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

Investigation of the impact of compression garments on endurance running performance and exercise induced muscle damage in the lower leg

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2017

Declarations

DECLARATION

I, Alda Grethe Geldenhuys, 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.

Signature Signed by candidate
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Date

_____15 August 2017_

Acknowledgements

"It always seems impossible until it is done."

(Nelson Rolihlahla Mandela)

My praise to God through whom all things are possible.

I would also like to take this opportunity to extend a heartfelt thank you to everyone without whom this study would not have been possible.

To my supervisors, A/Prof Andrew Bosch and Dr Jeroen Swart for sharing their expertise and invaluable knowledge and for providing guidance and assistance with the dissertation.

To the study participants, for their enthusiasm, and for dedicating their invaluable time to be involved in this research project.

To my course convenor, Dr Theresa Burgess, and co-convenor, Ms Kim Buchholtz for the advice, encouragement and support during the degree.

To University of Cape Town's Postgraduate Funding office for kindly granting an academic merit scholarship to enable my studies.

To Mr Brett Phillips for sharing his expertise and dedicating his time to training the researcher in the execution of ultrasound scans.

To Mr Thor Langley for his expertise and execution of the countermovement jump data collection while in South Africa on exchange from the University of Jyväskylä, Finland.

To Mr Trevino Larry for his assistance with logistical and practical arrangement surrounding the data collection period.

To A/Prof Brenda Morrow and Prof Mike Lambert for their valuable guidance with the statistical analysis component of the dissertation.

To the masters class of 2016-2018 for making this challenging journey considerably better with a great mix of comedy, intellectual discussions and kindness along the way.

To my amazing extended family, fantastic friends and all my loved ones who are the best part of my world. A special thanks to my wonderful parents Maretha and Albert, lovely siblings Marli and Norval Geldenhuys and brilliant significant other Byron Mawer, for their irreplaceable support, unconditional love and guidance in all my endeavours. I would be nothing and nowhere without all of you in my life.

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List of abbreviations

°	degrees
ANOVA	analysis of variance
ANCOVA	analysis of covariance
BP	blood pressure
BMI	body Mass Index
CK	creatine kinase
CO_2	carbon dioxide
Cohen's *d*	Cohen's effect size
CMJ	countermovement jump
DOMS	delayed onset muscle soreness
EIMD	exercise-induce muscle damage
EMG	electromyography
HR	heart rate
IL-6	interleukin-6
ILF-1	insulin-like growth factor 1
IL-1	interleukin-1
LT	lactate threshold
Mb	myoglobin
mm	millimetres
MVC	maximum voluntary contraction
MRI	magnetic resonance imaging
n	number of participants
NSAID	non-steroidal anti-inflammatory drug
NWB	non weight bearing
PPO	peak power output
RCT	randomised controlled trial
ROS	reactive oxygen species
ROM	range of motion
RPE	rates of perceived exertion
O_2	oxygen
OMTOM	Old Mutual Two Oceans Marathon
1RM	one-repetition maximum
SD	standard deviation
SEM	standard error of measurement
SWC	smallest worthwhile change
VAS	visual analogue scale
V_E	minute volume
VCO_2	ventilation of carbon dioxide
VO_2	ventilation of oxygen
VO_{2max}	maximal ventilation of oxygen
VO_{2peak}	peak ventilation of oxygen

Glossary of terms

Concentric contraction

This refers to the muscle action leading to shortening of the structure with joint movement[1].

Compression garment

This refers to a type of clothing/material designed to provide pressure to the body part it surrounds (i.e. compression applied to a segment of the body by a garment). Various different types of compression garments have been developed including:

I. Below knee compression garment
   This refers to a compression garment that starts below the knee and encloses the foot (resembling a knee height stocking).
II. Calf sleeve compression garment
   This refers to a compression garment that starts below the knee and ends above the ankle leaving the feet open.
III. Compression shorts
   This refers to compression garments that starts at the pelvis and ends above the knees.
IV. Full leg length compression
   This refers to a compression garment that starts at the pelvis and end above the ankles (resembling a pair of leggings/tights).
V. Whole body compression garment
   This refers to a compression garment that covers the entire body i.e. arms, legs and trunk in one full body suite.
VI. Upper limb sleeve compression garment
   This refers to a compression garment that starts below the armpit (axilla) and ends at the wrist.

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[2].

Eccentric contraction

This refers to the muscle action leading to lengthening of the structure with joint movement[1].

Endurance running

This is defined as the capability to utilise aerobic energy systems to run sustained distances[3].

Ergogenic aid

Any procedure or method related to nutrition, psychology, pharmacology, mechanics or physical science that is utilised to improve physical performance and/or athletic capability[1].

Exercise induced muscle damage

This refers to damage occurring to muscular structures following unaccustomed exercises with manifestations including a reduction in muscle force production, enhanced passive muscle tension, swelling/oedema, muscle pain, decreased range of motion and increased levels of blood proteins and inflammatory markers[4,5]

Isometric contraction

This refers to the muscle action where muscle length remains unchanged and the joint angle static (i.e. force is exerted without any movement occurring)[1].

Muscle thickness

This is defined as the space between the two aponeuroses ((i.e. connective tissue) of a muscle[6].

One Repetition Maximum

This refers to the highest load that can be moved once through full range of motion of a joint with acceptable form and posture before fatigue[1].

Peak power output

This refers to the maximum amount of power (i.e. the rate of performance of work) produced during exercise[1].

Pennation angle

This refers to the angle formed between the muscle aponeurosis and an individual muscle fiber[6].

Abstract

Introduction:

Compression garments utilisation is very popular among runners despite the relative lack of consensus in the literature regarding a beneficial impact.

Methods:

A randomised controlled experimental study was conducted in healthy, uninjured endurance runners (n=41) participating in the Old Mutual Two Oceans 56km race. The experimental group (n=20) trained for six weeks and participated in the race wearing below knee compression garments while the control group (n=21) did not. Participants were tested on four occasions for various markers of exercise induced muscle damage (EIMD) and running performance. Six weeks prior to the race, ultrasound scans of the medial gastrocnemius, mid-calf and figure-of-8 ankle circumference baseline measurements were performed. Shortly prior to the race, these measurements were repeated in addition to a countermovement jump (CMJ) test. Immediately following the race, circumference measurements and CMJ testing were repeated in addition to pain ratings on the visual analogue scale (VAS). Race performance times were also obtained. Two days following the race, the ultrasound scans, circumference measurements and VAS pain ratings were repeated.

Results:

Ankle circumferences measurements increased significantly less (*p=0.01, Cohen's d=0.9*) in the experimental group from immediately after the race until two days post-race compared to the control group. There were no further statistically significant changes over time in any other objective outcome measure (i.e. mean mid-calf circumference, medial gastrocnemius mean muscle thickness and mean pennation angle, mean CMJ height and estimated peak power output nor in race performance) between the experimental and control groups. Selected pain ratings were statistically significantly worse in the experimental group. Muscle thickness and pennation angles were significantly greater in the control group compared to the experimental group two days following the race.

Conclusion:

There were limited indications of a beneficial impact of compression garments with minor improvements in ankle circumference measurements, but no further significant effects related to EIMD were detected. Furthermore, no ergogenic impact was detected. Based on the results of the study, there is limited evidence to support the continued utilisation of commercially available below knee compression garments during running.

CHAPTER 1: Introduction and scope of dissertation

1.1 Introduction

Endurance running is becoming increasingly popular among individuals across a broad spectrum of ages and capabilities[3]. This popularity coincided with an enhanced interest in finding a balance between the health benefits and injury risks associated with endurance running. In addition, methods of improving performance are equally significant due to the competitive nature of humankind.

It is well-established that running, as a form of aerobic exercise, is associated with various health benefits. This includes improved cardiovascular fitness, weight loss or maintenance and enhanced psychological well-being[7]. In addition, regular exercise reduces the risk for the development of diabetes mellitus, obesity, hypertension, various rheumatic conditions, certain types of cancer and depression among others[7].

Conversely, long distance running may be associated with various acute and/or chronic neuromusculoskeletal conditions, with over-use injuries to the lower limb occurring most frequently[8,9]. Arguably, the most common ailment related to endurance running is exercise induced muscle damage (EIMD) which refers to damage occurring to muscular structures following unaccustomed exercise with various manifestations[4,5,10,11]. Signs and symptoms of EIMD include a reduction in muscle force production, enhanced passive muscle tension with decreased range of motion (ROM), swelling/oedema, muscle pain and increased levels of various blood proteins and inflammatory markers[4,5,11]. It is also associated with reduced endurance running performance in subsequent sessions if adequate recovery is not achieved[12].

To encourage continued participation in running and the associated health benefits, various methods have been suggested and investigated in an attempt to decrease the possible detrimental impact of EIMD and a subsequent reduction in performance. Warm-ups, cool-downs and stretching have been performed for several decades and remain common practice with the aim of decreasing injury risk[13–15]. Other methods used in an attempt to counter-act EIMD and/or improve performance with varying success include nutritional strategies, electrotherapy, cryotherapy, non-steroidal anti-inflammatory drugs (NSAIDs), massage, foam rolling, light intensity exercise and, more recently, modalities providing compression[5,16].

Compression garments have become particularly prominent in runners in recent years with the two-fold aim of reducing EIMD and promoting running performance[17]. In a review, it was suggested that compression used therapeutically to reduce muscle damage may be attributed to decreasing oedema, inflammation and pain sensitivity, while promoting circulatory cytokine dissipation post-exercise[11]. However, there is a lack of consensus in available research regarding its impact on both of these factors related to endurance runners[18,19]. Currently, it is unclear if compression garments have a beneficial impact over and above usual sporting attire to justify its popularity[17,19,20]. Further research is required to assess its impact both on performance and EIMD in the endurance running population. The aims and objectives of the current study were developed to shed light on this matter by means of a randomised controlled field experimental study.

1.2 Aim & Objectives

1.2.1 Aim

The aim of this study was to determine the impact of below knee compression garments on running performance and exercise induced muscle damage of the lower legs in an ultramarathon road race in

endurance runners training and competing with below knee compression garments compared to runners competing and training without compression garments.

1.2.2 Objectives

The specific objectives of the study were:

1) To determine if there were significant differences in finish times (in *hours:min)* of an ultramarathon in runners who trained in the final six weeks and participated in the race wearing below knee compression garments (experimental group); compared to runners who neither trained nor participated in the race with compression garments (control group).
    I. To determine if there were significant differences in average running pace (*min/km*) in runners in the experimental and control groups during an ultramarathon.
    II. To determine if there were significant differences in average running pace (*min/km)* in the last 14km (final 25% of 56km) in runners in the experimental and control groups during an ultramarathon.
2) To determine if there were significant differences in mid-calf and ankle circumferences (in c*m*) six weeks before, shortly (from three days) prior to, at the finish line and two days after an ultramarathon in runners in the experimental and control groups.
3) To determine if there were significant differences in pennation angles (in ^{o}) and thickness (in *cm*) of the medial gastrocnemius muscle at 90^{o} ankle plantarflexion six weeks before, shortly (from three days) prior to and two days after an ultramarathon in runners in the experimental and control groups.
4) To determine if there were significant differences in lower leg pain as recorded on the Visual Analogue Scale (VAS) upon completion and two days following an ultramarathon in runners in the experimental and control groups.
    I. To determine if there were significant differences in VAS pain ratings at rest in the anterior and posterior calf and anterior and posterior thigh between groups upon completion of the race and two days following the race.
    II. To determine if there were significant difference in VAS pain ratings with active non-weight-bearing (NWB) plantarflexion, dorsiflexion, knee flexion and knee extension between groups upon completion and two days following the race.
5) To determine if there were significant differences in countermovement jump (CMJ) heights and estimated peak power output (PPO) between runners shortly (from three days) prior to, upon completion and two days following an ultramarathon in runners in the experimental and control groups.

1.3 Plan of Development

To explore this topic further, a comprehensive review of the literature related to compression garment utilisation in sport, and specifically in endurance running, in relation to exercise induced muscle damage and running performance will be presented (Chapter 2). This sets the ground for the randomised controlled field experimental study conducted to investigate the impact of below knee compression garments in endurance runners during training and participation in an ultramarathon event (Chapter 3). Finally, the findings of the study will be summarised and concluding statements will be presented (Chapter 4).

Chapter 2: A review of the literature

2.1 Introduction

2.1.1 Overview

The utilisation of compression garments is increasing exponentially, especially among runners, despite the relative lack of consensus in the literature regarding a beneficial impact[18,19]. This literature review aims to investigate available research regarding compression garments utilised in a sporting environment, with emphasis on endurance running. The impact of compression garments on the body's physiology, with emphasis on intra- and post-exercise muscle damage and the influence thereof on the performance of athletes will be discussed.

2.1.2 Methods

An electronic search of the literature was performed using EBSCO Host (with Academic Search Premier, CINAHL, Health Source, MasterFile Premier and Medline selected), Web of Science and Google Scholar online databases. The key terms utilised to conduct the literature search included: "*compression garments", "compression socks", "compression stockings", "endurance", "sport", "exercise", "run*", "muscle damage", "muscle response", "delayed onset muscle soreness", "exercise induced muscle damage", "physiological response", "performance*" and "*recovery"* for the sections investigating the impact of compression garments in running and various other sports. Another search was performed for prior research at the targeted event using "*Old Mutual Two Oceans Marathon*" and "*run**" as key terms. The instrumentation section included the key terms "*validity", "reliability*" and various instrumentation (i.e. "*ultrasound", "pennation angle", "muscle thickness", "visual analogue scale", "countermovement jump*", *"figure-of-8 ankle measurement", "mid-calf circumference", "time trail"* and *"time-to-exhaustion test").*

Studies with randomisation were prioritised and only those studies where the full text could be retrieved were considered for inclusion. All of the studies were published in academic journals or as academic scripts (i.e. postgraduate dissertations).

2.1.3 Background

Compression garments were originally utilised in medical practice with the aim of promoting circulation for the prevention of venous thrombosis, oedema and the treatment of wounds, scars or venous ulcers[17,21–24]. Increased venous circulation may help to speed up removal of metabolic waste products while improving oxygen supply, enhancing arterial blood flow and decreasing space for swelling[19,20]. Intermittent compression therapy systems have successfully been linked to a reduction in the incidence of deep vein thrombosis in post-operative and/or bedridden patients[25]. However, recent systematic reviews concluded that the use of compression garments in medical practice are not fully supported by available research[26,27].

Compression garments were introduced into the field of sports with the aim of promoting recovery and as a possible ergogenic aid[11]. It is hypothesised to function by counter-acting exercise-induced oedema, enhancing scar tissue pliability, promoting proprioception, maintaining force production and decreasing exercise related pain responses[11]. In theory, the creation of an external pressure gradient through compression decreases space for swelling and provides mechanical support to soft tissue structures[11]. Consequently, an ergogenic effect would theoretically be possible with improved performance during and/or following training and competition while wearing compression garments[28]. It is suggested that any beneficial effect may result from a combination of physical, physiological and psychological factors influenced by compression garments[17].

However, a beneficial impact of compression garments on running related recovery and performance has not been consistently demonstrated by research studies suggesting that the increased popularity thereof may instead be due to anecdotal reports or marketing techniques. To ensure evidence based practice, further high quality research is required.

Findings in the literature:

2.2 Endurance running

2.2.1 Endurance running and the Old Mutual Two Oceans Ultramarathon

Endurance running is becoming increasingly popular with participation in marathons and ultramarathons increasing significantly over time[3]. This increased participation rate naturally coincided with an enhanced interest in minimising any associated detrimental effects and maximising performance.

One notable example is The Old Mutual Two Oceans Marathon (OMTOM) 56km event, hosted yearly in Cape Town, South Africa, over the Easter period. It was started in 1970, with merely 26 runners and has since increased dramatically with the limit of 11 000 entries reached for the year 2017[29]. The route covers 56km on road with an elevation gain of 1501m and an average slope of 3.7%[29]. This race has served as a setting for many previous endurance running related studies[30–33]. For instance, a prospective study performed over a four year period, reported the incidence of medical complications at the event at a rate of 8 per 1000 individuals who started the 21km and 56km OMTOM races[34]. No fatalities occurred in the ultramarathon, compared to two in the half-marathon, although the over-all incidence of medical complications were higher in the prior[34]. The most race related complications were exercise-associated collapse, and various dermatological and musculoskeletal ailments[34]. The large number of runners and other parties involved implies that it is likely to remain a popular setting for future studies.

2.2.2 Exercise-induced muscle damage (EIMD)

2.2.2.1 The impact of EIMD on runners

The health benefits of exercise such as running are well known, with associated reductions in all-cause morbidity and mortality[7]. Conversely, prolonged, novel and/or unaccustomed exercise, particularly with an eccentric (lengthening) component, such as endurance running with long downhill sections, may lead to muscle damage i.e. EIMD with various ramifications[4,5]. The OMTOM 56km sets the field for the development of EIMD due to its prolonged duration with various incline changes.

In general, muscle damage occurs through an initial degenerative phase involving muscle fibre necrosis and increased calcium concentration due to enhanced membrane permeability and is followed by an inflammatory phase with neutrophils and macrophages invading affected areas[35]. The symptomatic manifestations of EIMD include a transient reduction in muscle force production, enhanced passive muscle tension, swelling/oedema, muscle pain – specifically delayed onset muscle soreness (DOMS), decreased range of motion (ROM) and increased concentrations of blood proteins and inflammatory markers[4,5,11]. EIMD signs and symptoms may linger from days to weeks[4]. Pain tends to peak after 2-48hrs and last several days, whereas swelling peaks at 48hrs and remains for up to 10 days[4]. Muscle strength loss usually starts immeadiately and may last for 7-14 days following the precipitating event[4]. After EIMD induction, it has been reported that athletes had reduced performance in countermovement jump, squat jump and drop jump tests[36,37]. A significant decrement in running performance with increased ratings of perceived exertion (RPE) have been recorded in endurance runners[12]. Furthermore, reduced ankle and knee ROM have been reported in runners after induction of DOMS[38].

On a physiological level, Z-line streaming with ruptured myofilaments and sarcolemmas followed by disrupted intra-muscular calcium homeostasis and loss of membrane integrity may occur[5]. Elevated concentrations of myoglobin (Mb), creatine kinase (CK), myosin heavy chain fragment concentration,

lactate dehydrogenase, troponin and aspartate aminotransferase have been recorded following damage-inducing bouts of exercise[4]. Using these as markers of muscle damage may however be problematic due to the vast inter-individual variation in production and clearance rates[4].

In addition, it has been suggested that EIMD may be related to increased concentrations of reactive oxygen species (ROS) released with muscle contractions[35]. There is, however, minimal research to substantiate any lasting muscle damage related to increased ROS concentrations[35]. In healthy muscle tissue, the inflammatory phase is followed by a regeneration phase involving activation and proliferation of undifferentiated, mononuclear satellite cells to facilitate muscle tissue recovery[35]. Recovery methods generally aim to speed up or enhance these processes.

Evidence of EIMD has been observed following numerous running events. Increased concentrations of Mb, CK and interleukin-6 (IL-6) has also been reported following eccentric downhill running[39], a half marathon[40] and an ultramarathon[41]. Increased CK-myoglobin concentrations have also been detected specifically in the gastrocnemius muscle of long distance runners both before and after a marathon[42,43]. Biopsies performed on the gastrocnemius of runners after completing a marathon revealed several ultrastructural signs of muscle damage[42]. This included intra- and extra-cellular oedema, myofibrillar lysis, disruption of T-tubules and focal mitochondrial degeneration to varying degrees[42]. Due to structural differences, the medial gastrocnemius also appears to be at increased risk of muscle damage compared to the lateral gastrocnemius and the soleus[44]. The focus of prior research on the gastrocnemius muscle may also be on account of this muscle being the greatest contributor to force production during the propulsion phase of gait, which is critical during running[45].

2.2.3 Gender and age related differences in EIMD and running performance

Some controversies exist in terms of the difference in muscle responses to exercise between men and women[4]. In animal studies, females seem to have a less pronounced muscle damage response to eccentric exercise compared to males[4]. Human studies indicate that females tend to be more resistant to fatigue with similar intensity isometric contractions[46]. These changes may be attributed to altered gene expression among genders[47] and may also relate to the anti-oxidant protective effect of estrogen in females[48]. In general, a review found that females tend to have lower resting CK concentrations, but the difference in response to exercise in terms of this and other muscle damage markers is less clear between the genders[4]. Based on available research it appears that contrary to animal studies, human females may portray an aggravated initial EIMD response compared to males, but this effect remains minor[4].

It is well-known that average running performance times tend to differ among genders[49]. This may be partly due to the impact of the menstrual cycle on the performance of females[50]. Slightly improved absolute maximum oxygen consumption values have been recorded during the follicular phase compared to the luteal phase[50]. This may be related to increased female steroid hormones during the latter phase[50]. In general, studies have found that females report better athletic performance in the days following menstruation and worse performance in the days preceding menstruation[51]. Furthermore, utilisation of contraceptive medication may further decrease athletic performance[51]. In contrast, it appears that females may have less musculoskeletal injuries when utilising oral contraceptives[51].

Age related changes to muscle recovery mechanisms have been widely described between the elderly and the very young[35,52], hence muscle responses following exercises is likely to differ. With age, muscles tend to become smaller in cross-sectional area with associated reductions in force

production[35]. Muscle fibre degeneration tends to start at approximately 50 years of age and progresses gradually with older age[53]. Muscle atrophy occurs particularly in the type 2 fast glycolytic muscle fibres, with the relative proportion of type 1 slow oxidative fibres being maintained better[35]. Performance decrements appear to be inevitable even in trained marathon athletes where running performance decreases at approximately 40 years of age[53]. Animal studies have also demonstrated a prolonged duration of EIMD in older individuals compared to their younger counter-parts[35]. Human studies are limited due to ethical concerns, but it is anticipated that damage may be more severe and recovery extended in older adults[35]. This may be partly due to a reduction in the number of satellite cells in muscle tissue[35].

2.2.4 Methods to reduce EIMD

EIMD may cause difficulty in subsequent exercise performance and may impact on the compliance to exercise programmes[5], which may have repercussions through loss of health benefits as well as decreasing performance in competitions. Some of the methods, other than compression, used in an attempt to reduce EIMD and therefore counter-act these possible repercussions include antioxidant supplementation, β-Hydroxy-β-Methylbutyrate, electrotherapy, cryotherapy, ample carbohydrate and adequate protein intake, non-steroidal anti-inflammatory drugs (NSAID), analgesics, massage, stretching and low intensity exercise prescription[5,10]. Nutritional supplements such as protein, anti-oxidants and β-Hydroxy-β-Methylbutyrate may help to prevent or reduce EIMD if taken long-term[5]. However, there is limited evidence to support the use of these supplements if a well-balanced diet is followed[1]. NSAID's and analgesics may help reduce symptoms short-term but NSAID's may also inhibit recovery long-term[5,10]. Massage seems to decrease subjective pain ratings, but evidence is limited for any impact on subsequent performance measures[5]. Similarly, stretching has been found to have very limited or no impact on the incidence of DOMS[54]. There is also very limited support for the continued utilisation of cryotherapy, electrotherapy and high carbohydrate supplementation in the management of EIMD at present[5,55]. Gentle exercise has been suggested as a valuable method to reduce EIMD related pain, but it appears to have a limited impact long term[5,55]. More recently, the use of foam rollers after exercise has become popular. In one study, foam rolling was associated with reductions in lower limb pain and performance decrements following exercise compared to a control group and may therefore be promising as a recovery modality[16].

2.2.5 Methods to maximise performance

There is considerable overlap between recovery aids and performance enhancement methods, as improved recovery may enable improved subsequent performance as well as more rapid return to training following prolonged, intensive training sessions or competitions.

Other than compression, possible legal ergogenic aids utilised during running include caffeine, carbohydrate loading techniques, certain nutritional supplements and anti-oxidants[56]. Banned substances include anabolic steroids, erythropoietin, human growth hormones and insulin-like growth factor 1 (ILF-1) among others[56,57]. This review focused on those aids that can be used reasonably safely and are permitted in running competitions. Caffeine was prohibited in the past, but is now permitted and may enhance aerobic exercise performance, whereas creatine and pyruvate have no clear impact on activities such as endurance running[58]. Carbohydrate supplementation during running appears to enhance endurance capacity and performance[59]. This may relate to the maintenance of increased carbohydrate oxidation and inhibition of the development of hypoglycaemia[59]. Furthermore, runners who mouth-rinsed with a 6.4% carbohydrate-electrolyte solution significantly increased the distance covered in one hour of running compared to placebo mouth-rinsing, which may relate to a centrally

governed mechanism influencing the perception of exertion[60]. A well-balanced, nutritious diet is required for health and performance purposes, however additional anti-oxidants, amino acids or protein supplementation do not appear to have an additive impact on performance[58]. Stretching, also sometimes suggested as ergogenic aid, has not been linked to improved performance and may even reduce running economy[54].

Compression garments were introduced into the field of running related recovery and performance more recently than many other methods and its impact remains contentious. Studies investigating these factors will be discussed in more depth in the sections that follow.

2.2.6 Summary of the literature: Endurance running

Endurance running participation is increasing over time. Although the health benefits are numerous and commendable, endurance runners are at increased risk of injuries and exercise induced muscle damage. EIMD is associated with pain, swelling, reduced ROM, altered biochemical parameters and performance decrements among others. It appears to be prominent among long distance runners. Many attempts have been made to counter-act these possible detrimental effects and optimise running performance with varying success rates. Compression garments has become prominent among these methods in recent years. The following sections will investigate available literature regarding their impact on exercise induced muscle damage and sports performance.

2.3 Compression Garments in Runners

The lack of consensus in available studies currently confound interpretation[17,20]. Other confounding factors include the vast array of compression garments made by different manufacturers, varying pressure levels, anatomical areas of application, duration and timing of utilisation[17,19]. In addition, a diverse range of subjects with different age groups, genders and training statuses, as well as various sports and outcomes measures have been used for assessments[17,19]. Based on available systematic reviews, it appears there may be some beneficial effect of compression garments as a recovery method, although many studies have found no effects on recovery and a marginal impact on sporting performance[11,17,19]. Studies specific to endurance running are also inconclusive and are often of inadequate quality[20].

2.3.1 Compression garments worn during running

Twenty-four randomised controlled studies that assessed the impact of lower limb compression garments (CG) worn during exercise on various parameters in runners were identified. Significant improvements in one or more outcome measures were reported in the majority of these studies[18,28,41,61–71], with five studies finding no differences in any parameters[72–76] and three reporting some significant differences that may be undesirable[71,77,78]. Incongruence among results makes informed decision making difficult regarding the value of compression garments in running.

Below knee CG worn during running have been associated with significant (*p<0.05*) improvements in post-race subjective ratings of pain in some studies[41,61,63,69]. In addition, lower limb CG worn during running was associated with improved RPE values[65,66]. In contrast, it was associated with more discomfort[24] and increased[69] or unchanged pain[63,66] and RPE values[61,63,64,68,70,79] compared to controls in other studies. In one study conducted in nineteen recreationally active females, the findings of lowered pain ratings and increased RPE values[69] appear to be contradictory, seeing as one would expect lower perceived pain ratings to coincide with decreased RPE values. In addition, the lowered pain ratings were not associated with any significant changes in running performance during 5km time trials with CG compared to usual attire[69]. When different degrees of compression were compared, it was found that low grade compression represented the most comfortable rated running experience with high compression gradient levels rated as more uncomfortable than control condition[24,62].

Even less consensus in results were found regarding objective outcome measures. In terms of physical performance tests, improvements were found with the utilisation of below knee CG compared to control (none or placebo) with improved time-to-exhaustion treadmill tests (*p=0.01; p<0.05 respectively*)[70,80] and greater total work and duration of stepwise treadmill tests (*p<0.05; 0.3 and 0.4 effect sizes respectively*)[28]. Similarly, significant improvements (*p<0.05*) were found with full leg length CG compared to controls in terms of lower energy costs at 12km/hr pace on a treadmill[64] as well as improved sprint performance, altered running techniques with enhanced electromyography (EMG) activity of muscles and increased step lengths[65].

