, non-steroidal anti-inflammatories (NSAIDS) and nutritional supplementation (Howatson & Someren, 2008). As a relatively novel method to promote recovery, there has been increasing interest recently in the efficacy of compression garments on recovery and performance in endurance runners (Mizuno et al., 2016).

There is limited knowledge on the mechanisms underpinning the efficacy of compression garment usage in endurance runners, although there are several hypotheses on possible mechanisms. For example, Engel et al. (2016) theorised that there was reduced muscular microtrauma when utilising compression garments and Struhar, Kumstat & Kralova (2018) proposed reduced tissue vibration during exercise. Additional hypotheses focusing on neuromuscular aspects include a reduction of energy expenditure as a result of reduced muscle fibre recruitment, enhanced neuromechanics (i.e. reduced presynaptic inhibition) and improved coordinative function (Engel et al., 2016). Kraemer et al. (2004) are of the view that compression garments may be effective in reducing the swelling and inflammatory processes associated with muscle damage and proposed that compression garments work by creating an external pressure gradient that reduces the space available for swelling to occur, thereby reducing the secondary inflammatory responses. Another theory is that the compression garments improve venous return, reduce venous pooling and promote the removal of metabolites, due to the muscle pump function (MacRae et al., 2011). Hill et al. (2014) found that perceived muscle soreness was reduced in her participants that wore compression garments post a marathon run. In addition, increased arterial inflow and lymphatic outflow are believed to accelerate the removal of metabolic waste products in the recovery phase. Ali et al. (2007) reported that compression garment usage reduces the CK level and reduces the inflammatory response. However, French et al. (2008) found that compression garments have no effect on perceived muscle soreness, CK concentration, lactate dehydrogenase concentration and thigh girth measurements. Although the physiological and biochemical effects of wearing compression garments remain poorly understood, the positive claims associated with the compression garments has led to an increase in compression garments utilisation in sport (Davies et al., 2009).

Several studies have been conducted to determine the effectiveness of compression garments in sport due to its popularity in recent years but to our knowledge the current study is the first study investigating the effects of compression garments of the upper leg pre, during and post a marathon. It is anticipated that if compression garments reduce the impact of EIMD, it will ultimately improve the performance of the marathon runners. This randomised controlled experimental intervention study sought to determine the association of upper leg compression garments on the running performance and EIMD of the upper leg in endurance runners running a marathon road race. Runners competing with upper leg compression garments were compared to runners not competing with compression garments. The findings of this study will contribute to the existing literature and have an influence on the future use of compression garments in the performance and recovery process of endurance runners.

1.2 Aims and objectives

1.2.1 Aim

The aim of the study was to compare the performance, pain and thigh circumference changes in endurance runners using upper leg compression garments while competing against runners who did not use compression garments in the same marathon race. A key aspect of this study was to investigate any association between upper leg compression on the signs and symptoms of EIMD and running performance of endurance runners competing in a marathon road race.

1.2.2 Objectives

The objectives of this study were:

1.To determine if there were significant differences in marathon times in runners who participated in the race wearing upper leg compression garments (Compression garment group) compared to runners who did not wear compression garments in the race (Control Group).

a. To determine if there were significant differences in average running pace (minute/kilometre [min/km]) in runners in the compression garment and control group during a marathon.

2.To determine if there were significant differences in mid-thigh circumference (calculated in centimetres [cm]) prior to the marathon, at the finish line of the marathon and two days post the marathon, in runners in the compression garment and control group.

3.To determine if there were significant differences in upper leg pain as recorded on the Visual Analogue Scale (VAS) upon completion and two days post the marathon in runners in the compression garment and control groups.

a. To determine if there were significant differences in VAS pain ratings at rest in the anterior and posterior thigh between the groups. At both completion of the race and two days later.

b. To determine if there were significant differences in VAS pain ratings with active non-weight bearing (NWB) knee flexion, knee extension, hip flexion and hip extension between the groups upon completion of the race and two days later.

4. To determine if there were significant differences in muscle soreness as recorded on the Likert Scale upon completion of the race and two days later in both the compression garment and control group.

1.3 Plan of development of research

First a thorough literature review (chapter 2) was conducted in relation to the use of compression garments in running and other sports, in relation to running performance and EIMD. This was followed by a randomised controlled intervention (chapter 3) to investigate whether the use of upper leg compression garments improves running performance and/or reduces post-race DOMS in endurance runners participating in a standard marathon. Chapter 4 includes the summarised findings of the study and the conclusion.

Chapter 2: Literature review

2.1 Introduction

Despite the lack of scientific knowledge on the physiological and biomechanical effects of wearing compression garments, there has been an increase in the use of these garments in endurance running (Davies et al., 2009). In this review, the focus will be on investigating the use of full body and upper leg compression garments (excluding lower leg compression garments/socks) specifically in endurance running and its effects on endurance athlete's recovery processes after exercise and its effects on performance.

A comprehensive computer-based search of the electronic online databases which include EBSCOHost (the primary databases used were Academic Search Premier, CINAHL, Health Source, Masterfile Premier and Medline), PubMed and Google Scholar was performed.

The online search was divided into three main themes: an investigation of the impact of compression garments in running and various other sports, the actual event (Winelands Marathon) and instrumentation measures. For the investigation of the impact of compression garments in running and various other sports the following main terms were used "compression garments", "compression shorts", "lower body compression", "endurance", "sport", "exercise", "running", "muscle damage", "muscle response", "delayed onset muscle soreness", "exercise-induced muscle damage", "physiological response", "performance" and "recovery". For the actual event, the following terms were used "Winelands Marathon" and "running". For the instrumentation measure, the following terms were used "validity", "reliability" together with their respective instrumentation measure (e.g. "Likert scale", "visual analogue scale", "skin folds", "thigh circumference", "time trial" and "time-to-exhaustion test").

Each study included was reviewed thoroughly for selection and only randomised controlled trials (RCT), which had full text available, were selected. The selected studies were either published in a journal of academic nature or were part of academic work such as a dissertation.

2.1.1 Background

Knowledge is limited on compression garment efficacy specifically in endurance runners. There are various possible theories based on past medical practice used in the treatment or prevention of deep vein thrombosis, reduction of swelling in soft tissue structures and oedema and the treatment of scars and wounds (Felty & Rooke, 2005). These medical theories have increased the use of compression garments in sport, Engel et al. (2016) theorised that there was reduced muscular microtrauma when utilising compression garments and Struhar, Kumstat & Kralova (2018) proposed reduced tissue vibration during exercise. Additional hypotheses focusing on neuromuscular aspects include a reduction of energy expenditure as a result of reduced muscle fibre recruitment, enhanced neuromechanics (i.e. reduced presynaptic inhibition) and improved coordinative function (Engel et al., 2016). Furthermore, new scientific research shows that external compression can be useful to minimise swelling and improve proprioception in an injured joint due to eccentric muscle damage models and DOMS (Kraemer et al., 2004). Kraemer et al. (2004) states that compression garments can decrease the swelling and inflammation that is associated with muscle damage. This is achieved by the external pressure gradient that is produced by compression garments which decreases the available space for swelling and this prevents secondary inflammation from occurring. This theory was further supported by Ali et al. (2007) who found that CK levels were reduced when a compression garment was used. MacRae et al. (2011) found that compression garments used in sport improved venous return, decreased venous pooling and increased metabolite removal as a result of the muscle pump action when compression garments were utilised. Other factors that are thought to improve metabolic waste removal include increased arterial inflow and lymphatic outflow. Despite all these positive benefits French et al. (2008) disputed all the positive findings and reported that compression garments had no positive benefits on CK levels, perceived muscle soreness, thigh circumference, and lactate concentration when comparing it to passive recovery practices. Despite the lack of scientific knowledge of the physiological and biomechanical effects of wearing compression garments, there has been an increase in the use of compression garments in endurance running to promote recovery and improve performance (Davies et al., 2009). The lack of evidence to support the use of compression garments to aid running performance necessitates good evidence-based research to support or refute the use of compression garments by runners.

Findings in literature

2.2 Endurance Running

2.2.1 Endurance Running and the Winelands Marathon

Endurance running has become more competitive worldwide and has led to increased popularity in recent years as a result of its easy accessibility, popularity of iconic races and the associated health benefits (Schattke et al., 2014; van Gent et al., 2007). In South Africa the number of finishers in the

Comrades Marathon (including both recreational and elite) increased from 640 in 1970 to 16482 in 2018 (Comrades marathon association, 2020).

One important race in the South African context is the Winelands Marathon 42.2-kilometre (km) event, hosted yearly in the Winelands region of Stellenbosch, Western Cape, during the month of November. The full marathon (42.2km) race began in 1977, and later the half marathon (21.1km) race was added (Havenga, 2020). The half marathon was added to get more runners to participate to increase income. The race has a hilly undulating profile, covering 42.2km on road and sand surfaces. There were 1510 participants who participated and finished the full marathon (42.2km) in 2019. This race is used as a qualifier for the Old Mutual Two Oceans Marathon (Cape Town) and Comrades Marathon (Durban) (Havenga, 2020).

2.2.2 Exercise-Induced Muscle Damage

2.2.2.1 Impact of EIMD on runners

Besides its positive health benefits such as reduced cardiovascular risk factors, endurance running can lead to acute and chronic neuromuscular injuries. The most common site of injuries in runners is the lower extremity (ankle-foot, shank and knee) (Francis et al., 2019). During a marathon, the lower extremity absorbs 1.5 to 3 times the runner body mass at every step and to complete a marathon, runners need to take about 30000 foot strikes. It has been found that the distance covered during marathon training, is believed to be one of the most important factors for developing muscle injuries in marathoners (Areces et al. 2015).

Endurance running race profiles are made up of a variety of different ascents, descents and flat sections, which are all evident in the Winelands Marathon. The descents have the greatest impact on the lower extremity, as it invokes a high proportion of eccentric muscle action on the muscle of the upper leg such as the Quadriceps muscle (Eston et al., 1995). Exercise with a high concentration of eccentric muscle action such as unaccustomed exercise and endurance running (marathons and half marathons) results in negative signs and symptoms associated with EIMD (Hill et al., 2014).

During eccentric muscle actions, the muscle will lengthen while under tension, which results in mechanical damage to the sarcomeres of the muscle internally. The damage is specifically seen in the Z-line streaming with associated ruptured myofilaments and sarcolemma. This is followed by a disruption of intramuscular calcium balance and membrane integrity (Howatson & van Someren, 2008). This mechanical damage will lead to an inflammatory response with invasion of neutrophils and macrophages, which exacerbates the degree of damage present (Hill et al., 2014). The inflammatory response is preceded by an initial degenerative phase, in which muscle fibre necrosis occurs and there is increased calcium concentration (Close et al., 2005). The inflammatory response and muscle damage are indicated by increased CK levels, IL-6 and post subsequent exercise, by higher myoglobin levels post exercise than prior to the eccentric damage (Armstrong et al., 2015; Clarkson & Hubal, 2002; Gleeson et al., 1998). In marathon running IIL-6 and CK levels are highly correlated. Furthermore, marathon running has been found to increase IL-6 levels by 100-fold (Armstrong et al., 2015).

There are various other physiological signs of EIMD which include: increased concentration of reactive oxygen species released with muscle contraction, increased levels of myoglobin, increased myosin heavy chain fragment concentration, increased lactate dehydrogenase, troponin and increased aspartate aminotransferase (Clarkson & Hubal, 2002; Close et al., 2005). There is, however, controversy regarding the use of these measures as markers of muscle damage. This is due to the nature of variation in production and clearance of these products in individuals (Clarkson & Hubal, 2002).

The physical signs and symptoms of EIMD are manifested in the form of temporary muscle strength reduction (occurs immediately and can last for 1-2 weeks post-exercise), reduced rate of force development (power), reduced range of motion of joints, swelling (peaks at 2 days post-exercise and can remain for up to 10 days post-exercise), increased passive muscle tension, increased perception of soreness and muscle pain such as DOMS (which peaks after 2-48 hours [hrs] and can last for a number of days) (Hill et al., 2014). The signs and symptoms of EIMD can last from a few days to a few weeks (Clarkson & Hubal, 2002).

Marcora and Bosio (2007) found that there was a decrease in running performance together with an increased rating of perceived exertion (RPE) in participants in endurance running races. Therefore, the harder the runners perceived the race, the poorer their running performance results. Other performance measures used in athletes that is affected negatively by EIMD include drop jump tests, squat jumps, and countermovement jump (CMJ) (Byrne et al., 2004; Byrne & Eston, 2002).

2.2.2.2 Gender and Age-related differences in exercise-induced muscle damage and running performance

There is contradictory literature regarding the effects of EIMD in males and females. Animal studies have shown differences in response to resistance and endurance eccentric orientated exercises. The differences have been attributed to the effects of estrogen on the skeletal muscle system (Clarkson &

Hubal, 2001; Tidus, 1994). Amelink and Bar (1986) found that female rats that have decreased estrogen levels had higher CK levels after exercise compared to female rats that had normal levels of estrogen. Bar et al. (1988) found that male rats treated with estradiol before exercise had reduced muscle damage indicators. Although both the above-mentioned studies have shown benefits in animals, there is controversy regarding CK as a pure indicator of muscle damage in humans (Clarkson & Hubal, 2001). In human studies by Webber et al. (1989) males had higher CK levels post downhill running for 30 min at 24 hrs but there were no differences between males and females in perceived muscle soreness. Sorichter et al. (2001) reported contrary results to Weber et al. (1989), their study found no significant difference between males and females in CK, myoglobin, myosin heavy chain or skeletal troponin (indicators of muscle damage) after a 20 minute (min) downhill running experiment. Although females may have lower CK levels, further research is needed to clarify if this attenuated level of CK is an indicator of reduced muscle damage.

Cheuvront et al. (2005) studied the gender differences in running performance and concluded that running performance differs between genders to a certain extent. Men have a greater running performance ability due to increased aerobic capacity and increased muscle strength. Furthermore, the menstruation cycle of females is thought to impact their running performance (Lebrun & McKenzie, 1995). Frankovich and Lebrun (2000) state that females' running performance is at its best following menstruation and at its worst in the days preceding menstruation and when contraceptive medication is used.

There tends to be a difference in muscle response to endurance exercise between adolescents and elderly athletes (Close et al., 2005). As athletes age, changes in muscle structure occur. These differences include a reduction of cross-sectional area and reduction of force production (Faulkner et al., 2007). Running performance deficits are seen from the age of 40 years in individuals (Faulkner et al., 2007). There are limited studies on humans in terms of time-course of EIMD but according to animal studies, EIMD time-course until recovery is longer in older animals compared to younger animals (Close et al., 2005).

2.2.2.3 Strategies to eliminate exercise-induced muscle damage

Strategies to eliminate signs and symptoms of EIMD have become more prominent (Harty et al., 2019). Furthermore, recovery procedures such as compression garments have been frequently implemented to try to improve the performance of athletes (Barnett, 2006). Recovery and athletic performance run concurrently. If an athlete’s recovery is improved, whether by use of compression garments, massage, stretching, gentle exercise, foam rolling, cryotherapy, electrotherapy, nutritional supplementation (protein, antioxidants, and β-Hydroxy-β-Methylbutyrate) and the use of nonsteroidal anti-inflammatories, it will lead to being able to train harder, and improve performance (Howatson & van Someren, 2008).

The above-mentioned recovery modalities have limited evidence for long-term usage and effectiveness and require further research. Nonsteroidal anti-inflammatories can help reduce pain in a short-term period but slows down the recovery process in the long term. Chronic nutritional supplementation (antioxidants) which includes creatine, omega-3 polyunsaturated fatty acids, and vitamin D3 has been shown to help recovery if taken for a long period of time (Harty et al., 2019). Massage and gentle exercise have been shown to reduce subjective perceived pain rating but there is limited knowledge on its benefits for performance (Howatson & van Someren, 2008). Baxter et al. (2017) investigated the impact of stretching on the performance of endurance runners and found that stretching had minimal or no effect on the occurrence of DOMS. Current evidence suggests that cryotherapy and electrotherapy have no use in the reduction of EIMD and require further research (Howatson & van Somersen, 2008).

The use of compression garments by endurance runner’s forms part of the recovery modalities referred to above and has gained popularity in recent years. Consequently, there is an increased interest in its efficacy for recovery and performance (Mizuno et al., 2016).

2.2.2.4 Strategies to improve performance

Continuous exercise with inadequate recovery will hamper athletic performance. Therefore, the current belief is that to improve performance EIMD signs and symptoms need to be reduced prior to resumption of athletic competition or training.

Although this review will focus on the use of compression garments to improve performance, it will delve into various other methods too. There are various aids to improve performance apart from compression garments, some of the methods are legal while others are illegal. According to Juhn (2002) these methods include the use of caffeine, antioxidants, nutritional supplementation, stretching and carbohydrate intake. It has been stated that oral antioxidant supplementation has no added benefit to athletic performance (endurance and muscle strength). Furthermore, it has been found that nutritional supplementation (amino acids and proteins) also has no added athletic benefits (Juhn, 2003). Caffeine is used as an athletic performance aid in sports like cycling, but no added benefits have been found in runners (Juhn, 2002). There are various other methods to improve performance, but they have major side effects when ingested. Ephedrine, Pseudoephedrine and Erythropoietin have been found to increase the risk of cardiovascular diseases (Juhn, 2003). Carbohydrate ingestion has been found to aid performance in endurance runners. There were performance benefits found for running events that lasted more than two hours. Furthermore, it was found that consuming carbohydrate beverages above ad libitum levels would increase the effects of gastrointestinal discomfort and also hamper your performance (Wilson, 2016). Interestingly in participants running events between 16-21 km no benefit to performance was found when ingesting carbohydrate gels. In addition, performance benefits have been reported if multiple saccharides are ingested at a rate of more than 1.3 Carbohydrate oxidation rate ($g \cdot min^{-1}$) for running events that last more than two hours (Wilson, 2016).

2.2.2.5 Summary of literature on endurance running and exercise-induced muscle damage

The increased participation in endurance running has brought to our attention the negative effects of EIMD despite the benefits of running (Schattke et al., 2014). The most common recovery methods prior to the increased use of compression garments include massage, stretching, gentle exercise, foam rolling, cryotherapy, electrotherapy, nutritional supplementation (protein, antioxidants, and β-Hydroxy-β-Methylbutyrate) and nonsteroidal anti-inflammatories (Howatson & Somersen, 2008). Athletes have turned to the use of compression garments in pursuit of improved performance and reduced recovery time; despite there being a lack of research on its effectiveness. In the following chapters the use of compression garments on recovery and performance will be assessed.

2.3 Lower limb compression garments in running

The use of compression garments in sport remains controversial. There is a varying amount of research on the effects of compression garments on performance and recovery. Recovery is defined as a mixed (physiological and psychological) restoring process that is impacted by time and is affected by internal or external factors (Kellmann et al., 2018). Recovery is further broken down into active, proactive and passive modalities. Active recovery (walking or jogging) encompasses physical activity that aims to reduce the metabolic responses of physical fatigue. Proactive recovery (social activities) is the ability of an individual to self-select activities that address their individual needs and preferences. Passive recovery involves no activity (sleep) or an application of an external modality (massage) (Kellman et al., 2018). Performance is described as the achievement of goals by meeting or exceeding set benchmark standards. Furthermore, it is impacted by psychological (motivation and concentration) and physiological (endurance, speed or strength) factors (Kellman et al., 2018).

The heterogeneity amongst different studies, the different types, duration and intensity of exercises, the outcome measures used to determine performance and recovery, the variability of training status of participants in studies, the variability in timing, type, duration and pressure applied by the compression garments all contribute to the literature being inconclusive (MacRae et al., 2011). There is evidence that the use of compression garments in the recovery process may assist with reduction of DOMS and perception of pain (Engel et al., 2016; Marqués-Jiménez et al., 2016; Beliard et al., 2015; MacRae et al., 2011). Table 2.1 provides a summary of all the RCT utilised in this review.

2.3.1 Effect of lower limb compression garments while running

Eight RCTs were assessed to determine the effect of lower limb compression garments of the thigh or the full length of the leg. Both types were worn during exercise and the outcomes showed varied results which are included in the review. The majority of these studies were able to identify some significant differences or enhancements on various measured outcomes (Mizuno et al., 2017; Venckunas et al., 2014; Miyamoto & Kawakami, 2014; Rugg & Sternlicht, 2013; Goh et al., 2011; Dascombe et al., 2011; Bringard et al., 2006). One study found no significant difference (Barwood et al., 2013). Of the nine studies, only two studies by Miyamoto et al. (2014) and Bringard et al. (2006) used upper leg compression garment shorts covering the thighs, while the other studies used full-length compression garments starting at the waist to the ankle.

The use of compression garments while running has been linked with significant (p=0.05) improvements in RPE in some studies but not all (Rugg et al., 2013; Goh et al., 2011). No significant differences were found in RPE, for example, when comparing compression garments to a control by Barwood et al. (2013) who compared correctly sized compression garments and undersized compression garments to a control of no compression garments in eight recreationally active men. No significant changes in RPE were found in all three groups after participants ran for 35min on a treadmill at different speeds followed by a 5km time-trial. Furthermore, Bringard et al. (2006), who investigated upper leg compression garments compared to a control group in twelve trained male runners, found no significant difference in RPE after participants performed a maximal voluntary running protocol and constant running exercise at 80% of maximal oxygen uptake (VO_2max). Venckunas et al. (2014) found no significant difference between a group wearing compression garments and a control group after a 4km run followed by a 400m sprint in thirteen non-athletic females. Thus, there is a definite lack of consensus regarding the effect of compression garments on RPE. Although these protocols found no significant benefits, it can be stated that these protocols are not of sufficient length compared to endurance running events which include full and half marathons.

In terms of running performance measures, there were also differing results found. Barwood et al. (2013) found no significant difference in a 5km time-trial performance between all three groups of oversized and correctly sized compression garments to a control of no compression garments in eight recreationally trained men. Similarly, Venckunas et al. (2014) found no significant difference in a 4km time-trial performance between a compression garment group and a control group of non-athletic females. Likewise, there were no significant endurance performance benefits in eleven well-trained middle-distance runners and triathletes wearing compression garments in a time-to-exhaustion and a progressive maximal test when comparing compression garments to a control (Dascombe et al., 2011). Despite the lack of performance benefits in the above-mentioned studies, Bringard et al. (2006) who investigated upper leg compression garments and classic elastic tights compared to a control group found that energy cost was significantly lower at a speed of 12km/h for the upper leg compression garments and classic elastic tights groups. A significantly lower VO_2 slow component was present in the upper leg compression garment group compared to the classic elastic tights and control group. These findings suggest that there is an improvement in the running economy when utilising upper leg compression garments.

Muscle power in the studies by Mizuno et al. (2017); Rugg et al. (2013) were measured by performing a CMJ test. Mizuno et al. (2017) found that CMJ height was significantly ($p=0.05$) improved when wearing a medium compression garment shorts of 15 millimetres of mercury (mmHg) compared to wearing a compression garment with high or low pressure in a group of eight healthy but not well-trained males. In addition, Rugg et al. (2013) found the average post-run CMJ height was significantly increased ($p = 0.05$) in the compression garment group than both the pre-run group with compression garments and post-run group without compression garments in fourteen competitive runners. The results of the studies support Engel et al. (2016) hypothesis of enhanced neuromechanics (i.e. reduced presynaptic inhibition) and improved coordinative function.

Heat strain in prolonged exercise has been identified with increased cardiovascular strain associated with exercise, reduced ambition to exercise, alteration to muscle and hepatic blood flow, increased use of muscle glycogen and reduced performance times in untrained athletes who have not acclimatized to increased temperature levels and are poorly hydrated (González-Alonso et al., 2008; Sawka et al., 1993). It has been found that it is important to try to minimise heat storage during exercise to improve performance. Compression garments are seen as a barrier to heat loss, as it creates insulation on the surface area it covers (Barwood et al., 2013). Therefore, it is important to find out the impact of compression garments on performance. The literature on skin temperature varies and is inconclusive. The main purpose of thermoregulation of the body is to sustain homeostasis by maintaining core body temperatures within safe limits during exercise and at rest (Lim et al., 2008). When hyperthermia occurs, there is a reduction in activation of muscle motor units by the brain and increased sensation of fatigue resulting in exercise performance being severely impacted (Levels et al., 2012). Hyperthermia can occur as compression garments act as a restraint to heat dissipation (Levels et al., 2012). Goh et al. (2011) refuted this claim and found no difference in rectal temperature in a group of ten recreational male runners. Furthermore, no significant differences were found in sweat production, thermal sensation and thermal comfort sensitivity in the thigh and calf muscles insulated by compression garments (Barwood et al., 2013; Bringard et al., 2006). Contrary to these findings some studies found a significant ($p=0.05$) increase in skin temperature under the compression garments in the thigh and calf muscles when wearing compression garments compared to controls not wearing compression garments in a sample of non-athletic females and recreational male runners (Venckunas et al., 2014; Goh et al., 2011). Ultimately compression garments can be worn in hot temperatures without negatively or positively affecting the performance of runners with respect to temperature regulation (Barwoord et al., 2013; Goh et al., 2011).

There is a lack of consensus on physiological parameters such as oxygenation, haemoglobin, oxygen consumption, blood flow and HR in response to the wearing of compression garments. In contrast, Dascombe et al. (2011) found that in a sample of eleven well trained middle-distance runners and triathletes, there were significant increases ($p=0.05$) in oxygen consumption, oxygen pulse and deoxyhemoglobin. Furthermore, there was a decreased running economy, oxyhemoglobin and tissue oxygenation index when running at lower speeds in a maximal test in the compression garment group compared to a control group; at higher speeds it was found that there was an increase in blood flow, decreased HR and a decrease in tissue oxygenation while wearing compression garments. These parameters assist with blood flow through the body to respective damaged muscles. For the time-to-exhaustion test Dascombe et al. (2011) found that deoxyhemoglobin and regional blood flow increased significantly ($p=0.05$) while wearing compression garments compared to a control. With respect to heart rate (HR) measures Dascombe et al. (2011) found that HR decreased at higher speeds when wearing compression garments compared to a control group. Mizuno et al. (2017) found that HR decreased while wearing compression garments (>15mmHg) compared to a control of low pressure (<5mmHg) in a sample of eight healthy but not trained males. However, Venckunas et al. (2014) found no significant difference in HR. Furthermore, no significant difference in blood pressure. Based on these contrary findings, it is evident that the efficacy of compression garments has not been proven to impact the cardiorespiratory system in terms of performance. Furthermore, the findings do not support Engel et al. (2016) hypothesis of energy reduction with the use of compression garments.

Metabolic parameters such as lactate concentration were not affected while using compression garments in eleven well-trained middle-distance runners and triathletes (Dascombe et al., 2011). Plasma IL-6 was found to be significantly lower in the medium (15mmHg) compression garment group compared to the high (30mmHg) compression garment group and control group (<5mmHg) in eight healthy but untrained males (Mizuno et al., 2017). This indicates that medium compression garments support MacRae et al. (2011) hypothesis that compression garments may reduce the inflammatory response to exercise and influence blood markers.

Miyamoto et al. (2014) studied various upper leg compression garments with different pressure levels in twenty-two healthy young males performing submaximal running and found that medium pressured lower limb compression garments (15mmHg) had significantly (p=0.05) smaller changes in Magnetic Resonance Imaging (MRI) in terms of EIMD muscle structure changes through T2 signal intensity. This study favours the use of medium pressure upper leg compression garments to limit EIMD influenced changes in the muscles. The results support the hypotheses of a reduced muscle vibrations with the use of compression garments (Struhar et al., 2018).

The above-mentioned studies have used different outcome measures to investigate the efficacy of the use of compression garments in runners. The overall impact of compression garments is inconclusive despite some positive significant improvements. The lack of conclusive findings is a result of poor quality of the respective studies.

2.3.2 Effect of lower limb compression garment for recovery post-race

One RCT by Hill et al. (2014) was identified and this study used compression garments in the recovery phase after a marathon and during the marathon. Twenty-four recreational runners (seventeen males and seven females) took part in the study. Participants either wore full-length compression garment from the waist to ankle or were placed in the placebo ultrasound group for 72 hrs after completing a self-paced marathon (26.2miles) and their blood samples and subjective ratings of muscle soreness were taken at 24, 48 and 72hrs. This study found a significant (p=0.05) decrease in muscle soreness at 24hrs after the marathon in the compression garment group compared to the control group but no significant difference at 48 and 72 hrs between the groups. No significant differences were found in the maximal voluntary contraction of the knee extensors (Quadriceps) and blood markers: CK and C-reactive proteins. In this study, no objective measures improved which includes muscle strength and factors of inflammation and EIMD; the subjective outcome measures were improved for the first 24hrs only. This is an indication that compression garments likely have no valuable benefit after 24hrs in terms of muscle soreness and further research is needed for the objective markers of EIMD.

2.3.3 Study limitations

There are several limitations found in the studies included in this review. One major problem, gender exclusion in the studies, with many of the studies only including male participants (Mizuno et al., 2017; Miyamoto et al., 2014; Barwood et al., 2013; Bringard et al., 2006; Goh et al., 2011; Dascombe et al., 2011). Only two studies included both males and females (Hill et al., 2014; Rugg et al., 2013) and one only included females (Venckunas et al., 2014). This discrepancy between both genders calls for future research to include both genders equally. This will improve the quality of the studies. It is important to include both genders as female performance is impacted negatively by the menstruation cycle (days preceding a marathon) and the use of contraceptive medication (Frankovich & Lebrun, 2000).

There were limited studies, namely two, that specifically investigated upper leg compression garments of the thigh (Miyamoto et al., 2014; Bringard et al., 2006). While most investigated full-length compression garments from the waist to ankle. This can be a confounding factor as there is a lack of uniformity in the studies.

The sample size was a limitation in the studies, as they were relatively small. With a small sample size, it is hard to make broad inferences about the general running public. This was further emphasised by the studies not taking random samples from the population they were investigating. The lack of randomisation and convenience sampling reduces the internal and external validity and power of the study. This is a problem because there may be pre-existing differences when comparing the study samples to the general population.

Blinding was a concerning factor in the studies. Due to the practical nature of the studies this made it hard to double-blind the participants and researchers in the studies. Hill et al. (2014) used a different intervention (ultrasound) to the compression garment, this would further limit blinding as the participants would have preconceived ideas. The introduction of bias compromises the internal validity of the study's results.

Another limitation in the studies were the different pressures used in the studies and lack of uniformity between the studies. Furthermore, some studies did not measure the pressure of the compression garments used (Bringard et al., 2006).

Furthermore, the lack of studies investigating the impact of compression garments on performance and recovery in marathon running is a limitation in the current literature.

Overall, the studies used various outcome measures, compression garments, and type of athlete groups, therefore, making it hard to be able to compare results between studies. There is a discrepancy in the impact of compression garments on performance and recovery, so we are unable to form true conclusions from the studies.

2.3.4 Summary of lower limb compression garments in running

The use of compression garments by runners remains a controversial issue as there is a wide variety of findings in studies, with often contrasting results. There is poor literature and results on objective outcome measures of performance (time-trial tests, time to exhaustion test, progressive maximal tests and muscle strength tests), cardiorespiratory markers (temperature) and physiological markers (oxygenation, haemoglobin levels, blood flow, HR and oxygen consumption) (Venckunas et al., 2014; Barwood et al., 2013; Goh et al., 2011; Dascombe et al., 2011). Many studies found no positive effects on these outcome measures. If positive findings were found, they were disputed by studies reporting contrasting results. Based on the findings of the studies there is some evidence that medium pressure lower limb (upper leg) compression garments measured at 15mmHg have the best effects, but the evidence is of a poor standard and further investigations are needed (Mizuno et al., 2017; Miyamoto et al., 2014). There are various limitations found in the studies included in this review that impacted the internal and external validity of the studies and the power of the studies.

Table 2.1: Lower limb compression garments in running

Article	Study Design	Description of sample	Type of compression garments	Compression garment usage	Study protocol	Main findings	Additional information
Barwood et al. 2013	Repeated-measure RCT design. Oversized compression garments were compared to a correctly sized compression garment and a control group wearing running shorts. Participants were their own control in the study.	Eight recreationally active men.	Full length (waist to ankle) compression garments "correctly sized". The pressure was measured at 20mmHg at the calf and 11mmHg at the thigh. Full length (waist to ankle) compression garments "oversized". The pressure was measured at 10mmHg at the calf and 17mmHg at the thigh.	Compression garments were worn during the exercise.	Participants completed a 15 min treadmill running test at 35°C at a speed between 10–12 km/h, then had a 5 min rest followed by a 5km time-trial. RPE, thermal comfort and the thermal sensation were measured.	No significant differences were found in the 5km time-trial, RPE, sweat production and thermal sensation between all three groups	Compression garments did not enhance their performance in the hot temperatures.

Bringard et al. 2006	Repeated measures RCT design. Compared upper leg compression garments to classic elastic tights and a control group wearing conventional shorts. Participants were their own control in the study.	Part 1: 6 trained male runners. Part 2: 6 trained male runners.	Upper leg compression tights compared to classic elastic tights and conventional shorts (Pressure was not measured).	Upper leg compression garments were worn during the exercise.	Part 1: Participants took part in an incremental exercise test to voluntary exhaustion. The initial speed started at 10km/h and was increased by 2km/h for each stage, each staged lasted 3 min long and testing was done on 3 different days. Part 2: Participants performed a constant running exercise test at 80% of VO_2max for 15 min on three different days.	Part 1: At 12km/h there was a significantly lower energy cost when wearing upper leg compression garments and classic elastic tights compared to the control group. Part 2: There was a significantly lower VO_2 slow component in the upper leg compression garment group compared to classic elastic tight and control group. There were no significant differences in sweating, thermal and comfort sensations; or RPE between all three trials in both part 1 and 2.	No notable improvements in running economy measures were found.

					RPE and blood gases were also measured.	
Dascombe et al. 2011	Randomized crossover design (RCT). Compared “regular sized” compression garments and “undersized” compression garments to a control group not wearing compression garments. Participants were their own controls in the study.	11 well trained male middle-distance runners and triathletes.	Unisex full-length compression garments (waist to ankle). Undersized compression garments were measured at 15.9mmHg ±2.6 at the thigh and 21.7mmHg ±4.3 at the calf; Regular sized compression garments were measured at 13.7mmHg ± 2.3 at thigh and	Compression garments were worn during the exercise.	Participants performed a progressive maximal test and time-to-exhaustion test on a treadmill in each different compression garment and without the compression garments.	Progressive maximal test: at the lower speed there was a significantly increased oxygen consumption, oxygen pulse and decreased running economy, oxyhemoglobin and tissue oxygenation index in the compression garment trial compared to the control trial. At the higher speed, there was a significantly increased local blood flow and decreased HR and tissue oxygenation index in the compression garment trial compared to control trials. Time-to-exhaustion tests: there was a significantly increased deoxyhemoglobin concentration found in both compression trials. The

			19.2mHg ±3.2 at the calf.			undersized compression garment was found to increase regional blood flow significantly. There was no significant differences reported in endurance performance; VO_2max or lactate threshold.	
Goh et al. 2011	RCT. Compression garments compared to a control group. Participants were their own control in the study.	10 Recreational male runners.	Full-length compression tights (waist to ankle). The pressure measured at the calf was 13.6 mmHg ± 3.4 at and at the thigh 8.6 mmHg ± 1.9.	Compression garments were worn during the exercise.	Participants performed 4 sets of 20 min treadmill running with the compression garments and without the compression garments at a temperature of 10°C and 32°C.	Skin temperature in the lower body was 1.5°C higher at 10°C with the compression garments compared to control trials. RPE was found to be significantly decreased during submaximal running at 32°C with the compression garments compared with control trials. There were no significant differences found in all various other physiological outcomes, and rectal temperatures.	Compression garments can be worn in the hot temperatures without side effects.

Hill et al. 2014	RCT. Compression garments were compared to placebo ultrasound group.	24 Recreational runners (17 males and 7 females).	Full length compression garments. The pressure was measured to be 9.9 mmHg at thigh and 19.3mmHg at the calf.	Compression was used in the recovery phase for 72hrs.	Following completion of a self-paced marathon (26.6 miles/42.2km), the participants blood markers and subjective ratings were taken at 24hrs, 48hrs, and 72hrs.	Muscle soreness was significantly reduced at 24hrs in the compression garment group compared to the control group. There were no significant differences in the found in the groups' maximal isometric contraction of the knee extensors and the blood markers: CK and C-reactive proteins.	No objective outcome measure improved; only subjective outcome measures improved significantly.
Miyamoto et al. 2014	RCT. Part 1: Compared low and medium pressure upper leg compression garments to control group.	Part 1: 11 healthy young males. Part 2: 11 healthy young males.	Part 1: Low pressure upper leg compression garments pressure was measured at 8mmHg and medium upper leg compression	Upper leg compression garments were worn during the exercise.	Part 1: Participants performed a submaximal treadmill running protocol for 34.5 min at 6–12 km/h. Before and after the running	Part 1: MRI changes in the muscle was significantly smaller in the medium-pressure upper leg compression garments group compared to control group. Part 2: MRI changes were significantly lower in the medium-high upper leg	The ideal upper leg compression garment is 15mmHg which can prevent fatigue of exercising

	Part 2: Compared medium-high- and high-pressured upper leg compression garments to control group.		garments was measured at 15mmHg. Part 2: Medium-high upper leg compression garments measured at 20mmHg and high upper leg compression garment were measured at 25mmHg.		protocol a MRI from the right thigh was taken and RPE. Part 2: Participants performed a submaximal treadmill running protocol for 34.5 min at 6–12 km/h. Before and after the running protocol a MRI from the right thigh was taken and RPE.	compression garments group compared to the control group and the high-pressured lower limb compression garments.	muscles during submaximal running exercises in healthy adult males.
Mizuno et al. 2017	RCT. Compared high, medium and low pressure (control) compression garments.	8 healthy but not well-trained males.	Full-length compression garments (waist to ankle). Low pressure compression was measured at <5 mmHg. Medium pressure compression	Compression garments were worn during the exercise.	Three testing trials. Participants performed a 120 min of uphill running (gradient: 7%) on a treadmill at 60% of VO_2max while wearing one of three different types of	CMJ height was significantly higher (p=0.05) in the medium pressure compression trial in comparison to the high-pressure compression trial. Average HR was significantly lower in the medium pressure compression trial compared to the control trial. Plasma IL-6 was significantly (p=0.05) lower in the medium pressure	The inflammatory response was significantly smaller with compression garments of medium pressure equalling 15mmHg than

			was measured at 15mmHg. High pressure compression was measured at 30mmHg.		compression garments. At each trial the muscle power, RPE, HR and blood samples were measured.	compression trial compared to the control trial of low-pressure compression garments.	that with garment exerted < 5 mmHg.
Rugg et al. 2013	RCT Compression garments compared to control group wearing loose fitting shorts. Participants were their own control in the study	14 competitive runners (8 males and 6 females).	Full length (waist to ankle). C3fit graduated compression garments. The pressure was measured 18.0 mmHg at the ankle, 12.6mmHg at the calf and 7.2mmHg at the thigh.	Compression garments were worn during the exercise.	Each trial consisted of 15 min of continuous running with 5 min performed at each of the following intensities: 50%, 70% and 85% of the participants' max HR. Each participant performed 3 CMJ, both before and after the running trials. Participants RPE were also measured	The average post run CMJ height was significantly increased (p=0.05) in the compression garment group than both the pre-run with compression garments and post run with no compression garments. The participants RPE were significantly increased (p=0.05) after their run without compression garments compared with the run wearing the compression garments.	The main finding supports the use of compression garments for the maintenance of lower limb muscle power after submaximal endurance running.

Venckunas et al. 2014	Cross over design (RCT). Compared compression garment breeches to control loose fit breeches. Participants were their own controls.	13 non-athletic females.	Full-length compression garments were measured at 17mmHg at the calf and 18mmHg at the thigh.	Compression garments were worn during the exercise.	Participants ran 20 x 200m totalling 4km in an indoor track for 30 min and after had to perform a 400m sprint.	Running performance between the two trials had no significant differences. No significant differences were found in HR and blood pressure between the groups. No significant changes in RPE between the two trials. There was a significant increase in the temperature of the skin in the compression garment trial compared to control.	There were no clear differences in physiology or performance.

%= percentage
°C= degree Celsius
CK= Creatinine kinase
CMJ= counter movement jump
HR= heart rate
hrs= hours
km= kilometre
km/h= kilometre per hour
m= metres
mmHg= millimetre of mercury
min= minutes
MRI= Magnetic resonance imaging
RCT= Randomised control trial
RPE= rating of perceived exertion
VO_2max= maximal oxygen uptake

2.4 Lower Limb compression garments in other sport

Although this section is not specific to running, research results in other sports might provide insights into the efficacy of compression garments that might apply to runners.

2.4.1 Effect of lower limb compression garments while performing in other sports

Eight RCTs were identified for inclusion in this section of the review and assessed the effect of lower limb compression garments of the thigh specifically or the full-length of the leg that was worn during various sports (other than running) on a variety of outcome measures. Out of the eight studies included, only three studies looked at upper leg compression garments of the thigh muscle specifically (Doan et al., 2003; Kraemer et al., 1998; Kraemer et al., 1996). Four studies showed no significant differences (Gupta et al., 2015; Duffield et al., 2010; Scanlan et al., 2008; Kraemer et al., 1998). The remaining four studies found significant differences with the use of compression garments (Ravier et al., 2018; Duffield et al., 2008; Doan et al., 2003; Kramer et al., 1996).

Ravier et al. (2018) found no significant differences in muscle soreness after 24hrs in eighteen professional male handball players when wearing compression garments compared to the controls. This finding was further emphasised by Duffield et al. (2008) who found no difference in muscle soreness following an 80-min high-intensity exercise circuit when comparing the compression garments group to a control group in fourteen club-standard under twenty-one male rugby players. The other studies did not measure subjective measures in their protocols. These findings do not support the use of compression garments in terms of subjective measures, as no positive benefits were found in terms of muscle soreness.

Contrary results were found in terms of performance measures in other sports. Scanlan et al. (2008) found no significant differences between the compression garment group and the control group in time-trial performance in twelve well-trained cyclists. Doan et al. (2003) found a significant ($p=0.04$) improvement in hip flexion range of motion but this did not translate in improved running performance in ten male track athletes. The findings of both studies suggest that there are no performance benefits when wearing compression garments. Although cycling is different to running as there is no eccentric muscle action occurring. Therefore, only conservative inferences can be made based on these results on cycling

The findings on muscle power are inconclusive and require further investigation. Kraemer et al. (1996) found a significant ($p=0.05$) increase in average force and power production when comparing upper leg compression garments to controls in thirty-six college volleyball players (Eighteen males and eighteen females) when completing 10 CMJs, although this benefit did not result in improved maximum CMJ height. Ravier et al. (2018) also found no significant difference in jump height but found a significant ($p=0.001$) improvement in a maximal voluntary contraction of the knee extensors in eighteen professional male handball players when wearing compression garments. In addition, Kraemer et al. (1998) found no significant differences in knee flexion and extension peak power in 20 healthy, active males and females. Furthermore, Duffield et al. (2008) found no significant difference in peak power performance for a single-man scrum between both trials in a sample of twenty-one male rugby players. The results suggest that compression garments in other sport similar to running will not enhance muscle power.

Regarding temperature objective measures, two studies found increases in skin temperature under the compression garments while wearing compression garments compared to controls wearing no compression garments, but these increases had no adverse effects on the male rugby players and track athletes in terms of their performance (Duffield et al., 2008; Doan et al., 2003).

All eight of the studies included in this review found no significant difference in physiological, metabolic and cardiorespiratory markers such as CK, lactate, VO_2 Max, HR and muscle oxygenation (Ravier et al., 2018; Gupta et al., 2015; Dufflied et al., 2010; Scanlan et al., 2008; Duffield et al., 2008; Doan et al., 2003; Kraemer et al., 1998; Kraemer et al., 1996). The results are similar to the findings found in the running section as no benefits to metabolic and cardiorespiratory systems when wearing compression garments.

2.4.2 Effect of lower limb compression garments recovery in other sports

Five studies were identified and included in this section of the review focusing on the use of compression garments in the recovery phase in the following sports: rugby, netball and soccer (Duffield et al., 2010; Davies et al., 2009; Duffield et al., 2008; French et al., 2008; Gill et al., 2006). Three studies found no significant differences secondary to compression garment usage (Davies et al., 2009; French et al., 2008; Gill et al., 2006). No study specifically investigated upper leg compression garments of the thigh but rather full-length (waist to ankle) compression garments.

No significant differences in CK levels were found in four studies (Duffield et al., 2010; Davies et al., 2009; French et al., 2008; Duffield et al., 2008; Gill et al., 2006). This result indicates that blood markers are not affected by compression garments usage. Other measures to have no differences include CMJ height, sprinting speed, back squat strength and mid-thigh girth. The lack of difference is a sign that compression garment does not impact physiological markers of EIMD or performance measures.

No consensus has been found on muscle soreness, however two studies found significant differences in muscle soreness at 24hrs and 48hr respectively in moderately trained and under twenty-one male rugby players (Duffield et al., 2010; Duffield et al., 2008). Despite the benefit seen in the first 48hrs, the remaining three studies found no significant differences in muscle soreness in recreational, regional and elite male rugby and soccer players (Davies et al., 2009; French et al., 2008; Gill et al., 2006).

The only improvements found in favour of wearing compression garments is reduced muscle soreness although there are contrary findings in the literature and the results are similar to recovery in running.

2.4.3 Study limitations

The study limitations related to compression garments in other sports are similar to the study limitations mentioned in section 2.3.3. The limitations include gender discrepancy in studies, small sample sizes, lack of double blinding due to practical implications, different pressures of the compression garments, lack of randomisation, introduction of bias, limited studies looking specifically at compression shorts and various outcome measures used.

2.4.4 Summary of lower limb compression garments in other sports

As seen in running, compression garments are also popular in other sports although the literature is inconclusive. The only subjective measure found to improve with the use of compression was muscle soreness in the recovery phase, although there are contrary findings (Duffield et al., 2010; Duffield et al., 2008). This suggests compression garments, if utilised, should be worn after exercise. No performance benefits were found with compression garment utilization. Further research is needed to rectify the inconclusive findings.