However, there were no significant differences in the time trial performances in the same participants wearing no, low, medium or high pressure below knee CG respectively[62]. Many studies found no improvements in running performance when CG were utilised. For example, no significant changes were found with below knee CG compared to controls in a 10km road run or shuttle running test performance[61]; muscle function determined through countermovement jump tests[24,63]; average marathon and ultramarathon running pace and over-all time[41,63]; treadmill VO_{2max} values[28,71,74,81]; time-to-exhaustion treadmill testing[67,74]; 5km running performance[69]; 15.6km trail running performance[76];

nor in running economy measures[70]. Furthermore, no significant changes were found with full leg length CG compared to controls in terms of 4km and 400m indoor track running performance[78]. One study even reported a performance decrement with lower time-to-exhaustion treadmill test results with CG utilisation compared to a control trial[68]. Another study found reduced running economy with full leg length CG conditions compared to control conditions[71]. In addition, no significant changes were found in any running kinematic measures with calf compression sleeves compared to control conditions[75]. Based on these over-all findings, there seems to be mild support for improvements in treadmill running performance with compression garments compared to controls in some studies. However, there is currently no support for improvements in any field testing measures (from 400m track running[78] to ultramarathon races[41]).

When considering measures of muscle power, when low and medium pressure CG were used during a 10km track time trial, a less pronounced reduction (*p<0.05*) in CMJ performance were reported compared to control trials in 12 highly trained athletes[62]. However, other studies found no change in CMJ measures performed when CG were used compared to control conditions[63,76]. In addition, no significant changes were detected in maximal voluntary contraction (MVC) measures[76].

Regarding physiological measures, the majority of results appear to be non-significant. In terms of cardiopulmonary measures, below knee CG compared to control conditions was not associated with any significant changes compared to control in heart rate (HR) values[24,61,62,68,72–74,76]; cardiac output[73]; stroke volume[73]; minute ventilation[72,76]; oxygen uptake[24,68,73–75,82]; nor blood oxygen saturation[63,73]. Likewise, full leg length CG compared to control was not associated with significant differences in HR, blood pressure (BP)[78] or tissue oxygenation concentration[65]. One study, however, found increased VO_{2max}, lower HR measures and decreased tissue oxygenation index measures with full leg length CG compared to control conditions during progressive maximal and time-to-exhaustion treadmill testing[71]. In addition, significantly increased local blood flow was reported with CG compared to control conditions[71]. Only one study reported significantly improved (*p<0.05*) tissue oxygenation at rest and during recovery after a treadmill running test when utilising below knee CG compared to a control trial without CG[67]. Still, this did not translate to improved performance and it is unclear if it aided recovery as no markers of muscle damage were included. Based on these findings, there is very limited support for any beneficial or other impact of compression garments on any cardiopulmonary measures considered, except one isolated study with improvements in blood flow, decreased HR and increased oxygen consumption[71].

Besides the lack of perceived benefits to the cardiopulmonary system, below knee CG did not cause significant changes compared to control in various markers of possible muscle damage including blood lactate[24,62,73,83]; lactate threshold (LT)[68]; lactate dehydrogenase[63]; serum sodium, chloride or potassium[63]; CK[41,63]; or Mb concentrations[63]. From current literature it appears that CG have minimal measurable impact on biochemical processes in the neuromuscular system with only a few exceptions.

Some significant (*p<0.05*) improvements were found in a study performed at the OMTOM 56km among 40 male athletes in those wearing below knee compression socks with lower concentrations of Mb and decreased blood lactate concentrations reported in addition to improved Visual Analogue Scale pain ratings of the calf, hamstrings and quadriceps compared to a placebo control group[41]. Experimental participants in this study utilised CG during the race as well as during the subsequent 72hours. The results of the study are promising for those promoting CG utilisation, seeing that this was one of the largest studies (in terms of sample size) performed to date. However, these beneficial results were not accompanied by altered CK concentrations and it did not translate to improved

performance times[41]. Welman and others have suggested that future studies should focus on the utilisation of compression garments during training as opposed to only during an event as an adaptation period may be required for measurable improvements to occur[41,70]. Another study also reported lower blood lactate concentration at 1 and 5 minutes respectively, during a maximal treadmill test when below knee CG were utilised compared to a control trial without CG, although the lactate thresholds were unchanged[68]. This also did not translate to improved performance with poorer time-to-exhaustion test results with CG compared to controls and no alteration in cardiopulmonary outcome measures[68]. Another study performed in 14 untrained females found that full leg length CG were associated with significantly higher ($p<0.05$) venous emptying rates 30 minutes after running compared to control trials without CG[78]. Yet, similarly, this did not translate to improved performance or altered cardiopulmonary outcome measures[78] and the impact on exercise induced muscle damage was not tested physiologically.

Significantly decreased ($p<0.05$) swelling determined with circumference measures were detected in thirteen runners performing a 10km cross country track run with below knee CG on one leg compared to the opposite leg without CG[18]. In addition, decreased lower limb circumference measures were reported following the OMTOM ultramarathon in runners using CG compared to placebo socks[41]. In contrast, no significant differences in circumference measures were reported in thirty-four runners performing a marathon either with or without CG[63]. These conflicting results require further research into the topic. In addition, there is no correlation between decreased circumference measurements and other outcomes i.e. reduced inflammation and this may simply be due to the pressure reducing interstitial fluid localised to the calves.

Significantly higher ($p<0.05$) skin temperatures with full leg length CG were detected in two studies[66,78]. For this reason, CG may need to be used with caution in very hot conditions. However, neither of these studies reported temperature values high enough to cause serious concerns and compression garments are still considered reasonably safe in any weather conditions[66,78]. In addition, no impact on running performance was reported under any simulated temperature tested[66]. Nevertheless, seeing as these tests were of limited duration, there may not have been adequate time to properly assess the use of compression garments on heat stress[66].

Other measures that were not significantly different with the use of CG compared to controls include sweating, subjective thermal and comfort sensations[64]; blood glucose[63]; as well as red blood cell deformability[74].

It is clear that a variety of outcome measures have been considered in search of a possible explanation for the anecdotal popularity of compression garments. Although some significant improvements were detected, the impact of compression garments remains unclear. In addition, due to heterogeneity of the field and studies performed, results from isolated outcome measures in particular should be considered with caution.

2.3.2 Compression garments worn during recovery from running

Only two randomised controlled studies assessing the utilisation of CG during recovery from running were identified. The first study assessed the impact of below knee CG utilised for 48 hours during recovery from a marathon race compared to placebo in thirty-three trained men and women, randomly allocated to either group[80]. Significantly improved ($p=0.009$) time-to-exhaustion treadmill results were obtained two weeks after the marathon in those wearing CG compared to the control group[80]. The second study was conducted in forty-one men and women randomly allocated to wear

full leg length CG or receive sham ultrasound during the 72hrs of recovery following a marathon[84]. Some significant improvements (*p<0.05*) were also detected by means of subjectively lower ratings of muscle soreness in the CG group compared to the placebo recovery group. However, no significant changes were detected in any of the objective measures included with no difference in maximal voluntary isometric contraction of knee extensors, CK or C-reactive protein concentrations between groups[84]. The study was performed in experienced marathon runners who had completed several previous endurance events, thus training status is suggested as a possible reason for the lack of difference in objective markers compared to improved subjective pain measures in this study[84]. Trained runners tend to produce lower CK concentrations following exercise, therefore the exercise stress may have been inadequate to produce a measurable effect in blood markers[84]. Alternatively, the subjectively improved pain recordings may be due to a psychological belief that CG should be superior to therapeutic ultrasound. These findings are similar to some of the studies utilising CG during running (not recovery) with improvements in subjective measures not necessarily translating to any alterations in objective measures[61,63,66].

2.3.3 Problematic trends

The heterogeneity of study designs has made comparisons and drawing conclusions challenging[19,20]. Several problematic trends in the available studies have been identified.

Considering participant selection, males constitute the vast majority of total research participants (302 males compared to 101 females). In addition, the previous study testing compression garments at the OMTOM 56km race excluded females[41]. Future research should include females when testing the efficacy of compression garments in running.

Another problematic trend relates to blinding. Most of the studies did not utilise any form of blinding[28,61,64,65,67–70,72–74,78,84,85] or only used blinding for baseline measures[63,66] due to practical constraints. Furthermore, in the few selected studies where double blinded approaches (participants and examiners blinded) were utilised, participants still accurately assumed their allocation due to the feeling of the degree of tightness of garments[24,62,80]. Therefore, even when utilised, the efficacy of blinding drastically diminished. Practically, effective blinding may not be possible seeing as even "placebo" CG were easily distinguished from actual CG[24]. In addition, the most beneficial degree of compression has not been established[19] so any degree of compression in garments may have an impact and establishing a "placebo" level may not be possible at present. Conversely, if the garments were too loose, it may also confound results by inhibiting performance due to reduced aerodynamics with increased wind resistance[86].

One study compared CG to an apparently different intervention (placebo ultrasound), which may have been useful[84]. However, pre-conceived ideas of either of these interventions could still impact on participants' perceptions and therefore results are at risk of being biased based on participants' expectations for each intervention.

In addition, large discrepancies exist in terms of the different degrees of compression applied with some studies providing no information regarding the specifics of the CG products making interpretation difficult. However, a systematic review replicating previous studies to evaluate the impact of different degrees of compression concluded that there is no clear relationship between the amount of pressure applied and the impact of compression garments[19].

The relatively small samples sizes in most of these studies further limits generalisability to the rest of the running population. In addition it means that results may not truly reflect the impact of

compression garments. Practically it may be difficult to obtain large sample sizes as it requires dedication, compliance and often extensive time commitment on the part of participants.

None of the studies recruited a random sample from the population for inclusion in the study. Therefore, there may be pre-existing differences in the sample compared to the general population.

The large variety of pressure garments, outcome measures and participant groups tested limits comparability among studies. The conflicting results further complicates drawing conclusions with certainty. Clearly, the role of compression garments still remains controversial.

Table 2.1 presents a summary of randomised controlled trials in runners considered in this review section, with relevant details regarding the participants, compression garment specifications, methodology and outcome measures highlighted. This illustrates some of the problematic trends related to relatively small sample sizes and the heterogeneity of study designs among trials.

2.3.4 Summary of Literature: Compression Garments in Runners

Currently available literature regarding compression garments in runners is inconclusive and/or of insufficient quality to support related findings. There seems to be mild to moderate support for improved subjective measures when compression garments were worn during running compared to controls with associated decreased pain and exertion ratings detected in most studies, but opposed in others. There is also some support for reduced swelling measures (associated with reductions in circumference measurements), and enhanced time-to-exhaustion and running performance tests, although many studies found no impact on various performance measures and one even reported a decrement in performance with CG use compared to controls. Minimal improvements in physiological measures were detected with associated reductions in Mb and blood lactate in two studies, but with no effect detected in the majority of studies. No improvements were found in cardiopulmonary measures in the vast majority of studies.

There appears to be slightly more support for CG worn during recovery from running with improvement in subjective measures and subsequent running performance, but no impact on other physiological measures tested. In addition, the number of studies were limited and further research is required.

Some of the problematic trends in available research methodology include the exclusion of female participants, the inability to provide sufficient blinding due to practical constraints, small sample sizes and the heterogeneity among studies.

Table 2.1: Lower Limb Compression Garments in Running

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
Ali, et al., 2007[61]	RCT CG vs control repeated in same participants	Trial A: 14 M Trial B: 14 M Recreational runners	Below knee CG (18 – 22 mmHg)	CG worn during exercise	A: two multi-stage intermittent shuttle running tests B: 10km road run	A: No significant difference in exercise performance; HR; or RPE (A); 10km times; RPE (B) Significantly reduced pain ratings in CG trial at 24hrs; more ratings of pain located in calf for control trial.	CG appears to assist with decreased DOMS related pain in lower limbs –based on subjective ratings, but no ergogenic effect was detected.
Ali, et al., 2010[77]	RCT CG compared to light and high CG in counter-balanced order in same participants	9 M & 1 F Competitive runners	A: No compression B: Light below knee CG (12-15mHg) C: High below knee CG (23-32 mmHg)	CG worn during exercise	3 X 40min treadmill runs with A, B, C conditions	No significant differences in oxygen uptake; HR; blood lactate; counter-movement jump test and PPO between trials C perceived as tighter and more painful to wear than A & B.	No physiological benefits detected; more comfortable with low grade CG.
Ali, et al., 2011[62]	RCT None, low, medium and high CG conditions in randomised order in same participants	9M & 3F Highly trained, competitive runners	A: no compression B: low below knee CG (12–15 mm Hg; C: medium below knee CG (18–21 mm Hg) D: high below knee CG (23–32 mm Hg)	CG worn during exercise	10km time trial With CMJ test pre- and post-run	No compression and low compression was rated as more comfortable than medium and high compression conditions, whereas high compression was rated as the most painful. Significantly lower change from pre- to post-CMJ was	Minor improvement in CMJ measures, with no improvement in running performance, cardio-pulmonary or lactate levels.

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
						reported in low and medium CG trials. No significant change in running performance times; blood lactate; or mean HR between trials.	
Armstrong, et al., 2015[80]	RCT CG vs placebo socks groups	23 M & 10 F Moderately trained runners	Below knee CG compared to placebo socks (ankle: 30–40 mm Hg calf: 21–28 mm Hg)	CG worn for 48 hours during recovery period	Graded treadmill running test to exhaustion 2 weeks before and following actual marathons	Treadmill times increased significantly (2.7%) in CG group and decreased (3.4%) in control group.	CG appears to aid functional recovery when worn following a marathon.
Areces, et al., 2015[63]	RCT CG vs control group	30 M & 4 F Experienced endurance runners	Below knee CG (lowest at 25 to 20 mmHg) compared to control	CG worn during exercise	Marathon running performance and various blood markers	No difference in average running times or pace; RPE; blood oxygen saturation; serum sodium, chloride; potassium; blood lactate; blood glucose; Mb; CK; lactate dehydrogenase; lower leg volume measures; CMJ between groups. Significantly lower pain rating 24hrs (but not at 48 hrs) following marathon in CG group compared to control group	Limited improvements in pain measures, but not in performance or any other objective markers

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
Bringard et al., 2006[64]	Repeated measures RCT Three garment conditions in each subject over 2 months	A: 6 M B: 6 M Trained runners	Compression tights compared to classic elastic tights and conventional shorts (pressure not available)	CG worn during exercise	A: Incremental exercise test to voluntary exhaustion at 10, 12, 14, and 16 km/h on 3 different days B: Constant running exercise at 80% of VO_{2max} of 15 min duration on three different day	A: Significantly lower energy cost at 12 km/h with CG and elastic tights compared to conventional shorts. B: Significantly lower VO_2 slow component in CG compared to other garment conditions. No differences in sweating, thermal and comfort sensations; or RPE between clothing conditions in A or B.	Limited improvements in running economy measures.
Born, et al., 2014[65]	RCT CG vs control (without CG) in same subjects	24 F Track and female club members	Full leg length compression garment with adhesive silicone stripes (18.3-21.7mmHg)	CG worn during exercise	2 sets of 30 X 30m sprints	Significant difference in sprint times in the final third segment in the CG trial compared to control trial. RPE and running technique changed with increased EMG activity of rectus femoris and increased step length in CG trial compared to control. No significant difference in cardiorespiratory or metabolic parameters, tissue oxygenation and haemoglobin, and skin	It was suggested that the altered running style may result in performance and comfort improvements with CG.

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
						temperatures between trials.	
Bovenschen, et al., 2013[85]	Cross sectional experimental control study with CG on one leg only of each subject	8 M & 7 F Trained recreational runners	Below knee CG (25–35 mm Hg)	CG worn during exercise	10km track run & stepwise, speed-incremented maximum treadmill test until voluntary termination	Decreased lower leg volume after 10km and maximal treadmill test measured with perometer in CG leg compared to opposite. No difference in leg complaints between sides.	Leg volumes were improved but was not accompanied by subjective improvements.
Goh, et al., 2011[66]	RCT With CG compared to control (none) in same subjects in randomised counter-balanced order	10 M Recreational runners	Skins™ long tights CG (13.6 ± 3.4 mmHg at the calf and 8.6 ± 1.9 mmHg at the thigh)	CG worn during exercise	4 X 20 min treadmill running trials with and without CG performed in 10°C and 32°C respectively	Lower limb skin temperature was 1.5°C higher at 10°C with CG compared to control. RPE decreased during submaximal running at 32°C with CG compared with control. No significant differences in other physiological variables, including rectal temperature between garment conditions.	CG are not contra-indicated in the heat.
Dascombe, et al., 2011[71]	Randomized crossover design In same subjects With two CG conditions	11 M Well trained middle distance runners	Full length CG classified as "undersized" (15.9 ±2.6 mmHg at the thigh and 21.7 ±4.3	CG worn during exercise	Progressive maximal test and Time to exhaustion test performed on	During the progressive maximal test: Both CG conditions resulted in significantly increased oxygen	

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
	compared to control (none)		mmHg at the calf); Full length CG classified as appropriate by the manufacturer (13.7 ± 2.3 mmHg at thigh and 19.2 ±3.2 at calf)		treadmill in each CG condition and without CG	consumption, oxygen pulse and decreased running economy, oxyhemoglobin and tissue oxygenation index at low intensity speeds compared to control conditions. At higher speeds, CG conditions significantly increased local blood flow and decreased HR and tissue oxygenation index compared to controls. During the time to exhaustion tests: Both CG conditions significantly increased deoxyhemoglobin concentration; undersized CG increased regional blood flow significantly. No significant changes were reported in endurance performance; VO_{2max}, nor LT.	
Hill, et al., 2014[84]	RCT CG compared to placebo ultrasound groups	17 M & 7 F Recreational runners (approximately 9.9 mmHg at	Lower limb compression tights	CG worn for 72hr during recovery	After running a self-paced marathon distance, blood markers and	Significantly lower muscle soreness at 24hrs in CG group compared to control No significant differences in maximal $_{vo}$luntary isometric	Subjective markers improved but no objective markers significantly different

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
		thigh and2 19.3mmHg at calf)			subjective ratings collected at 24hrs, 48hrs and 72hrs	contraction of knee extensors; CK, and C-reactive protein between groups.	
Kemmler, et al., 2009[28]	RCT randomised cross-over design CG compared to control (none) in same subject	21 M Moderately trained runners	Below knee CG (24 mm Hg at ankle)	CG worn during exercise	Stepwise treadmill test up to a voluntary maximum, 2 trials, 10 days apart	Significantly increased the total work and duration achieved voluntarily; as well as anaerobic and aerobic thresholds in CG compared to the control trial No significant differences in $VO2_{max}$ values	
Ménétrier, et al., 2011[67]	RCT CG compared to none in same subjects in randomised order	14 M moderately trained athlete	Calf compression sleeves (15-27mmHg)	CG worn throughout sessions	2 treadmill running tests 7 days apart with and without CG	Significantly increased tissue oxygenation at rest and during recovery from exercise with CG compared to control No difference in time to exhaustion – no ergogenic effect on running performance	
Priego, et al., 2015[72]	RCT CG vs control (placebo stocking) in same subjects in randomised order	13 M & 7 F Recreation runners	Below knee CG (21-24mmHg)	CG worn during exercise and two groups randomly allocated to train with CG	2 X fatigue running test of 30 minutes at 80% of their maximal aerobic speed with or without CG	No difference in cardiorespiratory parameters considered i.e. V_E, HR, V_E/O_2 and V_E/VCO_2 between trials	This study does not support the notion that venous circulation is improved.

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
				or placebo for 3 weeks			
Sperlich, et al., 2011[73]	RCT With 5 different CG conditions with each subject	15 M Well trained runners	Below knee CG at 0, 10, 20, 30 and 40 mmHg respectively	CG worn during exercise	Five periods of submaximal running on treadmill with 5 CG conditions	No significant changes in cardiac output and index; SV; arteriovenous difference in oxygen saturation; oxygen uptake; arterial oxygen saturation; HR and arterial lactate concentration between CG conditions	
Stickford, et al., 2015[75]	Randomized cross-over design CG compared to control (none) in same subjects	16 M Well trained runners	Graduated calf compression sleeves (15-20 mmHg)	CG worn during exercise	Running economy tests on a treadmill	No significant changes in VO_2, running economy, ground contact time, swing time, step length or step frequency.	
Rider, et al., 2014[68]	Randomised cross-over design Experimental control with CG compared to control (none) in same participant	7 M & 3 F Collegiate cross-country runners	Below knee CG (with a minimum of 15 mm Hg exerted)	CG worn during exercise	Tests: Maximal treadmill test, X2, 7 days apart	Lower blood lactate levels at 1 and 5 minutes respectively with CG compared to control. Lower time to exhaustion in CG compared to control trial. No other significant differences in HR, Respiratory exchange ratio,VO_2, RPE and LT between trials.	CG may decrease performance - authors suggest it may be useful to ask how participants feel about CG e.g. if uncomfortable may deter performance Possibly aids muscle recovery with lowered blood lactate levels.

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
Treseler, et al., 2016[69]	Randomised cross-over design CG vs control (none) in same participant	19 F Recreational runners	Below knee CG (18–21 mm Hg at ankles to 12.6–14.7 mm Hg below the knee)	CG worn during exercise	2 X 5km run time trials on outdoor course, 7 days apart	Significantly increased RPE and decreased lower limb muscle pain (not localised to calf) in CG compared to control. No significant difference in 5km running times.	No impact on performance. May worsen subjective perception of effort. May decrease muscle pain in lower limb with subjective pain ratings, but not specific to region of CG.
Varela-Sanz, et al., 2011[70]	RCT CG vs control group A: Randomised repeated measures design. B: Randomised non-cross-over design.	A: 13 M & 3F endurance trained runners B: 12 of the above participants	Below knee CG (15–22 mm Hg at the ankle)	CG worn during exercise	A: 4 bouts of 6 minutes at a recent half-marathon pace on a treadmill in random order B: Time limit test on a treadmill at 105% of a recent 10-km pace Performed over a period of 2 weeks	Lower HR_{max} in CG group compared to control in B. Improved time to fatigue and lower VO_{2peak} in CG compared to control in B. No difference in running economy or RPE in A or B.	Authors suggest that accommodation period may be required for a true effect to be observed.
Venckunas, et al., 2014[78]	RCT Cross over design with CG compared to	13 F Non-athletic subjects	Breech CG (17 at upper calf and 18mmHg at thigh)	CG worn during exercise	4km indoor track running in 30 minutes followed by 400m sprint	No significant difference in running performance; HR & BP dynamics; or RPE during test between two trials.	No clear positive or negative impact on physiology or performance.

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
	control (loose fit breeches) in randomised order in same participant					Non-significant increased oxygenation with CG compared to control. Venous emptying rate slightly increased 30min after exercise in CG trial compared to control. Significant increase in skin tempareture in CG compared to control.	Increased temperature, but not enough to cause clinical concerns related to exercising in hot temperatures.
Vercruyssen, et al., 2014[76]	Randomised cross-over design With CG compared to control (none)	11 M Trained trail runners	Calf compression sleeves (18mmHg)	CG worn during exercise	15.6km trail run CMJ and MVC were performed pre- and post-run.	No significant changes in running times, HR, minute ventilation, blood lactate concentrations, RPE, MVC nor CMJ.	No significant changes in any variables considered.
Welman, 2011[41]	RCT CG compared to placebo socks group	40 M Competitive runners	Below knee compression (20-30mmHg)	CG worn during exercise and 72hrs of recovery	OMTOM 56km	No statistically significant differences were reported in race finish times nor in CK levels. Significantly decreased levels of Mb, blood lactate, improved VAS pain ratings of the calf, hamstrings and quadriceps and smaller calf and ankle circumferences in CG compared to a placebo.	

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
Wahl, et al., 2011[74]	Randomised cross-over repeated measures study. Different CG conditions in randomised order in same subject.	9 M Well trained athletes	Knee high CG compared to control in different trials (0, 10, 20, 40mmHg respectively)	CG worn during exercise .	Four trials of sub-maximal running at 70% of peak oxygen uptake for 30 min followed by a ramp test until exhaustion with different degrees of CG.	No significant differences in oxygen uptake, blood lactate, HR and time-to-exhaustion determined by a ramp test between the levels of compression All levels of compression had no impact on RBC deformability during exercise.	

RCT – randomised controlled trial
CG – compression garments
M – males
F – females

2.4 Compression garments in other sports

The utilisation of compression garments is not isolated to runners and can be used in a variety of different sports and activity settings. Many of these studies in other sporting disciplines also found limited or no differences in exercise performance and recovery with compression garments compared to usual sporting attire[17,19,87].

2.4.1 Compression garments worn during exercise

Similar to results in runners, five randomised controlled studies assessing the use of compression garments worn during other forms of exercise reported mixed results with no significant results reported in half of these[83,88,89] and selected significant changes in the rest[90,91].

No significant differences were reported between an experimental group utilising below knee CG compared to a control group during an Ironman 70.3 triathlon (i.e. 1.9km swim, 90km bike ride and 21.1km run) in terms of RPE and muscle soreness, total race time, jump height and leg power following the race, nor in Mb and CK blood test results[83]. Furthermore, no significant differences were reported with full leg length CG compared to placebo CG worn during single leg hopping in spatiotemporal and kinetic characteristics, or in total duration until volitional fatigue[88]; nor were any significant differences reported with these CG compared to usual sporting attire in handball players in jump and sprint performance, rate of force development of knee extensors and plantar flexors or pain pressure thresholds of the soleus[90]. Likewise, upper limb compression sleeves had no effect on subjects' isometric peak torques, muscle activation, ultrasound echo intensity, CK concentrations or perceived muscle soreness ratings of the arm compared to those utilising placebo sleeves[89]. Furthermore, no significant changes were found in blood lactate concentration, insulin like growth factor-1, free testosterone, Mb, CK, IL-6, interleukin-1 (IL-1) or receptor antagonists with full body CG compared to controls in resistance trained men[92]. The lack of significant changes may show that compression garments did not have any impact on EIMD or performance measures considered. However, it is also possible that the relatively small sample sizes were insufficient to detect differences between groups and/or inter-individual changes.

In contrast, a few studies have detected significant changes in certain outcome measures. One study detected significant improvements ($p<0.05$) in one-repetition maximum (1RM) recovery rates for chest presses and knee extensions as well as lower subjective ratings of muscle soreness and fatigue when full body CG were utilised during exercise and recovery as opposed to the control group[92]. Unfortunately the small sample size ($n=9$) limits the value of generalising the findings to the wider population. Likewise, improved MVC of knee extensors were reported for full leg length CG utilised during exercise compared to controls in a slightly larger, but still limited sample size of 18 handball players[90]. Another study found significantly decreased blood flow in the quadriceps femoris ($p<0.001$; *effect size= 1.55*) in six cyclists wearing compression shorts compared to their usual attire, which is contrary to the theory of increased circulation to the compressed area and is in contrast to previous research[17,91,93]. Further studies with larger sample sizes would be required to assess the impact on blood flow further.

2.4.2 Compression garments worn during recovery from sport

Compression garments used during recovery (as opposed to during exercise) in these studies have also shown a positive trend in improved outcome measures similar to running related studies. Full leg length CG resulted in non-significant improvements in sprint ($p=0.22$; *effect size=0.03*) and 3km time

trial (*p=0.12; effect size=0.23*) performance as well as better fatigue ratings (*p=0.08; effect size=0.51*) compared to placebo CG in male rugby players[94]. Another study in resistance trained individuals showed significant improvements (*p<0.05*) in subjective ratings of vitality, fatigue and pain as well as in ultrasound measured swelling, CK concentrations and bench press power in whole body CG compared to usual sporting attire[95]. The same trial found no significant differences in counter-movement vertical jump performance or circumference measures between groups[95]. The third study found significantly improved (*p<0.02)* MVC and contractile properties as well as lower pain ratings at 72hrs (*p<0.05*) in legs with CGs compared to the opposite legs without CGs[96].

2.4.3 Problematic trends

Problematic trends in the research relating CG to various other sports is similar to those discussed previously. As with running, the majority of sports related studies included predominantly or only male subjects (164 men across studies compared to only 17 females), reflecting the paucity of research relating to CG utilisation in females in sport. Blinding was also problematic in these studies with only one using a single-blind approach (participants blinded)[66], and none with double-blinding. This limits the validity of results obtained particularly with subjective ratings of pain and fatigue as it may be influenced by expectations for CG compared to no intervention. Due to practical constraints previously discussed it may not be feasible to include blinding without creating other possible confounding variables. Sample sizes of most studies were also all relatively small, which limits the ability to generalise results to a wider sports population.