2.5. Instrumentation

2.5.1 Instrumentation measuring perceived exercise-induced muscle damage

2.5.1.1 Subjective outcome measures

2.5.1.1.1 Visual Analogue Scale

The VAS questionnaire is a popular subjective pain rating scale which measures pain intensity. According to Gatchel et al. (2007) pain and VAS is affected by biopsychosocial factors, as it is a subjective feeling and rating. The pain rating scale is from 0-10. “0” represents no pain and “10” represents the worst imaginable pain; the scale is measured in millimetres (mm); “0” representing 0 mm and “10” representing 100mm. Participants of the test are required to mark a point on the line that best describes the perception of their current pain. (Hawker et al., 2011).

The numerical version of the VAS has high validity and reliability in chronic pain patients (McCormack et al., 1988; Downie et al., 1978). Regarding acute pain, it has been found to have high validity and reliability (Bijur et al., 2001). There is currently no gold standard pain measure, so in its absence the criterion validity for pain has not been evaluated. The construct validity has been evaluated in the numerical version of the VAS and it ranges between 0.71 and 0.91 (Hawker et al., 2011).

2.5.1.1.2 Likert Scale

According to Lozano et al. (2008), a Likert scale is a self-report ordinal measure, which is a point-based questionnaire. Typically, the scale ranges from 4 – 7 questions (this is the ideal number of questions). The response categories of the participants have a rank order (Jamieson, 2004). The validity and reliability of the Likert scale increases as the number of questions increases in the questionnaire (Lozano et al., 2008). The Likert scale has been found to be valid in measuring subjective outcomes in patients with lower back pain. It was also further emphasized that the Likert scale is easier to administer than the VAS scale (Harland et al., 2015). Bolognese et al. (2003) studied the correlation between the Likert scale and VAS of patients with osteoarthritis associated knee pain and found that there is a good correlation between both scales in this group.

The Likert scale is utilized for data collection purposes in research and used for various other domains in research such as pain, quality of life and stress (Köksal et al., 2014; Hartley & MacLean, 2006). Hartley et al. (2006) state that this self-report measure enables researchers to delve into their participant's subjective perspectives, behaviours, and mental attitudes.

2.5.1.2 Anthropometric measures

2.5.1.2.1 Circumference measurements

According to Geldenhuys et al. (2019), circumferential measurements in research have generally been used to measure the accumulation of swelling in soft tissue structures and oedema.

One commonly used method for circumference measurements is using a tape measure, as it is a cheap, efficient and rapid method. Furthermore, it has a high validity, for the measurement of upper limb circumference (Taylor et al., 2006). Marcora and Bosio (2007) used mid-thigh circumference as a measure of swelling associated with EIMD. The inter-rater and intra-rater reliability of using a tape measure to measure thigh circumference is high. According to O'Sullivan et al. (2009), the intra-rater reliability is 0.99 and inter-rater reliability is 0.99 when measuring the mid-thigh circumference. This was further emphasised by Gross et al. (1989) that found intra-rater reliability of 0.99 and inter-rater reliability of 0.92. The intra-rater and inter-rater reliability are 0.99 when measuring 10 centimetres above the knee (O'Sullivan et al., 2009).

2.5.1.3 Alternative measures for exercise-induced muscle damage

There are various alternative measures that are used to measure EIMD. The first measure that has been prominently used is radiographic imaging. MRI's, ultrasound and Computed Tomography (CT) are reliable measures for radiographic imaging (Yu et al., 2015; Dupont et al., 2001; Walton et al., 1997). Radiographic imaging for EIMD can be used to define the pennation angle and muscle thickness of muscles. The angle formed between the aponeurosis and fascicles of the muscle is defined as the pennation angle (Raj et al., 2012). The pennation angle is an indicator of muscle damage when DOMS is induced. The pennation angle increases for a period of 48hrs; after this period has lapsed it returns to its normal angle.

Endurance runners have been found to have a greater pennation angle of 24 degrees in the Vastus Lateralis of the Quadricep muscle compared to sprinters (19 degrees) (Abe et al., 2000). With the presence of EIMD, there is a subsequent increase in pennation angles and decrease in force production and muscle strength (Kawakami et al., 1993). The mechanism that causes this change has not been defined (Yu et al., 2015). Muscle thickness is defined by the distance between the two aponeuroses of the muscle. It is theorised that the greater the muscle thickness the more muscle strength and force production (Raj et al., 2012; Pillen et al., 2008). Endurance runners have been found to have a reduced muscle thickness of 2.47cms in the Vastus Lateralis muscle compared to sprinters as a result of sprinters needing greater running speed (Abe et al., 2000). With the presence of EIMD, there is a subsequent increase in muscle thickness. However, the increase in muscle thickness has been found to be a result of swelling (Yu et al., 2015). Both pennation angle and muscle are most affected in the first 48hrs post exercise as a result of EIMD, in which symptoms peak between 24 and 48hrs post exercise (Yu et al., 2015). Both pennation angle and muscle thickness return to their normal levels after 72hrs. Therefore, the change in pennation angle and muscle thickness should be monitored at 48hrs post exercise before the changes disappear.

The second measure used to measure EIMD is blood testing (Brancaccio et al., 2010). Apart from CK blood testing, there are various other blood testing that are utilised that includes protein, cytokines and muscle enzyme testing (Brancaccio et al., 2010). The above-mentioned testing is very expensive to administer in studies and therefore, is not generally used.

2.5.1.4 Perceived exercise-induced muscle soreness measures summary

Subjective pain measuring scores such as a Likert scale and VAS questionnaire are commonly used as they are cheap, quick, valid and reliable but pain is a subjective matter as everyone has a different pain perspective. Circumferential measurements are a reliable source for the measurement of swelling and oedema which are indicators of muscle damage. There are various other expensive tools used in the literature to measure EIDM which include blood markers and radiology. Radiology has been found to be reliable, while the use of blood markers still lacks conclusive evidence.

2.5.2 Instrumentation for running performance

2.5.2.1 Time-trials and time-to-exhaustion test

The most common type of running performance measurement is a time-to-exhaustion test or time-trial and they are commonly done in a laboratory (Amann et al., 2008). These two running performance tests have generally been used in athletes participating in endurance sports such as running and cycling (Amann et al., 2008; Nummela et al., 2008; Marcora et al., 2007). A time-trial is described as a test where a set amount of work is performed as quickly as possible or where as much work as possible is done in a set period (Amann et al., 2008). A time-to-exhaustion test is described as a test where a constant intensity is set until fatigue is reached and is commonly used as a test in runners and cyclists (Laursen et al., 2007). Time-to-exhaustion tests have a large error of measurement (10-30%) and this measurement error hides small percentage change in endurance performance. In contrast a time-trial test has a smaller error of measurement (1-3%) (Amann et al., 2008). There are various factors such as hypoxia, hyperoxia, ambient temperature, caffeine intake, respiratory muscle training, and prior high-intensity training that impacts time-to-exhaustion and time-trials. Furthermore, it has been found that the above-mentioned factors impact time-to-exhaustion more negatively and this indicates that time-trials are a better fit test as there is a less chance of change due to other factors and better validity (Amann et al., 2008; Currell & Jeukendrup, 2008). This is attributed to time-trials simulating actual race conditions and performance. A time-to-exhaustion test is found to be less reliable (r=0.455) than time-trials (r=0.953) and is found to be harder to reproduce the test as psychological factors can impact the test; the psychological impact is due to the test not having an endpoint like a time-trial test (Laursen et al., 2007; Jeukendrup et al., 1996). Despite time-to-exhaustion tests having poor reliability when compared to a time-trial test it should not be disregarded as the aim of the test should guide which test you would use. Time-trial tests work well for studies that want to simulate race conditions but at the same time participants can pace themselves which makes it hard to compare the effects of intervention in response to exercise (Amann et al., 2008).

2.5.2.2 Alternative running performance indicators

There are alternative running performance tests besides the time-to-exhaustion test and time-trial test. There are various cardiorespiratory indicators that have been used to measure performance in conjunction with treadmill test which include minute ventilation, pulmonary gaseous exchange, tidal volume, and carbon dioxide production. These factors have not been found to be significantly changed when wearing compression garments compared to a control (Marcora et al., 2007). VO_2max testing has been used as a running performance indicator and has been constantly used in the literature. VO_2max testing tests the maximal oxygen uptake of an individual and is used in conjunction with a treadmill (Bringard et al., 2006). According to Milani et al. (2006) it has been found that aerobic capacity and cardiorespiratory performance is associated with high values in the test and in contrast a lower value in the test is associated with better running economy, less fitness or running ability. Monitoring of HR has been used as a running performance indicator in studies and it has been found that endurance athletes have a rapid heart rate recovery after exercise. It has been found that a lower resting heart rate and submaximal heart rate are signs of improved adaptation and training (Borresen & Lambert, 2008; Marcora et al., 2007; Jeukendrup et al., 1996). Heart rate monitoring is regarded to have a high validity and reliability (r=0.99) (Giles et al., 2016; Brage et al., 2006). Muscle strength and power are indicators of running performance and a common test used to assess power and strength is the maximal voluntary contraction test or CMJ, these are reliable and valid tests (CMJ r=0.87) (Nummela et al., 2008; Markovic et al., 2004).

Majority of these running performance tests have been used in conjunction with a time-trial test or a time-to-exhaustion test, as this gives a better indication of performance. The above-mentioned test are adjuncts to running specific performance test and should not be used in isolation to measure running performance.

2.5.2.3 Running performance measures summary

Running performance tests are popular; the most reliable and valid test is the time-trial test which simulates race conditions. The type of study can influence what type of test you use. The time-trial test can be supplemented with cardiorespiratory outcome measures, muscle power tests and heart rate monitoring.

2.6 Conclusion

Compression garments use has had a rapid increase in running and other forms of exercise to try to improve performance and aid recovery (Davies et al., 2009). The findings in the literature review are inconclusive, with many studies finding benefits on performance and recovery and others finding no benefits at all.

It can be concluded that compression garments have its most impact on subjective measures which include muscle soreness, comfort levels of participants and RPE (Rugg et al., 2013; Goh et al., 2011). Majority of the studies suggested this finding but there were some studies that found no significant differences when using compression garments compared to a control group.

No conclusive evidence was found for the running performance outcomes measures. Furthermore, many studies suggested no benefits were found when wearing compression garments compared to a control group, as the studies were compromised (Venckunas et al., 2014; Barwood et al., 2012; Dascombe et al., 2011).

Based on the findings in the studies included in this review, the best form of instrumentation to measure subjective rating is the use of an RPE, or other alternatives similar to an RPE such as a Likert scale and VAS (Hill et al., 2014; Rugg et al., 2013; Goh et al., 2011). To measure objective performance, time-trial test is the preferred method of testing, as it mimics race conditions the best but the time-to-exhaustion test can also be utilised despite it being less reliable than the time-trial test and depending on the aim of the study (Amann et al., 2008; Currell & Jeukendrup, 2008). Therefore, the research aims should guide the selection of the test utilised. Other outcomes to measure the impact of EIMD include circumference measurements, blood markers, and radiographic imaging (Geldenhuys et al., 2019; Yu et al., 2015; Brancaccio et al., 2010; Marcora & Bosio, 2007). CK a blood marker has been used in past literature, but the findings are inconclusive, and the use of radiographic imaging is found to be relatively more expensive.

To conclude this section, there is a need for quality research, as a result of study limitations in the included studies. The study limitations identified in the literature review includes the lack of randomisation, lack of female participants in the studies, small samples sizes, introduction of bias in the studies, the lack of blinding and lack of uniformity across the studies. These factors reduce the internal and external validity of the studies and in addition reduces the power of the studies, which makes it hard to make broad inferences. It is important to address the study limitations as this will improve the quality of the research.

Chapter 3: Does the use of upper leg compression garments aid performance and reduce post-race DOMS?

Study Procedure

3.1 Introduction

There has been a rise in the increase in the use of compression garments amongst endurance runners. However, although there has been an increase in use, there is controversy surrounding the use of compression garments. Thus, further study is indicated.

Based on the literature review there are various confounding factors that surround previous studies. The study limitations reviewed include a lack of uniformity amongst studies, relatively small samples, exclusion of females, lack of randomisation and lack of blinding. These factors impact the validity of the studies and reduce the power of the studies (Mizuno et al., 2017; Venckunas et al., 2014; Miyamoto & Kawakami, 2014; Rugg & Sternlicht, 2013; Barwood et al., 2013; Goh et al., 2011; Dascombe et al., 2011; Bringard et al., 2006).

Furthermore, added to the above-mentioned failures of previous studies majority of the studies used a variety of different study designs, different compression garments used, different pressure levels in compression garments used, different outcome measures utilised and variety of different types of participants used in the studies. These factors leads to the lack of conclusive findings on the use of compression garments in endurance runners (Mizuno et al., 2017; Venckunas et al., 2014; Miyamoto & Kawakami, 2014; Rugg & Sternlicht, 2013; Barwood et al., 2013; Goh et al., 2011; Dascombe et al., 2011; Bringard et al., 2006).

The current study has attempted to overcome the above-mentioned challenges through conducting a RCT. Furthermore, it attempted to recruit several females amongst the participants. In addition, outcome measures were selected that gave reliable and valid results into the use of compression garments. It was hoped that results would give guidance to athletes, coaches and health professionals in sports on the use of compression garments to aid performance and recovery in runners.

3.2 Methodology

3.2.1 Research design

A randomised controlled intervention study was conducted in endurance runners participating at the 2019 Winelands Marathon. Before the study commenced, ethical approval was obtained from the University of Cape Town (UCT) Human Research Ethic Committee (HREC) (HREC:208/2019) *(Appendix A).*

The researchers contacted the Winelands Marathon organisers prior to recruitment of participants and the organisers sent out a notification to the participants and included the advertisement in the online race entry *(Appendix B).* Participants between the ages of 20-45, residing in Western Cape who entered the 42km race and had shown interest in participating in the research were required to contact the researchers independently. Participants were individually contacted by the means of an electronic bulk email providing information *(Appendix C).*

3.2.1.1 Inclusion criteria

Long distance male and female recreational club runners (specifically in the case of female participants, their menstrual cycle and contraceptive pill usage were monitored and recorded). In addition, a minimum average training distance of 50km per week was required and participants had to have completed at least one marathon in the 18 months preceding the start of data collection.

3.2.1.2 Exclusion criteria

Participants who had pre-existing musculoskeletal injuries to the lower limb 3 months prior to commencement of data collection or who had injuries that had not resolved, or past injuries and were still symptomatic (this was based on the developed screening tool and further verified by the Modified Nordic Musculoskeletal Questionnaire) (*Appendix D*) were excluded from the research study (Dawson et al., 2009). In addition, participants who had a history of: underlying chronic or acute neurological, musculoskeletal, orthopaedic, cardiac, endocrine or other medical diseases or complications that could have impacted on the safety of their participation and/or their performance (this was based on screening by the Physical Activity Readiness Questionnaire +/PAR-Q+) (*Appendix E*) were excluded (Warburton et al., 2011). Furthermore, any participants who had routinely used compression garments and/or who were unwilling to train and/or compete with or without compression garments based on the potential group allocation were also excluded.

3.2.2 Sampling

3.2.2.1 Sampling method

The recruitment process of the research study was completed through a sample of convenience. Forty runners responded to the advertisement. All 40 participants remained interested in participating after answering questions about the study.

Following this the 40 interested participants were sent an online self-developed screening tool (*Appendix F*) to indicate if they fit the inclusion and exclusion criteria. One participant was excluded from the study as they did not fit in the age group specified, therefore, 39 participants remained after this process. The 39 eligible and willing participants were encouraged to ask questions and enquire further electronically through email, telephonically and/or in person prior to obtaining written informed consent (*Appendix C*).

3.2.2.2 Sampling size calculations

In a previous similar study by Geldenhuys et al. (2019), a confidence level of 95%, a power of detectability of 80%, a variance of 4 and a hypothesized difference of 1.8 was used. Using this information, the required sample size was determined as 19 per group (38 runners in total) for the study to have statistical power.

3.2.2.3 Randomisation

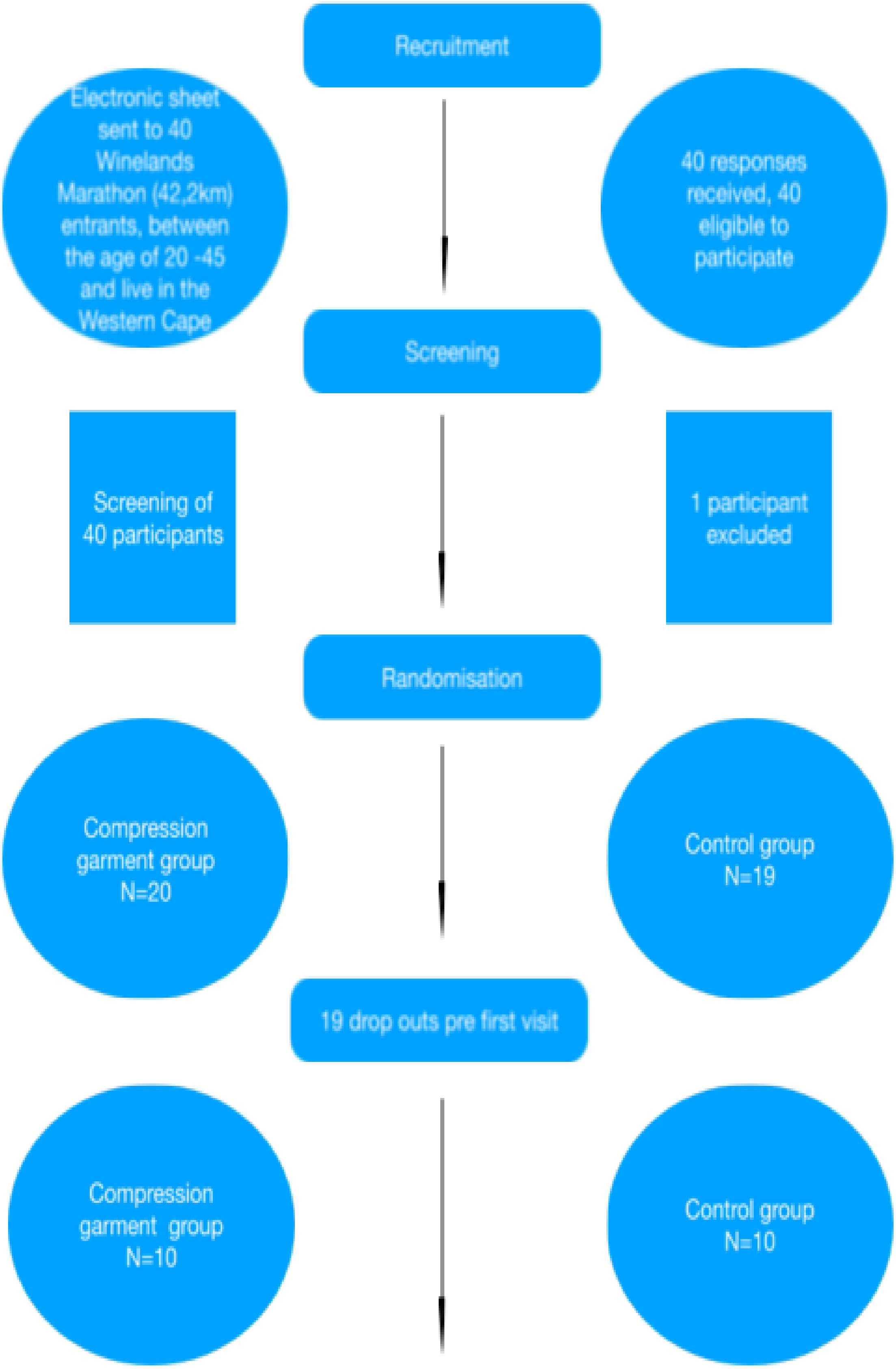
The participants were matched based on their sex, age and personal best marathon time before being randomly allocated to either the compression garment or the control group. The randomisation process was facilitated by the principal researcher using Microsoft Excel. The compression garment group included 20 participants who were instructed to train as usual and participate in the race while wearing upper leg compression garments. The control group included 19 participants who were instructed to neither train nor participate in the race with compression garments. The participants were informed about their allocated group prior to the start of data collection and expectations of each group was emphasized throughout the study.

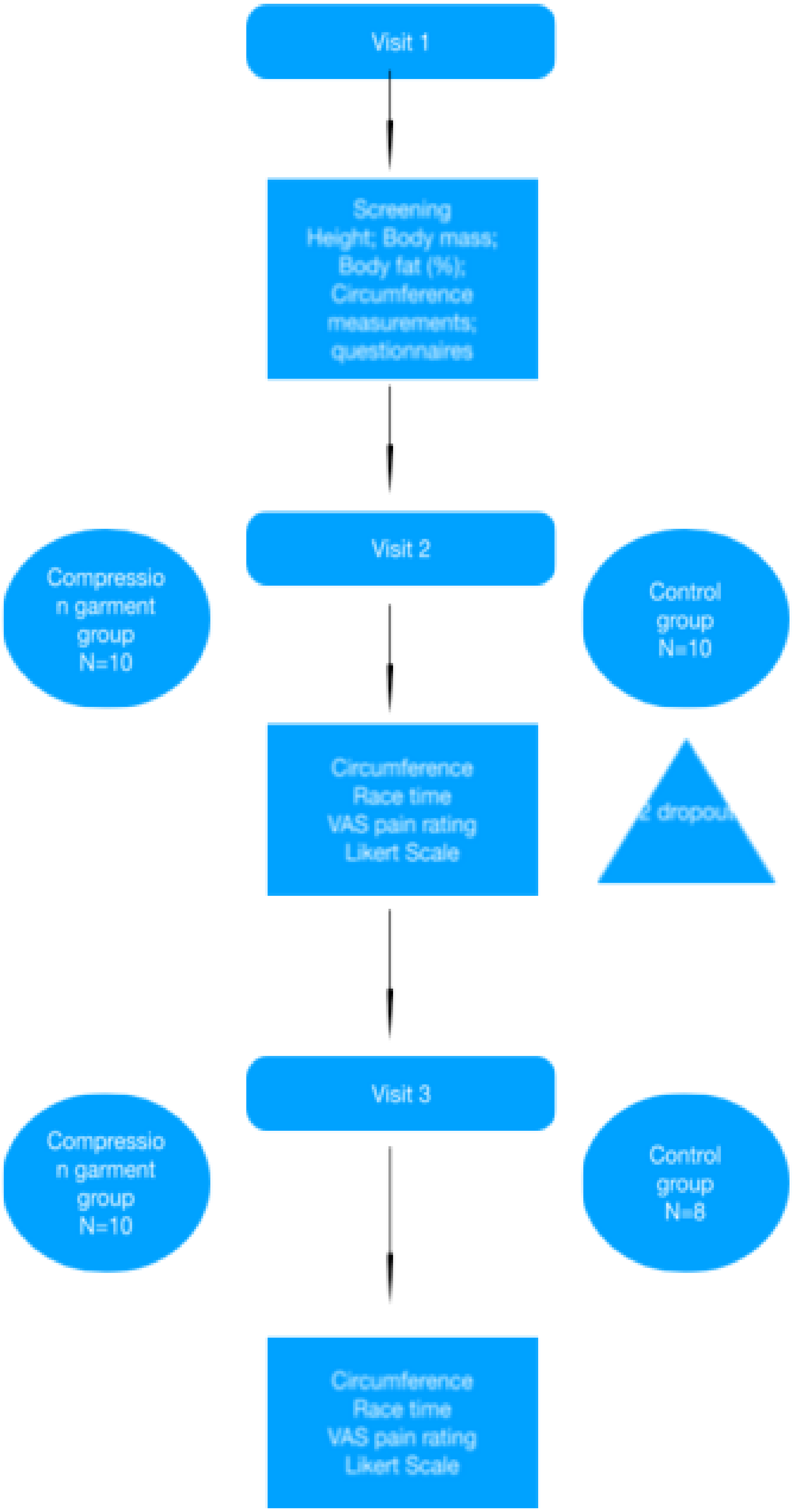
3.2.3 Completion of study

Following the baseline screening for the initial participants, there were a total of 39 participants. Following baseline screening and prior to the first date collection a further 19 participants decided to drop-out of the study, and this reduced the participation number to 20. The reasons of drop out included being too busy to attend the sessions, work commitments, transport issues, change of plans and deciding to race the half marathon (21.2km) instead. Thereafter, there were 10 participants in each group. A further two participants withdrew during the data collection process at visit 2 of data collection, one participant in the control group injured his hamstring during the race and was unable to complete the race. The second participant in the compression garment withdrew as a result of logistical issues as he did not show up for follow up visits. Only participants who completed all three visits of the data collection process were included in the final reporting of the study.

Figure 3.1 includes a summary of the recruitment process and screening of participants. Furthermore, it includes a summary of the three data collection points and the participant flow of the study.

Figure 3.1: Participant flow summary




Visit 1
Screening
Height; Body mass;
Body fat (%);
Circumference
measurements;
questionnaires
Visit 2
Compressio
n garment
group
N=10
Control
group
N=10
Circumference
Race time
VAS pain rating
Likert Scale
2 dropou
Visit 3
Compressio
n garment
group
N=10
Control
group
N=8
Circumference
Race time
VAS pain rating
Likert Scale

3.3 Measurement instrumentation

3.3.1 Informed Consent & Screening tools

3.3.1.1 Informed Consent

All participants were required to sign an informed consent form *(Appendix C)* prior to their participation in the study. All relevant information about the study and the associated testing that took place, in addition the risks and benefits to the participants were set out in the document. Participants were advised on their right to withdraw from the study at any given time and were encouraged to ask questions.

3.3.1.2 Questionnaires

3.3.1.2.1 Screening tool

A screening tool *(Appendix F)* adapted from Geldenhuys et al. (2019) was developed prior to commencement of testing and was sent to participants electronically to assess participant's preliminary eligibility to participate in the study based on the inclusion and exclusion criteria.

3.3.1.2.2 Physical Activity Readiness Tool

Participants were required to complete the PAR-Q+ questionnaire *(Appendix E).* This is a simple screening tool used to assess medical conditions (Warburton et al., 2011). This ensured the safe participation in the study without posing any risk to the participants' health. If the participants required medical assistance, they were advised accordingly, and referrals were made to respective health professionals. No participants in the study were referred for further assessments.

3.3.1.2.3 Nordic Musculoskeletal Questionnaire

Participants were required to complete the Modified Nordic Musculoskeletal Questionnaire *(Appendix D)*. The questionnaire screened them for musculoskeletal conditions specifically in the lower limb that could impact on the safety of participation or could impact the study outcomes (Dawson et al., 2009). If the participants required medical assistance, they were advised accordingly, and referrals were made to respective health professionals.

3.3.2 Study Instrumentation

3.3.2.1 Subjective outcome measures

3.3.2.1.1 Visual analogue scale pain ratings

The first objective was measured using the VAS questionnaire *(Appendix G)* which was administered for subjective pain ratings on a scale of 0 - 10. Zero represented no pain and 10 represented severe pain (Crichton, 2001). The VAS questionnaire was used in conjunction with NWB active movements of the hip and knee to measure the participants pain scores. The VAS questionnaire was completed by the participants directly post-race and two days post -race and was administered by the researcher. The participants gave feedback on their pain levels to the researcher and the researcher recorded the participant scores. The participants were required to mark on the line the point that they feel represented their perception of pain. The VAS score was determined by measuring in mm from the left-hand end of the line to the point that the participants marked.

3.3.2.1.2 Likert scale for determination of muscle soreness

The second objective was measured using the Likert scale for determination of muscle soreness *(Appendix H)* which was administered for subjective pain rating based on a seven-point system (Joshi et al., 2015). Zero represented a complete absence of muscle soreness and "6" represented severe pain that limited the ability to move. The Likert scale for determination of muscle soreness was completed by the participants directly post-race and two days post-race and administered by the researcher. The participants ticked what best described their muscle soreness perception at the time of administrating the tool. The participants were required to complete the tool at the end of the race and two days after the race.

3.3.2.1.3 Self-developed Questionnaire

The self-developed questionnaire *(Appendix I)* was administered to record information on compression garment utilisation; the training details during the six-week training period prior to the Winelands Marathon; the information regarding fluid and nutrition during the race; the recovery modalities utilised during and 2 days after the race; the menstrual cycle and contraceptive pill usage of females; and lastly a record of any difficulties encountered during the Winelands Marathon, this was to account for any possible confounding variables during the race. The information was used as descriptive data in the final results of the study. However, the reliability and validity were not accounted for as the nature of the questionnaire was such that it was objective data. The validity was self-evident, and reliability was dependent on participants being truthful in their answering of questions.

3.3.2.2 Anthropometric measurements

Body mass (kilogram [kg]) was measured with a calibrated digital scale (UWE, BW-150, no. 1). Stature was measured using a mechanical stadiometer (Detecto, UWE-BW-150). The body mass index (BMI) was calculated based on the body mass and stature measurements using the standard formula: 'mass (kg)/stature (m^2)' (Deurenberg et al., 1998).

Skin folds were measured with the standardised anatomical landmarks with a dial caliper using the four-point system of measuring at the following sites: Bicep, Triceps, Subscapularis and Suprailiac

Crest (Durnin & Womersley, 1974). All the measurements were obtained without any clothing over the skinfold site. The skinfolds were raised at the marked site and the skinfold measurement was taken after 2 seconds (sec) of pressure from the caliper on the measuring site. Each measurement was performed three times, and the average value was utilised to calculate the body fat percentage %. The researcher was experienced in the ISAK method.

This descriptive information obtained was used to describe the body composition of the participants.

3.3.2.2.1 Girths (Mid-thigh circumference)

The third objective was measured using mid-thigh circumference which was measured with the standardised anatomical landmarks with a tape measure (Baseline® Measurement Tapes – 72 inch) (in cm) according to the International Standards for anthropometric assessment (ISAK) (Marfell-Jones et al., 2012). All measurements were obtained without the compression shorts. The measurements were taken midway between the trochanterion and lateral border of the tibia, at the mid--trochanterion-tibiale laterale site (*Appendix J*). Each measurement was performed three times, and the average value was used.

3.3.2.3 Physical assessment

3.3.2.3.1 Time-trial with FinishTime timing chips

The fourth objective was measured using FinishTime timing chips which were used by the participants according to the Winelands Marathon regulations during the 42.2km race. The FinishTime timing chips are internationally recognised and are reliable. It was the official timing tool used for the Winelands Marathon and various other races (finishtime.co.za). The time durations to the 42.2km mark respectively were obtained online post the completion of the race. The information was used to calculate the overall average running pace (min:sec/km) during the race.

3.3.3 Training with instrumentation

3.3.3.1 Girth measurement training

The girth measurements were practiced according to the detailed description (as outlined in Section 3.3.2) on three voluntary participants. All three participants were tested on two separate days and at different times of the day in order to establish reliability (r) of the respective data collector (r=0.99 for mid-thigh circumference). The results of the participants were not included in the final study.

3.3.4 Compression garments

3.3.4.1 Compression garment composition

Commercially available graded upper leg compression garments produced internationally (China) were used in the study. The composition of the respective garments included 55% Nylon, 40% Polyester and 5% Elastane fabric. To avoid the introduction of bias to the study, the manufacturers (Mr Price) of the compression garment were not involved in financing the study.

3.3.4.2 Compression garment pressure level, sizing and usage

Compression garment pressure levels were not measured in the participants due to limited funds. The manufacturer of the compression garments does not specify level of pressure level. The participants reported to the researcher what compression garment size they were and were given correctly sized compression garments. The compression garment sizes ranged from extra-small to large. Participants in the compression garment group were only required to complete the Winelands Marathon with the compression garments.

3.4 Procedure

3.4.1 Data Collection

Testing and data collection happened during three separate occasions. The first visit during the data collection process was performed three days prior to the 2019 Winelands Marathon at Sport Science Institute of South Africa (SSISA) situated in Newlands, Cape Town. The participants were required to provide written informed consent, after which they had to complete the Nordic Musculoskeletal Questionnaire (to screen participants for any musculoskeletal injuries in the three months preceding the study) and the PAR-Q Questionnaire (to screen participants for any medical conditions that could hamper their safety of participation and performance). For descriptive purposes, at baseline each participant's body mass and stature were measured to calculate the BMI and body fat %. Mid-thigh circumference was measured using a tape measure. Female participants were required to fill out information regarding their menstrual cycle and all participants were required to fill out information regarding their training history using the self-developed questionnaire (*Appendix I)*.

The second data collection visit was performed directly after completion of the 2019 Winelands Marathon situated at Laerskool Eikestad in Stellenbosch, Western Cape. The girth measurements were repeated at this visit; participant's mid-thigh circumference was recorded. The participants completed a Likert Scale for determination of muscle soreness and the VAS pain ratings questionnaires. In addition to these measurements, the participants had to complete information on nutrition and fluid strategies utilised in the race, recovery strategies performed three days prior to the race and compression garment utilisation.

The third visit was performed two days following the 2019 Winelands Marathon at SSISA. The mid-thigh circumference measurements were repeated, as were the Likert Scale and VAS pain rating questionnaires.

The performance results of the participants were retrieved on the FinishTime website and participants' finish times and average race pace were recorded.

3.4.2 Data management

Personal identification of data collected throughout the study was and will be kept anonymous. The hardcopies of the data have been stored in a secured cupboard and access is only granted to the researchers. The electronic version of the data is stored on a password encrypted google drive (www.docs.google.com/spreedsheets). Participants were and will not be identified by their names but by number codes. Participants performance results can be found on the events official race time website (www.finishtime.co.za). To protect the participants' privacy their race times were not linked to their participation in the study.

3.4.3 Statistical analysis

All statistical analysis was performed using SAS software version 9.4 (2020) and Microsoft Excel software (2019). Due to the small sample size, a nonparametric approach for analysis of data was deemed appropriate. For the objectives of the study (i.e. the time taken to complete the Winelands marathon; mid-thigh circumference; VAS pain rating scores at rest and during movements and the Likert scale for determination of muscle soreness) and the descriptive data (age, height, body mass, BMI, body fat % and previous best marathon time) was compared for each group using a Mann-Whitney U test. In addition, a Hodges-Lehmann 95% confidence interval for the median difference was calculated. A repeated measures ANOVA test was performed to assess if there were statistically significant ($p=0.05$) differences among the groups. In order to adjust for the individual’s running fitness at the time of the race, the difference in race pace in the Winelands marathon from personal best was calculated. Proportional changes over time were calculated for mid-thigh circumference measurements over various time frames (i.e. Visit 1 to 2; Visit 2 to 3).

For the self-developed questionnaires, the responses that were recorded were converted into percentages. The responses were compared for each group using a Mann-Whitney U test to determine if there were any statistically significant differences between the compression and control group. In addition, a Hodges-Lehmann 95% confidence interval for the median difference was calculated. For certain responses on previous training history and recovery modalities utilised, a Fisher's exact test was performed to compare the proportion of participants who did additional training in each of the groups. In addition, an exact confidence interval for the difference in proportions was produced. In order to determine whether there was a difference in the frequency of use of compression garments prior to the study, the compression frequency scale was compared between the groups using a Cochran-Armitage test for trend.

The confidence intervals were set at 95% and statistical significance was determined as $p < 0.05$.

3.4.4 Ethical considerations

The study was conducted on the principles of the Declaration of Helsinki (Fortaleza, Brazil, 2013).

3.4.4.1 Risks and benefits

There was no financial remuneration provided to the participants. The participants received a single pair of cost-free compression garments for the study. The control group also received a single pair of cost-free compression garments at the completion of data collection. At the completion of the study participants were given a full report of their results and the overall findings of the study (*Appendix L*).

There was some risk to the participants in the study as a result of wearing the compression garments if worn incorrectly or if poorly distributed or excess pressure from compression garments. However, many runners use compression garments routinely without any complications. The objective measures posed minimal/no risk to the participants. The questionnaires did not contain any information that will potentially make the participants identifiable to the public, in order to respect the participants' privacy. During the race there were medical teams provided by Winelands Marathon which were based at different stations along the race route in case any medical emergencies occurred.

3.4.4.2 Significance and justification

Currently there is limited knowledge and conflicting evidence on the current use of upper leg compression garment utilisation by endurance runners. The study has the potential to contribute to the existing literature and have an influence on the future use of compression in the performance and recovery process of endurance runners. Firstly, the study was completed in an actual marathon race compared to a laboratory, that is generally used, which does not mimic actual race conditions and eliminates many road race related factors. Participants were also matched for personal best marathon time, age and sex, to eliminate any age and sex related advantages or disadvantages. Lastly, this was the first study to our knowledge to investigate mid-thigh circumference measurements of the upper leg.

Results

3.5 Descriptive data

The descriptive data for the participants in the compression garment and control group is summarised in Table 3.1.

Table 3.1: Initial baseline descriptive data

	CGG	CG	P-value
Total (n)	10	8	-
Males (n)	6	6	-
Females (n)	4	2	-
Median pace in PB marathon in past 18 months (IQR)	05:44 min:sec/km (04:51-06:18)	05:49 min:sec/km (05:39-06:48)	0.63
Median age (IQR)	38.50 years (28.00-42.00)	38.50 years (36.50-39.00)	1.00
Median body mass visit 1 (IQR)	74.30kg (63.90-88.85)	77.00kg (68.60-79.70)	0.97
Median body mass visit 2 (IQR)	72.20kg (62.60-86.50)	74.70kg (65.68-77.65)	0.97
Median body mass visit 3 (IQR)	74.40kg (62.40-89.00)	76.80kg (68.43-80.40)	0.97
Median height (IQR)	172.00cm (167.75-177.50)	174.00cm (167.88-177.00)	0.31
Median body fat % (IQR)	24.00% (21.70-29.60)	23.60% (21.20-26.65)	0.66
Median BMI (IQR)	25.70 kg/m^2 (23.70-26.40)	24.90 kg/m^2 (22.90-26.70)	0.86

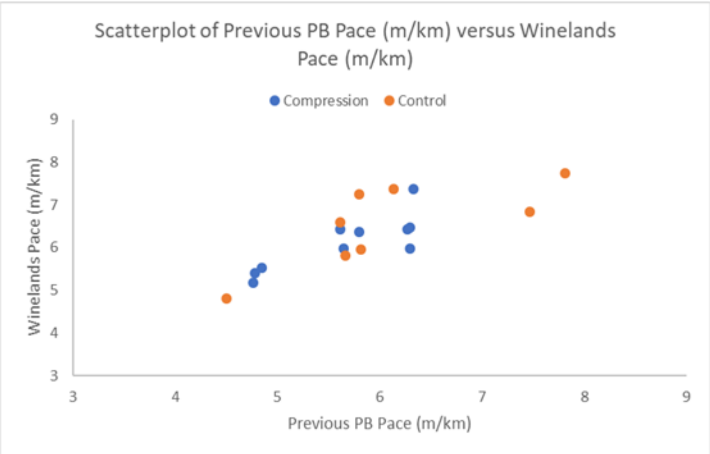
CGG= compression garment group
CG= control group
IQR= Interquartile range
n= number of participants
PB= personal best
p=0.05 (< statistically significant)

3.6 Overall changes overtime for main outcome measures

3.6.1 Race performance

Race pace was utilised to measure performance of the participants (from start to finish of the 42.2km marathon race). The compression garment group had an average race pace of 6:11 min:sec/km compared to 6:44 min:sec/km of the control group. Both groups had slower running pace (min/km) times compared to their personal best running pace time. In order to adjust for the individual's running ability, the difference in running pace (min/km) between the Winelands marathon and personal best was calculated and no statistically significant differences were found between the groups (p=0.69). Furthermore, there was no statistically significant difference (p=0.27) overall between groups in running pace for the race. The comparison between overall race pace and personal best marathon race pace is presented in Figure 3.2.

Figure 3.2: Average race pace during 2019 Winelands Marathon compared to personal best race pace



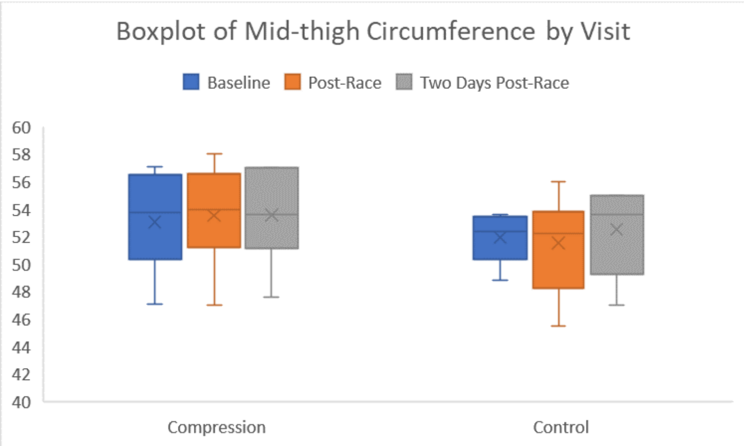
3.6.2 Circumference measurements

Over the three-day period prior (Visit 1) to the race through to two days post-race (Visit 3) there were no statistically significant changes (p=0.37) found over time for mid-thigh circumference in the compression garments group compared to the control group. Directly post-race there was no statistically significant differences (p=0.08) between the groups. Similarly, at two days post-race there was no statistically significant differences (p=0.08) between the groups. The mid-thigh circumference for both groups remained relatively similar throughout all the three visits.

Although both groups remained relatively similar, they followed a different pathway. The compression garment groups median mid-thigh circumference increased slightly from baseline testing (53.75cm) to immediately post-race (54.00cm) by 0.25cm compared to the control group who recorded a 0.15cm decrease from baseline (52.40cm) to immediately post-race (52.25cm) in the control group. Two days post-race the compression garment group median mid-thigh circumference decreased to 53.60cm and the control group increased to 53.60cm.

There were no statistically significant differences found between the groups in terms of proportional changes in mid-thigh circumference measurements from two days pre-race to immediately post-race (p=0.69); immediately post-race to two days post-race (p=0.14). None of these relative percentage changes to mid-thigh circumference measurements were statistically significant over time between the groups. The absolute mid-thigh circumference measurement changes over time is presented in Figure 3.3.

Figure 3.3: Mid-thigh circumference measurement means over time



3.6.3 Subjective pain ratings measurements

3.6.3.1 VAS pain ratings

Immediately at the completion of the race, the VAS pain ratings were taken in the compression garment and control group for the anterior and posterior upper leg at rest as well as pain ratings during hip flexion and extension and knee flexion (bend) and extension (straighten). Both groups decreased in median VAS pain rating scores from immediately post-race to two days post-race. There were significant differences found between the compression garment group and control group in overall median VAS pain scale rating scores during knee bend (p=0.01) and resting hamstring (p=0.05) for both legs. Although hip extension for both legs at each individual visit (immediately post-race and two days post-race) were significantly different (p=0.04), there was no overall statistically significant difference (p=0.06) found between the groups. Table 3.2 summarises the VAS pain ratings both immediately post-race and two days post-race.

Table 3.2: VAS pain ratings both immediately post-race and two days post-race

	CCG		**CG**		**p-value**	**p-value**	**CCG**	**CG**	**p-value**	**p-value**
	Immediately post-race						**Two days post-race**			
Side	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
Median VAS pain rating of quadricep at rest (IQR)	2.50 (2.00-4.00)	2.50 (2.00-4.00)	2.00 (1.00-3.00)	2.00 (1.00-3.00)	p=0.69	p=0.69	0.00 (0.00-1.00)	0.00 (0.00-1.00)	p=0.69	p=0.69
Median VAS pain rating of hamstring at rest (IQR)	2.50 (0.00-4.00)	2.50 (0.00-4.00)	4.00 (2.50-4.50)	4.00 (2.50-4.50)	p=0.04*	p=0.04*	0.00 (0.00-1.00)	0.00 (0.00-1.00)	p=0.04*	p=0.04*
Median VAS pain rating during knee bend-flexion (IQR)	2.50 (1.00-5.00)	2.50 (1.00-5.00)	5.00 (3.50-7.00)	5.00 (3.50-7.00)	p=0.02*	p=0.02*	1.00 (0.00-2.00)	1.00 (0.00-2.00)	p=0.02*	p=0.02*
Median VAS pain rating during knee straightening - extension (IQR)	2.50 (1.00-4.00)	2.50 (1.00-4.00)	3.50 (2.00-4.50)	3.50 (2.00-4.50)	p=0.21	p=0.21	0.50 (0.00-2.00)	0.50 (0.00-2.00)	p=0.21	p=0.21
Median VAS pain rating during hip flexion (IQR)	3.50 (2.00-4.00)	3.50 (2.00-4.00)	3.00 (2.00-4.50)	3.00 (2.00-4.50)	p=0.33	p=0.33	1.00 (0.00-2.00)	1.00 (0.00-2.00)	p=0.33	p=0.33
Median VAS pain rating during hip extension (IQR)	2.50 (2.00-4.00)	2.50 (2.00-4.00)	4.00 (2.00-5.50)	4.00 (2.00-5.50)	p=0.04*	p=0.04*	1.00 (0.00-2.00)	1.00 (0.00-2.00)	p=0.04*	p=0.04*

CCG = compression garment group

CG = control group

IQR = Interquartile range

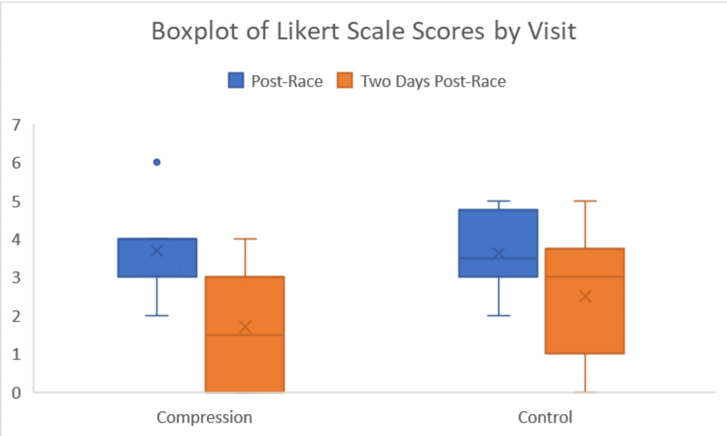
* = Statistically significant (p=0.05):

- Hamstring at rest
- Knee flexion/bending
- Hip Extension

3.6.3.2 Likert Scale for determination of muscle soreness

Immediately post-race, the Likert scale for determination of muscle soreness scores were recorded. Both groups decreased in median score for the Likert scale for determination of muscle soreness from immediately post-race to two days post-race. The compression garment group recorded a median score of 4.00 immediately post-race compared to 3.50 for the control group (p=0.51). The control group recorded a median score of 3.00 two days post-race compared to 1.50 for the compression garment group (p=0.51). No statistically significant differences (p=0.46) were found between the groups in overall change in median scores. The absolute change in median Likert scale for determination of muscle soreness is presented in Figure 3.4.