Table 2.2 presents a summary of randomised controlled studies testing compression garments in sports other than running. This illustrates similar problematic trends with sample sizes and heterogeneous methodology compared to running related studies.

2.4.4 Summary of the literature: Compression garments in sport

Compression garments are commonly used in various sports and modes of activity, despite inconsistencies in the literature as to their effectiveness. A common trend in the results of studies performed to test compression garments' impact in various sports other than running were improved subjective ratings of RPE and muscle soreness and some improved physical performances measures with only isolated improvements in physiological tests and specific sporting performance. In addition, improvements were more common when compression garments were worn during recovery from exercise as opposed to only during exercise, which represents the most common timing of utilisation for CG. The discrepancies in the literature necessitates further research utilising objective measures to assess the true impact of compression garments in sport.

Table 2.2: Compression garments in various other sports

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
Del Coso, et al., 2014[83]	RCT CG vs control (regular socks) group	30 M & 4 F Triathletes	Ankle to knee CG (60% polyamide, 25% elastane and 15% polyester; pressure not provided)	Worn during exercise	Half ironman triathlon	No significant differences in total race time; jump height; leg muscle power; RPE; muscle soreness; Mb or CK between groups.	No impact of compression garments on physiology or performance.
Goto & Morishima, 2014[92]	RCT CG vs control (regular attire) in randomised order	9 M Resistance rained	Full body CG (pressure not provided)	Worn during recovery for 24hrs	Resistance exercises; 1 month apart	Significantly improved 1RM recovery rate in CG group for chest press and knee extension; lower muscle soreness and subjective fatigue scores with CG compared to control. No significant differences in blood lactate, insulin like growth factor-1, free testosterone, Mb, CK, IL-6, and IL-1 receptor antagonist concentration.	Muscle strength recovery improved with CG.
Gupta, et al., 2015[88]	RCT CG vs placebo CG vs no CG in same participants	38 M Recreational activity	Full leg length CG (Skins™, pressure not provided)	Worn during exercise	Single leg hopping to volitional fatigue	No significant difference in total duration of tests and between conditions for spatiotemporal or kinetic characteristics between trials.	No impact detected.
Hamlin, et al., 2012[94]	Randomized single-blind crossover study with CG vs placebo CG	22 M Well-trained rugby union Players	Full leg length CG (8.6±2.6 mmHg at ankle)	Worn during recovery	3km and sprint performance	Non-significant improvements in sprint and 3km time trail performance times, fatigue and pain ratings in CG compared to placebo.	Improved performance and subjective ratings, but no change in objective blood measures.

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
						No difference in CK concentration.	
Kraemer, et al., 2010[95]	RCT CG vs control (usual attire)	11 M & 9 F Resistance trained	Whole body CG (pressure not provided)	Worn during recovery for 24hrs	Heavy resistance training	Significant improvements in vitality ratings, resting fatigue ratings, muscle soreness, bench press power and ultrasound measured swelling and lower CK concentration in CG group compared to control. No significant differences in countermovement vertical jump performance or circumference measures between trials.	Moderate improvements found in subjective ratings and come physiological and physical markers.
Perrey, et al., 2008[96]	RCT CG on one leg only, opposite as control	8 M Healthy, recreational activity	Calf CG (Supportiv^{TM}, pressure not provided)	Worn during recovery 5hrs per day for 3 days	Eccentric backwards downhill walking	MVT and contractile properties of CG leg improved quicker than control leg. Lower pain ratings in CG leg.	Improved recovery and subjective ratings.
Pereira, et al., 2014[89]	RCT CG vs placebo control	22 M Resistance trained	Upper limb compression sleeves	Worn during exercise	Isokinetic eccentric/ concentric elbow flexion repetitions	No significant differences In isometric peak torque, muscle activation, ultrasound echo intensity, perceived muscle soreness or CK concentration.	No impact detected.
Ravier, et al., 2016[90]	RCT cross-over design	18 M Handball players	Full-leg length CG	Worn during exercise	Handball specific circuit	Significantly improved MVC of knee extensors. No significant difference in jump and sprint performance; rate of force development of knee	Improvement in isolated measure of muscle power only, with no improvement in other performance

Article	Study Type	Sample	Compression garments	Timing	Protocol	Findings	Additional information
	CG vs control (usual attire) in random order					extension and ankle plantarflexion; or pain pressure threshold for soleus between trials.	measures or subjective ratings.
Sperlich, et al., 2013[91]	Experimental control trial with	6 M Healthy	Compression shorts (applying 37 mmHg) on one leg only compared to usual clothing on opposite leg	Worn during exercise	Blood flow measured in hamstrings and quadriceps during a cycling ramp test to exhaustion	Decreased blood flow was detected with CG condition during recovery from exercise.	Contrary to theory of enhanced blood flow with CG.

RCT – randomised controlled trial
CG – compression garments
M – males
F – females

2.5.1 Review Studies of Compression Garments

Four systematic reviews over the past decade relating to compression garments in sport were identified in the literature. It was unanimously concluded that the impact of compression garments in sport remain controversial due to the large heterogeneity between study designs, compression garment types, outcome measures, participants and results[17,19,20]. This is apparent in the studies discussed above.

The findings of the earliest review were that any ergogenic impact of CG worn during exercise is very limited, except perhaps with certain explosive activities such as jumping[17]. This is in contrast to most of the above studies that found no significant differences in jump height or performance[83,90] nor in counter movement jump tests[24,63]. One study discussed above did, however, find a reduced performance decrement in CMJ when low and medium pressure below knee CG were utilised compared to control conditions[62]. Most of these studies were only performed after this initial review was conducted. One out-dated study (1998) considered by MacRae and colleagues[17] found improvements in mean jumping power output in men and women utilising compression shorts[97]. In addition, the study detected improvements in proprioception and a reduction in muscle oscillations on landing with CG compared to control conditions[97]. Unfortunately, these results have not been reproduced in more recent times and these isolated outcomes should be considered with caution.

The use of CG during recovery showed some promising results in power and torque related outcome measures[17]. The earliest review also mentioned some evidence for enhanced blood flow[17], although this appears to be limited to one study that detected increased forearm perfusion with upper limb compression sleeves compared to controls considered above[93]. More recently, a reduction in blood flow has been detected in cyclists wearing compression shorts[91]. As increased circulation is one of the major theoretical considerations in promoting CG, further research is critical.

Similar to the studies previously discussed testing compression garments in running and other sports, muscle soreness ratings were generally improved, but not in all studies[17]. Most physiological blood markers and swelling measures showed limited or no improvements with compression garments compared to controls[17]. Likewise, the latest meta-analysis of randomised controlled trails for CG in sport, reported that blood markers such as CK were not associated with any significant differences between experimental and control groups, whereas lactate dehydrogenase may be reduced with CG compared to controls[20]. This is similar to studies discussed above. Blood lactate was also reportedly reduced in males utilising CG in the OMTOM 56km previously discussed[41]. However, even so, the high inter- and intra-individual differences among these blood markers brings into question the validity of utilising these measures to assess impact[20].

Compression garments have been associated with reduced swelling with the greatest effect seen after the second and third days following exercise respectively[20]. Similarly, the above studies reported decreased circumference and swelling measures with lower limb CG[18,41]. Still, others contradicted these findings with no significant reductions in circumference measurements reported[63,95].

In general, there appears to be more support for CG worn during recovery than during running[19]. This is similar to the findings in the studies discussed previously with a trend for more improvements with CG used during recovery. However, in practice, athletes appear to utilise these garments more commonly during exercise, necessitating further research of this mode of utilisation.

One of the systematic reviews included only studies performed in runners[98]. Similar to the results discussed above, a trend for minor improvements in endurance performance was detected with better time-to-exhaustion tests, although it was not replicated in all studies[98]. In contrast, running time trial performance across a vast range of running distances from 400m sprints to marathons, did not change significantly with utilisation of compression garments compared to control groups[98]. This echoes the results discussed above with the same studies considered with no significant changes in short sprint distances[78], middle to long distances[61–63,69,78], nor in the ultra-endurance event referred to above[41]. The exception was limited improvement reported in a repeated very short sprint distance of 30m[65]. The lack of improvements in cardiopulmonary measures and various physiological and blood marker measures mentioned in the review[98] also echoes the findings discussed above. As with all of the other reviews and the currently discussed studies, psychological improvements were reported with better subjective ratings of pain and fatigue[17,19,20,98]. The mean sample sizes of included studies were relatively small with an average of 15 participants (with a range of 6 to 36 participants) per study[98], therefore results should be interpreted with caution until it is reproduced by studies with larger sample sizes.

One of the issues identified in available research was the large heterogeneity among pressure gradient levels applied[17,19,20,98]. One review assessed this specifically and found that there were no significant differences between low and high pressures and the results obtained[19]. Beneficial alterations to predominantly subjective measures were reported across a wide range of compression gradient levels applied, although the underlying mechanism is unclear[19]. This is similar to findings above with subjective improvements often not translating to alterations in objective physiological or performance measures, with only isolated or mixed results. Further investigations should aim to identify if there are truly benefits related to CG, and if so, establish the underlying mechanisms.

2.5.2 Summary of review studies of compression garments

Systematic reviews performed to date to assess the utilisation of CG in various forms of exercise concluded that the impact thereof remains controversial as is evident in the studies discussed. The same conclusion was drawn from a fourth systematic review considering only runners. A trend for improvements in subjective measures such as pain ratings have been observed with limited improvements in objective measures with more benefits detected when worn during recovery than during exercise alone.

2.6 Instrumentation

2.6.1 Instrumentation for exercise induced muscle damage

2.6.1.1 Circumference measurements

Circumference measurements are commonly used to determine the presence of swelling or oedema in various body segments. Using a tape measure is a quick, easy and affordable method of determining circumferences.

Tape measurements has specifically been used with high reliability in mid-calf circumference[99,100] and high validity and reliability in upper limb circumference measures[101]. The figure-of-8 ankle tape measurements has also been used with high validity in detecting oedema with high inter- and intra-reliability of measurement[102–105]. A standard error of measurement (SEM) of 0.5cm has been reported for mid-calf circumferences[106,107]. SEM values of 0.47cm[105] and 0.44[102] have been reported for the figure-of-8 ankle circumference measurement method.

2.6.1.2 Ultrasound and other radiographic imaging

Ultrasound can be used to obtain a representation of muscle damage following a precipitating event. For instance, ultrasound imaging has previously been used to assess muscle damage in male runners after inducing delayed onset muscle soreness[108]. Researchers have investigated changes over time in the medial gastrocnemius muscles of the non-dominant legs of participants[108]. Significantly increased ($p<0.05$) muscle thickness was detected at 48hrs compared to baseline and started to decrease by 72hrs following DOMS-induction[108]. Likewise, pennation angles also increased significantly ($p<0.05$) until 48hrs and decreased by 72hrs[108]. Based on these findings, the peak changes compared to baseline should be observed by 48hrs following a race.

Ultrasound has been included in two previous studies identified in the literature as an alternative method to measure muscle echo intensity[89] and lower limb swelling[95] which may also relate to muscle damage. No significant changes were detected in terms of the prior when utilising upper limb compression sleeves[89]. However, the latter study, found significant improvements ($p<0.05$) in ultrasound measured swelling when whole body CG were worn during recovery from resistance training compared to usual clothing[95]. It has not previously been included as an outcome measure in research on CG utilisation in runners. However, the results with resistance training individuals reported previously indicates its potential for inclusion in future research.

Diagnostic ultrasound has acceptable validity for assessing trunk muscle size[109] and has high inter- and intra-reliability for measuring pennation angle and muscle thickness in the medial gastrocnemius muscle[6,110]. Another study found no statistically significant changes in intramuscular swelling after repeated eccentric biceps contractions to induce DOMS using diagnostic ultrasound[2].

Other radiographic imaging that may be used to analyse musculoskeletal systems include computed tomography (CT) and Magnetic Resonance Imaging (MRI) scans. However, both of these measurements tend to be expensive and subjects participants to radiation and enclosed spaces. In addition, CT scans may not be able to detect changes in soft tissue structures. Furthermore, muscle thickness measurements were similar between ultrasonography, MRI and CT scans[111]. Ultrasound is therefore the most affordable, convenient and suitable alternative measure to obtain a representation of possible muscle damage following a precipitating event.

2.6.1.2A Pennation angle

Pennation angle is defined as the angle created between the deep aponeurosis and the muscle fascicles' attachment[6]. Ultrasound imaging can be utilised to visualise muscle architecture and consequently calculate the degrees of angulation between the deep aponeurosis and the muscle fascicles[6]. Values of pennation angles have been obtained from cadaver dissection with values obtained for prominent leg musculature[112]. Based on this study, the average pennation angle is 17° for medial gastrocnemius; 8° for lateral gastrocnemius; 25 ° for the soleus; 5 ° for rectus femoris, vastus lateralis and vastus medialis; 15 ° for semimembranosus; 5 ° for semitendinosis and 23 ° for biceps femoris long head[112]. In distance runners, values of 23° for the medial gastrocnemius and 16 ° for the lateral gastrocnemius have been reported[113]. A further study reported pennation angle values of 33 ° (in males) and 32 ° (in females) for the right medial gastrocnemius muscle in runners[114].

Pennation angles may be related to muscle strength as greater pennation angles allows for larger quantities of contractile muscle tissue to be contained within a certain volume with a consequent enhancement of force production[115,116]. Pennation angles also tend to decrease with age[117,118]. However, endurance runners represent a special population as pennation angles have been reported to be greater in certain muscles such as the medial gastrocnemius in endurance runners compared to sprinters[113]. This may be due to shorter fascicle lengths observed in endurance runners and the associated lower average velocities during long distance running[113]. A longer fascicle length may limit the alteration in pennation angle usually associated with hypertrophy, which may explain the above phenomenon[113]. This also highlights the complex nature of muscle architecture and adaptation. For example, after inducing DOMS, pennation angles have been found to increase transiently for 48hrs before starting to return to normal[108]. Theoretically, this may relate to EIMD related swelling, exerting pressure on muscle fibres which may cause an increase in angulation. Furthermore, it has been found that pennation angles tend to increase as muscles shorten[119]. Thus considering that temporary muscle shortening may occur with EIMD, pennation angles may increase with the associated reduction in ROM.

The measurement of pennation angle with ultrasound imaging is considered reliable (*r>0.8*) if performed by the same investigator under the same conditions[120]. Ultrasound imaging has been used with high inter- and intra-reliability to measure pennation angles in the medial gastrocnemius muscle[6,110]. Standard error of measurement values of 0.1-1.2° have been reported for pennation angles determined by ultrasonography[121].

2.6.1.2B Muscle thickness

Muscle thickness is defined as the space between the superficial and deep aponeuroses[6,118]. Ultrasound imaging can be utilised to visualise muscle architecture and subsequently calculated by measuring the distance between the superficial and deep aponeuroses, usually at the midpoint between the proximal and distal musculotendinous junctions[6]. Previous ultrasound imaging studies reported muscle thickness values of 1.97cm and 1.59cm for the medial and lateral gastrocnemius respectively in controls compared to 2.10cm and 1.69cm respectively in distance runners[113]. Another study reported right medial gastrocnemius thickness values of 1.8cm and 1.7cm in male and female runners respectively[114].

Muscle thickness is also an important factor in predicting muscle strength and greater muscle thickness generally related to enhanced force production[6,116]. Similar to pennation angles, muscle thickness tends to decrease with aging[115,118]. In endurance runners, muscle thickness may increase

slightly compared to controls, but tends to be smaller than in sprinters[113]. After inducing DOMS, muscle thickness has been found to increase compared to baseline[108], which may be due to swelling related to EIMD.

The measurement of muscle thickness with ultrasound imaging has been found to be highly reliable (*r>0.88*) when performed on the same day by the same investigator and same conditions[120]. Ultrasound imaging has been used with high inter- and intra-reliability in measuring muscle thickness in the medial gastrocnemius muscle[6,110]. Standard error of measurement values of 0.1-0.4cm have been reported for medial gastrocnemius muscle thickness with ultrasonography[122].

2.6.1.3 Subjective ratings

The Visual Analogue Scale represents a commonly used numerical tool to assess pain among other subjective ratings. Generally, a scale of 0-10 is used with 0 representing no pain and 10 representing the worst pain imaginable. Participants are instructed to rate their pain with a number based on this scale. Visual representations of facial emotions are also sometimes used to visually enhance testing.

Numerical VAS questionnaires have been used to assess pain with high reliability and validity in many research settings[123–126]. However, it will always remain a subjective rating and is therefore susceptible to various internal and external factors. Pain is a biopsychosocial concept influenced by personal experience, mood and the external environment[127]. For example, if someone anticipates that a modality will work, is in an amiable mood and have not had any negative experiences related to the situation, (s)he may be more likely to give a low VAS rating compared to opposite conditions.

2.6.1.4 Blood/Serum testing

Various skeletal muscle enzymes, cytokines and proteins are frequently utilised as markers of the physiological and/or pathological state of muscle tissue[128]. An increase in some of these enzymes is typically related to the degree of EIMD and/or other injuries.

Prominent among these markers of muscle damage, is creatine kinase, an enzyme which transfers to interstitial fluid with excess exercise[40,128]. CK concentrations tend to be most elevated following endurance events and remains high for 24 hours before starting to return to resting concentrations[129]. However, there may be vast differences in CK levels amongst individuals as it may be altered by many factors including the individual's age, sex, lean muscle mass and the weather conditions[129–131]. Other commonly used measures include IL-6, as the greatest proportion of this cytokine is produced during physical activity[132].

These measure have been used in several previous studies related to compression garment use[17,39,41,63,133–135]. Unfortunately, due to its heterogeneity, studies comparing CK and other blood markers may not be the most accurate representation of muscle damage across the spectrum. In addition, interpretation of blood tests may be expensive and the invasive nature of testing may lead to anxiety and/or associated discomfort in some individuals[136].

2.6.1.5 Summary of instrumentation for exercise induced muscle damage

Various types of instrumentation has been utilised to assess muscle damage related to exercise and running performance. Blood markers of muscle damage include increased concentrations of CK, IL-6, IL-1 and Mb following unaccustomed or prolonged exercise; however its value for comparison is decreased due to vast inter-individual variations. Ultrasound represents an affordable, safe and convenient imaging technique to assess soft tissue and is valid and reliable in detecting muscle characteristics such as pennation angles and thickness. Circumference measurements may be used to

indicate the degree of swelling of limbs and has been used with high reliability and validity in the lower leg. Subjective pain measures are commonly assessed by the VAS rating system and is considered valid and reliable, although it is not necessarily indicative of alterations in objective measures.

2.6.2 Instrumentation for running performance

2.6.2.1 Time trials and time-to-exhaustion tests

Assessing performance is an important aspect in the field of sports and physiology and should aim to simulate specific skills or capacities required for particular sports or activity types[137]. Time trials and time-to-exhaustion tests are commonly used methods of assessing performance in endurance sports such as running or cycling[138]. Time trials consists of running or cycling until a predetermined endpoint such as a distance (i.e. participants aim to reach this in the shortest possible time) or set time (i.e. participants aim to cover the greatest work load within this time limit)[137,138]. Due to the known distance or duration, participants are able to pace intensity accordingly[138]. Time-to-exhaustion tests involve performing an activity such as running at a set intensity until volitional fatigue[137,138]. This test may be particularly useful to assess the impact of certain interventions on performance as other factors are standardised[137]. However, time trials may be a closer simulation of race conditions and are therefore considered a more valid predictive performance measure for running or cycling competitions[137]. In addition, a study performed in male runners, found higher reliability rates for running time trials compared to time-to-exhaustion tests[138]. All performance tests should aim to be a close replication of actual exercise conditions for more accurate results[137]. Fortunately, activities such as running may be easier to simulate in laboratory conditions compared to others incorporating a vast range of techniques and skills such as tennis or rugby. However, treadmill conditions likely to be utilised in a laboratory setting is still different to road running, cross country or trial running respectively. Whenever possible, athletes should be assessed within conditions that most closely simulate actual competitions. Using a running competition to assess the impact of an intervention on performance has the advantage of representing a time trial of actual race conditions. Conversely, it is not possible to control other factors such as weather conditions, making comparisons among such trials difficult. During races, timing chips such as RaceTec™ are utilised to provide time to predetermined points and time to completion for each participant. RaceTec™ is the official timing device for the OMTOM event and is internationally accepted as a valid and reliable timing system[139].

2.6.2.2 Other running performance tests

Numerous other methods have also been utilised in an attempt to measure running performance or aspects thereof such as cardiorespiratory fitness, muscle power and endurance. A device to measure the rate of oxygen consumption can be utilised in conjunction with an exercise test on a treadmill (for running) to determine VO_{2max} or VO_{2peak} values[28,64,68,74]. Higher values are indicative of cardiorespiratory performance and aerobic capacity[140]. However, lower values are paradoxically associated with improved running economy[141]. Heart rate monitoring devices can also be used as indicators of the relative intensity of exercise[24,61,70,72,91]. If the same absolute intensity is associated with a lower HR, it may be indicative of improved training status[142]. Other cardiopulmonary measures such as minute ventilation, carbon dioxide flow and oxygen saturation may also be utilised, although it was not associated with any significant changes related to compression garments in past studies[63,72,73].

Muscle power can be determined in various ways depending on the muscle group. 1RM measures are commonly used and represents the maximum value an individual can lift once with proper form and

technique before fatigue[143]. It has been utilised with high validity in detecting leg strength[143]. Maximal voluntary contraction tests are also commonly used to test a muscle group such as the knee extensors[84,90,96] and can be determined through incorporation of electromyography[144]. Peak torque tests can also be performed through isokinetic strength testing[89]. Other functional tests include bench presses, chest presses and squats among others.

Unfortunately, isolating aspects related to running does not necessarily provide a direct indication of running performance[145]. Therefore, running specific performance testing remains the preferred option[145]. Nonetheless, it may be useful in adjunct to other measures.

2.6.2.3 Countermovement Jump testing

Various functional jump tests such as single leg hopping and countermovement jump (CMJ) tests may provide insight into spatiotemporal characteristics, muscle power and endurance. The CMJ test activates the stretch-shortening cycle[146], which may provide insight into muscle power related changes for instance following a muscle damage inducing bout of running. CMJ testing has previously been performed by runners utilising low and medium pressure CG with improved performance of CMJ after a 10km run compared to control conditions reported[62]. In addition, the CMJ can be performed as indication of the degree of loss of muscle power in the lower limb related to EIMD[36].

This test requires participants to start in a static position with their hands on their waist with the hips and knees extended to a neutral position. This is followed by a countermovement self-selected squat to approximately 90° of knee flexion immediately followed by jumping to maximal capacity while keeping the legs extended, and landing with both feet simultaneously[147,148]. It incorporates the stretch-shortening cycle through the downward countermovement[36].

Countermovement jump tests have been used with high reliability and validity in determining explosive power measurements in the lower limb when performed on a force place[148]. A SEM value of 0.79cm has been reported for CMJ height measurments[149]. It has also been performed with high reliability in determining peak power[144], peak force[147,150] and peak velocity measures in the lower limb[147]. Furthermore, a relatively recently developed application named MyJump has been found to be valid and reliable in CMJ variables compared to CMJ tests performed on a force plate[151]. Power-, force- and velocity-time curves derived from CMJ testing on force plates have been used to provide insight into training status between two groups of trained and untrained individuals respectively[152].

In the absence of a force plate, for instance during field experiments, the peak power output (PPO) can be estimated with validated formulas. Johnson & Bahamonde (1996) validated the estimation of PPO calculated as follows:

$$‘P_{peak}=(78.6XCMJ_{height})+(60.6Xmass)-(15.3Xheight)-1308’$$

where P_{peak} is PPO (in Watt), CMJ_{height} is the vertical jump height (cm), mass is the body mass (kg) and height is stature (cm)[153]. The standard error for PPO using this formula is 462W[153].

2.6.2.4 Summary of Literature: Instrumentation

Running time trials and time-to-exhaustion tests are commonly used as it closely simulates actual running conditions, with time trials preferred. CMJ tests may be used to estimate lower limb muscular power and incorporates the stretch-shortening cycle. Various other measures of cardiorespiratory fitness and muscle power may be included in adjunct to this.

2.7 Summary of the literature review

Compression garments, initially utilised in medical practice, was introduced into sporting activities such as running with the aim of aiding muscle recovery and improving performance. Its utilisation has been tested in various activity modes, with different types of CG and using a variety of outcome measures with conflicting results. The heterogeneity among studies has made comparisons difficult and its utilisation remains controversial.

A trend has been found for improvement in subjective measures such as ratings of pain, RPE and comfort in the majority, but not all, of the studies identified. Objective measures showed limited improvements in measures of swelling, blood/serum testing and almost no changes in cardiopulmonary measures.

Performance benefits were limited with some improvements in time-to-exhaustion, energy cost, workload and other variables during treadmill testing in certain studies. There were no significant changes in the majority of performance outcome measures. It appears that there is slightly more support for wearing CG during recovery as opposed to during exercise based on current literature.

Various types of instrumentation have been utilised in an attempt to determine the impact of CG on EIMD and performance with variable success. Blood/serum markers are commonly used as indicators of muscle damage, but the vast inter-individual variability limits the value of comparisons. Ultrasound imaging may be a suitable, safe, affordable alternative to assess muscle damage. Time trials and time-to-exhaustion tests may be used to assess running performance by simulating race conditions either in a controlled environment or field conditions. CMJ testing may be used to test lower limb muscle power. The advantages and disadvantages of various types of instrumentation should be considered carefully before selecting the appropriate measurements for research studies assessing the efficacy of compression garments.

Based on available literature, the efficacy of compression garments are yet to be established. Due to the high rate of utilisation in endurance runners, research studies conducted in an attempt to establish the impact of compression garments on running performance and muscle recovery rates in this population is of utmost importance.

CHAPTER 3: Investigation of the impact of below knee compression garments on exercise induced muscle damage and performance in endurance runners

Study Procedure

3.1 Introduction

The anecdotal popularity of the utilisation of compression garments amongst endurance runners and the controversy in the literature regarding its impact as discussed necessitates further research with high methodological quality specific to the field of running. This should help to guide the appropriateness of their continued use.

In general, the large heterogeneity between study designs, compression garment types, outcome measures, participants, sports and results limit the comparison value among studies currently available in the literature[17,19,20]. The impact of compression garments on exercise induced muscle damage and performance in various exercise forms such as running remains controversial[17,19,20].

A vast range of participant characteristics are among the identified issues in the objective assessment of the usefulness of CG. For example, gender differences were not accounted for in many of the previous studies considered although muscle recovery may differ in men and women for example following MVC's[154] or resistance training[155]. In addition, it is well known that performance times differ among the sexes, which may relate to different aerobic capacities and muscle power[49]. Matching groups for gender may help to minimise the effect of these changes. In addition, as discussed in the literature review, the research basis has consisted predominantly of males, indicating the need for inclusion of females in research studies. Similarly, age related changes to muscle recovery mechanisms have also been widely described between the elderly and the very young[52,156] and hence accounting for age could also impact on results.

Furthermore, selecting appropriate, valid and reliable outcome measures and instrumentation is challenging. Creatine kinase, myoglobin, interleukin-1 and -6 among other blood and serum markers are commonly used indicators of muscle damage, yet researchers have mostly failed to detect any changes when compression garments have been used compared to controls[83,89,92,94]. It is unclear if this is due to a lack of impact on physiological responses or due to the vast inter-individual variation among these measures[4]. Ultrasound represents an affordable, convenient, suitable alternative measure to obtain a representation of possible muscle damage following a precipitating event[108]. For instance, ultrasound imaging has previously been used to assess muscle damage in male runners after inducing delayed onset muscle soreness and detected significant increases in pennation angles and muscle thickness of the medial gastrocnemius[108].

No previous study has included a significant training period with compression garments, and none have allowed familiarisation with compression garments for longer than two weeks. It has been suggested that future studies should focus on the utilisation of compression garments during training to analyse any additive effect on performance during a race and recovery responses thereafter[41,70]. Previous research including a six week period have proven to be adequate in detecting significant changes in parameters of muscle adaptation[157,158]. Furthermore, following a muscular injury, a period of 4-6 weeks is generally recommended for sufficient tissue adaptation for return to activity, depending on the severity[159]. In addition, many programmes for endurance running includes peak

distances around 3-6 weeks prior to the race and a tapering period in the final 2-3 weeks[160], thus a 6 week training period will generally include some longer and heavier sessions in training in addition to the anticipated tapering period.

Research of the utilisation of compression garments in runners is still inconclusive[98]. The current study aimed to address the paucity in research by conducting a randomised controlled field experimental study. Previously identified issues in the literature were considered in the design in an attempt to shed light on the true impact of compression garments worn during running.

It was anticipated that the chosen methodology would substantially impact on results obtained to provide a more accurate depiction of the effect of below knee compression garments on performance and muscle responses during training and participation in endurance running events. The information obtained may help to guide decision making for sports health professionals, coaches and athletes alike. Since this study was performed as a mini-dissertation, the long term impact of compression garments was not determined. However, it may set the grounds for further research in the field.

3.2 Methodology

3.2.1 Research design and recruitment

A randomised controlled field experimental research study was conducted in healthy endurance runners participating in the Old Mutual Two Oceans ultramarathon. Prior to initiating the study, ethical approval was obtained from the University of Cape Town (UCT)'s Human Research Ethics Committee and from the OMTOM event organisers (*Appendix A*).

Participants were recruited from the OMTOM data-basis of entrants. The OMTOM organisers provided a list of 1685 individuals between the ages of 20-45, residing in the Western Cape (for logistical data collection purposes) who entered the 56km race and indicated an interest in participating in research studies during the entry process. Each individual provided on the list was contacted by means of a bulk e-mail distributing electronic information sheets *(Appendix B)*.

3.2.1.1 Inclusion criteria

Long distance runners between the ages of 20 and 45 who were entered for the OMTOM 56km race in 2017 were recruited for inclusion in the study. In addition, participants needed to have a minimum average training distance of 50km per week and have completed one or more marathons or ultramarathons in the 18 months preceding the start of data collection.

3.2.1.2 Exclusion criteria

Participants with pre-existing musculoskeletal injuries to the lower limb in the past 3 months and/or with any unresolved symptoms from past injuries (based on the screening tool and verified by Nordic Musculoskeletal Questionnaire) (*Appendix C*) were excluded from the study. Furthermore, participants with a history of underlying chronic or acute neurological, musculoskeletal, orthopaedic, cardiac, endocrine or other medical diseases or complications that may have impacted on safety of participation and/or performance (based on screening by the Physical Activity Readiness Questionnaire+/PAR-Q+) (*Appendix D*) were also excluded. In addition, participants who were routinely using compression garments and/or were unwilling to train and/or compete with or without compression garments based on potential group allocation were excluded.

3.2.2 Sampling

3.2.2.1 Sampling and recruitment

A sample of convenience was obtained during the recruitment process. Ninety-eight people responded to the advertisements sent out per bulk email to OMTOM 56km race entrants between the age group specified. Eighty-eight of these individuals showed an initial interest in the study. After sending further information and answering any questions or concerns raised, 53 individuals remained interested in participating. Reasons for losing interest involved living too far away from the site for data collection, lack of monetary reward, or undisclosed (i.e. lack of subsequent response).

All interested participants (n=53) were screened with a preparatory self-developed online screening tool *(Appendix E)* for a preliminary indication of inclusion and exclusion criteria for eligibility to participate. Five participants were excluded from the study due to self-reported lower limb injuries. Two further participants were excluded - one indicated that he operated as pacer at the OMTOM making it impractical to measure performance, whereas another participant was excluded as she did not qualify to participate in the race. Participants were encouraged to ask questions and be satisfied with responses electronically (per email), telephonically and/or in person prior to obtaining written informed consent (*Appendix F*) from 46 potentially eligible and willing participants. One participant withdrew after being informed of his random allocation to the experimental group due to personal preferences (therefore he also did not meet exclusion criteria regarding compression garment use).

3.2.2.2 Sample size calculation

With a selected confidence level of 95%, a power of detectability of 80%, a hypothesised difference of 1.8, and a variance of 4 (based on data from a previous study by Welman, 2011[41]), the required sample size was calculated as 19 participants per group. Standard programmes using variants in effect size were used for the power calculation. This is similar to the calculations in a prior doctoral dissertation for a study performed to test compression garments during the OMTOM 56km race in which some significant differences were reported[41].

A minimum of 38 participants (i.e. 19 per group) were required to ensure adequate statistical power. Twenty-three participants were initially included for each group in this study.

3.2.2.3 Random allocation

The participants were matched based on sex, age and personal best (PB) marathon times (converted to pace per kilometre) before being randomly allocated to the experimental or control group (using Microsoft excel, 2013 simple randomisation). The experimental group consisted of 22 participants who were instructed to train as usual in the final six weeks and participate in the race while wearing below knee compression garments (the 23rd participant withdrew at the start of the study). Compression garments were thus only worn during running and not during the recovery period. The control group consisted of 23 participants who were instructed to neither train nor participate in the race with compression garments. Participants were informed regarding allocation and group expectations throughout the study prior to the start of data collection.

3.2.3 Completion of study

Following baseline screening and data-collection for the initial participants, four did not complete the study, with equal numbers from each group. During the training period, one experimental group participant withdrew due to thermal discomfort while using the compression garments. A further two participants withdrew, one for personal reasons (too busy to attend follow up sessions) and the other due to falling ill and consequently being unable to compete in the OMTOM 56km race. At the final

visit, one participant did not arrive for his appointment and confirmed telephonically that due to other obligations, he would no longer be able to attend. In addition, for logistical reasons, three participants were unable to access the medical tent and missed out on circumference measurements, however they were not excluded from the study seeing as data on all other variables were collected. Only the data of those participants who completed the study were included in the final report of findings.

3.3 Measurement instruments

3.3.1 Screening tools and consent

3.3.1.1 Informed consent

Prior to participating in the study, each individual was required to sign written informed consent forms to confirm willingness to comply to study procedure, with an emphasis on his/her right to withdraw at any point for whatever reason with no detrimental impact on his/her well-being. The informed consent form provided information regarding the study purposes, procedure, risks, benefits and institution affiliation and participants were encouraged to ask questions if anything was unclear. This was to ensure participants were well-informed prior to providing written consent.

3.3.1.2 Self-developed screening tool

A screening tool was developed to assess participants' preliminary eligibility to participate in the study based on the inclusion and exclusion criteria. The form was sent to participants electronically to complete prior to commencement of further testing. Further screening was performed by means of the Nordic Musculoskeletal Questionnaire and the Physical Activity Readiness Questionnaire (PAR-Q+) at the first data collection session.

3.3.1.3 Nordic Musculoskeletal Questionnaire

Participants were required to complete a revised Nordic Musculoskeletal Questionnaire to screen for musculoskeletal conditions specifically in the lower limb that may have impacted on safety of participation and performance. If conditions were identified, appropriate referrals would be made for further assessment by an appropriate health professional.

3.3.1.4 Physical Activity Readiness tool

Participants were required to complete the PAR-Q+ to screen for any medical conditions that may have impacted on safety of participation and performance. If conditions were identified, appropriate referrals were made for further medical assessment.

3.3.2 Study instrumentation

3.3.2.1 Anthropometric measurements

For group descriptive purposes, the body mass index (BMI) was calculated based on body mass and stature measurements. Body mass (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 standard formula: 'mass(kg)/stature(m^2)' was used to calculate BMI[161].

3.3.2.2 Time trial with RaceTec timing chips

The first objective was assessed with RaceTec timing chips as utilised by all runners according to OMTOM regulations during the 56km race. Time durations to 42km and 56km respectively was obtained online following completion of the race. This information was used to calculate the average running pace (*min:sec/km)* over-all as well as during the first 75% and the final 25% of the race.

RaceTec is the official timing device for the OMTOM event. It is considered internationally as a valid and reliable timing system and is utilised at many other running events[139].

3.3.2.3 Ultrasound imaging

The second objective was assessed by measuring the pennation angle and muscle thickness of the medial gastrocnemius using ultrasound imaging. A Siemens ACUSON X150 diagnostic ultrasound machine was utilised. Brightness mode (B-mode) with musculoskeletal (MSK) setting selected was utilised during imaging[114]. The right leg of participants were tested with the participant in the prone position with the ankle positioned in 90^0 plantarflexion maintained by a firm footplate. Participants were instructed to relax the muscle while ultrasound imaging was performed. The mid-point between the proximal and distal musculotendinous junctions of the medial gastrocnemius was utilised to obtain the scans[114]. Each measurement was performed at least twice and average values used (*Appendix G*). The same data collector performed all measurements.

3.3.2.3A Pennation angle

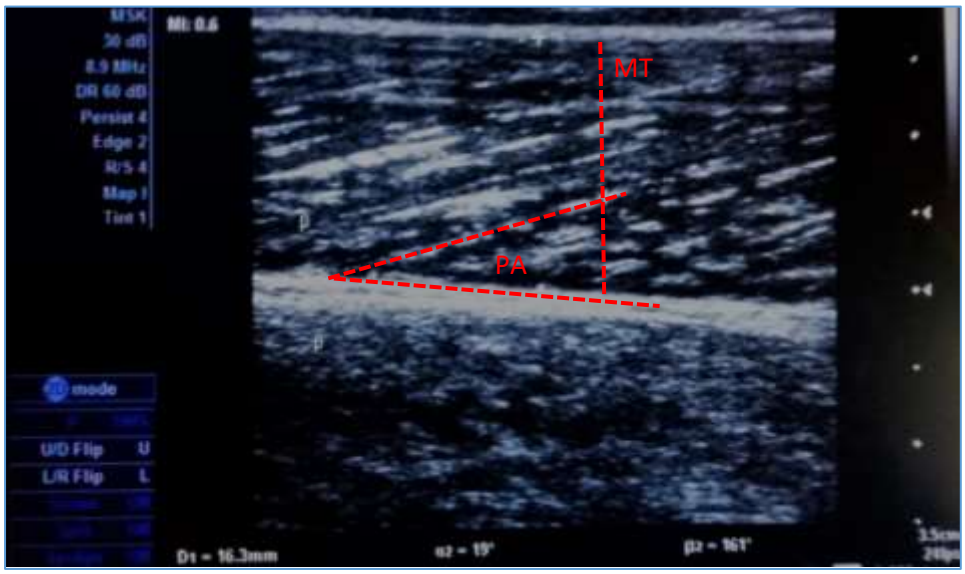
Pennation angle was calculated as the angle formed between the muscle fascicles and the deep aponeurosis[6,114]. The scan was performed at the midpoint between the proximal and distal musculotendinous junctions of the medial gastrocnemius muscle. For each scan, two angles were calculated and average values were utilised.

3.3.2.3B Muscle thickness

The thickness was calculated as the "distance between the superficial and deep aponeuroses"[6,114]. The scan was performed at the midpoint between the proximal and distal musculotendinous junctions of the medial gastrocnemius muscle. For each scan, measurements were taken perpendicularly at the middle of each image and the average of two muscle thickness values were utilised.

An example of pennation angles (PA) and muscle thickness (MT) measurements can be seen in Figure 2.1 below.

Figure 2.1: Ultrasound measurements



Original photo by investigator

3.3.2.4 Circumferences with tape measurement

The third objective was assessed by measuring mid-calf and figure-of-8 ankle circumferences with standardised anatomical landmarks with a tape measure (in *cm*). Participants were positioned in sitting with feet extending over the edge of the plinth and instructed to relax the muscles while the measurements were taken. The same data collector performed all measurements.

3.3.2.4A Ankle measurement:

The ankle circumference was taken with the right ankle in a relaxed neutral position with a standardised figure-of-8 method[103]. Each measurement was performed twice and average values used.

3.3.24B Mid-calf measurement:

The mid-calf measurement was taken at the widest girth section (standardised protocol[162]) between the ankle malleoli and the fibular head. Each measurement was performed twice and average values used.

3.3.2.5 Visual Analogue Scale for pain ratings

The fourth objective was assessed with the administration of the VAS questionnaire with subjective pain ratings on a scale of 0-10 with 0 representing no pain and 10 representing the worst pain imaginable. The numerical VAS scale was adapted and applied to evaluate pain at rest and during active NWB lower limb movements. (*Appendix H and I.*)

3.3.2.6 Countermovement jump

The fifth objective was assessed by video recording a CMJ test and analysing data using the MyJump application in the three days prior to, upon completion and two days following the race. Peak power output was subsequently estimated using the Johnson & Bahamonde (1996)[153] formula utilising body mass, stature and MyJump App derived CMJ vertical height values.

An iPhone 6s (*Apple Inc., Cupertino, California*) sampling at 240 Hz was used to analyse three CMJ trials in the right sagittal plane. The camera was secured and positioned in a steady position, level with the ground in line with the lateral malleolus, which was used as marker, for each participant.

The CMJ test was performed based on standardised procedures[147,148,151]. Participants started in a static position with their hands on their waist with the hips and knees extended to a neutral position. Participants were then instructed to squat to approximately 90° of knee flexion immediately followed by jumping as high and as fast as possible while keeping the legs extended, and landing with both feet simultaneously[147]. Participants were instructed to perform the test to their maximal capability[147,148,151]. After two practice jumps for familiarisation purposes[150], three CMJ tests were performed with 30 seconds of passive rest separating attempts. Average values were calculated.

3.3.2.7 Self developed questionnaire

A self-developed questionnaire was utilised to assess records of compression garment utilisation and training details during the six week training period. Further self-developed questionnaires were utilised to provide a record of fluid and nutrition during the race as well as any muscle recovery modalities utilised in the week prior, during or two days following the race[5,16]. Females were also requested to provide information regarding their menstrual cycle and utilisation of the contraceptive pill. In addition, participants were questioned regarding any issues that may have occurred during the race. This was to provide a qualitative component to account for any possible confounding variables such as being ill or cramping during the race. Participants were instructed to refrain from any muscle

recovery techniques if possible from one week prior to the race until the final data collection. However, if recovery modalities were utilised, participants were asked to report on frequency and timing of utilisation. These records served to provide descriptive data on possible confounding factors and is reported alongside results.

3.3.3 Training with instrumentation

3.3.3.1 Ultrasound training

The data collector was trained in utilising the Siemens Diagnostic Ultrasound equipment for imaging the gastrocnemius muscle by an experienced instructor. A total of four hours under supervision and 12 hours of independent practice was performed. The pennation angle and muscle thickness of the medial gastrocnemius muscle measurements (as described in Section 3.3.2) were performed on seven voluntary participants, who were recreationally active. Two of these were also assessed on separate days and at different times of the day to establish reliability (*r=0.95 for pennation angle and r=0.99 for muscle thickness obtained*). The results of these participants were not included in the research study.

3.3.3.2 Circumference measure training

The measurements were practiced according to precise specifications (as described in Section 3.3.2) on seven voluntary participants. Two subjects were also tested on separate days and at different times of the day to establish reliability of the data collector (*r=0.98 for figure-of-8 ankle measurement and r=0.99 for mid-calf circumference were obtained*). The results of these participants were not included in the study.

3.3.4. Compression Garments

3.3.4.1 Composition

Commercially available below knee compression garments produced locally were utilised in the study. The composition of these garments are 68% polyamide, 30% Drynamix (containing predominantly polyester) and 2% elastane fabric. The manufacturers were not financially involved in the study to avoid introducing any bias to produce desirable outcomes. The garments utilised were within a price range that should be accessible to the majority of South African endurance runners, across the socio-economic range.

3.3.4.2 Pressure level

Due to financial limitations it was not viable to establish the pressure level exerted by the garments on each participant. However, the product is advertised to provide light to moderate levels of compression. Previous studies have defined light to moderate compression in below knee garments as those exerting pressures ranging from 15-21mmHg at the ankle[19] and gradually decreasing towards the calf. Another classification system categorises light CG as below 20mmHg, medium as between 20-30mmHG and high as greater than 30mmHg[163]. No significant change in impact was detected when utilising low, medium or high level compression garments[19] and considering that low and medium level compression has been rated as more comfortable[62] this should be the preferred choice.

3.4 Procedure

3.4.1 Data collection

Data collection was performed on four occasions. The initial data collection (Visit 1) was performed six weeks prior to the race at UCT's Division of Exercise Science & Sports Medicine (ESSM) of the Department of Human Biology at the Sport Science Institute of South Africa (SSISA). After obtaining written informed consent, the Nordic Musculoskeletal Questionnaire[164] was administered to verify

that participants had been injury-free for 3 months; and the PAR-Q+ questionnaire was administered to verify that participants were without any medical condition that could have inhibited safety of participation. Each participant's stature and body mass was measured to calculate BMI for group descriptive purposes. Ultrasound imaging was used to determine pennation angles and muscle thickness of the medial gastrocnemius muscle and mid-calf and figure-of-8 ankle circumferences were recorded with a tape measure. Participants were instructed to refrain from analgesics, NSAIDs, excessive alcohol consumption, sports massage, foam rolling, extensive stretching[5,16,165] and any other muscle recovery strategies from one week prior to OMTOM until completing the final data collection visit as far as possible. If utilised, they were requested to keep a record of utilisation. In the three days prior to the race (Visit 2), these measurements were repeated. An optional CMJ test recorded using the MyJump app was completed by willing participants. In addition, each participant received a questionnaire regarding compression garment utilisation and training schedule over the six week training period (*Appendix J*). At the finish line of the OMTOM (Visit 3), circumference measurements and VAS pain ratings were repeated in an allocated area of the medical tent facilities. The additional CMJ test was completed by the same participants. In addition, reports of nutrition and fluid intake as well as possible recovery strategies were obtained (A*ppendix I)*. Two days following the event (Visit 4), the circumference measurements, ultrasound imaging and the optional CMJ tests were repeated as above at ESSM, SSISA. VAS pain ratings and records of recovery strategies were obtained (A*ppendix I)*. Electronic appraisal of results based on RaceTec timing values were obtained for each participant's finish time and 42km split times. This was used to calculate the average race pace to 42km, overall (to 56km) and during the final 14km.

(A*ppendix K*).

3.4.2 Data management

Autonomy and confidentiality is maintained with representation of data. Hard copies of data are stored in a secure, locked cabinet. It was and will only be appraised by the researchers concerned. Data is recorded electronically on a password protected personal laptop and secure online Dropbox folder (*www.dropbox.com*). This data is also stored on a removable hard-drive, and stored in a secure, locked cabinet along with the hard copies. Electronic records of RaceTec times are available on the OMTOM event website (*http://www.twooceansmarathon.org.za*). However, participants' identities were not linked to the research study on this public accessible site.

3.4.3 Statistical Analysis

All statistical analysis was performed with Statisitica software (Statistica13; 2017) and Microsoft Excel (2013). Statistical significance was accepted as $p < 0.05$.

The Shapiro-Wilk tests for normality were conducted to determine if data were normally distributed. The data were considered normally distributed if $p > 0.05$. All descriptive data (i.e. age, PB marathon race pace, weight and height) except BMI were normally distributed. Means and standard deviations (SD) were calculated and a t-test for independent samples was performed to determine if there were any statistically significant ($p<0.05$) differences between groups. The median and interquartile range was calculated for the BMI.

The race pace data were normally distributed, therefore means and SD of the average race pace were calculated and compared between groups for over-all race pace and during the first 75% and the last 25% respectively. A repeated measures ANOVA test was performed to assess if there were statistically significant (*$p<0.05$*) differences among the groups.

Muscle architecture values, circumference measurements and CMJ variables were normally distributed. Therefore the mean and SD of medial gastrocnemius pennation angles and muscle thicknesses, ankle and mid-calf circumferences as well as CMJ height and PPO's were calculated for each period of data collection (Visit 1 to 4). This data was analysed with Repeated-measures-ANOVA tests to compare values between groups at each visit to assess for statistical significance ($p<0.05$). T-tests for independent samples were also used to assess if there were significant differences ($p<0.05$) between groups at any point in time. In addition, proportional changes over time were calculated for circumference measurements and muscle architecture values over different time frames (i.e. Visit 1 to 2; Visit 2 to 3; Visit 3 to 4; and Visit 2 to 4) and presented as percentages. Effect sizes of absolute and proportional changes over time and between variables at each visit were calculated using Cohen's formula: '$(mean_1\text{-}mean_2)/SD_{pooled}$'[166]. Values of >0.2 is considered a "small" effect size, >0.5 a "medium" effect size and >0.8 a "large" effect size[167]. Values smaller than 0.2 were considered trivial. The smallest worthwhile change (SWC) was determined as: '(SD)(0.2)'. These values were compared to Standard Error of Measurement values to assess its relative relevance. Values considered of practical significance refers to a large difference (in effect size) which exceeds SWC and therefore may be considered to have practical significance regardless of statistical significance.

The frequency and medians of VAS scores were calculated. In addition, the relative change in VAS ratings over time (from visit 3 and visit 4) was determined. As it was not normally distributed, a Mann-Whitney-U test was performed to assess for statistically significant ($p<0.05$) differences from Visit 3 until Visit 4.

The frequencies (converted to percentages) of responses were recorded for each self-developed questionnaire and a Mann-Whitney-U test was performed to determine if there were any statistically significant differences between the two groups.

3.4.5 Ethical considerations

The study adheres to the principles of the Declaration of Helsinki (2013). It was submitted and approved by the University of Cape Town's, Faculty of Health Sciences, Human Research Ethics Committee (HREC REF: 872/2016) *(Appendix A).* Informed consent was obtained from each participant to determine willingness to comply to the study procedure, with emphasis on their right to withdraw at any point for whatever reason with no detrimental impact on their well-being. Study participants were well-informed of study purposes, procedure, risks and benefits and institution affiliations. All data obtained were and will continue to be kept in a secure, locked (hard copies) or password protected (electronic copies) location. No personal information was divulged during the study procedure and presentation thereof.

3.4.5.1 Risks and benefits

No financial remuneration was provided. However, at different phases of the study conduction, all participants received cost-free compression garments. In addition, a report of personal results and findings have been provided to study participants (*Appendix M*). Each participant will also receive a copy of the over-all study results once it is finalised. Furthermore, the value of the study in a field with relative paucity in research was explained to participants with implications regarding the utilisation of compression garments in endurance running.

Anthropometric measures of height and weight, lower limb circumference tape measurements and VAS ratings pose no/minimal known risks to participants. Ultrasound as utilised in this study poses minimal risks in the assessment of human tissue[114,168]. The CMJ test also poses minimal risks to

participants. None of these measures, including ultrasound, is associated with any discomfort to participants.

3.4.5.2 Significance and Justification

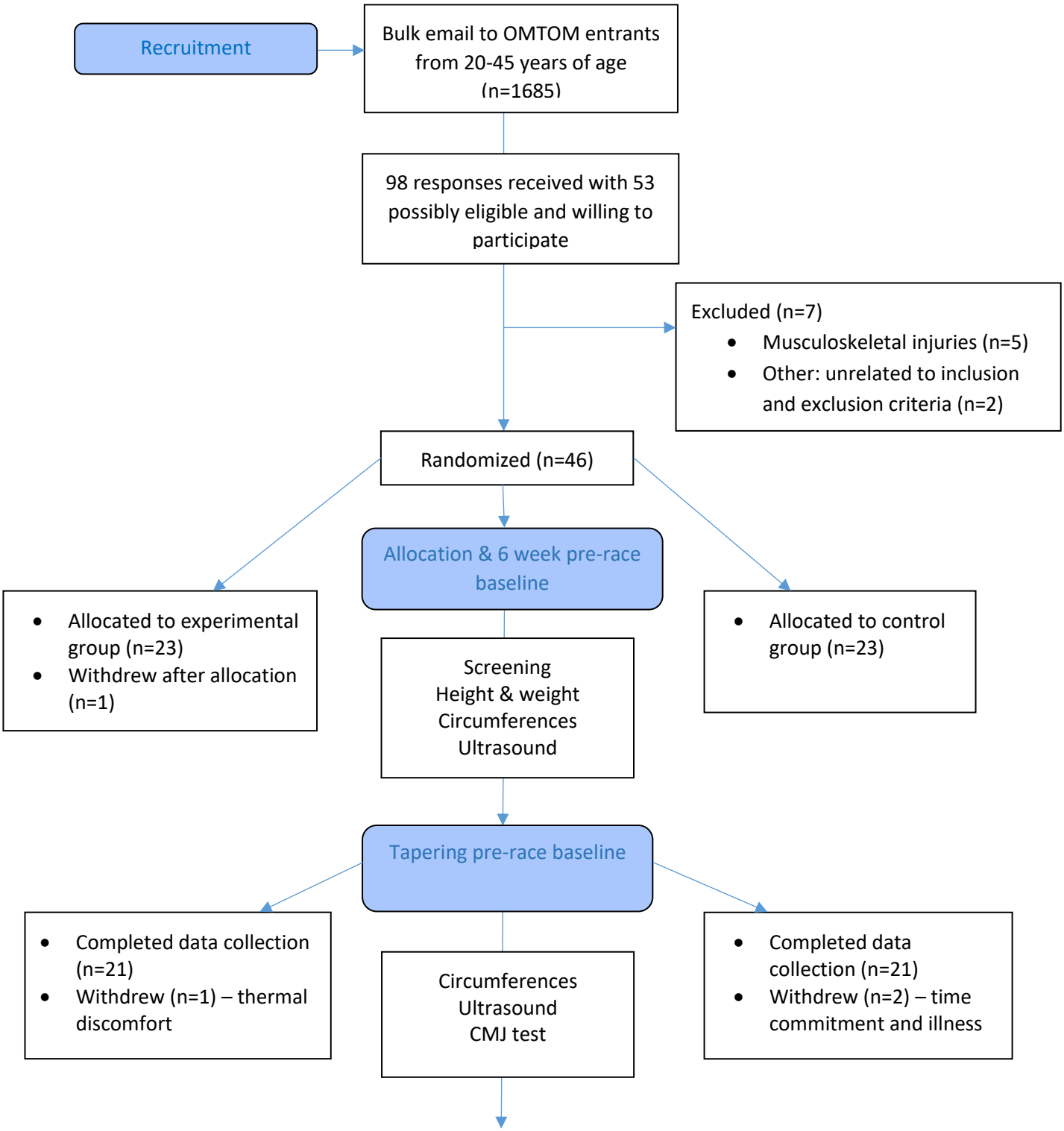
This investigation differed to previous studies in several ways. Firstly, the study was conducted at an actual ultramarathon event. Laboratory conditions may not be an accurate depiction of the natural running conditions in which compression garments are mostly utilised. Secondly, the groups were matched for sex, age and performance times to account for gender, age and performance related differences in running pace and muscle recovery. Thirdly, ultrasound imaging was used to analyse objective changes to the medial gastrocnemius muscle between a group training and competing with compression garments compared to controls not utilising compression garments. This is the first study, to our knowledge, to investigate compression garments in runners by means of ultrasound imaging to analyse exercise induced muscle damage. Only the medial gastrocnemius was used for comparison purposes, due to time-constraints (relatively large sample to be tested in short space of time with only one ultrasound device available for testing) and, importantly, due to prior research to confirm reliability and validity of ultrasound imaging to detect changes in this muscle[6,169]. Fourthly, this study assessed the impact of routine utilisation of compression garments in the final training and tapering period to no utilisation at any stage. To our knowledge, no previous study has included such a long training component to investigate the impact of routine utilisation of compression garments on performance in a long distance running event. Finally, this study investigated performance in the final 25% of the race in addition to over-all performance. It was anticipated that if compression garments decreased muscle damage, changes may only have become apparent following a prolonged period of exercise (i.e. following 42km of running). Past studies performed at marathon distances did not find statistically significant results in performance[63,84].