Figure 3.4: Difference in median Likert scale for muscle soreness over time



3.7 Additional information

3.7.1 Baseline additional information

3.7.1.1 Training history for the preceding 6 weeks

Many of the participants in both groups took part in some form of weight training (40% of the compression garment group and 75% of the control group). This was closely followed by participants taking part in cardio training, flexibility training and to a lesser extent some form of skills development training or team sports. In all these forms of alternative training no statistically significant differences (p=1.00) were found between the groups. Table 3.3 summarises the training history of both groups.

Table 3.3: Training history 6 weeks prior to Winelands Marathon

	CGG	CG	p-value
Median overall number of marathons (IQR)	10.00 (2.00-10.00)	8.00 (2.00-16.50)	0.82
Median of weekly runs in the previous 6 weeks (IQR)	27.00 (24.00-30.00)	24.00 (21.00-30.00)	0.40
Median mileage in the previous 6 weeks [km] (IQR)	60.00km (50.00-80.00)	50.00km (50.00-65.00)	0.21
Median running duration per training session in the previous 6 weeks [min] (IQR)	67.50min (60.00-80.00)	60.00min (60.00-77.50)	0.60
Median longest running duration in the previous [min]6 weeks (IQR)	235.00min (62.40-89.00)	291.50min (68.43-80.40)	0.42

CGG = compression garment group
CG = control group
IQR = Interquartile range
km = Kilometres
min = minutes
p=0.05

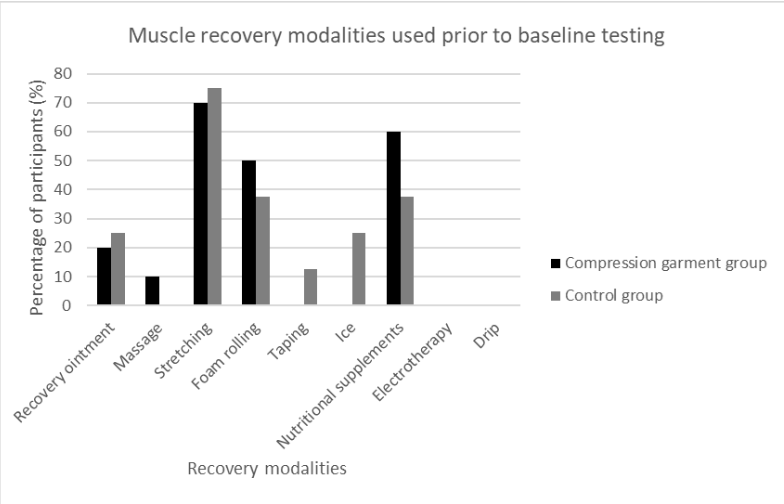
3.6.3.2 Compression garment utilisation for the preceding 6 weeks

A low proportion of the participants in both groups (2 participants in each group) utilised upper leg compression garments for their training and runs prior to the 2019 Winelands Marathon (20% of the compression garment group and 25% of the control group used compression garments), furthermore, there were no statistically significant differences (p=1.00) found between groups. Only 1 participant in each group utilized compression garments for their long runs. Two participants in the control group utilised the compression garments occasionally (less than 1-2 times a week) and 1 participant in the compression garment group used it occasionally (less than 1-2 times a week). Only 1 participant in the compression garment group used compression garments most of the time (3-4 times a week) for their runs.

3.6.3.3 Muscle recovery strategies used prior to baseline testing

Leading up to the race, participants in both groups reported that they utilised different forms of recovery modalities that included ointments (p=1.00), massage (p=1.00), stretching (p=1.00), foam rolling (p=0.67), taping (p=0.45), ice (p=0.19) and nutritional supplementation (p=0.64). There were no statistically significant differences found between the groups. Recovery modalities utilised 3 days prior to race day are summarised in Figure 3.5.

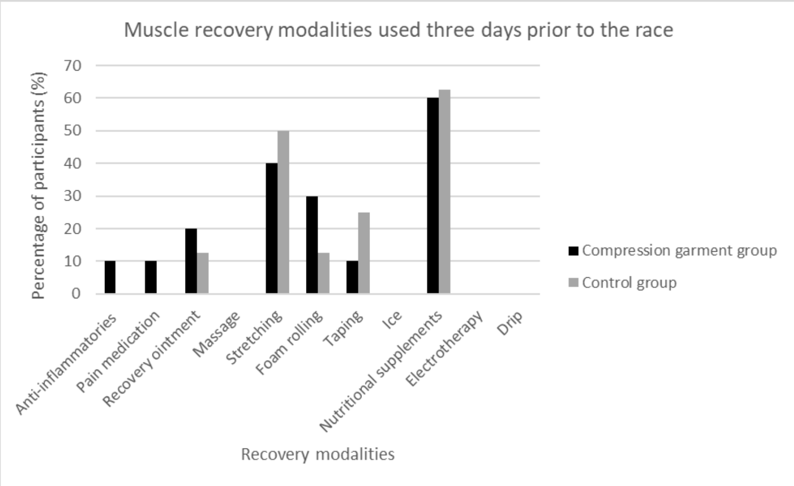
Figure 3.5: Muscle recovery modalities used prior to baseline testing



3.6.3.4 Muscle recovery strategies used three days prior to the race

Following the completion of the race, participants in both groups reported that they utilised different forms of recovery modalities that included ointments (p=1.00), stretching (p=1.00), foam rolling (p=0.59), taping (p=0.56) and nutritional supplementation (p=1.00). Interestingly, only a small percentage (10%) of participants in the compression garment group utilised pain medication and anti-inflammatories compared to no participants in the control group. There were no statistically significant differences found between the groups. Recovery modalities utilised three days prior to the race are summarised in Figure 3.6.

Figure 3.6: Muscle recovery modalities used three days prior to the race



3.7.2 Immediately post-race additional information

3.7.2.1 Nutritional and fluid intake during the race

Nutritional and fluid intake during the race was recorded directly post-race. The nutritional and fluid intake during the race is summarised in Figures 3.7-3.8.

Figure 3.7: Nutritional intake

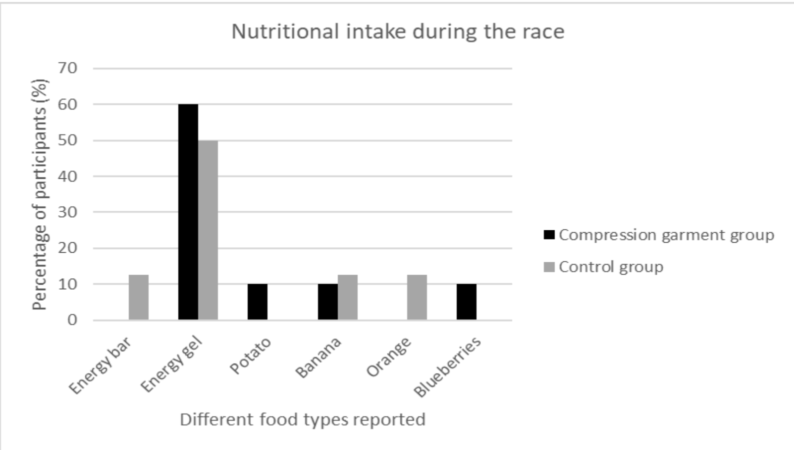
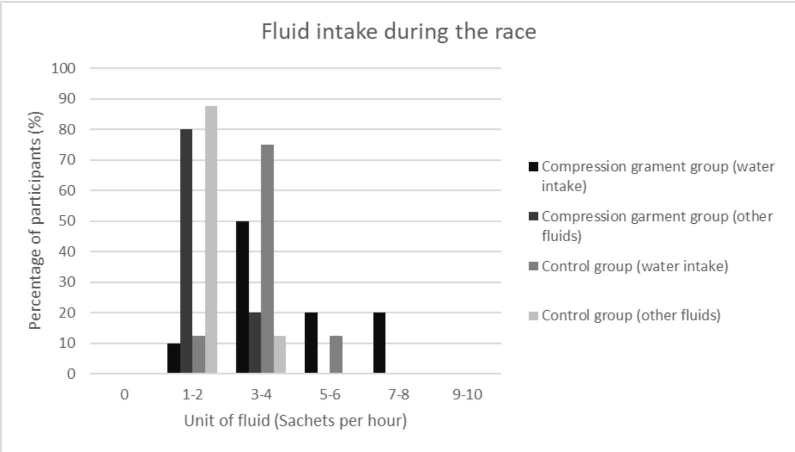


Figure 3.8: Fluid and other fluid intake



3.7.2.2 Menstruation cycle of females

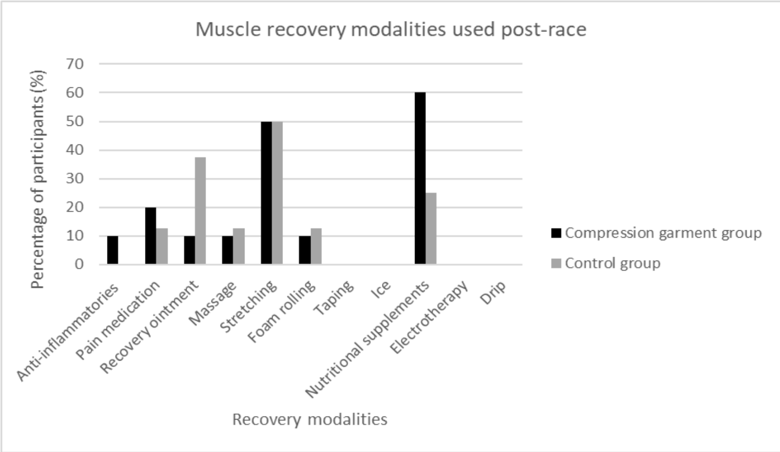
Although the number (n=6) of female participants in the study is low, 75% of the female participants in the compression garment group reported no menstruation cycle abnormalities and 50% in the control group. In addition, all (100%) of the participants in the compression garment group did not utilize contraceptive pills compared to half (50%) of the participants in the control group. There were no statistically significant differences found between the groups.

3.7.3 Two days post-race additional information

3.7.3.1 Muscle recovery strategies two days post-race

Following the completion of the race for a period of two days after the race, participants in both groups reported that they utilised different forms of recovery modalities that included pain medication (p=1.00), ointments (p=0.28), massage (p=1.00), stretching (p=1.00), foam rolling (p=1.00) and nutritional supplementation (p=0.19). Recovery modalities utilised two days post-race are summarised in Figure 3.9.

Figure 3.9: Muscle recovery modalities used post-race



3.8 Overall summary of significant findings

No statistically significant findings were detected for the following main outcome measures: race performance measurements, mid-thigh circumference measurements and Likert scale for determination of muscle soreness. These insignificant findings were consistent throughout the duration of the visits.

However, there were statistically significant findings for one main outcome measure (VAS pain rating). There were statistically significant differences (p=0.04) detected at each respective visit (immediately post-race and two days post-race) for both left and right resting hamstring scores. The overall significant difference (p=0.05) was detected between the groups for resting hamstring scores. There were significant differences (p=0.02) detected at each respective visit (immediately post-race and two days post-race) for both left and right knee bend movement (knee flexion) and an overall significant difference (p=0.01) was also detected between groups for knee bending (knee flexion). Furthermore, there were statistically significant differences (p=0.04) detected at each respective visit (immediately post-race and two days post-race) for both left and right hip extension movements. Although no statistically significant difference (p=0.06) was detected for overall left and right hip extension.

Although mid-thigh circumference measurements were not statistically significant, at each respective visit (three days prior, immediately post-race and two days post-race) the difference between the groups for each visit was detected at p=0.07. However, there was no significance overall between the groups (p=0.37).

Discussion

3.9.1 Introduction

Despite the benefits of compression garments in respect to performance and recovery enhancement not being conclusive, compression garments are still being used by runners (Davies et al., 2009). The aim of this study was to compare the performance, pain and thigh circumference changes in endurance runners using upper leg compression garments while competing against runners who did not use compression garments in the same marathon. A key aspect of this study was to investigate any association between upper leg compression on the signs and symptoms of EIMD and running performance of endurance runners competing in a marathon road race.

Previously published studies on endurance runners have found no statistically significant differences between compression garment utilisation and the non-use of compression garments in respect to specific outcomes measures (Barwood et al., 2013). The current study found minimal statistically significant findings between runners using upper leg compression garments compared to a control group in terms of race performance, post-race soreness, signs and symptoms of EIMD and thigh circumference changes. This agrees with previous studies which have found some statistically significant findings (Mizuno et al., 2017; Venckunas et al., 2014; Miyamoto & Kawakami, 2014; Rugg & Sternlicht, 2013; Goh et al., 2011; Dascombe et al., 2011; Bringard et al., 2006). Furthermore, the study detected significant differences post-race in terms of subjective pain ratings (VAS pain ratings) when comparing runners using upper leg compression garments to a control group in the recovery phase. These findings were in correlation with a previous study that found a statistically significant difference in subjective pain ratings in the recovery phase (post-race) in runners wearing compression garments (Hill et al., 2014).

3.9.2 Participants

The study had a sample size of 18 participants, which is fewer than the sample size hoped for, but which is, nevertheless, greater than previous similar studies identified in the literature review (Mizuno et al., 2017; Venckunas et al., 2014; Barwood et al., 2013; Rugg & Sternlicht, 2013; Goh et al., 2011; Dascombe et al., 2011; Bringard et al., 2006). However, two studies in the literature review had a bigger sample size (Hill et al., 2014; Miyamoto et al., 2014). The sample size in these studies were 24, 24 and 22. Gender exclusivity is another factor that majority of the reviewed studies could not address, the majority of studies in the literature having excluded females entirely in the studies (Mizuno et al., 2017; Miyamoto et al., 2014; Barwood et al., 2013; Goh et al., 2011; Dascombe et al., 2011; Bringard et al., 2006). However, a further one study did not include males in their samples (Venckunas et al., 2014). Interestingly, the current study included both females (33%) and males (67%) in the study population sample. The female representation at the 2019 Winelands Marathon constituted 426 out of the total 1084 participants (i.e. 39% compared to 61% of males). This is an indication that the study is in line with the gender representation of the race. Although previous studies have failed to represent females adequately, the inclusion of females in the current study and future studies is important. As stated by Schattke et al. (2014) marathon participation numbers are on the rise in recent times, therefore, it is important to include more females in future studies.

In terms of descriptive data there were no statistically significant differences found for age, body mass, height, BMI, body fat % and personal best marathon time between the groups. The descriptive data was similar to previous studies utilizing recreational athletes in terms of body mass, height and BMI (Hill et al., 2014; Venckunas et al., 2014; Barwood et al., 2013; Goh et al., 2011). The age average of the current study was 37 years ± 5 years, determined by the age restriction of the protocol (20-45 years). It has been theorized that running performance deficits start to appear from the age of 40 years old (Faulkner et al., 2007). Therefore, the age restriction protocol was put in place to limit age related muscle changes and deficits in running performance.

The training history 6 weeks prior to the 2019 Winelands Marathon between the groups was similar. Hill et al. (2014) recorded training history for a period of 5 weeks prior to testing. This is a similar training period utilised in the current study of 6 weeks. Participants recorded their training history using their electronic watches and running apps and this allowed for accurate data which limited recall memory bias.

Majority of the participants in the current study ran more than 4 times a week and accumulated between 50-89 km's per week in the 6 weeks preceding the 2019 Winelands Marathon. The low training volume and relatively slow times indicate that the participants were not elite endurance athletes. This is similar, to previous studies in which recreational or untrained runners were used (Mizuno et al., 2017; Hill et al., 2014; Venckunas et al., 2014; Barwood et al., 2013; Goh et al., 2011). The fact that the participants were trained, versus the untrained in some of the previous studies, is a strength in the research design of the current study, as participants were of equal levels of running. It is quite likely that responses from untrained runners are different from trained runners. Furthermore, a limited number of studies reviewed described the training history of their participants (Mizuno et al., 2017; Venckunas et al., 2014; Hill et al., 2014; Goh et al., 2011; Dascombe et al., 2011).

History of recovery modalities utilised prior to baseline testing was recorded, and no statistically significant differences were found between the compression garment and control groups. Majority of participants (>70%) in both groups utilised stretching as a form of recovery. However, Baxter et al.

(2017) theorised that stretching has a minimal impact on DOMs effects from training. Other forms of recovery modalities were rarely utilised by participants in both groups leading up to the race and no statistically significant difference was found between the groups. Previous studies have not documented the recovery modalities utilised by their participants. Another approach was used by Hill et al. (2014) that restricted participants from utilising recovery modalities prior to the race.

There were no statistically significant differences between groups for nutritional and fluid intake during the marathon. The majority (>50%) of participants in both groups consumed between 3-4 sachets (250ml) of water during the race, in addition, more than 80% of participants also consumed 1-2 sachets (250ml) of other fluids during the race. A high percentage (>55%) of participants in both groups consumed energy gels containing carbohydrates during the race. It is well established that performance benefits occur when consuming carbohydrates in events lasting more than 2 hrs (Wilson, 2016). However, it was highly unlikely that participants were affected positively as their race times were generally slow.

With the relatively low percentage (33%) of females participating in the current study, no statistically significant findings were present in terms of menstruation history. A low percentage (17%) of females utilized contraceptive pills, which has been found to impact running performance negatively (Frankovich & Lebrun, 2000). Therefore, we can predict that the female athletes were not negatively impacted by the contraceptive pill due to the low number of users. However, an elevated oestrogen level is proposed to have a protective effect against skeletal oxidative muscle damage and therefore, might assist in a marathon as there is less damage occurring (Persky et al., 2000).

There were no statistically significant differences between groups in terms of prior utilisation of compression garments. There was a high percentage (77.50%) of participants who did not utilise compression garments shorts prior to the marathon. To avoid introducing a confounding factor, participants in the compression garment group were asked to run at least once in the compression garments shorts prior to the 2019 Winelands Marathon. This enabled them to get some form of familiarisation with the upper leg compression garments and prevented compression garments from impacting their usual running routine.

3.9.3 Performance measurement

3.9.3.1 Race performance

Possibly the most important finding from this study is that no statistically significant findings were detected between the groups for overall race pace. No previous studies have specifically investigated the use of upper leg compression garments in aiding performance. However, two previous studies investigated the use of compression garments socks in terms of performance and found no benefits utilising compression garments to aid performance (Geldenhuys et al., 2019; Welman, 2011).

The participants personal best marathon times were taken in consideration when assessing performance in the current study. The participants were of recreational standard and had general slow race times. With the hilly profile of the race, there is a high percentage of downhill running. This should theoretically make any beneficial effect from compression garments more pronounced because the downhill sections have the greatest impact on the lower extremity, as it invokes a high proportion of eccentric muscle action on the muscle of the upper leg such as the Quadriceps muscle and results in negative signs and symptoms associated with EIMD (Hill et al., 2014; Eston et al., 1995). Marcora and Bosio (2007) found that there was a decrease in running performance when EIMD is present. According to the findings the compression garments did not benefit the runners and results were similar to the control group.

Based on the findings of the study it supports the theory that compression garments provide no added performance benefits in endurance running.

3.9.4 Main exercise-induced muscle damage outcome measures

3.9.4.1 Circumference measurements

Both groups followed a similar trend in mid-thigh circumference from initial baseline testing to the final testing two days post-race. There were no statistically significant differences between the groups in mid-thigh circumference. In both groups, the mid-thigh circumference increased from baseline testing to the final testing two days post-race but was not statistically significant. Girth circumferences of limbs tend to typically increase after strenuous activity has taken place and it is most pronounced in the first 48 hrs post exercise and the increase can last for up to a period of 10 days (Hill et al., 2014; Welman, 2011). The increase in overall mid-thigh circumference in the current study and in past studies has been theorised to be associated with tissue swelling and potential inflammation induced by exercise (Kramer et al., 2004; Clarkson & Hubal, 2002). Furthermore, it has been theorised that an increase in girth circumference is associated with tissue swelling and potential inflammation which is regarded as a result of muscle damage (Kramer et al., 2004). Other potential theories related to an increase in mid-thigh circumference although not significant in this study, can be a result of reduced sweat loss or increased consumption of fluids during the race compared to the control group (Cheuvront et al., 2007). The control group's decrease in mid-thigh circumference can be potentially a result of decrease in body weight (mass) directly post-race as a result of decreased hydration status and increased sweat loss (Lara et al., 2017; Del Coso et al., 2013; Cheuvront, Montain & Sawka, 2007).

However, upper leg compression garments had no greater impact than the control group regarding mid-thigh circumference changes.

No previous studies investigating upper leg compression garments assessed the changes in mid-thigh circumference. However, based on MacRae et al. (2011) theory of compression garments improving venous return, reducing venous pooling and promoting the removal of metabolites, due to the muscle pump function, we can deduce that the results of this study did not support this theory. The most muscle damage is found in the thigh muscle in endurance runners. Therefore, it is assumed that change will most likely be detected.

Kramer et al. (2004) stated that the lower limb compression garments must exert a pressure between 60mm and 100mmHg to increase blood flow. The equipment to measure the external pressure of the compression garments was not available in this study which may potentially impact the thigh circumference measurements in the compression garment group, as perhaps the pressure could be insufficient to exert an effect or alternatively could be too high.

Based on the findings in the current study, there appears to be no evidence that compression garments help reduce swelling in the thigh that is associated with EIMD. Therefore, there is no evidence that upper leg compression is beneficial.

3.9.4.2 Subjective pain rating measurements

3.9.4.2.1 VAS pain ratings

The main findings of the current study were found within the VAS pain rating outcome measure with a number of statistically significant findings in favour of the compression garment group on resting hamstring VAS pain rating score, hip extension and knee flexion movements immediately post-race. Interestingly, all three significant findings were detected for both left and right legs making it more likely that this is a 'real' finding as both legs had similar findings. This finding was in contrast to Geldenhuys et al. (2019), in which side differences were found between left and right sides within movements, although these findings were in a study evaluating effectiveness of compression socks, not upper leg compression garments. Such differences may have been associated with road camber. Furthermore, the above mentioned statistically significant findings in the current study were carried over to two days post-race and this indicates clinically that the compression garments have a protective effect on pain ratings for a minimum period of 48hrs post completion of a marathon. Overall resting hamstring and knee flexion pain ratings were significantly reduced in the compression garment group compared to the control group. This is of positive significance because athletes who struggle with hamstring pain post-race can alleviate their pain by utilising upper leg compression garments while running. According to van Gent et al. (2007) endurance athletes are prone to hamstring injuries (pain and stiffness) and therefore, this finding supports the use of upper leg compression garments to reduce hamstring pain.