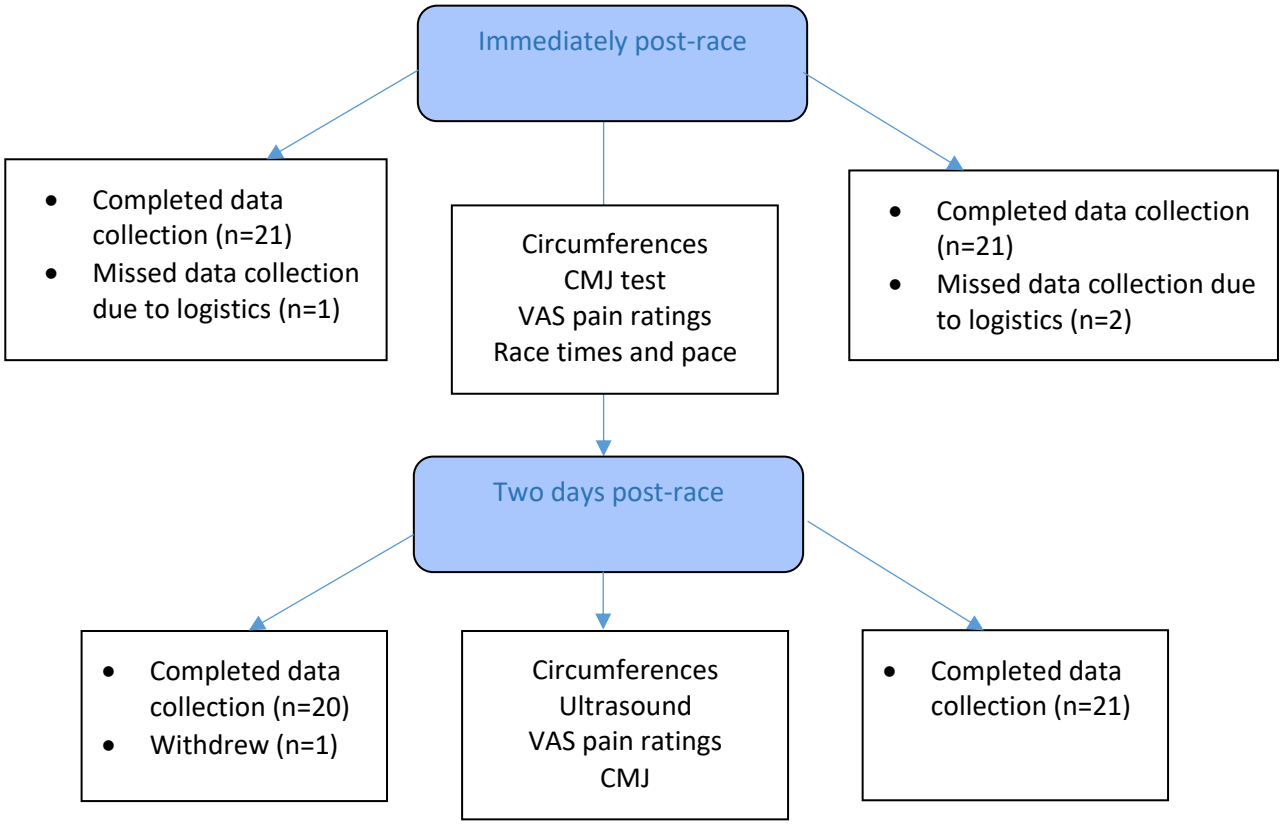
Results

3.6 Participant flow

Forty-six eligible and willing participants were recruited for the study of which forty-one remained at the final data collection session. The process of recruitment, screening and the four respective data collection sessions are summarised in Figure 3.1 below.

Figure 3.1: Participant flow




Immediately post-race
Completed data collection (n=21)
Missed data collection due to logistics (n=1)
Circumferences
CMJ test
VAS pain ratings
Race times and pace
Completed data collection (n=21)
Missed data collection due to logistics (n=2)
Two days post-race
Completed data collection (n=20)
Withdrew (n=1)
Circumferences
Ultrasound
VAS pain ratings
CMJ
Completed data collection (n=21)

3.7 Baseline Data

3.7.1 Visit 1

3.7.1.1 Descriptive characteristics

After matching, random allocation and screening, the experimental group originally consisted of six females and sixteen males, whereas the control group consisted of six females and seventeen males. At baseline, the average pace calculated from the best marathon times reported in the 18 months preceding the study was 06:03 min:sec/km for the experimental group and 06:02 min:sec/km for the control group. The average age for the experimental group at the start of the study was 34 years for each group respectively. When considering only those who completed the study, the group averages remained similar with no statistically significant differences between the groups at any stage. More specifically, group descriptive measures of participants who completed the study were not significantly different between groups in terms of average age (*p=0.57*), body mass (*p=0.17*), height (*p=0.18*), BMI (*p=0.78*) or reported PB marathon pace times (*p=0.98*) at baseline. Furthermore, analysis of covariance (ANCOVA) revealed no significant differences in descriptive characteristics of males and females between the two groups.

Group descriptive measures of the forty-one participants who completed the study are presented in Table 3.1. Only the data of these participants have been considered in further analysis.

Table 3.1: Descriptive data of participants at completion of study

	Experimental Group	Control Group
Total	**20**	**21**
Males	14	15
Females	6	6
Average pace in PB marathon in past 18 months ± SD	06:04 ± 00:37 min:sec/km	06:04 ± 00:45 min:sec/km
Average age ± SD	34 ± 4.8 years	34 ± 6.4 years
Average body mass ± SD	72.1 ± 10.5kg	76.6 ± 9.9kg
Average height ± SD	1.7 ± 0.9m	1.8 ± 0.09m
Median BMI (interquartile range)	24.3kg/m^2 (18.0-28.8 kg/m^2)	23.8kg/m^2 (20.8-29.0 kg/m^2)
SD=standard deviation		

3.7.1.2 Baseline circumference measures

At the initial data collection, six weeks prior to the OMTOM 56km race, circumference measurements were similar for the experimental and control groups with figure-of-8 ankle mean measurements of 54.6 ± 3.9cm and 55.3 ± 3.1cm and mid-calf circumference means of 38.8 ± 3.2cm and 39.4 ± 2.3cm respectively. These measurements were normally distributed in both groups as determined by Shapiro-Wilk testing (*p>0.05*). Although the control group circumferences were both somewhat higher than the experimental group at the onset of the study, there were no significant differences between mean ankle circumferences (*p=0.56*) or mid-calf circumferences (*p=0.39*) as determined by t-test for

independent groups. Small effect sizes were detected in mean ankle circumference (*Cohen's d=0.2*) and mean mid-calf circumference (*Cohen's d=0.3*) at baseline.

Baseline circumference measures are presented in Table 3.2 below.

Table 3.2 Baseline circumference measures 6 weeks prior to the race

6 week baseline pre-race:	Experimental group	Control Group	Difference between groups
Mean ankle circumference measures ± SD (n=38)	54.6 ± 3.9cm (n=19)	55.3 ± 3.1cm (n=19)	p=0.56 Cohen's d=0.2 "small" effect size Difference in means: -0.7cm
Mean mid-calf circumference measures ± SD (n=38)	38.8 ± 3.2cm (n=19)	39.4 ± 2.3cm (n=19)	p=0.39 Cohen's d=0.3 "small" effect size Difference in means: -0.6cm
n=number of participants *SD=standard deviation*			

3.7.1.3 Baseline muscle architecture

The muscle architecture measurements at baseline were similar for the medial gastrocnemius muscles with a normal distribution of data (*p>0.05*). The pennation angle mean for the experimental group was slightly lower at 18.6 ± 1.3° compared to 19.8 ± 2.4° for the control group. Similarly the muscle thickness mean of 1.7 ± 0.2cm for the medial gastrocnemius was slightly lower for the experimental group than the mean of 1.82 ± 0.2cm for the control group. However, there were no significant differences between the two groups, albeit with a tendency towards statistical significance in both pennation angles (*p=0.06*) and muscle thickness (*p=0.05*). There were medium effect sizes in average pennation angles (*Cohen's d=0.6*) and muscle thickness (*Cohen's d=0.6*) of the medial gastrocnemius in the two groups at baseline.

The baseline muscle architecture measurements for both groups are summarised in Table 3.3 below.

Table 3.3 Baseline muscle architecture 6 week prior to the race

6 week baseline pre-race:	Experimental group	Control Group	Difference between groups
Mean medial gastrocnemius pennation angles ± SD (n=41)	18.6 ± 1.3° (n=20)	19.8 ± 2.4° (n=21)	p=0.06 Cohen's d=0.6 "medium" effect size Difference in means: -1.2°
Mean medial gastrocnemius thickness ± SD (n=41)	1.70 ± 0.2cm (n=20)	1.82 ± 0.2cm (n=21)	p=0.05 Cohen's d=0.6 "medium" effect size Difference in means: -0.12cm
n=number of participants *SD=standard deviation*			

3.8 Follow up data

3.8.1 Visit 2

In the three days preceding the OMTOM race, when it was anticipated that the runners would be in their tapering phase, the circumference measurements and diagnostic ultrasound scans of the medial gastrocnemius muscle were repeated. Furthermore, those participants who were willing performed an additional countermovement jump test analysed by the MyJump Application.

3.8.1.1 Tapering baseline circumference measures

The circumference means remained very similar compared to baseline for ankle and mid-calf measurements in both groups. There were still no significant differences and small effect sizes detected in the experimental and control groups' ankle circumference means (*p=0.44; Cohen's d=0.2)* and mid-calf circumference means (*p=0.44; Cohen's d=0.3)*. No significant changes over time for ankle (*p=0.95)* or mid-calf (*p=0.37)* measurements were detected.

The results of the tapering baseline circumference measurements are summarised in Table 3.4 below.

Table 3.4: Tapering baseline circumference measurements

Tapering baseline pre-race:	Experimental group	Control Group	Difference between groups
Mean ankle circumference measures ± SD (n=38)	54.3 ± 3.7cm (n=19)	54.9 ± 3.2cm (n=19)	p=0.44 Cohen's d=0.2 "small" effect size Difference in means: -0.6cm
Mean mid-calf circumference measures ± SD (n=38)	38.8 ± 2.0cm (n=19)	39.3 ± 2.1cm (n=19)	p=0.44 Cohen's d=0.3 "small" effect size Difference in means: -0.5cm

n=number of participants

SD=standard deviation

3.8.1.2 Tapering baseline muscle architecture

Muscle architecture values changed only by small margins in both groups and data remained within a normal distribution (*p>0.05*). Medial gastrocnemius pennation angle means increased minimally to 18.7 ± 1.4° in the experimental group and slightly more to 20.5 ± 2.2° in the control group (i.e. less than 1° increase in each group). The muscle thickness values also increased to 1.79 ± 0.2cm and 1.90 ± 0.2cm for the experimental and control groups respectively (i.e. an 8mm increase in each group). At this point in time, the muscle thickness values were significantly higher (*p=0.03*) in the control group. A medium effect size was detected in muscle thickness at the same point in time, whereas a large effect size was detected in mean pennation angles between the two groups at tapering baseline. However, there were no significant changes (*p=0.70*) over the 6 week training period between the two groups. The pennation angles were neither statistically significantly different at the tapering baseline (*p=0.06*) nor over time from 6 weeks pre-race to shortly pre-race (*p=0.27*) between the two groups.

The results of the tapering baseline muscle architecture of the medial gastrocnemius are summarised in Table 3.5 below.

Table 3.5: Tapering baseline muscle architecture measurements

Tapering baseline pre-race:	Experimental group	Control Group	Difference between groups
Average medial gastrocnemius pennation angles ± SD (n=41)	18.7 ± 1.4° (n=20)	20.5 ± 2.2° (n=21)	p=0.06 Cohen's d= 0.9 "large" effect size Difference in means: -1.8°
Average medial gastrocnemius thickness ± SD (n=41)	1.79 ± 0.2cm (n=20)	1.90 ± 0.2cm (n=21)	p=0.03 Cohen's d= 0.6 "medium" effect size Difference in means: -0.11cm
n=number of participants *SD=standard deviation*			

3.8.1.3 Tapering baseline countermovement jump measures

Thirty-five participants agreed to perform the optional CMJ test with eighteen from the experimental group and seventeen from the control group. The control group, in accordance with the higher muscle architecture values, had a slightly higher average jumping height of 23.1 ± 6.2cm with estimated PPO of 2684 ± 1156W compared to 22.5 ± 5.3cm and estimated PPO of 2400 ± 694W in the experimental group. The data were normally distributed (*p>0.05*). Despite the slightly higher mean jump height in the control group, there were no statistically significant differences between the groups at this point in time in terms of CMJ height (*p=0.74)* or PPO (*p=0.39)*. A trivial effect size was detected in CMJ height (*Cohen's d=0.1*) and a small effect size was detected for estimated CMJ PPO (*Cohen's d=0.3*) at tapering baseline between the two groups.

The results of the tapering baseline CMJ testing are summarised in Table 3.6 below.

Table 3.6: Tapering baseline Countermovement jump measurements

Tapering baseline:	Experimental group	Control Group	Difference between groups
Mean CMJ height ± SD (n=35)	22.5 ± 5.3cm (n=18)	23.1 ± 6.2cm (n=17)	p=0.74 Cohen's d=0.1 "trivial" effect size Difference in means: -0.6cm
Mean calculated PPO ± SD (n=34)*	2400 ± 694W (n=17)	2684 ± 1156W (n=17)	p=0.39 Cohen's d=0.3 "small" effect size Difference in means: -284W

n=number of participants

SD=standard deviation

**missing body mass data for one participant*

3.8.1.4 Additional information

3.8.1.4A Compression garment utilisation over the 6 week training period

The majority (65%) of experimental group participants reported utilising the below knee compression garments provided for most of their runs, with 30% reporting utilising the compression garments during all of their runs. A small percentage reported using compression garments during long runs only. The majority of participants (75%) reported that compression garments were utilised approximately three to four times per week. The control group confirmed that no compression garments were utilised during the six week training period.

3.8.1.4B Training history over the 6 week period

The largest percentage (40%) of participants in the experimental group reported running on average five times per week, compared to four runs per week over the six week period for the largest percentage (33%) of the control group. In general, the average number of runs per week over the six week period was quite varied for both groups ranging from three to more than eight in both groups. The total distance of running performed per week was 50-59km for 30%, 60-69km for 25% and 70-79km for a further 30% of the experimental group with the remaining participants reporting above and below these distances. The largest percentage (43%) of the control group reported an average weekly distance of 50-59km with the vast majority of the remaining participants reporting values between the categories of 60-69km, 70-79km and 80-89km per week. A small percentage reported values above and below these. This also shows that although all participants reported a minimum of 50km per week at the start of the study, three of these (two in the experimental group and one in the control group) did not maintain the minimum distance of running required to enter the study. Furthermore, the majority of individuals from both groups performed other types of training in addition to running. The largest percentage of each group reported performing strength training on a weekly basis (40% of the experimental group and 48% of the control group). This was followed by flexibility, swimming and cycling in both groups. Smaller percentages also reported performing team

sports and surfing (classified as “other”) in the experimental group and skill specific training in the control group. There were no statistically significant differences detected ($p>0.05$) between groups for any aspect related to the training history.

The training history of both groups over the 6 week period considered is summarised in Figures 3.2-3.4 below.

Figure 3.2: Average number of runs per week

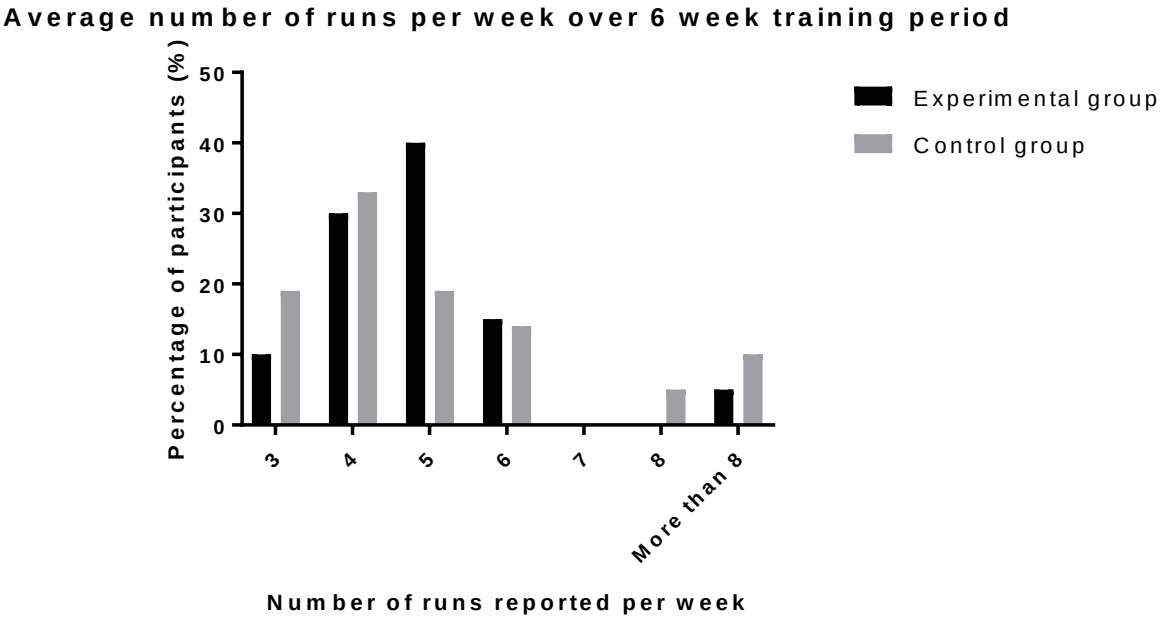


Figure 3.3: Average distance per week:

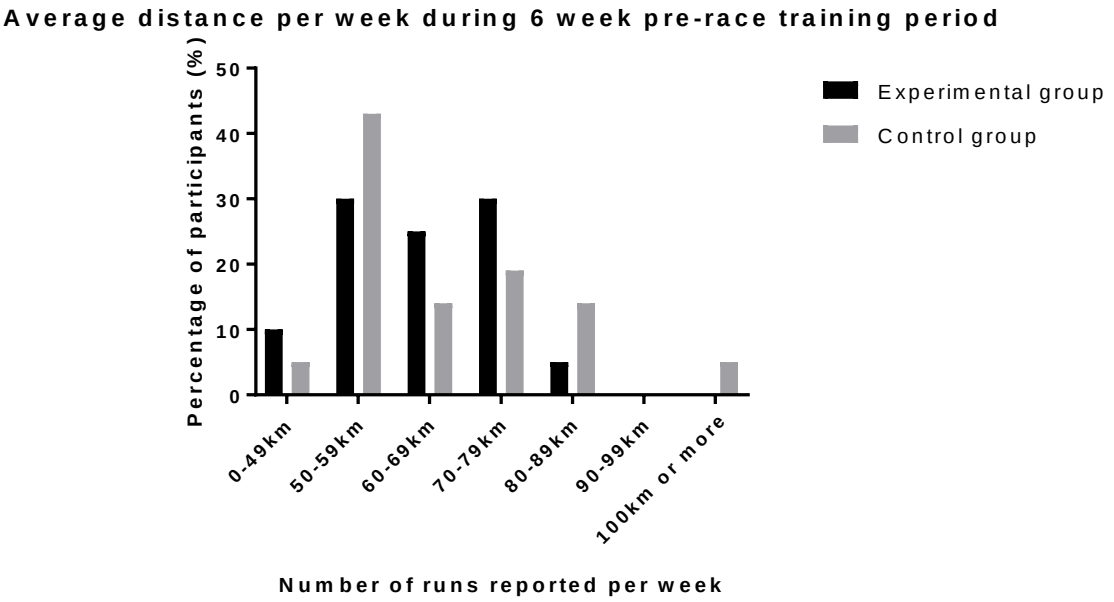
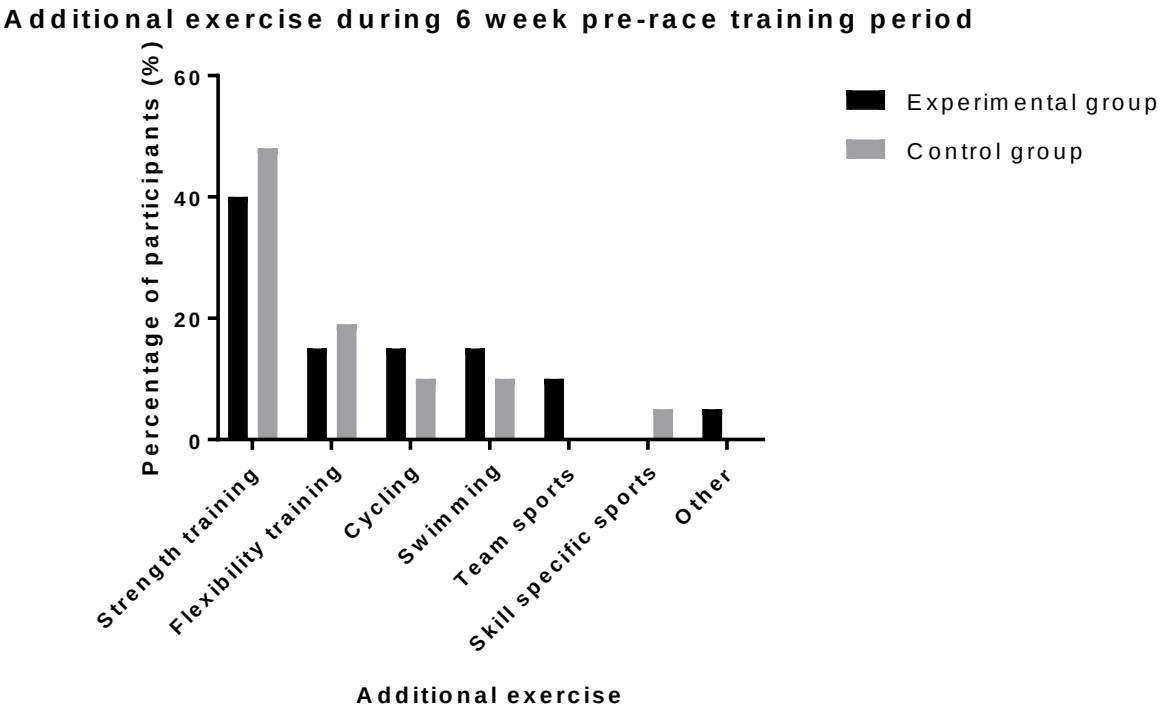


Figure 3.4: Additional training types



3.8.2 Visit 3

The circumference measurements and CMJ tests were repeated immediately following the race at the medical tent facility adjacent to the finish line. In addition, RaceTec timing frames were obtained once results were finalised on the public accessible OMTOM-website (http:// www. twooceansmarathon.org.za/events/info/results).

3.8.2.1 Immediately post-race circumference measures

The ankle and mid-calf circumference measurements decreased slightly in both groups. There were no significant differences between the two groups immediately following the race in terms of average ankle circumferences (*p=0.67)* or mid-calf circumference *(p=0.26)* measurements. A trivial effect size (*Cohen's d=0.1*) in average ankle circumference measurements was detected immediately post-race. However, there was a medium effect size (*Cohen's d=0.4*) between the two groups in average mid-calf circumferences. No significant difference over time in comparison to tapering baseline measurements for the ankle *(p=0.66)* and mid-calf (*p=0.*27) were detected.

Circumference measurements obtained shortly following the race are summarised in Table 3.7 below.

Table 3.7: Post-race circumference measurements immediately post-race

Immediately post-race	Experimental group	Control Group	Difference between groups
Average ankle circumference measures ± SD (n=38)	54.1 ± 3.6cm (n=19)	54.6 ± 3.1cm (n=19)	p=0.67 Cohen's d= 0.1 "trivial" effect size Difference in means: -0.5
Average mid-calf circumference measures ± SD (n=38)	38.2 ± 1.9cm (n=19)	39.0 ± 2.2cm (n=19)	p=0.26 Cohen's d= 0.4 "small" effect size Difference in means: -0.8cm
n=number of participants *SD=standard deviation*			

3.8.2.2 Immediately post-race countermovement jump measures

As expected following an ultra-endurance race, the CMJ heights decreased in both groups with mean maximum heights of 17.4 ± 7.2cm with estimated PPO of 1874 ± 870W in the experimental group compared to 18.9 ± 7.5cm with estimated PPO of 2204 ± 1199W for the control group. This means that the experimental group maintained approximately 77% of the original mean height and PPO, whereas the control group maintained approximately 81% of the original mean height and PPO. However, there were no statistically significant differences between the two groups in terms of CMJ height (*p=0.54)* and estimated PPO *(p=0.37)* immediately following the race. Small effect sizes in mean CMJ height (*Cohen's d= 0.2*) and CMJ PPO (*Cohen's d= 0.3*) were detected immediately post-race. No statistically significant change over time for CMJ height (*p=0.68)* and PPO *(p=0.8)* in comparison to pre-race values were detected.

CMJ test characteristics immediately post-race is presented in Table 3.8 below.

Table 3.8: Countermovement Jump heights immediately post-race

Immediately post-race	Experimental group	Control Group	Difference between groups
CMJ height ± SD (n=35)	17.4 ± 7.2cm (n=18)	18.9 ± 7.5cm (n=17)	p=0.54 Cohen's d= 0.2 "small" effect size Difference in means: -1.5cm
Mean calculated PPO ± SD (n=34)	1874 ± 870W (n=17)	2204 ± 1199W (n=17)	p=0.37 Cohen's d= 0.3 "small" effect size Difference in means: -357W

n=number of participants

SD=standard deviation

3.8.2.3 Race performance

Race pace was calculated from the start until 42km (approximately marathon distance), during the final 14km and over-all for the 56km race. The experimental group had an average race pace of 06:23 ± 00.39 min:sec/km up until 42km compared to 06:16 ± 00.52 min:sec/km for the control group with a normal distribution of data (*p>0.05*). During the final 25% of the race, both groups' race pace deteriorated as anticipated with the experimental group averaging 07:16 ± 01.17 min:sec/km compared to 07:05 ± 01.19 min:sec/km in the control group. This indicates that both groups' pace deteriorated on average 13% during the final 14km's of the race compared to the average pace to the 42km mark (i.e. 87% of the race pace from 0-42km maintained in the final 42-56km of OMTOM). The over-all race pace was similar for both groups. There were no significant differences in the pace from 0-42km (*p=0.59*), the final 14km (*p=0.68*) or in the over-all (*p=0.60*) race pace. A small effect size (*Cohen's d=0.3*) was detected in average race pace from 42-56km between the two groups. Effect sizes were negligible in pace from 0-42km and overall (0-56km).

Average race pace during different sections of the 56km OMTOM race are summarised in Table 3.9 below.

Table 3.9: Average race pace during 56km OMTOM event

	Experimental group	Control Group	Difference between groups
Average pace from 0-42km ± SD (n=41)	06:23 ± 00.39 min:sec/km (n=20)	06:16 ± 00.52 min:sec/km (n=21)	p=0.59 Cohen's d=0.1 "trivial" effect size Difference in means: 00:07 min:sec/km
Average pace from 42-56km ± SD (n=41)	07:16 ± 01.17 min:sec/km (n=20)	07:05 ± 01.19 min:sec/km (n=21)	p=0.68 Cohen's d=0.3 "small" effect size Difference in means: 00:11 min:sec/km
Average pace from 0-56km ± SD (n=41)	06:36 ± 00.48 min:sec/km (n=20)	06:27 ± 00.54 min:sec/km (n=21)	p=0.6 Cohen's d=0.1 "trivial" effect size Difference in means: 00:09 min:sec/km
n=number of participants *SD=standard deviation*			

3.8.2.4 Subjective pain ratings

Immediately following the race, the median VAS ratings were slightly lower for the posterior lower leg, anterior and posterior upper leg at rest as well as during dorsiflexion, knee extension and knee flexion in the experimental group compared to the control group. In contrast, the experimental group had slightly higher pain ratings for the anterior lower leg and during plantarflexion compared to the control group. The only statistically significant result was detected in the anterior lower leg at rest on the right (*p=0.03*) and left (*p=0.04*), with the control group reporting a median of 0 compared to 2 in the experimental group.

Pain ratings on VAS scale immediately following the race are presented in Table 3.10 below.