The reduction in VAS pain ratings at two days post-race supports the findings of Hill et al. (2014), in which muscle soreness was reduced in marathon runners when utilising compression garments. However, participants in Hill et al. (2014) study utilised compression garments in their recovery phase. The participants' VAS pain ratings were assessed similarly to the current study as the participants were required to perform movement-based tests and report on their pain (Hill et al., 2014). The reduction in VAS pain ratings can be attributed to the ability of the compression garment group to recover more rapidly and effectively. As stated previously by Hill et al. (2014) the sensation of muscle soreness is suggested to be as a result of mechanical damage to the tissue, which causes structural damage resulting in inflammation. It is suggested that compression garments create an external pressure gradient that decreases the available space for swelling and this prevents secondary inflammation from occurring (Kraemer et al., 2004). In general terms, the compression garment group had lower VAS pain ratings scores for all movements observed two days post-race. Similar studies to the current study specifically investigating upper leg compression garments in endurance runners have not assessed VAS pain ratings in their participants (Mizuno et al., 2017; Venckunas et al., 2014; Miyamoto & Kawakami, 2014; Barwood et al., 2013; Rugg & Sternlicht, 2013; Goh et al., 2011; Dascombe et al., 2011; Bringard et al., 2006).

The use of the VAS pain rating scale to report on subjective pain finding has been found to have a high reliability and validity in acute pain (Bijur et al., 2001). Based on the findings of the current study, it suggests the use of upper leg compression garments during running is beneficial as it can assist with specific recovery of the hamstring muscle post-race within the first 48 hrs and reduce inflammation associated with EIMD. The practical importance of this may be limited unless it extends to long distance training runs, as runners who have participated in a marathon race will move into a recovery phase of training, and thus it is of limited importance whether or not the wearing of compression garments during a race marginally speeds up recovery.

3.9.4.2.2 Likert scale for muscle soreness

No previous studies have utilised the Likert scale for determination of muscle soreness when investigating the use of upper leg compression garments in endurance runners. To our knowledge this is the first study to utilize this subjective assessment assessing muscle soreness. Previous studies have used a Likert scale-based assessment to measure thermal comfort levels in participants utilizing compression garments (Venckunas et al., 2014; Bringard et al., 2006). In the current study, no statistically significant findings were detected between the groups. However, a common trend was detected between the groups, in that both groups, the Likert scale for determination of muscle soreness decreased from directly post-race to two days post-race. Interestingly, the control group reported a lower Likert scale for muscle soreness median score of 3.50 compared to the compression garment group score of 4. It would be anticipated that the compression garment group would report lower scores with the use of compression garments. However, the compression garment had a greater drop of 2.50 in the Likert score for muscle soreness two day's post-race compared to the control group who only decreased by 0.50 to 3.00. Although the findings were not found to be statistically significant, it is likely the compression garment group was able to recover more rapidly in terms of muscle soreness as seen with the VAS pain ratings. Nevertheless, based on the findings we cannot make inferences as these were not statistically significant. Further research will be needed using the Likert scale for determination of muscle soreness as a subjective tool in investigating the use of compression garments to aid recovery.

3.9.5 Contributing factors

Participants in the current study were not prohibited from utilising specific recovery modalities or other nutritional and fluid strategies used commonly by runners to improve the ecological validity of the study. Previous studies have restricted participants specifically using recovery aids such as NSAIDS, massage and cold-water immersion (Hill et al., 2014). Other restrictions have included strenuous activities, training, alcohol and caffeine (Mizuno et al., 2017; Goh et al., 2014). These restrictions would isolate the impact of compression garments on recovery and would eliminate a confounding factor from impacting the results. However, the lack of restriction and allowing normal pre-race preparation in the current study mimics real life race situations.

The drop-out rate of participants in each group was similar after baseline testing. One participant in the control group was unable to complete the 2019 Winelands Marathon as he suffered a hamstring injury and one participant in the compression garment group did not attend testing immediately post-race for unknown personal reasons.

To limit the impact of confounding variables, a thorough training history, compression garment utilisation history, menstruation cycle history, nutritional and fluid intake history and muscle recovery strategies were taken into consideration. No statistically significant findings were detected for the above-mentioned factors and the results were similar between groups and thus the impact, if any, would have been similar in both groups.

3.9.6 Race day conditions

The race-day weather conditions of the 2019 Wineland Marathon were relatively hot, the maximum temperature was 30°C and a low of 17°C with clear skies. The race started at 05:30 in the morning, as race organisers generally take account of hot weather conditions later in the day. There is lack of consensus on the effects of compression garments on body temperature, however, compression garments can be worn in hot temperatures without negatively or positively affecting the performance of runners (Barwood et al., 2013; Dascombe et al., 2011). Thus, it is unlikely that our results would have been influenced by environmental condition on the day.

Chapter 4: Conclusion

4.1 Summary

Despite the lack of scientific knowledge on the physiological and biomechanical effects of wearing compression garments, there has been an increase in the use of compression garments in endurance running (Davies et al., 2009). A randomised controlled intervention study was conducted to compare the performance, pain and thigh circumference changes in endurance runners using upper leg compression garments while competing against runners who did not use compression garments in the same marathon. The results of the study found some indication for the use of upper leg compression garments during marathon. There is one principal finding from the study that impacts EIMD. The finding advocates for the use of upper leg compression garments to aid recovery post-race. The runners wearing upper leg compression garments during the marathon showed signs of improvement in VAS pain ratings for hamstring at rest, knee flexion and hip extension immediately post-race and two days post-race. The results suggest that upper leg compression garments have a perceived pain protective effect on the hamstring muscle in runners in the first 48hrs post-race.

However, there is no evidence that the use of upper leg compression garments during marathon running aids race performance. Furthermore, no statistically significant differences were detected for the other EIMD measures (i.e. mid-thigh circumference and muscle soreness) between the groups.

Therefore, there is evidence to support the use of upper leg compression garments during marathon running for the purpose of hamstring muscle recovery post-race, but from a practical application point of view, the slight improvement in recovery post-race is probably of limited value as runners will have a short rest phase anyway following a marathon race.

4.2 Practical application

According to Welman (2011) recovery is theorised as an important component to allow for successful training and performance. Furthermore, EIMD signs and symptoms can hamper performance, and to counter the impact an appropriate and adequate recovery modality is needed. The current study supports the use of upper leg compression garments to aid the process of reducing pain-ratings post-race in the hamstring muscle. If the findings of reduction of muscle soreness within the compression garment group extends to long training runs over 30km, this will enable them to return to training faster. For example, if a runner did a long training run on the weekend using upper leg compression garments, they might be able to do a high intensity speed session on the following Tuesday and another high intensity run later in the week. Otherwise, the first high intensity session may only be done on the Wednesday after the weekend long training run, with the result that only one high intensity session can be done in a training week instead of potentially two session being completed.

4.3 Study limitations

Many past studies have used a smaller sample size than the current study and it is rare to find a study investigating upper leg compression garments utilizing a sample size bigger than 18 (Mizuno et al., 2017; Venckunas et al., 2014; Barwood et al., 2013; Rugg & Sternlicht, 2013; Goh et al., 2011; Dascombe et al., 2011; Bringard et al., 2006). However, although the sample was bigger than previous studies, the sample size of 18 is smaller than the sample size determination. Participants dropout was the main reason the study failed to reach the required number of participants. It was calculated that a sample size of 38 was needed. The current study failed to achieve this and as a result it makes it difficult to make broad inferences.

The ideal pressure of compression garments is 15mmHg or alternatively referred to as medium-pressure compression garments. Benefits of the medium-pressure compression garments have been stated to include reduced heart rate, reduction of metabolic parameters, reduced changes in muscle structure and reduction of the inflammatory process (Mizuno et al., 2017; Miyamoto et al., 2014; Dascombe et al., 2011). However, in the current study the pressure exerted by the compression garments on the individual participants was not measured as a result of financial constraints as stated in the discussion (section 3.3.4.2). This is an important factor as all participants are different in body size and shape and individualised compression garments would be ideal. Therefore, there is a possibility that the compression garments did not provide enough compression. Furthermore, the measurement of pressure of the compression garments would make it easier to replicate the study and this can be achieved if substantial funding is available.

The current study only assessed perceived muscle soreness utilising VAS pain rating and Likert scale for determination of muscle soreness and mid-thigh circumference which are not direct objective measures of EIMD. In future research blood markers or muscle biopsy could be utilised. Furthermore, future studies should assess baseline VAS pain ratings and the Likert scale for determination of muscle soreness scores to eliminate the potential of pre-race muscle damage impacting scores.

The study utilised recreational type marathon runners, future research should utilize elite marathon runners.

Reference List

Abe, T., Kumagai, K., & Brechue, W. (2000). Fascicle length of leg muscles is greater in sprinters than distance runners. *Medicine and Science in Sports and Exercise, 32(*6), 1125-1129.

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

Amann, M., Hopkins, W., & Marcora, S. (2008). Similar sensitivity of time to exhaustion and time-trial time to changes in endurance. *Medicine and Science in Sports and Exercise, 40*(3), 574.

Amelink, G., & Bär, P. (1986). Exercise-induced muscle protein leakage in the rat: effects of hormonal manipulation. *Journal of the Neurological Sciences, 76*(1), 61-68.

Areces, F., Salinero, J., Abian-Vicen, J., González-Millán, C., Ruiz-Vicente, D., Lara, B., Lledo, M., & Del Coso, J. (2015). The use of compression stockings during a marathon competition to reduce exercise-induced muscle damage: are they really useful? Journal of orthopaedic & sports physical therapy, 45(6), 462-470.

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

Bär, P., Amelink, G., Oldenburg, B., & Blankenstein, M. (1988). Prevention of exercise-induced muscle membrane damage by oestradiol. *Life Sciences, 42*(26), 2677-2681.

Barnett, A. (2006). Using recovery modalities between training sessions in elite athletes. *Sports Medicine, 36*(9), 781-796.

Barwood, M., Corbett, J., Feeney, J., Hannaford, P., Henderson, D., Jones, I., & Kirke, J. (2013). Compression garments: no enhancement of high-intensity exercise in hot radiant conditions. *International Journal of Sports Physiology and Performance, 8*(5), 527-535.

Baxter, C., Mc Naughton, L., Sparks, A., Norton, L., & Bentley, D. (2017). Impact of stretching on the performance and injury risk of long-distance runners. *Research in Sports Medicine, 25*(1), 78-90.

Beliard, S., Chauveau, M., Moscatiello, T., Cros, F., Ecarnot, F., & Becker, F. (2015). Compression garments and exercise: no influence of pressure applied. *Journal of Sports Science & Medicine, 14*(1), 75.

Bijur, P., Silver, W., & Gallagher, E. (2001). Reliability of the visual analog scale for measurement of acute pain. *Academic Emergency Medicine, 8*(12), 1153-1157.

Bolognese, J., Schnitzer, T., & Ehrich, E. (2003). Response relationship of VAS and Likert scales in osteoarthritis efficacy measurement. *Osteoarthritis and Cartilage, 11*(7), 499-507.

Borresen, J., & Lambert, M. (2008). Autonomic control of heart rate during and after exercise. *Sports Medicine, 38*(8), 633-646.

Brage, S., Brage, N., Franks, P., Ekelund, U., & Wareham, N. (2005). Reliability and validity of the combined heart rate and movement sensor Actiheart. *European Journal of Clinical Nutrition*, *59*(4), 561-570.

Brancaccio, P., Lippi, G., & Maffulli, N. (2010). Biochemical markers of muscular damage. *Clinical Chemistry and Laboratory Medicine, 48*(6), 757-767.

Bringard, A., Perrey, S., & Belluye, N. (2006). Aerobic energy cost and sensation responses during submaximal running exercise-positive effects of wearing compression tights. *International Journal of Sports Medicine, 27*(5), 373-378.

Byrne, C., & Eston, R. (2002). The effect of exercise-induced muscle damage on isometric and dynamic knee extensor strength and vertical jump performance. *Journal of Sports Sciences, 20*(5), 417-425.

Byrne, C., Twist, C., & Eston, R. (2004). Neuromuscular function after exercise-induced muscle damage. *Sports Medicine, 34*(1), 49-69.

Cheuvront, S. N., Carter, R., DeRuisseau, K. C., & Moffatt, R. J. (2005). Running performance differences between men and women. *Sports Medicine, 35*(12), 1017-1024.

Crichton, N. (2001). Visual analogue scale (VAS). *Journal of clinical nursing*, *10*(5), 706-6.

Clarkson, P., & Hubal, M. (2001). Are women less susceptible to exercise-induced muscle damage?

Current Opinion in Clinical Nutrition & Metabolic Care, 4(6), 527-531.

Clarkson, P., & Hubal, M. (2002). Exercise-induced muscle damage in humans. *American Journal of Physical Medicine & Rehabilitation, 81*(11), S52-S69.

Close, G., Kayani, A., Vasilaki, A., & McArdle, A. (2005). Skeletal muscle damage with exercise and aging. *Sports Medicine, 35*(5), 413-427.

Comrades marathon association. (2020). Race history. Comrades. https://www.comrades.com/index.php/home/home-nav-a/history

Currell, K., & Jeukendrup, A. (2008). Validity, reliability and sensitivity of measures of sporting performance. *Sports Medicine, 38*(4), 297-316.

Dascombe, B., Hoare, T., Sear, J., Reaburn, P., & Scanlan, A. (2011). The effects of wearing undersized lower-body compression garments on endurance running performance. *International Journal of Sports Physiology and Performance, 6(*2), 160-173.

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

Dawson, A., Steele, E., Hodges, P., & Stewart, S. (2009). Development and test–retest reliability of an extended version of the nordic musculoskeletal questionnaire (NMQ-E): a screening instrument for musculoskeletal pain. *The journal of pain*, *10*(5), 517-526.

Deurenberg, P., Yap, M., & Van Staveren, W. (1998). Body mass index and percent body fat: a meta-analysis among different ethnic groups. *International Journal of Obesity, 22*(12)*,* 1164.

Doan, B., Kwon, Y., Newton, R., Shim, J., Popper, E., Rogers, R., Bolt, L., Robertson, M & Kraemer, W. (2003). Evaluation of a lower-body compression garment. *Journal of Sports Sciences, 21(*8), 601-610.

Downie, W., Leatham, P., Rhind, V., Wright, V., Branco, J., & Anderson, J. (1978). Studies with pain rating scales. *Annals of the Rheumatic Diseases, 37*(4), 378-381.

Duffield, R., Edge, J., Merrells, R., Hawke, E., Barnes, M., Simcock, D., & Gill, N. (2008). The effects of compression garments on intermittent exercise performance and recovery on consecutive days. *International Journal of Sports Physiology and Performance, 3(*4), 454-468.

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

Dupont, A., Sauerbrei, E., Fenton, P., Shragge, P., Loeb, G., & Richmond, F. (2001). Real-time sonography to estimate muscle thickness: Comparison with MRI and CT. *Journal of Clinical Ultrasound, 29*(4), 230-236

Durnin, J., & Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *British Journal of Nutrition, 32*(1), 77-97.

Engel, F., Holmberg, H., & Sperlich, B. (2016). Is there evidence that runners can benefit from wearing compression clothing? *Sports Medicine, 46*(12), 1939-1952.

Engel, F., Stockinger, C., Woll, A., & Sperlich, B. (2016). Effects of compression garments on performance and recovery in endurance athletes. *Compression garments in sports: athletic performance and recovery*, 33-61.

Eston, R., Mickleborough, J., & Baltzopoulos, V. (1995). Eccentric activation and muscle damage: biomechanical and physiological considerations during downhill running. *British Journal of Sports Medicine, 29*(2), 89-94.

Faulkner, J., Larkin, L., Claflin, D., & Brooks, S. (2007). Age-related changes in the structure and function of skeletal muscles. *Clinical and Experimental Pharmacology and Physiology, 34*(11), 1091-1096.

Felty, C., & Rooke, T. (2005). Compression therapy for chronic venous insufficiency. *Vascular Surgery, 18*(1), 36-40.

FinishTime. https://finishtime.co.za/. [DOA:11/2019].

Francis, P., Whatman, C., Sheerin, K., Hume, P., & Johnson, M. I. (2019). The proportion of lower limb running injuries by gender, anatomical location and specific pathology: a systematic review. Journal of sports science & medicine, 18(1), 21.

Frankovich, R., & Lebrun, C. (2000). Menstrual cycle, contraception, and performance. *Clinics in Sports Medicine,19*(2), 251-271.

French, D., Thompson, K., Garland, S., Barnes, C., Portas, M., Hood, P., & Wilkes, G. (2008). The effects of contrast bathing and compression therapy on muscular performance. *Medicine and Science in Sports and Exercise, 40*(7), 1297-1306.

Gatchel, R., Peng, Y., Peters, M., Fuchs, P., & Turk, D. (2007). The biopsychosocial approach to chronic pain: scientific advances and future directions. *Psychological Bulletin, 133*(4), 581.

Geldenhuys, A., Swart, J., & Bosch, A. (2019). Investigation of the impact of below-knee compression garments on markers of exercise-induced muscle damage and performance in endurance runners: A prospective randomized controlled trial. *Sports health*, *11*(3), 254–264. https://doi.org/10.1177/1941738119837644

Giles, D., Draper, N., & Neil, W. (2016). Validity of the Polar V800 heart rate monitor to measure RR intervals at rest. *European Journal of Applied Physiology*, *116*(3), 563-571

Gill, N., Beaven, C., & Cook, C. (2006). Effectiveness of post-match recovery strategies in rugby players. B*ritish Journal of Sports Medicine, 40*(3), 260-263.

Gleeson, M., Blannin, A., Walsh, N., Field, C., & Pritchard, J. (1998). Effect of exercise-induced muscle damage on the blood lactate response to incremental exercise in humans. *European Journal of Applied Physiology and Occupational Physiology*, *77*(3), 292-295.

Goh, S., Laursen, P., Dascombe, B., & Nosaka, K. (2011). Effect of lower body compression garments on submaximal and maximal running performance in cold (10 C) and hot (32 C) environments. *European Journal of Applied Physiology, 111*(5), 819-826.

González-Alonso, J., Crandall, C., & Johnson, J. (2008). The cardiovascular challenge of exercising in the heat. *The Journal of Physiology, 586*(1), 45-53.

Gross, M., McGrain, P., Demilio, N., & Plyler, L. (1989). Relationship between multiple predictor variables and normal knee torque production. *Physical Therapy, 69*(1), 54-62.

Gupta, A., Bryers, J., & Clothier, P. (2015). The effect of leg compression garments on the mechanical characteristics and performance of single leg hopping in healthy male volunteers. *Biomedical Central Sports Science, Medicine and Rehabilitation, 7*(1), 10.

Harland, N., Dawkin, M., & Martin, D. (2015). Relative utility of a visual analogue scale vs a six-point Likert scale in the measurement of global subject outcome in patients with low back pain receiving physiotherapy. *Physiotherapy, 101*(1), 50-54.

Hartley, S., & MacLean Jr, W. (2006). A review of the reliability and validity of Likert-type scales for people with intellectual disability. *Journal of Intellectual Disability Research, 50(*11), 813-827.

Harty, P., Cottet, M., Malloy, J., & Kerksick, C. (2019). Nutritional and supplementation strategies to prevent and attenuate exercise-induced muscle damage: A brief review. *Sports Medicine Open, 5*(1), 1.

Havenga, J. (2020). Winelands marathon 2020. Retrieved from https://www.roadrunning.co.za/event/Winelands-Marathon-2020

Hawker, G., Mian, S., Kendzerska, T., & French, M. (2011). Measures of adult pain: Visual analog scale for pain (vas pain), numeric rating scale for pain (nrs pain), mcgill pain questionnaire (mpq), short-form mcgill pain questionnaire (sf-mpq), chronic pain grade scale (cpgs), short form-36 bodily pain scale (sf-36 bps), and measure of intermittent and constant osteoarthritis pain (icoap). *Arthritis Care & Research,63*(11), 240-252.

Hill, J. A., Howatson, G., Van Someren, K. A., Walshe, I., & Pedlar, C. R. (2014). Influence of compression garments on recovery after marathon running. *The Journal of Strength & Conditioning Research, 28(8),* 2228-2235.

Howastson, G., & Van Someren, K. (2008). The prevention and treatment of exercise-induced muscle damage. *Sports Medicine, 38*(6), 483-503.

Jamieson, S. (2004). Likert scales: how to (ab) use them. *Medical Education, 38*(12), 1217-1218.

Jeukendrup, A., Saris, W., Brouns, F., & Kester, A. (1996). A new validated endurance performance test. *Medicine and Science in Sports and Exercise, 28*(2), 266-270.

Joshi, A., Kale, S., Chandel, S., & Pal, D. K. (2015). Likert scale: explored and explained. *Current journal of applied science and technology*, 396-403.

Juhn, M. S. (2002). Ergogenic aids in aerobic activity. *Current Sports Medicine Report, 1*(4), 233-8.

Juhn, M. S. (2003). Popular sports supplements and ergogenic aids. S*ports Medicine, 33*(12), 921-939.

Kawakami, Y., Abe, T., & Fukunaga, T. (1993). Muscle-fiber pennation angles are greater in hypertrophied than in normal muscles. *Journal of Applied Physiology, 74*(6), 2740-2744.

Kellmann, M., Beckmann, J., Bertollo, M., Bosquet, L., Brink, M., Coutts, A., Duffield, R., Erlacher, D., Halson, S., Hecksteden, A., Heidari, J., Meeusen, R., Mujika, I., Robazza, C., Skorski, S., Venter, R., & Kallus, K. (2018). Recovery and performance in sport: consensus statement. *International Journal of Sports Physiology and Performance, 13*(2), 240-245.

Köksal, M., Ertekin, P., & Çolakoglu, Ö. (2014). How differences among data collectors are reflected in the reliability and validity of data collected by likert-type scales? *Educational Sciences: Theory and Practice, 14*(6), 2206-2212.

Kraemer, W., Bush, J., Bauer, J., Tripleft-McBride, N., Paxton, N., Clemson, A., Perry Koziris, L., Mangino, L., Fry, A., & Newton, R. (1996). Influence of compression garments on vertical jump performance in NCAA Division I volleyball players. *Journal of Strength and Conditioning Research, 10*, 180-183.

Kraemer, W., Bush, J., Triplett-McBride, N., Perry Koziris, L., Mangino, L., Fry, A., McBride, J., Johnston, J., Volek, J., Gomez, A., Newton, R., & Young, C. (1998). Compression garments: Influence on muscle fatigue. *Journal of Strength and Conditioning Research, 12*, 211-215.

Kraemer, W., French, D., & Spiering, B. (2004). Compression in the treatment of acute muscle injuries in sport. *International Sport Medicine Journal, 5*(3), 200-208.