Table 3.10: Pain ratings immediately post-race

Immediately post-race:	Experimental group		Control Group		Difference between groups	Difference between groups
Right/Left lower limb:	Right	Left	Right	Left	Right	Left
Median VAS rating of anterior lower leg at rest (range) [IQR]	2 (0-8) [0.5-5]	2 (0-80 [0.5-5]	0 (0-5) [0-2]	0 (0-8) [0-2]	p=0.02 Difference in medians: 2	p=0.04 Difference in medians: 2
Median VAS rating of posterior lower leg at rest (range) [IQR]	1.5 (0-7) [0-3.5]	1.5 (0-7) [0-3.5]	3 (0-8) [0-5]	3 (0-8) [0-5]	p=0.53 Difference in medians: -1.5	p=0.3 Difference in medians: -1.5
Median VAS rating of anterior upper leg at rest (range) [IQR]	1.5 (0-8) [0-5.5]	1.5 (0-8) [0-5.5]	2 (0-9) [0-4]	2 (0-9) [0-4]	p=0.42 Difference in medians: -0.5	p=0.42 Difference in medians: -1.5
Median VAS rating of posterior upper leg at rest (range) [IQR]	2 (0-9) [0-5]	1.5 (0-9) [0-4.5]	2 (0-8) [0-3]	2 (0-8) [0-3]	p=0.98 Difference in medians: 0	p=0.72 Difference in medians: -0.5
Median VAS rating with plantarflexion (range) [IQR]	4 (0-8) [0-7]	4 (0-8) [0-7]	3 (0-8) [0-5]	3 (0-6) [0-5]	p=0.73 Difference in medians: 1	p=0.73 Difference in medians: 1
Median VAS rating with dorsiflexion (range) [IQR]	1.5 (0-7) [0-4]	1.5 (0-7) [0-4]	3 (0-7) [0-4]	2 (0-7) [0-4]	p=0.6 Difference in medians: -1.5	p=0.95 Difference in medians: -0.5
Median VAS rating with knee extension (range) [IQR]	2 (0-9) [0-5.5]	2 (0-9) [0-5.5]	4 (0-9) [0-6]	4 (0-9) [0-6]	p=0.48 Difference in medians: -2	p=0.47 Difference in medians: -2
Median VAS rating with knee flexion (range) [IQR]	1.5 (0-8) [0-2.5]	1.5 (0-8) [0-2.5]	2 (0-9), [0-3]	1.5 (0-8) [0-2.5]	p=0.87 Difference in medians: -0.5	p=0.93 Difference in medians: 0

**IQR: interquartile range*

3.8.2.5A Additional information: Nutrition and Fluid during race

The majority of participants in both groups reported drinking between 3-4 and 5-6 sachets (approximately 200ml) of water on average per hour during the race (72% of the experimental group and 74% of the control group). In addition, both groups most frequently reported drinking 1-2 or 3-4 sachets of other fluids per hour during the race (89% of the experimental group and 79% of the control group).

Energy gel intakes were most frequently reported followed by energy bars, potatoes and bananas in both groups. Other food types reported included various sweets, biscuits and biltong. There were no statistically significant differences detected (*p>0.05*) between groups in terms of fluid or nutritional intake.

Fluid and nutritional details are captured in Figure 3.5-3.6 below.

Figure 3.5: Fluid utilisation during OMTOM 56km

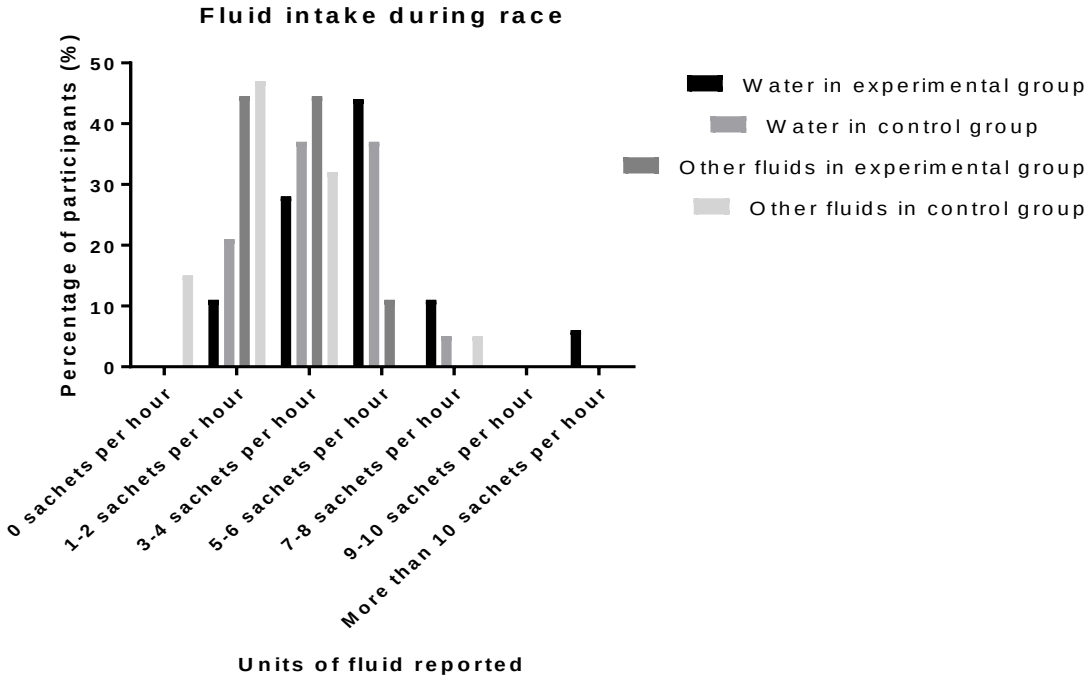
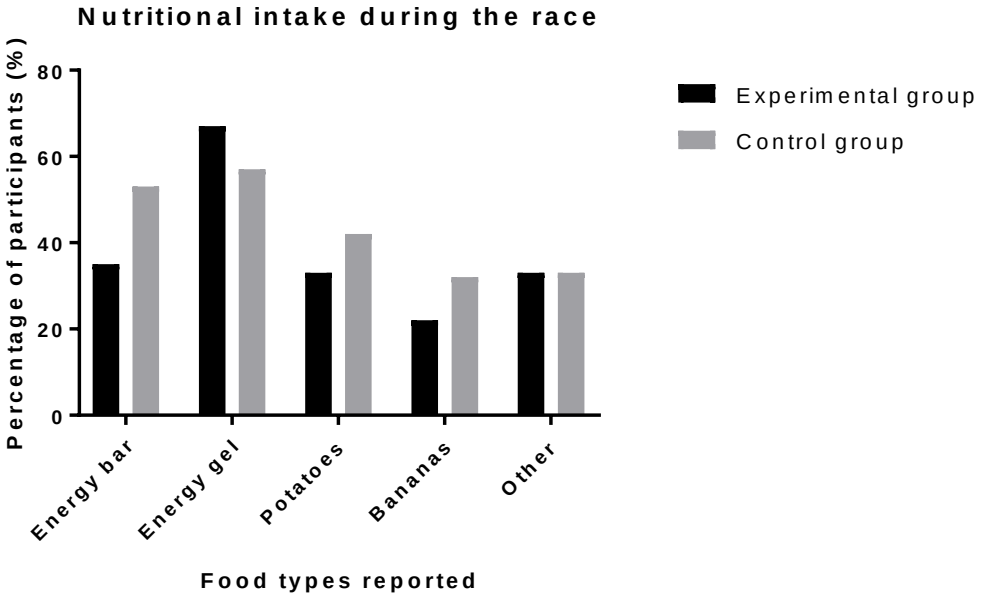


Figure 3.6: Nutrition during OMTOM 56km



3.8.2.5B Muscle recovery strategies pre-race and during race

Although participants were requested to refrain from using other muscle recovery strategies as much as possible from the week prior to until the final data collection, some recovery modalities were utilised in both groups. In the week prior to the race, a few participants from each group reported utilising stretching, cryotherapy, massage, foam rolling, nutritional supplements and electrical therapy modalities. The frequencies were similar between the two groups with no statistically significant differences detected between groups for any modality (*p>0.05*).

On race-day small percentages from each group reported using analgesics and anti-inflammatory medication, with a slightly higher percentage of utilisation reported in the experimental group. In addition, some participants from both groups reported utilising taping, nutritional supplements, post-race massage and stretching with similar values reported between groups. There were no statistically significant differences detected between groups for any modality (*p>0.05*).

Recovery modalities utilised in race week and on race day are summarised in Figure 3.7-3.8 below.

Figure 3.7: Race week modalities

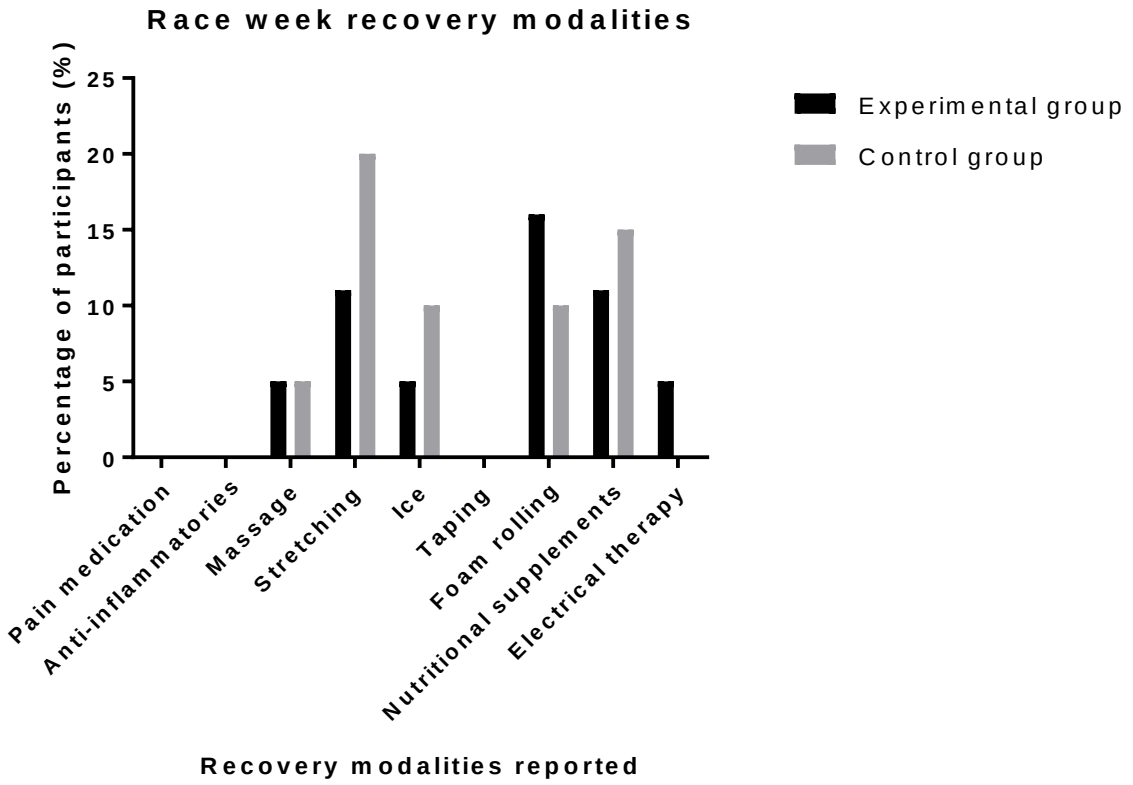
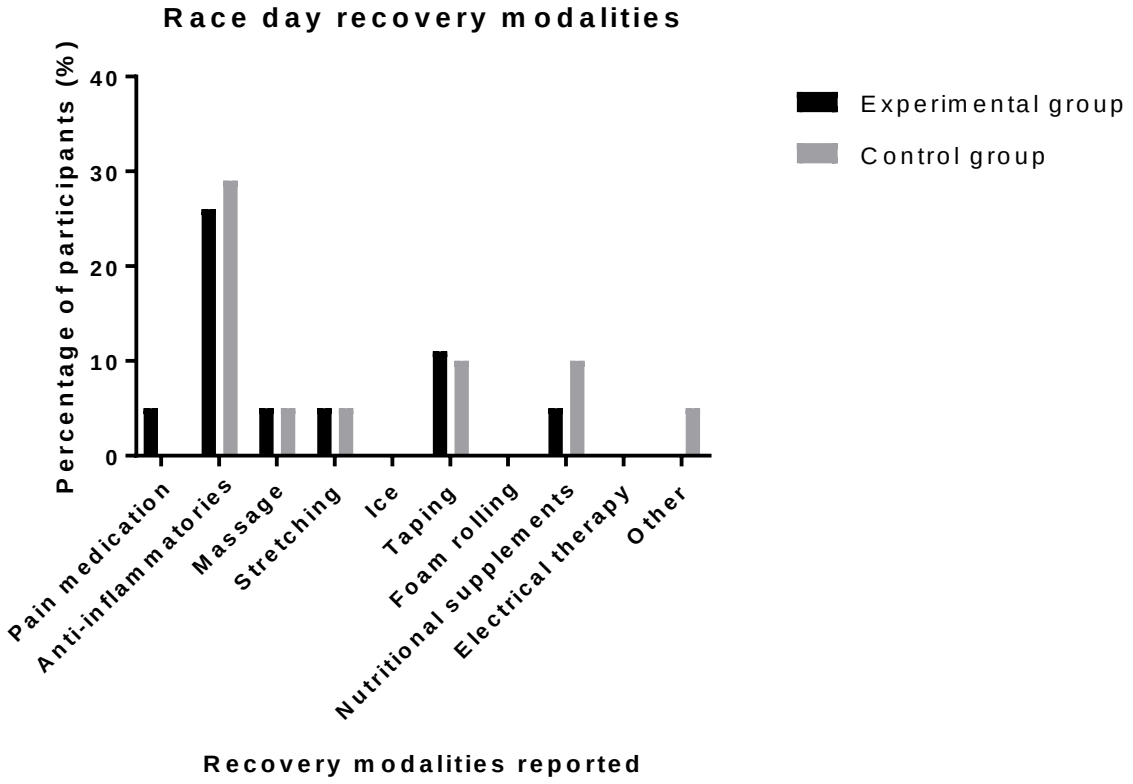


Figure 3.8: Race-day modalities



3.8.2.5C Additional information: Menstruation history in female participants

80% (*n=4*) of the females in the experimental group reported abnormal menstruation, with the majority reporting contraceptive use. In contrast, 80% (*n=4*) of the females in the control group reported normal menstruation with slightly less reporting contraceptive use. These differences were not statistically significant (*p>0.05*) and due to the small female sample size, it should be interpreted with caution.

3.8.3 Visit 4

The final data collection occurred two days following the completion of the race. Circumference measurements, diagnostic ultrasound scans, CMJ heights and VAS pain ratings were repeated.

3.8.3.1 Two days post-race circumference measures

The ankle circumference measurements were very similar in both groups compared to immediately post-race with a mild increase in the control group only. Mid-calf circumference measurements increased marginally on average to 38.8 ± 1.9cm for the experimental group and 39.7 ± 2.2cm for the control group. There were no significant differences in ankle measurements *(p=0.39*) or calf measurements *(p=0.37)* between the groups two days following the race. Small effect sizes were detected in average mid-calf (*Cohen's d=0.4*) and ankle circumference (*Cohen's d=0.4*) measurements two days post-race. There were also no significant changes from race day to two days post-race between groups for mid-calf circumference means (*p=0.39*). However, the ankle figure-of-8 circumference means changed significantly from immediately post-race to two day post-race (*p=0.01*). The latter implies that the control group values increased statistically significantly more than the experimental group over the two day period.

The circumference measurements are summarised in Table 3.11 below.

Table 3.11: Circumference measurements two days post-race

Two days post-race:	Experimental group	Control Group	Difference between groups
Average ankle circumference measures ± SD (n=38)	54.1 ± 3.7cm (n=19)	55.1 ± 3.2cm (n=19)	p=0.39 Cohen's d=0.4 "small" effect size Difference in means: -1cm
Average mid-calf circumference measures ± SD (n=38)	38.8 ± 1.9cm (n=19)	39.7 ± 2.2cm (n=19)	p=0.37 Cohen's d=0.4 "small" effect size Difference in means: -0.9cm

n=number or participants

SD=standard deviation

3.8.3.2 Two days post-race ultrasound measures

Ultrasound scans of the medial gastrocnemius muscle revealed that mean pennation angles increased slightly (less than 1°) in both groups to 19.2 ± 1.4°and 20.9 ± 2.3° in the experimental and control groups respectively, whereas muscle thickness values were very similar compared to tapering baseline values. Pennation angles (*p=0.01*) and muscle thickness (*p=0.02*) were significantly higher in the control group compared to the experimental group. A large effect size (*Cohen's d=0.9*) was detected in mean pennation angles two days post-race, whereas a medium effect size (*Cohen's d=0.7*) was detected in mean muscle thickness of the medial gastrocnemius. However, there were no significant changes in pennation angle means (*p=0.92)* or muscle thickness *(p=0.93)* over time from tapering baseline to post-race values.

The muscle architecture values are summarised in Table 3.12 below.

Table 3.12: Muscle architecture values two days post-race

Two days post-race:	Experimental group	Control Group	Difference between groups
Average medial gastrocnemius pennation angles ± SD (n=41)	19.2 ± 1.4° (n=20)	20.9 ± 2.3° (n=21)	p=0.01 Cohen's d=0.9 "large" effect size Difference in means: -1.7 °
Average medial gastrocnemius thickness ± SD (n=41)	1.78 ± 1.7cm (n=20)	1.91 ± 2.0cm (n=21)	p=0.02 Cohen's d=0.7 "medium" effect size Difference in means: -0.13cm

n=number or participants

SD=standard deviation

3.6.5.3 Two days post-race CMJ measures

CMJ performance improved by two days post-race compared to immediately post-race for both groups but still remained lower than pre-race values with jump heights of 19.9 ± 6.0cm (PPO: 2242 ± 808W) in the experimental group and 21.2 ± 6.8cm (2532 ± 1173W) in the control group. However, these differences were not statistically significant between groups at two days post-race in terms of CMJ heights (*p=0.57)* or PPO (*p=0.41)*. Small effect sizes in mean CMJ height (*Cohen's d=0.2*) and mean estimated PPO (*Cohen's d=0.3*) were detected two days post-race. No significant changes were detected over time from immediately post-race until two days post-race in CMJ height (*p=0.84*) or CMJ PPO (*p=0.77*).

The CMJ heights two days following the race are summarised in Table 3.13 below.

Table 3.13: Countermovement jump 2 days post-race

	Experimental group	Control Group	Difference between groups
CMJ height ± SD (n=35)	19.9 ± 6.0cm (n=18)	21.2 ± 6.8cm (n=17)	p=0.57 Cohen's d=0.2 "small" effect size Difference in means: -1.3cm
Mean calculated PPO ± SD (n=34)	2242 ± 808W (n=17)	2532 ± 1173W (n=17)	p=0.41 Cohen's d=0.3 "small" effect size Difference in means: -290W
n=number of participants *SD=standard deviation*			

3.8.3.3 Two days post-race subjective pain ratings

Two days following the race, VAS pain ratings were very similar at rest and with non-weight bearing movements for both groups. There were no significant changes between groups at this point in time (see Table 3.14). However, the control group reported significantly reduced pain ratings from immediately post-race until two days post-race compared to the experimental group while performing dorsiflexion and knee extension with the right leg (but not the left leg), respectively. No further significant changes over time were detected.

The VAS pain ratings obtained two days following the race are summarised in Table 3.14 below.

Table 3.14: Pain ratings 2 days post-race

Two days post-race:	Experimental group		Control Group		Difference between groups	Difference between groups
	Right	Left:	Right	Left:	Right:	Left:
Median VAS rating of anterior lower leg at rest (range) [IQR]	0.5 (0-6) [0-2]	0.5 (0-6) [0-2]	0 (0-2) [0-0]	0 (0-2) [0-0]	p=0.1 Difference in medians: 0.5	p=0.1 Difference in medians: 0.5
Median VAS rating of posterior lower leg at rest (range) [IQR]	1 (0-3) [0-1]	1 (0-3) [0-1]	0 (0-3) [0-1]	1 (0-3) [0-1]	p=0.58 Difference in medians: 1	p=0.58 Difference in medians: 0
Median VAS rating of anterior upper leg at rest (range) [IQR]	1 (0-5) [0-2.5]	1.5 (0-5) [0-2.5]	1 (0-8) [0-2]	1 (0-7) [0-2]	p=1 Difference in medians: 0	p=0.8 Difference in medians: 0.5
Median VAS rating of posterior upper leg at rest (range) [IQR]	0.5 (0-8) [0-2]	0.5 (0-8) [0-2]	1 (0-8) [0-1]	1 (0-8) [0-1]	p=0.76 Difference in medians: -0.5	p=0.76 Difference in medians: -0.5
Median VAS rating with plantarflexion (range) [IQR]	1.5 (0-8) [0.5-3]	1.5 (0-8) [0.5-3]	1 (0-6); [0-2]	1 (0-6) [0-2]	p=0.53 Difference in medians: 0.5	p=0.53 Difference in medians: 0.5
Median VAS rating with dorsiflexion (range) [IQR]	1.5 (0-8) [0.5-2]	1.5 (0-8) [0.5-2]	1 (0-3) [0-1]	1 (0-3) [0-1]	p=0.12 Difference in medians: 0.5	p=0.12 Difference in medians: 0.5
Median VAS rating with knee extension (range) [IQR]	2.5 (0-6) [1-4]	2.5 (0-7) [1.5-4]	2 (0-6) [1-4]	2 (0-6) [1-4]	p=0.47 Difference in medians: 0.5	p=0.47 Difference in medians: 0.5
Median VAS rating with knee flexion (range) [IQR]	2 (0-8) [0.5-3]	2 (0-8) [0.5-3]	1 (0-8) [0-2]	1 (0-8) [0-2]	p=0.2 Difference in medians: 1	p=0.2 Difference in medians: 1

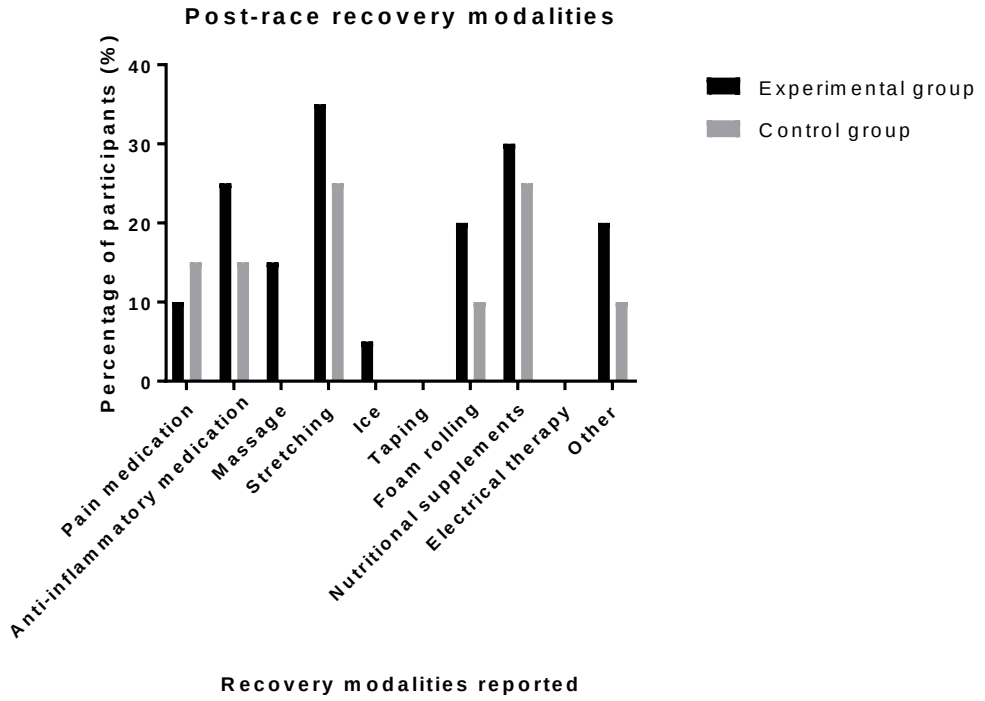
**IQR: interquartile range*

3.8.3.4A Additional information: Muscle recovery strategies post-race

Both groups reported using nutritional supplements, stretching, analgesics and anti-inflammatory medication since completing the race. Other recovery strategies utilised included massage (experimental group only), foam rolling and "other" (mostly alcohol consumption reported). The utilisation of recovery modalities was varied in both groups with no statistically significant difference *(p>0.05)* between the groups.

The recovery modalities reportedly utilised in each group in the two days following the race is summarised in Figure 3.9 below.

Figure 3.9: Post-race modalities



3.8.3.4B Additional information: Other issues

Additional issues were reported for both groups. In the experimental group, complaints during the race included dizziness (two participants), stomach cramps (one participant), quadriceps cramps (one participant) and other musculoskeletal complaints i.e. lower back pain and knee pain (two participants). Another experimental group participant reported having flu in the week prior to the race, whereas another said he ran slower than usual for personal reasons. It seems unlikely that any of these issues are related to compression garment utilisation.

In the control group, three participants reported falling and one reported calf cramps. None of these issues are likely to be related to not wearing compression garments. Over-all, additional, unrelated complaints were lower in the control group than the experimental group.

3.9 Changes over time of main outcomes

3.9.1 Circumference measurements

Over the period from six weeks pre-race until two days post-race, there were no significant changes over time in mid-calf *(p=0.75)* or figure-of-8 ankle *(p=0.34)* mean measurements in the experimental compared to the control group. In both groups, mid-calf circumferences remained similar during the two pre-race visits, with a decrease immediately post-race followed by an increase by two days following the race.

The mid-calf measurements remained virtually unchanged over the training period with a 0.05 ± 1.5% average increase in the experimental group compared to a 0.3 ± 1.8% decrease in the control group. Following the race, values decreased on average 1.4 ± 1.3% in the experimental group compared to 0.9 ± 1.7% in the control group. By two days following the race, these values increased on average 1.8 ± 1.2% in the experimental group compared to 1.5 ± 1.2% in the control group. There were no statistically significant differences between the two groups in terms of proportional changes in mid-calf measurements during the training period (*p=0.54*); from shortly pre-race until immediately post-race (*p=0.26*) or two days post-race (*p=0.64*); nor from immediately post-race until two days post-race (*p=0.35*). None of these relative percentage changes to mid-calf measurements were statistically significant over time between the two groups (*p>0.05*). Furthermore, there were small effect sizes from six weeks pre-race until shortly pre-race in proportional (*Cohen's d=0.3)* and absolute values (*Cohen's d=0.2; SWC=-0.1cm*); from shortly pre-race until immediately post-race in proportional (*Cohen's d=0.4*) and absolute values (*Cohen's d=0.4; SWC=-0.1cm*); from immediately post-race until two days post-race in proportional (*Cohen's d=0.3*) and absolute (*Cohen's d=0.4; SWC=0.06cm*) change; as well as in proportional (*Cohen's d=0.2*) and absolute (*Cohen's d=0.4, SWC=0.1cm*) change from shortly pre-race until two days post-race. The smallest worthwhile changes and differences in means were smaller than the standard error of measurement of 0.5cm[106,107] hence it is unlikely to be significant. The effect size of the absolute change in mid-calf measurements from tapering baseline until two days post-race was trivial (*Cohen's d=0.1*).

The figure-of-8 ankle measurements remained virtually unchanged over time in the experimental group with an average reduction of 0.6 ± 1.2% over the training period, a further minimal decrease of 0.2 ± 1.9% until immediately post-race and 0.3 ± 1.2% until two days post-race. The control group also remained virtually unchanged over the training period with a 0.2 ± 2.2% decrease over the six week period. These values decreased a further 1 ± 2.6% until immediately post-race and increased 0.8 ± 1.5% by two days following the race. There were no significant differences in proportional changes of ankle measurements over the training period *(p=0.48*); from tapering baseline to immediately post-race *(p=0.31)* or two days post-race *(p=0.5)*. However, from immediately post-race until two days post-race, the absolute ankle measurements *(p=0.01)* and the proportional difference *(p=0.01)* changed significantly over time in the two groups, with higher values in the control group. There were small effect sizes from six weeks until shortly pre-race in proportional (*Cohen's d=0.2*) and absolute (*Cohen's d=0.3; SWC=0.2cm)* change; from shortly pre-race until immediately post-race in proportional (*Cohen's d=0.3*) and absolute (*Cohen's d=0.4; SWC=0.2cm*) change; as well as from shortly pre-race until two days post-race in proportional (*Cohen's d=0.4*) and absolute (*Cohen's d=0.2; SWC=0.2cm*) change. These small effect sizes are unlikely to be significant since the changes in the means and SWC are smaller than the standard error of measurement of 0.4cm[102]. However, there was a large effect size from immediately post-race until two days post-race in proportional (*Cohen's d=0.9*) and absolute (*Cohen's d=1.1; SWC=0.1cm*) change, with the change in means (-0.7cm) exceeding the SEM.