Laursen, P., Francis, G., Abbiss, C., Newton, M., & Nosaka, K. (2007). Reliability of time-to-exhaustion versus time-trial running tests in runners. *Medicine and Science in Sports and Exercise, 39*(8), 1374-1379.

Lebrun, C., McKenzie, D., Prior, J., & Taunton, J. (1995). Effects of menstrual cycle phase on athletic performance. *Medicine and Science in Sports and Exercise, 27*(3), 437-444.

Levels, K., de Koning, J., Foster, C., & Daanen, H. (2012). The effect of skin temperature on performance during a 7.5-km cycling time trial. *European Journal of Applied Physiology, 112*(9), 3387-3395.

Lieberman, D., & Bramble, D. (2007). The evolution of marathon running. *Sports Medicine*, *37*(4-5), 288-290.

Lim, C. L., Byrne, C., & Lee, J. K. (2008). Human thermoregulation and measurement of body temperature in exercise and clinical settings. *Annals Academy of Medicine Singapore*, *37*(4), 347.

Lozano, L., García-Cueto, E., & Muñiz, J. (2008). Effect of the number of response categories on the reliability and validity of rating scales. *Methodology, 4*(2), 73-79.

MacRae, B., Cotter, J., & Laing, R. (2011). Compression garments and exercise. *Sports Medicine, 41*(10), 815-843.

Marcora, S., & Bosio, A. (2007). Effect of exercise-induced muscle damage on endurance running performance in humans. *Scandinavian Journal of Medicine & Science in Sports, 17*(6), 662-671.

Marfell-Jones, M., Stewart, A., & De Ridder, J. (2012). *International standards for anthropometric assessment.* International Society for the Advancement of Kinathropometry.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *The Journal of Strength & Conditioning Research*,*18*(3), 551-555.

Marqués-Jiménez, D., Calleja-González, J., Arratibel, I., Delextrat, A., & Terrados, N. (2016). Are compression garments effective for the recovery of exercise-induced muscle damage? A systematic review with meta-analysis. *Physiology & Behaviour, 153,* 133-148.

McCormack, H., David, J., & Sheather, S. (1988). Clinical applications of visual analogue scales: a critical review. *Psychological Medicine, 18*(4), 1007-1019.

Milani, R., Lavie, C., Mehra, M., & Ventura, H. (2006). Understanding the basics of cardiopulmonary exercise Testing. *Mayo Clinic Proceedings 81*(12), 1603-1611.

Miyamoto, N., & Kawakami, Y. (2014). Effect of pressure intensity of compression short-tight on fatigue of thigh muscles. *Medicine and Science in Sports and Exercise, 46*(11), 2168-2174.

Mizuno, S., Morii, I., Tsuchiya, Y., & Goto, K. (2016). Wearing compression garment after endurance exercise promotes recovery of exercise performance. *International Journal of Sports Medicine, 37*(11), 870-877.

Mizuno, S., Arai, M., Todoko, F., Yamada, E., & Goto, K. (2017). Wearing lower-body compression garment with medium pressure impaired exercise-induced performance decrement during prolonged running. *PLos One, 12*(5).

Newton, R. (1996). Influence of compression garments on vertical jump performance in NCAA Division I volleyball players. *Journal of Strength and Conditioning Research, 10*, 180-183.

Nummela, A., Heath, K., Paavolainen, L., Lambert, M., Gibson, A., Rusko, H., & Noakes, T. (2008). Fatigue during a 5-km running time trial. *International Journal of Sports Medicine, 29*(09), 738-745.

Oosthuyse, T., & Bosch, A. (2017). The Effect of Gender and Menstrual Phase on Serum Creatine Kinase Activity and Muscle Soreness Following Downhill Running. *Antioxidants, 6(1),* 16.

O'Sullivan, K., Sainsbury, D., & O'Connor, R. (2009). Measurement of thigh muscle size using tape or ultrasound is a poor indicator of thigh muscle strength. *Isokinetics and Exercise Science, 17*(3), 145-153.

Persky, A., Greene, P., Stubley, L., Howell, C., Zaulyanov, L., Brazeau, G., & Simpkins, J. (2000). Protective effect of estrogens against oxidative damage to heart and skeletal muscle In vivo and in vitro (44463). *Proceedings of the Society for Experimental Biology and Medicine*, *223*(1), 59-66.

Pillen, S., Arts, I., & Zwarts, M. (2008). Muscle ultrasound in neuromuscular disorders. *Muscle & nerve: Official Journal of the American Association of Electrodiagnostic Medicine, 3*7(6), 679-693.

Raj, I., Bird, S., & Shield, A. (2012). Reliability of ultrasonographic measurement of the architecture of the vastus lateralis and gastrocnemius medialis muscles in older adults. *Clinical Physiology and Functional Imaging, 32*(1), 65-70.

Ravier, G., Bouzigon, R., Beliard, S., Tordi, N., & Grappe, F. (2018). Benefits of compression garments worn during handball-specific circuit on short-term fatigue in professional players. *The Journal of Strength & Conditioning Research, 32*(12), 3519-3527.

Rugg, S., & Sternlicht, E. (2013). The effect of graduated compression tights, compared with running shorts, on countermovement jump performance before and after submaximal running. *The Journal of Strength & Conditioning Research, 27*(4), 1067-1073

Saunders, P., Pyne, D., Telford, R., & Hawley, J. (2004). Factors affecting running economy in trained distance runners. *Sports Medicine, 34*(7), 465-485.

Sawka, M., Wenger, C., Young, A., & Pandolf, K. (1993). Physiological responses to exercise in the heat. *Nutritional Needs in Hot Environments: Applications for Military Personnel in Field Operations*, 55.

Scanlan, A., Dascombe, B., Reaburn, P., & Osborne, M. (2008). The effects of wearing lower-body compression garments during endurance cycling. *International Journal of Sports Physiology and Performance, 3*(4), 424-438.

Schattke, S., Xing, Y., Lock, J., Brechtel, L., Schroeckh, S., Spethmann, S., Baumann, G., Borges, A., & Knebel, F. (2014). Increased longitudinal contractility and diastolic function at rest in well-trained amateur Marathon runners: a speckle tracking echocardiography study. *Cardiovascular Ultrasound, 12*(1), 11.

Sorichter, S., Mair, J., Koller, A., Calzolari, C., Huonker, M., Pau, B., & Puschendorf, B. (2001). Release of muscle proteins after downhill running in male and female subjects. *Scandinavian Journal of Medicine & Science in Sports, 11*(1), 28-32.

Struhár, I., Kumstát, M., & Králová, D. (2018). Effect of compression garments on physiological responses after uphill running. *Journal of human kinetics*, *61*(1), 119-129.

Taylor, R., Jayasinghe, U., Koelmeyer, L., Ung, O., & Boyages, J. (2006). Reliability and validity of arm volume measurements for assessment of lymphedema. *Physical Therapy, 86*(2), 205-214.

Tiidus, P. (1995). Can estrogens diminish exercise induced muscle damage? *Canadian Journal of Applied Physiology, 20*(1), 26-38.

Van Gent, R., Siem, D., van Middelkoop, M., Van Os, A., Bierma-Zeinstra, S., & Koes, B. (2007). Incidence and determinants of lower extremity running injuries in long distance runners: A systematic review. *British Journal of Sports Medicine, 41*(8), 469-480.

Venckunas, T., Trinkūnas, E., Kamandulis, S., Poderys, J., Grunovas, A., & Brazaitis, M. (2014). Effect of lower body compression garments on hemodynamics in response to running session. The Scientific World Journal, 2014.

Walton, J., Roberts, N., & Whitehouse, G. (1997). Measurement of the quadriceps femoris muscle using magnetic resonance and ultrasound imaging. *British Journal of Sports Medicine, 31*(1), 59-64.

Warburton, D., Jamnik, V., Bredin, S., & Gledhill, N. (2011). The physical activity readiness questionnaire for everyone (PAR-Q+) and electronic physical activity readiness medical examination (ePARmed-X+). *The health & fitness journal of canada*, *4*(2), 3-17.

Webber, L., Byrnes, W., Rowland, T., & Foster, V. (1989). Serum creatine kinase activity and delayed onset muscle soreness in prepubescent children: a preliminary study. *Paediatric Exercise Science, 1(*4), 351-359.

Welman, K. (2011). *The value of graduated compression socks as a post-exercise recovery modality in long distance runners* (Doctoral dissertation, Stellenbosch: University of Stellenbosch).

Wilson, P. (2016). Does carbohydrate intake during endurance running improve performance? A critical review. *The Journal of Strength & Conditioning Research*, *30*(12), 3539-3559.

Yu, J., Jeong, J., & Lee, B. (2015). Evaluation of muscle damage using ultrasound imaging. *Journal of Physical Therapy Science, 27*(2), 531-534.

Appendices

Appendix A: Human Research Ethics Committee Approval

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E53-46 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6626
Email: shuretta.thomas@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

15 April 2019

HREC REF: 208/2019

A/Prof Andrew Bosch
Sport Science Institute

Dear A/Prof Bosch

PROJECT TITLE: DOES THE USE OF UPPER LEG COMPRESSION GARMENTS AID PERFORMANCE AND REDUCE POST-RACE DOMS? (SUB-STUDY LINKED TO 872/2016) (MSC CANDIDATE: MR K KABONGO)

Thank you for submitting your response to the Faculty of Health Sciences Human Research Ethics Committee.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until 30 April 2020.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

The HREC acknowledge that the student, Ken Kabonga will also be involved in this study.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
NHREC-registration number: REC-210208-007

HREC 208/2019

UNIVERSITY OF CAPE TOWN

HUMAN RESEARCH ETHICS COMMITTEE
15 MAY 2020

FACULTY OF HEALTH SCIENCES
Human Research Ethics Committee

FHS016: Annual Progress Report / Renewal

HREC office use only (FWA00001637; IRB00001938)			
This serves as notification of annual approval, including any documentation described below.			
☑ Approved	Annual progress report	Approved until/next renewal date	30.05.2021
☐ Not approved	See attached comments		
Signature Chairperson of the HREC		Date Signed	17/5/2020

Comments to PI from the HREC

Principal Investigator to complete the following:

1. Protocol information

Date (when submitting this form)	06 March 2020		
HREC REF Number	208/2019	Current Ethics Approval was granted until	30 April 2020
Protocol title	Does the use of upper leg compression garments aid performance and reduce post-race DOMS?		
Protocol number (if applicable)			
Are there any sub-studies linked to this study?	☐ Yes ☐XNo		
If yes, could you please provide the HREC Ref's for all sub-studies? **Note:** A separate FHS016 must be submitted for each sub-study.			
Principal Investigator	Prof AN Bosch		
Department / Office Internal Mail Address	UCT Div of Exercise Science & Sports Med Sports Science Institute Building, Boundary Rd, Newlands		

(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)

1.1 Does this protocol receive US Federal funding?	☐ Yes	☐ XNo
1.2 If the study receives US Federal Funding, does the annual report require full committee approval? **Note:** Any annual approvals for **Full Committee** review MUST be submitted on the monthly HREC submission dates. (Please send electronic copy for full committee review to hrec-enquiries@uct.ac.za)	☐ Yes	☐ XNo

If yes in 1.2 please complete section 1.3 below for invoicing purposes	
1.3 Annual Approval for **full committee** review	- R 3450 (inclusive of vat)
For invoicing purposes, please provide:	
Sponsor's name	
Contact person	
Address	
Telephone number	
Email Address	

2. List of documentation for approval

3. Protocol status (tick ✓)

☐	Open to enrolment
☐✓	Closed to enrolment (tick ✓)
☐	Research-related activities are ongoing
☐	Research-related activities are complete, long-term follow-up only
☐✓	Research-related activities are complete, data analysis only
☐	Main study is complete but sub-study research-related activities are ongoing
☐	Study is closed → Please submit a Study Closure Form (FHS010)

4. Enrolment

Number of participants enrolled to date	40
Number of participants enrolled, since last HREC Progress report (continuing review)	

(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)

Additional number of participants still required	0

5. Refusals

Total number of refusals (participants invited to join the study, but refused to take part)	0

6. Cumulative summary of participants

Total number of participants who provided consent	40
Number of participants determined to be ineligible (i.e. after screening)	1
Number of participants currently active on the study	0
Number of participants completed study (without events leading to withdrawal)	18
Number of participants withdrawn at participants' request (i.e. changed their mind)	19
Number of participants withdrawn by PI due to toxicity or adverse events	0
Number of participants withdrawn by PI for other reasons (e.g. pregnancy, poor compliance)	0
Number of participants lost to follow-up. Please comment below on reasons for loss of follow-up.	1
Participant did not attend follow up, so was excluded from the study	
Number of participants no longer taking part for reasons not listed above. Please provide reasons below:	1
Did not complete the marathon event, so could not be included in the study	

7. Progress of study

Please provide a brief summary of the research to date including the overall progress and the progress since the last annual report as well as any relevant comments/issues you would like to report to the HREC:
Data collection has been completed, busy with Data analysis. Study to be completed by June 2020.

8. Protocol violations and exceptions (tick ✓ all that apply)

☐✓	No prior violations or exceptions have occurred since the original approval
☐	Prior violations or exceptions have been reported since the last review and have already been acknowledged or approved

(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)

☐	Unreported minor violations that have occurred since the last review, as well as significant deviations not yet reported, are attached for review

9. Amendments (tick ✓ all that apply)

☐	No prior amendments have been made since the original approval
☐✓	Prior amendments have been reported since the last review and have already been approved
☐	New protocol changes/ amendments are requested as part of this continuing review (See note below)

Note: If new protocol changes are being requested in this review, please complete an amendment form (FHS006).
Specific changes in the amended protocol and consent/assent forms must be **bolded**, *italicised* or tracked and all changes must include a rationale.

10. Adverse events

10.1 Please provide below or attach a narrative summary of serious adverse events and/ or unanticipated problems since the last progress report. Please indicate changes made to the protocol and informed consent document(s) as a result (if not already reported to the HREC). Please comment on whether causality to any study procedure or intervention could be established.
None

10.2 Have participants received appropriate treatment/ follow-up/ referral when indicated (e.g. in the case of abnormal or incidental clinical findings, distress or anxiety)?		
☐ Yes	☐ No	☐ ✓ Not applicable
If yes, please describe:		

11. Summary of Monitoring and Audit Activities (tick ✓)

11.1 Was this study monitored or audited by an external agency (e.g. SAHPRA, FDA)?		
☐ Yes	☐ No	☐ ✓ Not applicable

11.2 Did a Data and Safety Monitoring Board publish a report?		
☐ Yes	☐ No	☐ ✓ Not applicable

11.3 If yes, please identify the agency and attach a summary of the findings.					
Agency Name		Report attached	☐ Yes	☐ No	☐✓ Not applicable
		DSMB report attached	☐ Yes	☐ No	☐✓ Not applicable

(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)

11.4 Has there been any agency, institutional or other inquiry into non-compliance in this study, or any finding of non-compliance concerning a member of the research team?	
☐ Yes	☐ ✓No
If yes, please explain:	

12. Level of risk (tick ✓)

12.1 In light of your experience of this research, please indicate whether the level of risk to participants has:	
☐	Increased
☐	Decreased
☐✓	Shown no change
If there has been a change, please explain:	
N/A	

12.2 Please provide a narrative summary of recent relevant literature that may have a bearing on the level of risk.
N/A

13. Statement of conflict of interest

Has there been any change in the conflict of interest status of this protocol since the original approval? (tick ✓)	
☐ Yes	☐✓ No
If yes, please explain and if necessary, attach a revised conflict of interest statement (Section #7 in the New Protocol Application Form FHS013):	

14. Signature

My signature certifies that the above is complete and correct.			
Signature of PI		Date	6/03/20

(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)

Appendix B: Advertisement

Appendix C: Informed consent

University of Cape Town

Faculty of Health Sciences

Department of Health and Rehabilitation Sciences

Divisions of Communication Sciences and Disorders;
Nursing and Midwifery; Occupational Therapy;

Consent to participate in a research study: Does the use of upper leg compression garments aid performance and reduce post-race delayed onset muscle soreness (DOMS).

Dear Participant

You are invited to participate in a research study being conducted by Ken Kabongo, an MSc student in Exercise and Sports Physiotherapy, under the supervision of Associate Professor Andrew Bosch from the Division of Exercise Science and Sport Medicine (ESSM) at the University of Cape Town (UCT). Information obtained within the study will be used by the MSc student for his dissertation.

The aim of the study: Is to investigate any association between compression of the upper leg by a “compression garment” on muscle soreness and the running performance of endurance runners competing in a marathon road race. A key aspect of the study will be to compare the performance of endurance runners using upper leg compression garments while competing against runners who do not use compression garments in the same marathon race.

Background: In recent years,’ strategies to reduce symptoms of Exercise Induced Muscle Damage (EIMD) and recovery processes have been investigated and implemented to help improve performance of endurance athletes. EIMD results in delayed onset muscle soreness after taking part in unaccustomed exercise, particularly prolonged exercise or in an exercise that requires a lot of muscle lengthening. For runners, this would be a race such as a marathon or ultra-marathon in an attempt to prevent or reduce muscle soreness several post exercise recovery strategies have been used and researched, including massage, stretching, cryotherapy, foam rolling, electrotherapy, Nonsteroidal anti-inflammatories (NSAIDS) and nutritional supplementation. Recently, runners have started using compression garments in an attempt to promote recovery, and this had led to an increase in interest in whether the use of compression garments during races improves performance and recovery.

<u>**Why are we using compression garments?**</u>

There is limited knowledge and conflicting literature on the use of compression garments in terms of performance and recovery benefits. Some studies have shown benefits, most have not. However, most of these studies were not well designed. In the study we are going to do, we will use upper leg compression garments to see if doing so offers any benefits to race performance and also recovery after a race.

We will be testing the effects of upper leg compression garments compared to runners not wearing upper leg compression garments on:

- Your running performance in terms of how fast you finish a marathon
- Your level of muscle soreness after a marathon and two days after
- Mid-thigh size differences before and after a marathon

Details of participants: <u>Who can volunteer?</u>

We invite male and female runners to participate in this research study if you:

- Are between the ages of 20-45 years;
- Have entered the Winelands Marathon (42.2km race) for 2019;
- Are running a minimum of 50km per week;
- Have completed one marathon in the 18 months preceding the start of data collection.

Do I have to take part: You are under no obligation to take part in this research study; participation is voluntary. However, if you decide to take part, you will be required to read and keep this information sheet and sign the consent form at the end. You may withdraw from the research at any time, without giving any reason.

What will happen to me if I take part: <u>What does the study involve?</u>

You will be randomly allocated to one of the groups, either the group who will compete in the upper leg compression garments or the group who will not compete with the upper leg compression garments.

The study will be divided into three visits. In each of the three visits a questionnaire will be administered to record information regarding the upper leg compression garment shorts utilisation; your training details during the six-week training period prior to the Winelands Marathon; your information regarding fluid and nutrition during the race; your recovery modalities utilised; your menstrual cycle and contraceptive pill usage (female participants); and lastly record of any of the difficulties encountered during the Winelands Marathon (such as muscle cramps, etc).

Procedures: **<u>What will you do in each exercise session?</u>**

Your first visit which will be three days prior to the Winelands Marathon at the Sports Science Institute, situated in Newlands, Cape Town. You will be required to complete the Nordic Screening questionnaire and Physical Activity Readiness Questionnaire. This will evaluate if you are injury free and medically fit to participate in the study. Your body mass and stature will be measured for descriptive purposes. Girth measurements of the mid-thigh and skin fold measurements of the thigh will be measured. The Likert scale for determination of muscle soreness will be completed. Visit one will take approximately 30 minutes to complete. On your second visit, which will happen directly post completion of the Winelands Marathon at the finish line of the race, girth measurements and pain ratings score using the Visual analogue scale and Likert scale for determination of muscle soreness will be measured. Visit two will take approximately 10 minutes to complete. The third visit will be two days after the Winelands Marathon, at the Sports Science Institute. Girth measurements, pain ratings scores will be done. Race times from the Finish Time timing chip will be obtained from the Winelands Marathon website, and this will be utilised to calculate your average race pace for the overall race pace. Visit three will take approximately 10 minutes to complete. Participants will receive water as a refreshment at all three visits, and an energy drink if required at the assessment done at the finish of the race.

Study Timing: The study will commence prior to the race and will be completed after the race in November 2019.

Cost of participation: There will be no costs to you for taking part in this study.

Compensation: Your participation in the study is voluntary, without financial remuneration.

Benefits of the study: The findings will be useful in advising endurance athletes of whether or not there are any benefits from using upper leg compression garments on performance and/ or recovery. The overall study findings will also be made known to you once all data collection and analysis has been completed.

Risks of the study: There will be minimal/no risks to you from wearing the compression garments and the testing procedures also pose minimal/no risk to you. During the race there will be the standard medical teams based at different locations along the race route as described in the race literature if any medical emergencies occur. If any medical emergency should occur when testing at the Sports

Science Institute, such as falling while in the building, this will be attended to by a doctor on site and managed accordingly.

Confidentiality: Reference to your data obtained throughout the study will be kept anonymous by using a number code and only the researchers will have access to the codes.

What happens if I get hurt taking part in this study?

There is minimal to no risk with participation in this study. Nevertheless, risk will be minimized by a standard questionnaire (PAR-Q) to assess readiness to participate in exercise. This is over and above the screening on entering the race. There will be insurance policy cover for participants who are injured during the study. The insurance will be administered by the University of Cape Town.

The insurer will pay for all reasonable medical costs required to treat your bodily injury, according to the South African Good Clinical Practice Guidelines 2006, which is based on the Association of the British Pharmaceutical Industry Guidelines. The insurer will pay without you having to prove that the research was responsible for your bodily injury.

If you are harmed and the insurer pays for the necessary medical costs, usually you will be asked to accept the insurance payment as full settlement of the claim for medical costs. However, accepting this offer of insurance cover does not mean you give up your right to make a separate claim for other losses based on negligence, in a South African court.

The University will not be liable for any loss, injuries and/or harm that you may sustain where the loss is caused by

- The use of banned medicine or substances during the study.
- Failure to follow instructions or protocol given to you by me.
- Negligence that results in injury.

It is your duty to report incidents immediately to the researchers and to comply to the instruction given by researchers.

Questions:

If you have any queries, please feel free to contact any of the individuals listed below. Do not hesitate to call me if any problems arise on the following number:

Ken Kabongo 0793387826

Should you have and further queries, feel free to contact:

Associate Professor A. Bosch

Physical Address: Division of Exercise Science & Sports Medicine

Department of Human Biology

Sports Science Institute of South Africa

University of Cape Town

Boundary Road

Newlands 7700

Tel number: 021 650 4578

E-mail: andrew.bosch@uct.ac.za

If you have any questions or concerns about your rights or welfare as a research participant, please contact Professor Marc Blockman,

Chairperson of the Faculty of Health Sciences Research and Ethics Committee

(Tel: 021 406 6492).

By accepting to participate in the study, it serves as confirmation that you have understood the consent form and that you are willing to participate in this study. You have the right to withdraw at any time, you may ask questions at any time during the study and all the information recorded will be confidential. Your confirmation to participate is an approval that you are aware of the possible risks involved in this study.

Do you provide your consent to take part in this study?

(Investigator to initial option selected by participant)

Yes

No

Investigator declaration

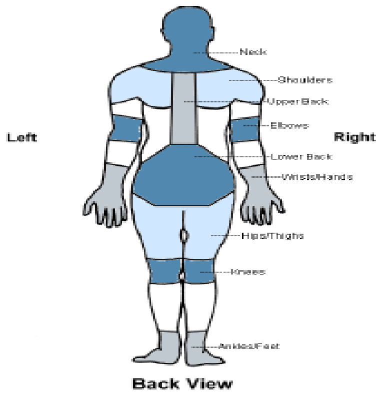
I hereby confirm that (insert participant name) did/did not consent to take part in the study.

Signature of Investigator Name (Please Print) Date

Appendix D: Nordic Musculoskeletal Questionnaire

How to answer the questionnaire:

Picture: In this picture you can see the approximate position of the parts of the body referred to in the table. Limits are not sharply defined, and certain parts overlap. You should decide for yourself in which part you have or have had your trouble (if any).



Name:

Gender:

How long have been running for?

How many hours do you run for each week?

Instructions: If you have any questions ask. Column 1 of the questionnaire is to be answered even if you have never had trouble in any part of your body; Column 2 and 3 are to be answered if you answered yes in column 1

To be answered by everyone (Please circle appropriate answer)	**To be answered by those who have had trouble (Please circle appropriate answer)**	**To be answered by those who have had trouble (Please circle appropriate answer)**
Have you at any time during the last 12 months had trouble (ache, pain discomfort, numbness) in:	Have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble?	Have you had trouble at any time during the last 7 days?
Lower back (small of back) Yes/No	Yes/No	Yes/No
One or Both Hips/Thighs Yes/No	Yes/No	Yes/No
One or Both Knees Yes/No	Yes/No	Yes/No
One or Both Ankles/Feet Yes/No	Yes/No	Yes/No

Appendix E: Physical Activity Readiness-Questionnaire+

CSEP approved Sept 12 2011 version

PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

SECTION 1 - GENERAL HEALTH

	Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1.	Has your doctor ever said that you have a heart condition OR high blood pressure?	☐	☐
2.	Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?	☐	☐
3.	Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4.	Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?	☐	☐
5.	Are you currently taking prescribed medications for a chronic medical condition?	☐	☐
6.	Do you have a bone or joint problem that could be made worse by becoming more physically active? Please answer NO if you had a joint problem in the past, but it does not limit your current ability to be physically active. For example, knee, ankle, shoulder or other.	☐	☐
7.	Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.

Go to Section 3 to sign the form. You do not need to complete Section 2.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow the Canadian Physical Activity Guidelines for your age (www.csep.ca/guidelines).
- You may take part in a health and fitness appraisal.
- If you have any further questions, contact a qualified exercise professional such as a CSEP Certified Exercise Physiologist® (CSEP-CEP) or CSEP Certified Personal Trainer® (CSEP-CPT).
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the questions above, please GO TO SECTION 2.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes – please answer the questions on Section 2 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity programme.

CSEP | SCPE

 1 / 4

SECTION 2 - CHRONIC MEDICAL CONDITIONS

		Please read the questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1.		Do you have Arthritis, Osteoporosis, or Back Problems?	☐ If yes, answer questions 1a-1c	☐ If no, go to question 2
	1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	☐	☐
	1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	☐	☐
2.		Do you have Cancer of any kind?	☐ If yes, answer questions 2a-2b	☐ If no, go to question 3
	2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck?	☐	☐
	2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	☐	☐
3.		Do you have Heart Disease or Cardiovascular Disease? This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm	☐ If yes, answer questions 3a-3e	☐ If no, go to question 4
	3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	3b.	Do you have an irregular heart beat that requires medical management? (e.g. atrial fibrillation, premature ventricular contraction)	☐	☐
	3c.	Do you have chronic heart failure?	☐	☐
	3d.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure)	☐	☐
	3e.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	☐	☐
4.		Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes	☐ If yes, answer questions 4a-4c	☐ If no, go to question 5
	4a.	Is your blood sugar often above 13.0 mmol/L? (Answer YES if you are not sure)	☐	☐
	4b.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?	☐	☐
	4c.	Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?	☐	☐
5.		Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome)	☐ If yes, answer questions 5a-5b	☐ If no, go to question 6
	5a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	5b.	Do you also have back problems affecting nerves or muscles?	☐	☐

CSEP | SCPE

Please read the questions below carefully and answer each one honestly: check YES or NO.			YES	NO
6.	Do you have a Respiratory Disease? This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure		☐ If yes, answer questions 6a-6d	☐ If no, go to question 7
	6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	6b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	☐	☐
	6c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	☐	☐
	6d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	☐	☐
7.	Do you have a Spinal Cord Injury? This includes Tetraplegia and Paraplegia		☐ If yes, answer questions 7a-7c	☐ If no, go to question 8
	7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	7b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	☐	☐
	7c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	☐	☐
8.	Have you had a Stroke? This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event		☐ If yes, answer questions 8a-c	☐ If no, go to question 9
	8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	8b.	Do you have any impairment in walking or mobility?	☐	☐
	8c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	☐	☐
9.	Do you have any other medical condition not listed above or do you live with two chronic conditions?		☐ If yes, answer questions 9a-c	☐ If no, read the advice on page 4
	9a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?	☐	☐
	9b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	☐	☐
	9c.	Do you currently live with two chronic conditions?	☐	☐

Please proceed to Page 4 for recommendations for your current medical condition and sign this document.

CSEP | SCPE

PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active:

- It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP or CSEP-CPT) to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually – 20-60 min. of low- to moderate-intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate-intensity physical activity per week.
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the follow-up questions about your medical condition:

- You should seek further information from a licensed health care professional before becoming more physically active or engaging in a fitness appraisal and/or visit a or qualified exercise professional (CSEP-CEP) for further information.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise profesional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes - please talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity programme.

SECTION 3 - DECLARATION

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The Canadian Society for Exercise Physiology, the PAR-Q+ Collaboration, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.
- Please read and sign the declaration below:

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME ______________________________ DATE ______________________________

SIGNATURE ______________________________ WITNESS ______________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________________

For more information, please contact
Canadian Society for Exercise Physiology
www.csep.ca

KEY REFERENCES

1. Jamnik VJ, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.

2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

CSEP | SCPE

Appendix F: Self developed screening tool

Department of Health and Rehabilitation Sciences

Faculty of Health Sciences

Divisions of Communications Sciences and Disorders,

Nursing and Midwifery, Occupational Therapy, Physiotherapy

F45 Old Main Building, Groote Schuur Hospital

Name of Participant: ___________________________

To assess if you qualify/do not qualify to participate in the research study: ***"Does the use of compression garments aid performance and reduce post-race DOMS?"***, please complete the following questionnaire.

- **Definition: Medical consultation refers to a visit to:** Doctor, Pharmacist, Physiotherapist, Biokineticist, Chiropractor, Nutritionist, Massage therapist and any other profession not mentioned

A. Please tick the appropriate statement with an "X".

Do the following statements apply to you?	Yes	No
1.Between the age 20 and 45 years?		
2.Have you completed 1 marathon in the past 18 months?		
3.Have a weekly average mileage above 50km's?		
4.Have you entered and are you planning to run the Winelands Marathon (42.2 km) in 2019?		
5.Would you be willing to have data collection performed on three occasions (3 days prior to, at the finish line and 2 days following the Winelands Marathon)?		

If you have answered "Yes" to all the above questions, please proceed to the next section to confirm that none of the following questions may apply to you.

A. Please tick the appropriate question with an "X".

Do the following questions apply to you?	Yes	No
In the past 3 months have you experienced aching, discomfort, pain or abnormal sensations in your legs that necessitated a medical consultation?		
In the 3 months have you been diagnosed and/or received treatment for any injuries or have known damage to your muscles, bones or nerves that necessitated a medical consultation?		
In the past 3 months have you required medical treatment for any previous injuries to your muscles, bones or nerves in your legs that still bothers you (e.g. causes pain regularly)?		
Do you suffer from any known medical conditions or complications relating to your nervous system, muscles, skeleton, heart or hormones that would inhibit safe participation and that may impact on your running performance?		
Are current routinely using compression garments or would you be opposed to training/competing with/without compression garments provided depending on group allocation?		

If you have answered "No" to all the above questions, you have qualified to participate in this study

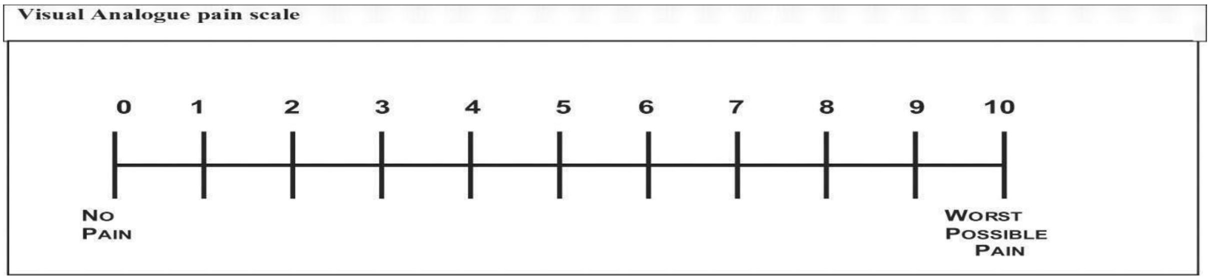
Appendix G: Visual Analogue Scale

Name of Participant: _____________________________ Group number: 1 2

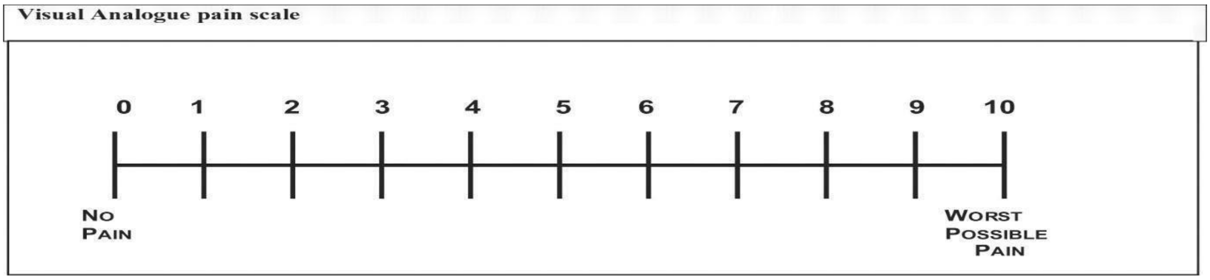
To assess your pain level, please circle the appropriate number.

<u>Adapted Visual Analogue Scale</u>

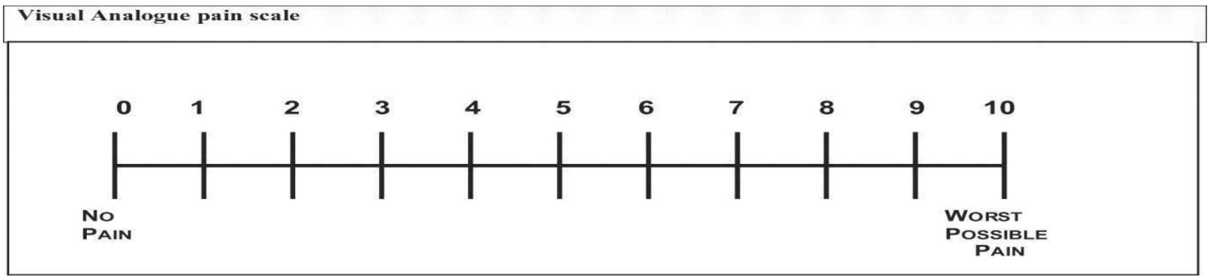
1. While sitting comfortably on a chair, what are your pain levels in the front of your upper leg?



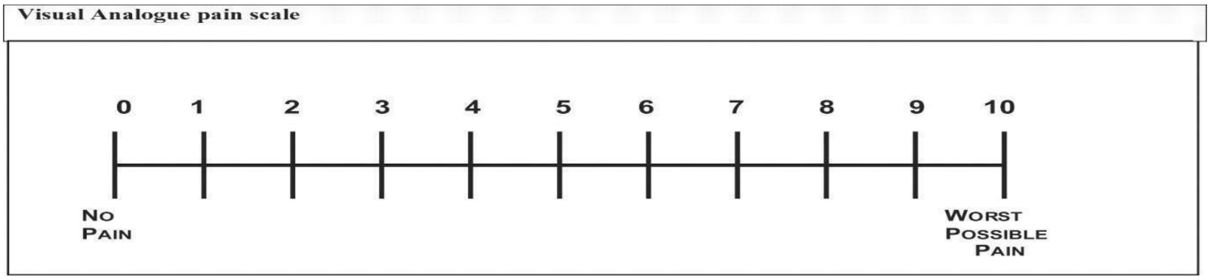
2. While sitting comfortably on a chair, what are your pain levels in the back of your upper leg?



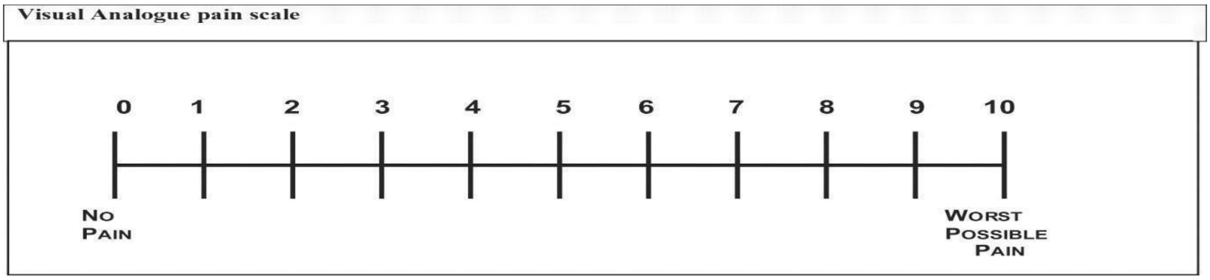
3. What are your pain levels when you bend your knee while standing?



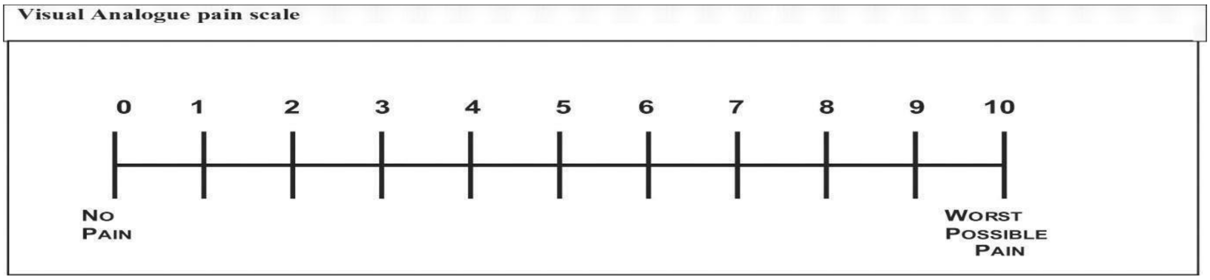
4. What are your pain levels when you straighten your knee up while standing?



5. What are you pain levels when you bring your leg forward while keeping knee straight in standing?



6. What are your pain levels when take your leg backward while keeping you knee straight in standing?



Appendix H: Likert Scale for muscle soreness

Name of Participant: ___________________________ Group number: 1 2

To assess your muscle soreness, please tick the appropriate sentence below that best describes your level of muscle soreness currently

[ ] 0 A complete absence of soreness

[ ] 1 A light pain felt only when touched / a vague ache

[ ] 2 A moderate pain felt only when touched / a slight persistent pain

[ ] 3 A light pain when walking up or down stairs

[ ] 4 A light pain when walking on a flat surface / painful

[ ] 5 A moderate pain, stiffness or weakness when walking / very painful

[ ] 6 A severe pain that limits my ability to move

Appendix I: Self developed questionnaire

Self-designed Questionnaire: Demographics, Training and race history, Recovery Strategies, Nutrition & Fluid intake and Menstrual cycle.

*The information stated in this questionnaire will only be used for this study. All information will remain strictly confidential. This questionnaire will be used in conjunction with the vas scale.

Please answer each question in the space provided or by checking the boxes as appropriate. Please ask for help if you do not understand any of the questions.

Investigator: Ken Kabongo

Email: kkabongo03@gmail.com

Supervisor: Associate Professor Andrew Bosch

Email: Andrew.Bosch@uct.ac.za

Please complete the following sections:

Section A: Demographics (Visit 1)

Section B: Training and race History (Visit 1)

Section C: Recovery Strategies (Visit 1,2,3)

Section D: Compression garment usage (Visit 1)

Section E Nutritional & Fluid intake (Visit 2)

Section F: Menstrual Cycle (Females only) (Visit 2)

Section A: Demographics

Name:	
Gender:	
Group allocation:	

Section B: Training and race history

Questions:	**Answers**
How many years have you been running for?	
How many marathons (42km) have you run?	
What is your personal best time for: – Marathons	
How many weekly runs have you done in the past 6 weeks?	
What was your average weekly mileage in km's in the past 6 weeks?	
What was your average running duration (min) per training session per week in the past 6 weeks?	
What was your longest running duration (min) in the past 6 weeks	
Do you participate in any form of strength training (Weight training/CrossFit etc.)? If yes, please state how often in the week you do it	
Do you participate in any form of alternate cardio (swimming/cycling etc.)? If yes, please state how often in the week you do it	
Do you participate in any form of flexibility exercise (yoga/stretch class? If yes, please state how often in the week you do it	
Do you participate in any team sport (Soccer, netball rugby etc.)? If yes, please state how often in the week you do it	
Do you participate in any form of skill specific development (Agility, stability, Pilates etc.)? If yes, please state how often in the week you do it	
Do you participate in any other form of exercise? If yes, please state how often in the week you do it	

Section C: Recovery strategies

Questions:	**Answers**
Have you taken pain medication (Oral/IV) in the past two days? If yes, please state when, how many times and for how long	
Have you had a drip in the past two days? If yes, please state when, how many times and for how long	
Have you taken Anti-inflammatories in the past two days? If yes, please state when, how many times and for how long	
Have you used any form of recovery ointment in the past two days? If yes, please state when, how many times and for how long	
Have you gone for a massage in the past two days? If yes, please state when, how many times and for how long	
Have you stretched in the past two days? If yes, please state when, how many times and for how long	
Have you used a foam roller the past two day? If yes, please state when, how many times and for how long	
Have you taped yourself in the past two days? If yes, please state when, how many times and for how long	
Have you used ice in the past two days? If yes, please state when, how many times and for how long	
Have you taken any nutritional supplements in the past two days? If yes, please state when, how many times and for how long	
Have you used any form of electrotherapy in the past two days? If yes, please state when, how many times and for how long	
Have you used any other form of recovery strategy not mentioned above in the past two days? If yes, please state when, how many times and for how long	

Section D: Compression garment usage

Please select all the appropriate statements regarding your compression garment usage over the last 6 weeks (more than one may apply).

	I did not wear compression garments at all during training.
	I used the compression garments occasionally during my runs.

	I used the compression garments for half of my runs.
	I used the compression garments for most of my runs.
	I used the compression garments for all my runs.
	I used the compression garments only during my long runs.
	I did not use the compression garments during my long runs.
	I used the compression garments for one or two runs per week.
	I used the compression garments for three or four runs per week.
	I used the compression garments five or six times per week.
	I used the compression garments seven or more times per week.

Section E: Nutritional and fluid intake

1. Please indicate approximately how many units (sachets) of water you consumed during the race? Please tick the most appropriate answer.

0 units/hr	
1-2 units/hr	
3-4 units/hr	
5-6 units/hr	
7-8 units/hr	
9-10 units/hr	
More than 10 units/hr	

2. Please indicate approximately how many units (sachets) of other fluids (e.g. energy drinks, soft drinks, juice) you consumed during the race? Please tick the most appropriate answer.

0 units/hr	
1-2 units/hr	
3-4 units/hr	
5-6 units/hr	
7-8 units/hr	
9-10 units/hr	
More than 10 units/hr	

3. Please indicate which, if any, of the following items were consumed during the race. Please tick all appropriate responses and indicate the number consumed.

Energy bar	
Energy gel	
Other (Please specify)	

Section F: Menstrual cycle **(to be completed by females only)**

1.Are you currently menstruating regularly (at least once every 1 to 2 months)?

YES	**NO**	**Prefer not to answer**

2. If yes, please indicate how long ago (weeks and days) was the onset of your last menses?

____

3.If no, please indicate when was your last menses (month and year)?

____

4. Are you currently taking a contraceptive pill?

YES	**NO**	**Prefer not to answer**

5. If yes, please indicate brand name.

Appendix J: Circumference measurement protocol

Mid-thigh circumference

Testing procedure:

Participants must be sitting over the edge of a chair and be instructed to relax the muscles during testing.

Mid-thigh measurement (mm) - the measurements are taken midway between the trochanterion and lateral border of the tibia, at the mid-trochanterion-tibiale laterale site

Each measurement will be repeated three times and the average will be taken

Appendix K: Data collection summary

Visit 1	**Initial baseline data collection**
Timeframe	Three days prior to 2019 Winelands Marathon
Location of testing	Division of Exercise Science and Sports Medicine (ESSM) within the Department of Biology, University of Cape Town (UCT), located at Sport Science Institute of Sports (SSISA)
Outcome measures	• Height and body mass (BMI) • Body fat % • Pre-race mid-thigh measurements • Racetec finish times (Average race pace) • Screening and questionnaires
Testing duration	± 30 minute slots per participant

.

Visit 2	**Race day data collection**
Timeframe	Immediately post 2019 Winelands Marathon
Location of testing	Laerskool Eikestad, Stellenbosch, Western Cape
Outcome measures	• Post-race mid-thigh measurements • Post-race VAS pain rating • Post-race Likert Scale for muscle soreness • Questionnaires
Testing duration	± 20 minute slots per participant

Visit 3	**Initial baseline data collection**
Timeframe	Two days post 2019 Winelands Marathon race
Location of testing	Division of Exercise Science and Sports Medicine (ESSM) within the Department of Biology, University of Cape Town (UCT), located at Sport Science Institute of Sports (SSISA)
Outcome measures	• Post-race mid-thigh measurements • Post-race VAS pain rating • Post-race Likert Scale for determination of muscle soreness
Testing duration	± 15 - 20 minute slots per participant

Appendix L: Data collection sheet

Name of Participant: ______________________________ Group number: 1 2

To be completed by examiner:

Personal Best Marathon Time (past 18 months): _____________________

Calculated average pace: _____________________

Anthropometric information

	Visit 1
Height (cm)	
Weight (kg)	
BMI	

Body fat percentage (%)

Bicep: __________________

Triceps: __________________

Subscapularis: __________________

Suprailiac: __________________

Total: __________________

Circumference measures

	Visit 1	Visit 2	Visit 3
Mid-thigh Circumference *(cm)*			

Winelands Marathon FinishTime timing results

a. Overall time to 42km: ________________

b. Calculated race pace: ________________