The absolute circumferences measurement changes over time are presented in Figure 3.10-3.11 below.

Figure 3.10: Ankle circumference means over time

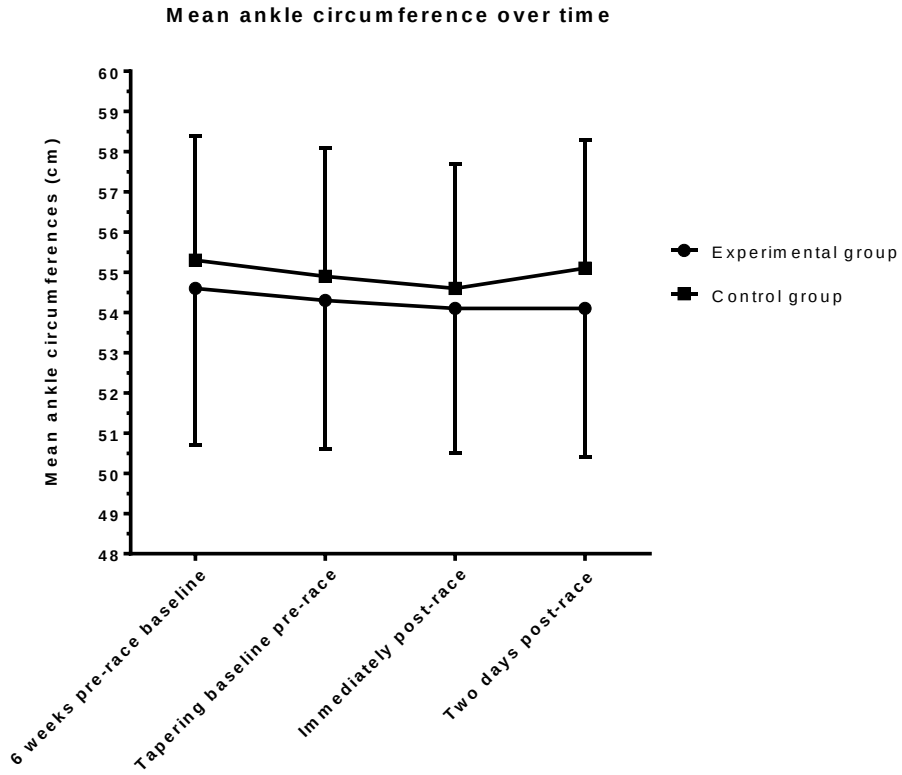
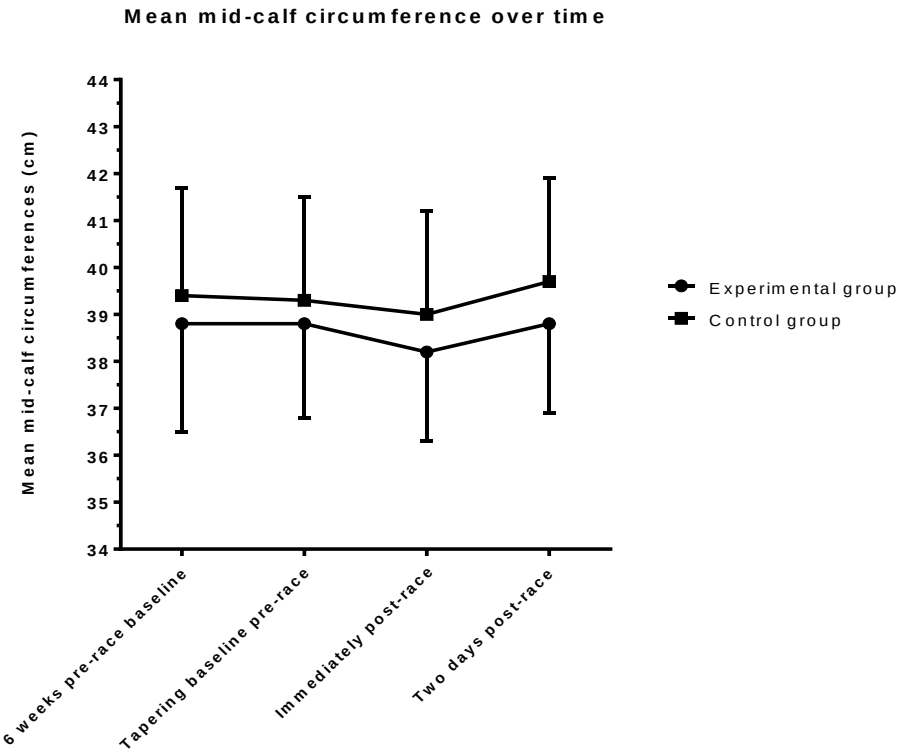


Figure 3.11: Mid-calf circumference means over time



3.9.2 Muscle architecture values

Both groups showed an increase in pennation angles and muscle thickness from the start until the completion of the study. Muscle thickness of the medial gastrocnemius increased on average 4.3 ± 7.9% in the experimental group and 4.8 ± 7.7% in the control group from six week pre-race until shortly pre-race. There was no statistically significant changes between the two groups (*p=0.83*) as determined by t-test for the normally distributed proportional (%) changes in muscle thickness over the six week period. A further increase was detected in both groups from shortly pre-race until two days post-race, with an average increase of 1.1 ± 4.6% in the experimental group and 0.8 ± 5.9% in the control group. This proportional (%) change was not statistically significant (*p=0.86*) between groups from shortly pre-race until two days post-race. In addition, there were no statistically significant changes between the two groups over time in absolute values of muscle thickness (*p=0.91)* throughout the study. Effect sizes were trivial for average muscle thickness proportional (*Cohen's d= -0.06*) and absolute (*Cohen's d=0.1*) change from six weeks pre-race until shortly pre-race; as well as from shortly pre-race until two days post-race in proportional (*Cohen's d=0.05*) and absolute (*Cohen's d=0.03*) values.

Pennation angles increased from the first until the final data collection in both groups. The experimental group's pennation angles increased slightly with an average of 0.5 ± 8.8% from 6 weeks until tapering baseline, whereas the control group increased 4 ± 10.7% on average over the training period. There were no significant proportional changes between the two groups over the training period (*p=0.25*). A further average increase of 3 ± 7.6% was observed from tapering baseline until two days following the race in the experimental group compared to an average of 2.6 ± 9.4% increase in the control group. This change from tapering baseline to two days post-race was also not statistically significant between groups (*p=0.89*). There were no statistically significant changes over time between the two groups in absolute values for pennation angles (*p=0.46)* throughout the study. There was a small effect size in average proportional (*Cohen's d=0.3*) and absolute (*Cohen's d=0.4; SWC=0.4°*) pennation angle changes from six weeks pre-race until shortly pre-race. However, this is unlikely to be of significance since the change in the means was smaller than the standard error of measurement of 0.1-1.2°[121]. Effect sizes from shortly pre-race until two days post was trivial in proportional (*Cohen's d=0.04*) and absolute (*Cohen's d=0.04; SWC=0.2°*) pennation angle changes.

The absolute muscle architecture measurements over time are presented in Figure 3.12-3.13 below.

Figure 3.12: Medial gastrocnemius muscle thickness changes over time

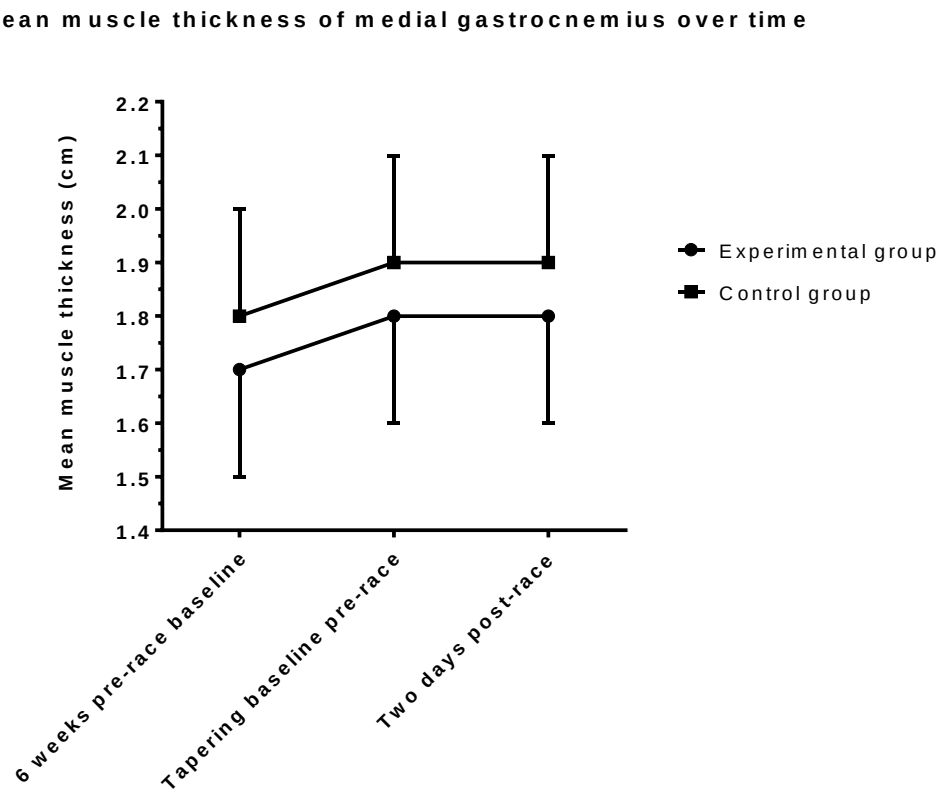
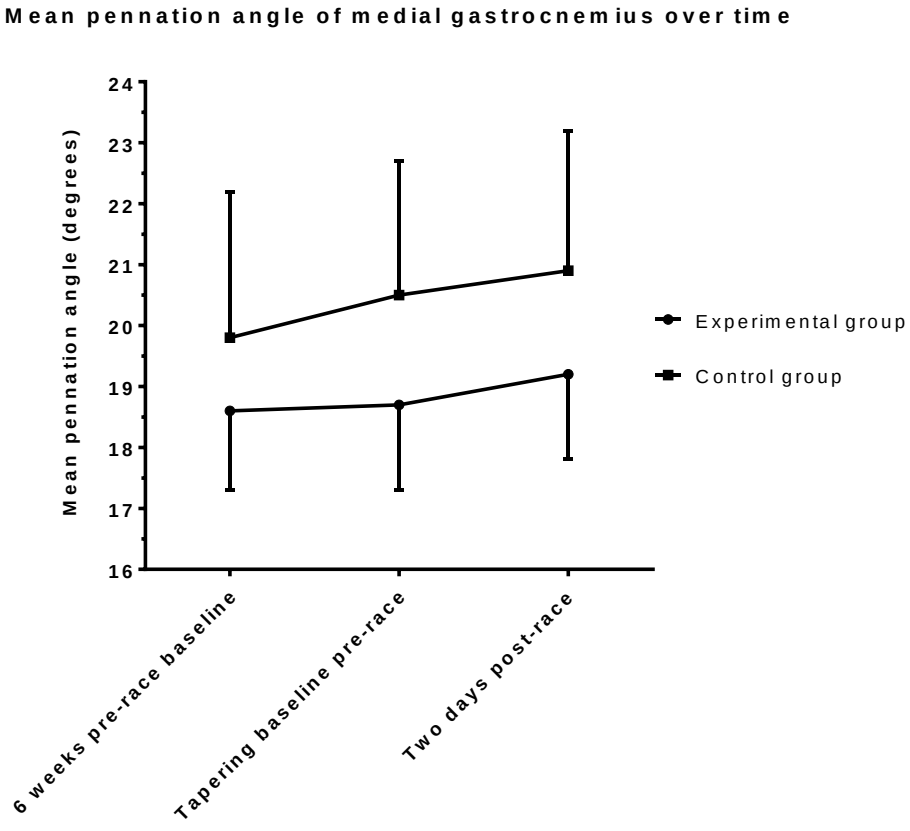


Figure 3.13: Medial gastrocnemius muscle pennation angle changes over time



3.9.3 CMJ heights

Both groups decreased from pre-race to immediately post-race and regained most of the original jumping height and estimated PPO by two days following the race. However, there were no statistically significant differences between the groups over time in CMJ height (*p=0.87*) nor in estimated PPO (*p=0.94*).

The CMJ height reduced on average 24 ± 23% in the experimental group and 17 ± 26% in the control from the tapering baseline pre-race until immediately post-race, with a small effect size in proportional change (*Cohen's d=0.3*) detected. The absolute change in CMJ height had a trivial effect size (*Cohen's d=0.01; SWC=1.3cm*). The estimated CMJ PPO reduced on average 31 ± 35% in the experimental group and 17 ± 25% over the same period, with a medium effect size in proportional change (*Cohen's d=0.5*) and trivial effect size in absolute change (*Cohen's d=0.08; SWC=104W*) detected. The average CMJ height increased on average 14 ± 20% in the experimental group and 9 ± 25% in the control group from immediately post-race until two days post-race, with a small effect size in proportional change (*Cohen's d=0.2*) and a trivial effect size for absolute change (*Cohen's d=0.05; SWC=1.1cm*) detected. The average estimated CMJ PPO increased by 32 ± 56% in the experimental group and 13 ± 21% in the control group over the same period, with a medium effect size in proportional change (*Cohen's d=0.5*) and trivial effect size in absolute change (*Cohen's d=0.1; SWC=64W*) detected. The small effect sizes in CMJ heights may be of significance since the SWC exceeds the standard error of measurement of 0.8cm[149]. In contrast, the medium effect sizes in PPO are unlikely to be of significance, since the changes in the means and SWC are smaller than the SEM of 464W[153] reported.

The absolute CMJ jump heights and PPO changes over time are presented in Figure 3.14-3.15 below.

Figure 3.14: CMJ heights changes over time

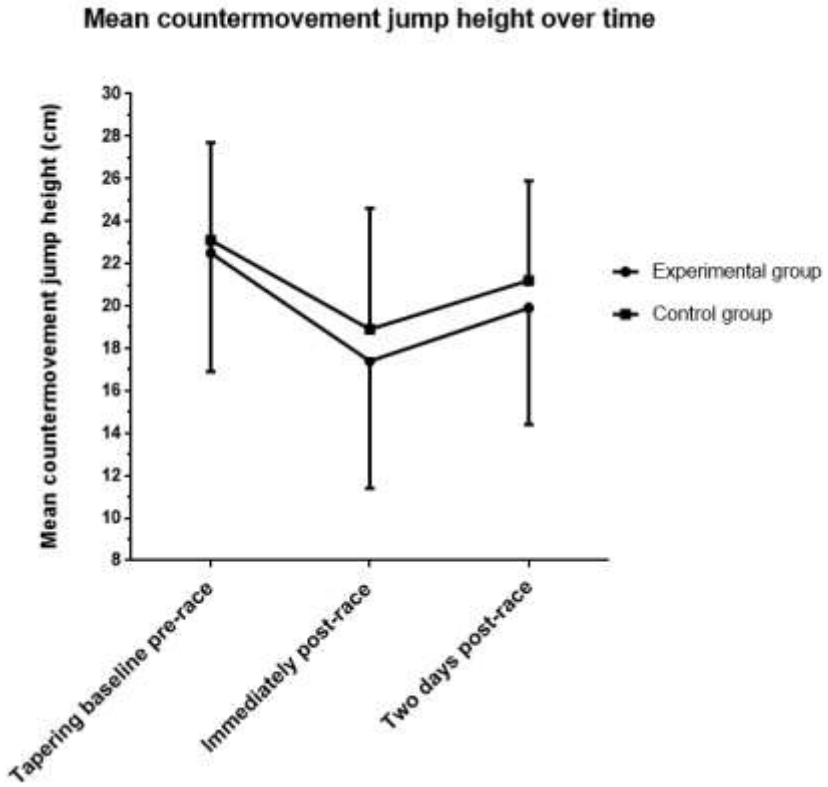
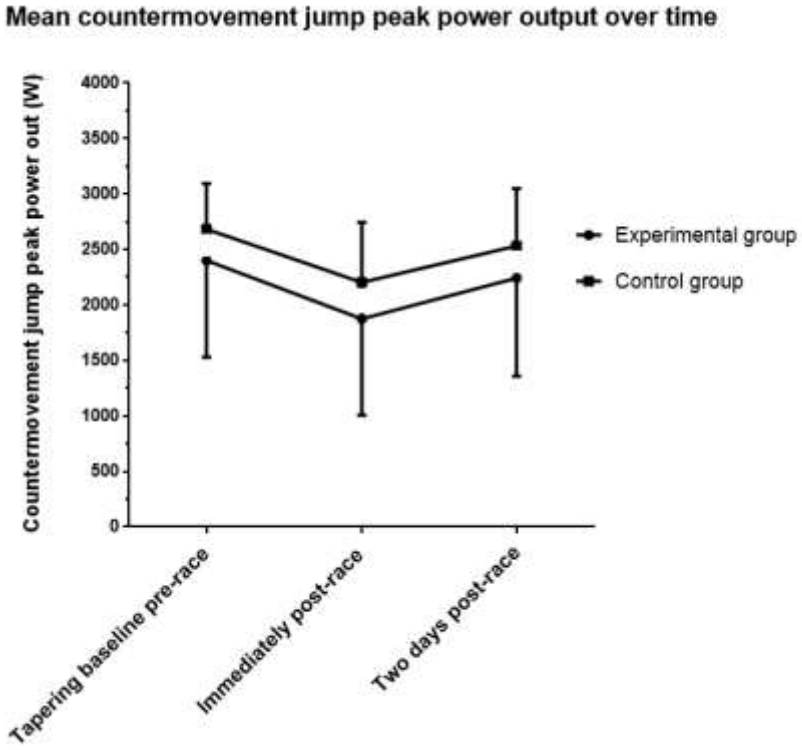


Figure 3.15: Average peak power output changes over time

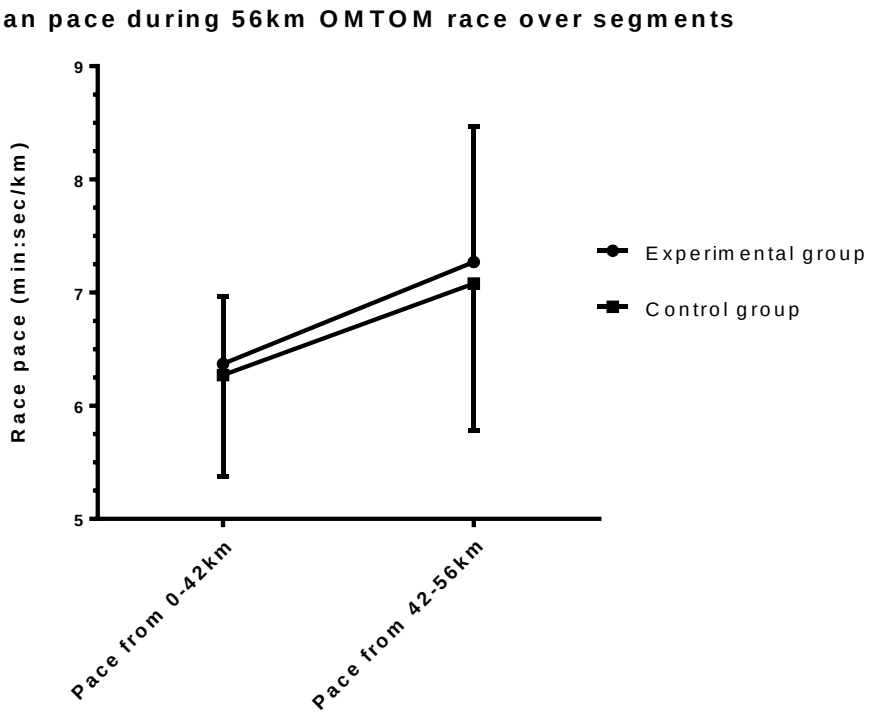


3.9.4 Race performance

Both groups had a slower running pace per kilometre during the final 25% of the race compared to the first 75%; however there were no significant changes between groups at any point in time, nor over-all (*p=0.97*). Effect sizes were trivial in both proportional (*Cohen's d=0.02*) and absolute (*Cohen's d=0.04*) changes in pace from 0-42km compared to 42-56km pace between the groups.

The race pace to 42km and during the final 14km are presented in Figure 3.16 below.

Figure 3.16: Average race pace during different stages of the 56km OMTOM race

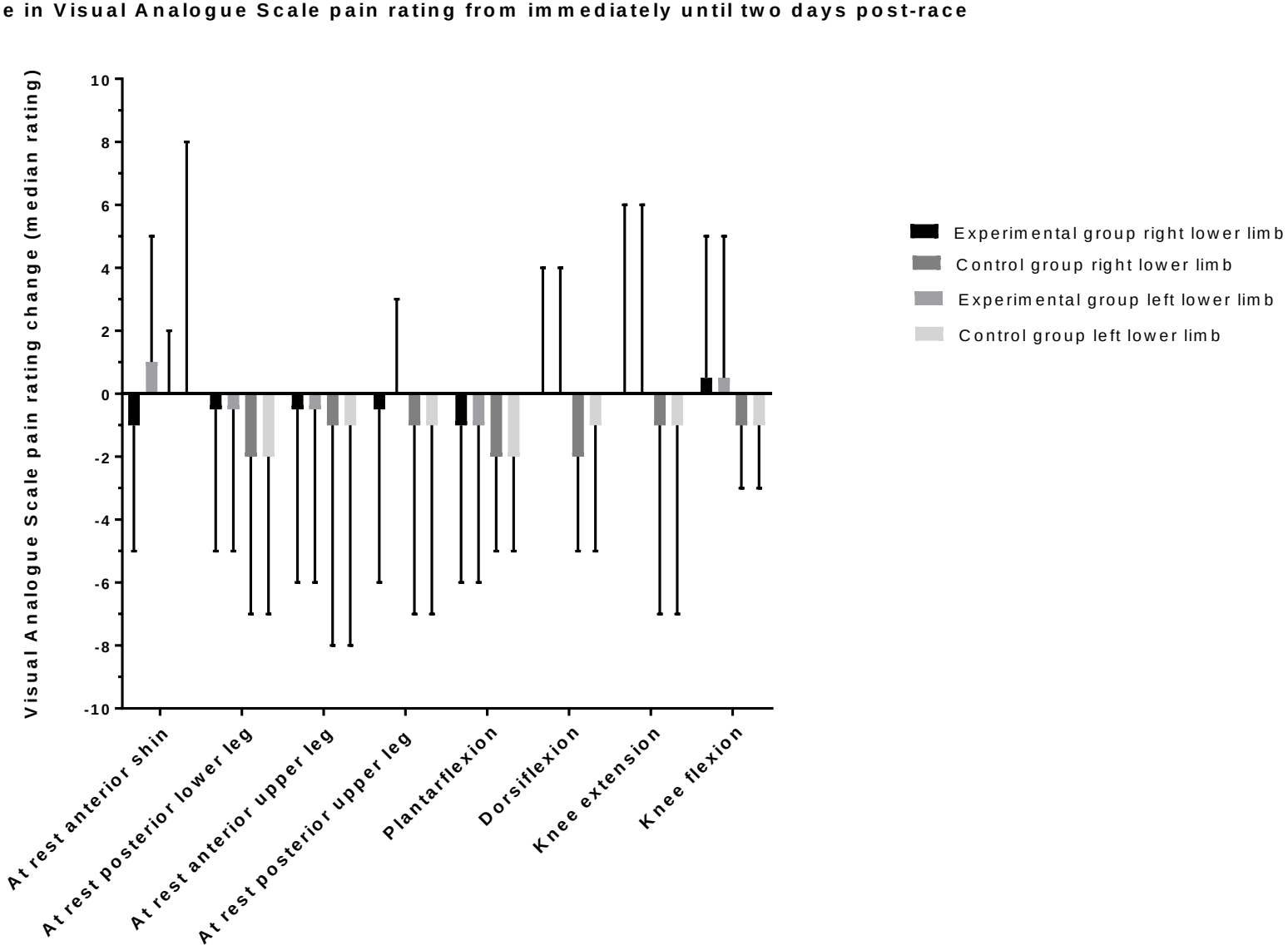


3.9.5 Subjective pain ratings

The control group had a significantly greater improvement in median VAS pain rating during dorsiflexion *(p=0.03)* and during knee flexion *(p=0.04)* of the right leg, but interesting this was not reciprocated in the left leg. There was a trend for decreased pain rating by two days following the race, yet no other statistically significant changes were detected over time.

The relative change in rating from immediately post-race until two days post-race are presented in Figure 3.17 below.

Figure 3.17: Difference in pain ratings from immediately until two days post-race



3.10 Summary of significant main outcomes

No statistically significant changes were detected between the two groups from six weeks prior to the race until two days following the race for any of the main objective outcome measures i.e. circumferences, medial gastrocnemius muscle thickness and pennation angles, CMJ heights and race performance.

There was, however, a statistically significantly (*p<0.05*) increase in absolute and proportional ankle circumference measurements from immediately post-race until two days post-race in the control group compared to the experimental group. In addition, a large effect size in proportional (*Cohen's d= -0.9*) and absolute change (*Cohen's d=1.1*) for ankle circumference measurements was detected. The difference in absolute change in means (-0.7cm) exceeds the SEM (*0.44cm*[102]), hence this finding is significant.

Small effect sizes were detected in mean proportional and absolute ankle circumference measurements changes respectively from 6 weeks baseline until tapering baseline (*Cohen's d=0.2 and d=-0.3; SWC=0.2cm; difference in means:0.25cm)*; from tapering baseline until immediately post-race (*Cohen's d=0.3 and d=0.4; SWC=0.2cm; difference in means:0.25cm);* as well as from tapering baseline until two days post-race (*Cohen's d=0.4 and d=-0.4; SWC=0.2cm; difference in means:0.2cm).* Since the SWC and difference in means are smaller than the SEM (*0.44cm*[102]), these findings are unlikely to be of significance.

Small effect sizes were also detected in mean proportional and absolute calf circumference changes from 6 weeks baseline pre-race until tapering baseline (*Cohen's d=0.3 and d=0.2; SWC=-0.1cm; difference in means=0.1cm*); from tapering baseline until immediately post-race (*Cohen's d=-0.4; SWC=-0.4cm; difference in means=0.2cm*); from immediately post-race until two days post-race (*Cohen's d=0.3; SWC=0.1cm; difference in means=0.1cm*); as well as from tapering baseline until two days post-race (*Cohen's d=0.2; SWC=0.1cm; difference in means=-0.1cm*). The SWC and difference in means is smaller than the SEM (*0.5cm*[106,107]) hence these findings are once again unlikely to be of significance.

Small effect sizes were detected in mean proportional change in CMJ height from tapering baseline until immediately post-race (*Cohen's d=03*); and from immediately post-race until two days post-race (*Cohen's d=0.2*). Medium effect sizes were detected in CMJ PPO over the same time periods (*Cohen's d=-0.5 and d=0.5 respectively*). The absolute changes in CMJ height and PPO over time had trivial effect sizes. The small effect sizes in CMJ heights may be of significance since the SWC (*1.3cm; 1.1cm*) exceeds the SEM (*0.8cm*[149]). In contrast, the medium effect sizes in PPO are unlikely to be of significance, since the changes in the means (*-41W; 64W*) are smaller than the SEM (*462W*[153]) .

Small effect sizes were detected in mean proportional (*Cohen's d=0.3*) and absolute (*Cohen's d=0.4*) pennation angle changes from 6 weeks baseline pre-race to tapering baseline pre-race. However, the effect size was trivial from tapering baseline until two days post-race. In addition, effect sizes were trivial in mean proportional muscle thickness changes over time. Since the SWC (*0.2cm*) and difference in means (*-0.6cm*) are smaller than the SEM (*0.1-1.2*^{o} [121]), these findings are unlikely to be of significance.

At certain points in time, selected variables were also statistically significant between the two groups. The muscle thickness mean was significantly higher in the control group shortly pre-race (*p=0.02*) as

well as two days post-race (*p=0.02*). The pennation angle mean was also significantly higher (*p=0.01*) in the control group post-race, but not at any of the prior three data collection sessions.

The control group had statistically significant lower pain ratings in the anterior shin (*p=0.03 on right and p=0.04 on left*) immediately post-race, but this did not persist by two days post-race. In addition, the pain ratings improved statistically significantly (*p<0.05*) more in the right leg with dorsiflexion and knee flexion from immediately post-race until two days post-race in the control group compared to the experimental group.

Discussion

3.11.1 Introduction

Compression garments are utilised by numerous runners during training and competitions, despite paucity in research in support of a favourable impact[11,20]. Inconclusive results reported in past studies led some authors to suggest that a training period may be necessary to assess the additive impact of compression garments[41,70]. The current study aimed to address this through conducting a randomised controlled trial to compare exercise induced muscle damage and performance of ultra-endurance runners training and competing with below knee CG compared to those training and competing with conventional socks.

Only limited statistically significant changes over time in measures of exercise induced muscle damage and race performance were found between the two groups. Many previous studies also failed to detect statistically significant differences in related outcome measures[24,61,72–76,78]. The ankle circumference measurements did, however, increase significantly more in the control group compared to the experimental group from immediately post-race until two days post-race, when swelling associated with exercise-induced muscle damage is expected to peak[4]. This was accompanied by a large effect size in both proportional and absolute ankle circumference change over this period. Medial gastrocnemius parameters (pennation angles and muscle thickness) were also statistically significantly larger in the control group compared to the experimental group two days post-race, but as these changes were not significant in comparison to pre-race measures, interpretation is challenging and this may relate to pre-existing differences in muscle strength. Medium effect sizes were detected with proportionately worse performance immediately-post race in countermovement jump peak power output in the experimental compared to the control group. However, the experimental group had a proportionately greater improvement with a medium effect size in CMJ PPO by two days post-race compared to the control group. Since the difference in means is less than the standard error of measurement for peak power output, this is unlikely to be of practical significance.

The findings of each outcome measure as well as descriptive data will be discussed in more depth in the sections that follow. Each study objective will be considered and over-all findings presented.

3.11.2 Research Participants

The sample size of 41 participants in the current study was somewhat larger than previous studies identified in the literature, with numbers ranging from 9 to 40 participants[18,28,41,61–78,80,84]. The majority of these studies had less than 20 participants in total. Most previous studies included exclusively or predominantly males subjects with a low percentage of female participants in the literature. In the current study, 29% of the participants were female. Although this is still a relatively low value, it is exactly in proportion to the 3287 female entrants out of a total of 11264 entries (i.e. 29% of total entries constituted females), thus it can be considered representative of the gender proportion based on OMTOM 56km entries. There is a trend for proportionally lower female to male participation rates particularly in ultra-endurance events world-wide, although both male and female participation rates are increasing[170]. The paucity of prior research in female subjects regarding compression garment utilisation illustrates the importance of their inclusion in the current and future research studies.

There were no statistically significant differences in age, weight, height or PB marathon times between groups, indicating that the groups were similar at the onset of the study in terms of their characteristics. A previous study at the OMTOM 56km race included only males (n=40), with the

average age (42 ± 8 years; range 27-57 years) almost a decade greater than in the current study. The age limits set at 20 to 45 years, which would explain the lower age group (34 ± 6 years; range 23-45 years) of the current study, was implemented to help control for age related variability in muscle responses and recovery[52,156]. Similar statures and body masses were reported in the two studies[41].

Training history was quite varied among individuals in both groups in the current study, but the majority in each group reported running between four and six times per week (ranging from three to more than eight) with a total distance of 50-79km (ranging from under 50km to over 100km) reported in the six week training period. A training distance of 60-110km/week[41] with no record of other training types were reported in the prior comparable OMTOM 56km study to test CG[41]. In the current study, almost half of each group reported weekly strength training sessions in addition to running. This study seems to be the first to provide details regarding additional exercise forms used in training in addition to endurance running. This may be as it is the first, to our knowledge, to include a significant training period with the compression garments prior to the main testing period (in this case preceding the OMTOM 56km race).

A few participants in each group utilised other recovery modalities in the week prior to the race, during 1the race and post-race, which may have impacted on results. However, utilisation was very similar between the groups with no statistically significant differences in utilisation detected between groups. Most previous studies did not provide records of possible other recovery modalities. In addition, it may be more difficult to control for utilisation during a field experiment such as in the current study. Notwithstanding, the setting of training for and participation in an actual ultramarathon may provide a more realistic depiction of natural running conditions, making it more likely that results can be appropriately transferred to a real-life running environment.

During the race, most participants in each group reported drinking between one and six sachets of water and between one and four sachets of other fluids per hour. Other nutritional strategies included energy gels, energy bars, bananas, potatoes and others in both groups. There were no statistically significant differences in fluid and nutrition strategies between groups.

The menstrual history was non-significantly different between the two groups, although reports on regularity could be confounded by the use of various contraceptive methods. In addition, the number of females per group were relatively low so it is difficult to draw conclusions. It is possible, yet unlikely, that these factors may have impacted on results[51].

At 6 week pre-race baseline, circumference measurements, CMJ heights and medial gastrocnemius muscle architecture were also not significantly different. The group averages for ankle circumference measurements of 54.6cm and 55.3cm at the start of the study are slightly higher compared to previous values of 53.6cm and 53.5cm reported in the literature[105], although values specific to runners could not be found. The 6 week pre-race baseline mid-calf circumference measures of 38.8cm and 39.4cm are also slightly higher than in a previous study that reported values of 37.8cm and 38.7cm in ultra-distance runners[41]. The 6 week pre-race CMJ heights of 22.5cm and 23.1cm are slightly lower than previously reported values of 27.8cm[146] and 26.8cm[63] reported in long distance runners although values over 40cm have been reported in competitive triathlon and distance runners[77]. Calculated PPO values of 2400W and 2684W at tapering baseline are lower than the value of 3659W reported previously in highly competitive runners and triathletes[77], most likely as the current study included a wider performance range of recreational distance runners participating in ultramarathon distances.

The medial gastrocnemius muscle thickness values of 1.82cm and 1.7cm are very similar to values previously reported in trained runners[114]. In contrast, the medial gastrocnemius pennation angles of approximately 19° and 20° are lower than previous values reported in long distance runners[113,114]. The reason for this is unclear.

The control group had higher 6 week pre-race baseline values in circumferences, muscle thickness, pennation angles and CMJ heights compared to the experimental group but these were not statistically significant. Muscle thickness and CMJ heights have both been positively correlated to muscle strength[115,171], indicating that the control group may have had marginally higher muscle strength in the calves and/or lower limb at the onset of the study. These findings were accompanied by a medium effect size in both pennation angle and muscle thickness of the medial gastrocnemius at baseline. The difference in means were larger than the lowest values for reported standard error of measurement[121,122] using this method and equal or lower to the highest values for SEM[121,122] reported, hence this may be of practical significance. The CMJ PPO at tapering baseline had a small effect size, which is unlikely to be of significance since the SWC and difference in means are smaller than the SEM[149] value reported. Small effect sizes for the ankle circumference where the SWC is larger than the SEM[102] and for the mid-calf circumference where difference in means exceeded the SEM[106], may also be of significance. In theory, increased muscle strength may possibly contribute to improved performance and possible protection against EIMD. These potential pre-existing differences may therefore have had some influence on the subsequent results.

3.11.3 Main outcome measures related to exercise-induced muscle damage

3.11.3.1 Circumference measurements

The over-all trend for ankle and mid-calf measurements in both groups showed an initial decrease post-race followed by an increase in the subsequent two days. This is similar to prior studies which demonstrated an immediate reduction in lower limb volume following a marathon distance[63] and subsequently an increased volume until 72 hours following an ultramarathon[41]. The initial decrease coincided with body mass losses, which is likely to be an indication of reduced hydration status which is to be expected immediately post-race[172].

There was no main group effect in lower limb circumference measurements in the experimental and control group from six weeks prior to the race until two days following the race. However, post-hoc analysis revealed a statistically significant (*p=0.01*) increase and large effect size (*Cohen's d=1.1*) in figure-of-8 ankle circumference measurements in the control group compared to the experimental group from immediately post-race until two days following the race. The difference in proportional change in means and SWC is larger than the SEM[102] and so this is likely to be of practical significance. This implies that the control group may have had a larger degree of swelling related to EIMD[4] compared to the experimental group by two days post-race.

A prior study detected significantly smaller increases in mid-calf and ankle circumference measurements at 24h, 48h and 72hrs post-race when below knee compression garments were utilised during the 56km race and during recovery compared to placebo socks[41]. Ankle circumferences in this prior study were measured as the narrowest section adjacent to the malleoli. The figure-of-8 ankle measurements in the current study may present a more encompassing presentation of ankle swelling[103]. The current study in contrast to the prior, did not detect any significant changes in mid-calf circumference measurements from immediately post-race until two days following the race. The small effect size differences in mid-calf circumferences are also unlikely to be meaningful (SWC<SEM).

Similarly, no significant changes were detected pre- and post-marathon running in lower leg volume assessed by water displacement in another study[63]. In contrast, a further study assessed lower leg volume with a perometer following a 10km race and found significant reductions with compression garment use immediately after the run, but this effect vanished as soon as 5 minute post-run[85]. Due to the large number of participants tested in the medical tent at the finish line of the current study, it was not possible to test each participant immediately as they finished, and some would have had a short waiting period. Considering reduced measurements in a prior study had disappeared by five minutes post-race[85], even a short waiting period could potentially have impacted on the different results obtained. Ideally, if more individuals were able to collect data at once, with high inter-rater reliability established, it would be easier to ensure no waiting period for data collection in future studies.

Based on these findings and that of previous studies, there appears to be some evidence that compression garments may help to reduce measures of swelling in the ankle and/or lower leg following a running event[41,85].

3.11.3.2 Medial gastrocnemius muscle architecture

There was no main group effect over time for muscle thickness and pennation angles of the medial gastrocnemius for the experimental and control group. However, non-significant changes occurred over time in both groups with certain significant between-group differences at particular points in time.

There was a trend for muscle thickness to increase from six weeks pre-race until the tapering baseline shortly prior to the race in both the experimental and control group. As muscle thickness is positively associated with muscle strength[115], this may indicate improved calf muscle strength following the training period in both groups. The mean tapering baseline muscle thickness was significantly higher in the control group compared to the experimental group. As there was no significant effect over time between the two groups, this is unlikely to relate to compression garment utilisation or lack thereof. In addition, the change in muscle thickness over the training period had a trivial effect size. There was also a trend toward statistical significance between values at the six-week pre-race baseline data collection. This implies that the control group most likely had stronger calf musculature prior to the race[115]. A medium effect size in muscle thickness was detected at tapering baseline, which may be of significance with the difference in means larger than the low range, but smaller than the high range of SEM reported in the literature[122]. Although the training history was similar between the two groups, a slightly higher percentage of the control group reported higher weekly running distances in the range of 80km to over 100km in addition to a slightly higher percentage reporting additional weekly strength training sessions. This may account for the higher muscle thickness values on average in this group, rather than relating to the lack of compression garment utilisation.

There was also a mild increase in muscle thickness values from tapering baseline compared to two days post-race in both groups with significantly higher values reported in the control group. A previous study reported a statistically significant increase in muscle thickness values peaking at 48hours following exercise[108]. However, the latter study induced EIMD in participants who had been sedentary for at least two weeks prior to testing, which may have resulted in a greater extent of EIMD compared to the highly trained runners who participated in the current study. As there were no significant changes over time from pre-race to post-race in muscle thickness values, it is not clear if the higher

value is simply due to the pre-existing difference between the groups or perhaps indicative of a greater severity of EIMD in the control group.

Medial gastrocnemius pennation angle means increased steadily over time in the control group, whereas the values in the experimental group remained unchanged following the training period where after it increased to post-race. These changes were not significant over time, although a prior study detected a statistically significant increase in pennation angles by 48 hours following DOMS induction[108]. As discussed for muscle thickness, the current study involved highly trained runners, thus the extent of EIMD may have been attenuated. Post-race pennation angles were significantly higher in the control group compared to the experimental group. This could possibly indicate a higher degree of EIMD in the control group. However, as for the muscle thickness values, there was a trend toward statistical significance at both pre-race sessions, accompanied by medium (6 weeks baseline) and large (tapering baseline) effect size which may be indicative of a pre-existing difference rather than an effect related to compression garment use or lack thereof. The difference in means exceeds the SEM at tapering baseline and two days post-race, hence it may be of practical significance at these points in time. However, proportional percentage and absolute change in muscle thickness and pennation angles from tapering baseline until post-race had trivial effect sizes. Therefore, the underlying reason for this finding is not clear.

Interpretation of the muscle architecture parameters considered is further complicated as this study was the first to our knowledge to test the extent of EIMD with ultrasound in trained endurance runners making comparisons difficult. However, this study may set the grounds for future comparisons. In the past, ultrasound has, however, been utilised in other sports environments with different parameters considered. For instance, ultrasound measured swelling was found to be significantly lower post-exercise in a group utilising whole body compression garments during recovery from resistance training compared to controls[95], whereas the use of upper limb sleeves during resistance training did not alter ultrasound echo intensity compared to a control group[89].

Both groups showed a trend for improvement in medial gastrocnemius strength over time due to increased muscle thickness and pennation angles detected. This is in line with the expectation that most runners will perform peak training volumes followed by a lower volume tapering period in preparation for the ultramarathon in the final six weeks pre-race. Although there were significant differences in muscle thickness at the tapering baseline and post-race and in pennation angle post-race only, it is unlikely that this relates to compression garment utilisation or lack thereof. It is more probable that this reflects pre-existing differences in medial gastrocnemius muscle architecture between the two groups as there was a tendency towards statistical significance and medium effect size differences with higher muscle thickness in the control group compared to the experimental group at the onset of the study.

3.11.3.3 CMJ test

As would be anticipated following a long distance race[63,172], both groups showed a reduction in CMJ heights and estimated PPO from tapering baseline to immediately post-race. Reduced muscle power is one of the indications of EIMD[4] and fatigue[172]. Both groups improved on average by two days post-race, but did not regain pre-race jumping height and PPO. The deterioration in performance of CMJ immediately and two days post-race is indicative of EIMD related reductions in muscle strength and lower limb power[4,36,37] due to the OMTOM 56km race. Neither the CMJ height nor the PPO changes were statistically significant over time between the two groups. However, a medium effect size in CMJ

PPO indicates that the experimental group performed proportionally worse than the control group immediately post-race. In contrast, by two days post-race, a medium effect size in PPO indicates that the experimental group improved proportionally more than the control group. This may indicate that the experimental group made a quicker recovery in lower limb muscle power in the two days post-race. However, the absolute change in PPO over this period is below the SEM[153] reported in the literature, therefore it is unlikely to be of practical significance.

These results are similar to those reported in previous studies. No statistically significant changes in jumping height or estimated PPO were detected in competitive long distance runners in the 48hours following treadmill running when using no, light or high pressure below knee CG[77]. Another study did not find any significant differences in CMJ height and PPO following a marathon in a group utilising below knee CG compared to controls (conventional socks) during exercise[63]. In addition, calf compression sleeves appeared to have no impact when worn during a middle-distance trail run compared to controls in terms of CMJ height[76]. In contrast, one study found improved maintenance of CMJ height following a 10km time trial when low and medium pressure level below knee CG were utilised compared to controls with no significant changes when high level CG were utilised[62]. This study unfortunately had a small sample size (n=12), thus results may not be generalizable to a wider running population.

Based on the current study and reinforced by similar results in previous studies, it seems unlikely that CG utilisation or lack thereof had a significant impact on performance in CMJ testing following long distance running. However, the medium effect size improvement in CMJ PPO may indicate a faster recovery in muscle power by two days following a race. Based on a previous study, it is also possible that CG may improve CMJ performance following shorter distances of running (10km and under)[62].

3.11.3.4 Subjective pain ratings

The current study found significantly lower VAS ratings in the anterior lower leg immediately post-race compared to the experimental group, but this effect disappeared by two days following the race. In addition, the control group showed statistically significant improvements in pain ratings from immediately post-race until two days post-race during right leg dorsiflexion and knee extension compared to the experimental group. No further significant changes in pain ratings were detected between groups.

These results are different to the majority of prior studies that reported improved VAS pain ratings following various running events when compression garments were utilised compared to conventional clothing. For example, runners utilising CG during exercise reported lower VAS pain ratings in the lower leg compared to control group runners both shortly after and 24 hours following a 10km race[61] and a 5km race[69].

Another study conducted in marathon runners detected lower VAS ratings at 24 hours post-race[63,84]. However, this no longer applied at 48 hours post-race[63]. This may be due to the higher training status of endurance runners, such as in the current study – quicker recovery may thus occur with subsequent reductions in pain ratings. Another study found reduced pain ratings at 24h, 48h and 72hr post-ultramarathon, when CG were utilised during the race as well as for the subsequent three days[41]. It may be suggested that pain reductions are only maintained when CG are utilised post-exercise in addition to during long distance running.

In contrast, higher ratings of discomfort have been reported in general in runners utilising high and medium level compression garments compared to low pressure CG and conventional socks[62,77]. It is possible that the higher pain ratings in the shins at rest in the current study could relate to discomfort caused by the socks, rather than being an indication of DOMS. Moreover, this did not coincide with differences in pain ratings in the posterior lower leg, which constitutes the bulk of lower limb muscle mass with DOMS anticipated to be worse in this region. The significant improvements with selected movements (dorsiflexion and knee flexion) was not accompanied by significant improvements in the left leg, nor with any other movements. As the below knee garments were worn on both sides in the experimental group and not on either side in the control group, it seems unlikely that the one sided change is due to compression garment use or lack thereof. Instead, it could perhaps relate to additional issues reported on race day, with a greater number of unrelated (to CG) complaints reported in the experimental group compared to the control group.

Considering the isolated nature of the significant changes, it is unlikely to be cause for concern. However, the current findings challenge those of previous research (which generally consisted of much smaller sample sizes) that suggested subjectively reduced pain ratings with CG use during running compared to conventional clothing.

3.11.4 Performance measures

3.11.4.1 Race performance

As anticipated, both groups had a slower pace on average during the final 14km (i.e. the final 25%) of the race. There were no statistically significant differences and trivial effect sizes in race pace to the marathon distance and in the final section of the race between the groups. The lack of significant changes in the over-all pace and finish times, is similar to a previous RCT testing compression garments conducted at the OMTOM 56km, with no significant changes detected[41]. The average over-all race pace and finish times reported were also similar, although somewhat slower in both groups in the current study compared to the previous study[41]. This may be due to the inclusion of females in the prior as opposed to only males in the latter. Unfortunately, a break-down of running times in different sections of the race was not available for comparison.

Only one prior study could be found that analysed pace over time in a running event. This study, conducted at a marathon, also found a trend for decreased pace towards the end of the race, with no significant differences in race pace at any stage during the 42.2km in a group utilising below knee CG compared to a group wearing conventional socks[63]. Likewise, many other studies failed to detect any significant changes in running performance over a range of distances and terrains (from 400m track to a 15km trail run) when utilising compression garments compared to control conditions[61,69,76,78]. The current study reinforced previous findings that it is unlikely that compression garments have any impact on running performance, including in ultra-endurance events.

3.11.5 Further possible contributing factors

The use of additional recovery aids reported were similar between the two groups. Ideally, no additional recovery methods should have been utilised to avoid confounding factors. It appears to be common-practice in long distance running to utilise various recovery modalities particularly analgesics and NSAIDs[173]. For this reason, this study may be a more realistic depiction of normal running conditions as opposed to laboratory conditions. Frequencies of utilisation of other recovery modalities

is not clear in the available literature. Nonetheless, the similarity of utilisation with no significant differences between groups means it is unlikely to have impacted results.

Nutrition and fluid strategies were similar with no significant differences during the race. The menstrual history was non-significantly different between the two groups, and may have been confounded by contraceptive use. It is thus not clear if these differences may account for different severity of EIMD and performance in female participants in each group[51].

In addition, a number of participants in each group reported additional issues on race-day such as dizziness, cramping and falls, which may have impacted on results obtained. However, none of these complaints were likely to be related to CG use or lack thereof.

The drop-out rate of participants following baseline measurements was the same in each group, with two participants not completing the study per group. Only one of these were related to CG use with the concerned participant complaining that it caused thermal discomfort during training. The average temperatures during the six week training period was 20°C and 19°C on average, ranging from minimum values of 11°C and 9°C and maximum values of 36°C and 38°C in the two months of testing, respectively[174]. Interestingly, a prior study found significantly increased skin temperatures with CG use compared to controls in a controlled environment of 10°C but no such difference in a 32°C enviroment[66] – the latter being closer to peak temperatures reached during the testing period. In addition, there was no significant association between these changes and running performance[66]. Another study found no difference in ratings of thermal discomfort in participants utilising CG compared to controls[64]. It seems unlikely that thermal discomfort would be a problem for the majority of participants, although individual preferences apply. Other reasons for discontinuing the study were of a personal nature (illness and lack of time) and apparently unrelated to CG use or lack thereof.

3.11.6 External Conditions

The OMTOM occurred on a reasonably hot day with a maximum temperature of 26°C. It is possible that when compression garments are tested in cooler conditions such as 18°C more typical of laboratory temperatures, the impact may be different. Thermal clothing have been suggested as a possible preventative measure against muscle strains[175]. Compression garment utilisation in cooler conditions may thus potentially work more efficiently by keeping the muscles warmer. This may also partly explain the differences observed in comparison to the previous study conducted at the OMTOM 56km where testing was performed at 18-20°C[41].

3.11.7 Training period

This study pioneered the inclusion of a six week training period prior to competition to allow for familiarisation with the product in addition to assessing if the impact changed following routine utilisation. All prior studies identified tested participants within a shorter period of time, often without accounting for prior routine utilisation or lack thereof and without a formal period of routine utilisation or lack thereof.

During the training period, it was unfortunately difficult to control aspects of training as well as specifics regarding compression garments utilisation. The training histories over the six week period was varied between individuals and the minimum running distance was not maintained in a few participants in each group. Although most experimental participants reported using the garments during three to four runs, small percentages reported above and below these rates. To avoid introducing a confounding variable, participants were instructed to continue their usual training

regimes, rather than implementing a standardised programme for all runners. Although this would have been easier to control, it may have caused differences in muscle responses and performance related to the training programme rather than the CG.

No statistically significant changes were detected from six weeks pre-race until shortly pre-race, except in terms of muscle thickness of the medial gastrocnemius muscle. As discussed previously, this more likely relates to training history and a pre-existing underlying increased muscle strength in the control group, and is unlikely to relate to lack of CG use. Based on these findings, it appears that routine utilisation of CG did not results in any obvious changes over time compared to the control conditions in preparation for an ultramarathon.

3.11.8 Study limitations and future directions

Recovery modalities were utilised by a few participants in both groups pre-race, during the race and post-race and although there were no statistically significant difference between groups, it may confound results obtained. More stringent restriction of alternative recovery modalities should be implemented in future studies. However, it is also possible that some previous studies assumed that other recovery modalities were not utilised without specifically asking participants to report on utilisation.

This study included both genders due to the relative paucity of prior studies involving females. However, the percentage of females was still much lower than males. This could possibly relate to the higher numbers of male participants in long distance events. It is recommended that future studies include females to increase the research basis relating to compression garments use in this gender in addition to males.

This study pioneered the use of ultrasound to help detect EIMD related changes in muscle architecture in long distance endurance runners in relation to CG use. Muscle architecture parameters considered presents a suitable alternative to assess EIMD changes, but more extensive measurements such as anatomical cross sectional areas may add value to future studies. Furthermore, subtle differences may have occurred if the tested leg was selected based on dominance (rather than standardising to the right leg only) and this may be improved upon in subsequent studies.

The current study was the first to our knowledge to include a significant training period to assess for an additive impact of compression garments in endurance running. However, it was difficult to control the training history and frequency of compression garment utilisation during this period as previously discussed. It may be beneficial to include stricter entrance criteria in follow up studies specifying number of weekly runs, minimum and maximum running distances, additional training components and personal best marathon times within a more narrow range to allow more control over the training period. Furthermore, although six weeks should allow sufficient time for muscle adaptation, a longer training period with compression garment utilisation may add value to future studies. Closer monitoring of CG use and providing more pairs of garments (for practical purposes) should also be beneficial.

Ideally, participants and data collectors should be blinded to group allocation. Unfortunately, for practical reasons as discussed in the literature review (Section 2.2.3), it is very difficult to blind participants and even when placebo socks were utilised, the majority of participants accurately assumed their group allocation. An external, blinded examiner to perform data collection in future studies would reduce the risk of any unintentional observer bias.

Commercially available compression garments were utilised in this study as this is more likely to be accessible to a greater proportion of the socio-economic groups in South Africa, a developing nation. As discussed in Section 3.4, it was unfortunately not possible to determine the exact pressure level exerted by the garments, thereby limiting reproducibility. In addition, individually-tailored graduated compression garments would be preferable in ideal conditions where it would be socio-economically accessible to more runners in developed nations and this should be assessed in future studies.

CHAPTER 4

Summary & Conclusion

Compression garments are commonly utilised in endurance runners, despite paucity in the literature regarding its impact[17,20]. A randomised controlled field experimental study was conducted to assess the impact of below knee compression garments on exercise induced muscle damage and performance in endurance runners. The results of the study detected limited indications of any impact of below knee compression garment utilisation during training for and participation in an ultramarathon running event compared to control conditions. Selected measurements suggest a possible protective impact with a reduction in ankle circumferences (both with statistical significance and a large effect size), possibly related to attenuated swelling, detected over time following the race. However, this was not the case for mid-calf measurements with no impact detected. Some differences were detected at certain points in time for medial gastrocnemius muscle architecture values, although this is more likely to be due to pre-existing group differences than reflecting an impact due to CG use or lack thereof. Although statistically significant changes were not detected, a medium effect size indicated that the experimental group regained lower limb muscle power better (with improved countermovement jump peak power output) in the two days following the race than the control group. In addition, it appears that the compression garments may be associated with some discomfort in the shins at rest, and smaller improvements in pain ratings with dorsiflexion on the right were detected over time. However, these effects seem to be transient and minor. Moreover, compression garments appear to have no impact on running pace and performance at any stage during an ultramarathon.

The majority of EIMD related measures considered showed no or minimal statistically significant differences between groups indicating a relative lack of effect. More specifically, it seems unlikely that below knee CG utilisation or lack thereof during training and competing in an ultramarathon had a significant impact over time on mid-calf swelling (i.e. circumference measures), muscle architecture of medial gastrocnemius (i.e. pennation angles and muscle thickness) determined by ultrasound scans, lower limb power (i.e. countermovement jump heights) or in ultramarathon race performance. However, a medium effect size in CMJ PPO indicates greater improvement in lower limb muscle power in the experimental group compared to the control group in the two days post-race. Conversely, compression garments may be associated with more discomfort in the shins than control conditions. Herewith the objectives described in Section 1.2 is answered.

Currently, there appears to be limited evidence to support the utilisation of commercially available below knee compression garments during training and participation in long distance running events with mild improvements in isolated measures of exercise induced muscle damage. Moreover, the only improvements detected occurred in the 48 hours following the race, with no significant impact detected during training and the race itself. Furthermore, it seems extremely unlikely that compression garments can be considered an effective ergogenic aid. It is possible that individually tailored compression garments may have a different impact. In addition, it is likely that utilising CG both during running and the subsequent recovery period may yield greater benefits for muscle recovery based on previous research[17,20,41].

There is relatively limited evidence to support the utilisation of below knee compression garments during long distance running events for the purpose of muscle recovery and it is not recommended as

a performance enhancer. The popularity of commercially available below knee compression garments utilised during running should be revisited.

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APPENDICES

Appendix A: HREC approval

Appendix Removed Due to Visible Signature

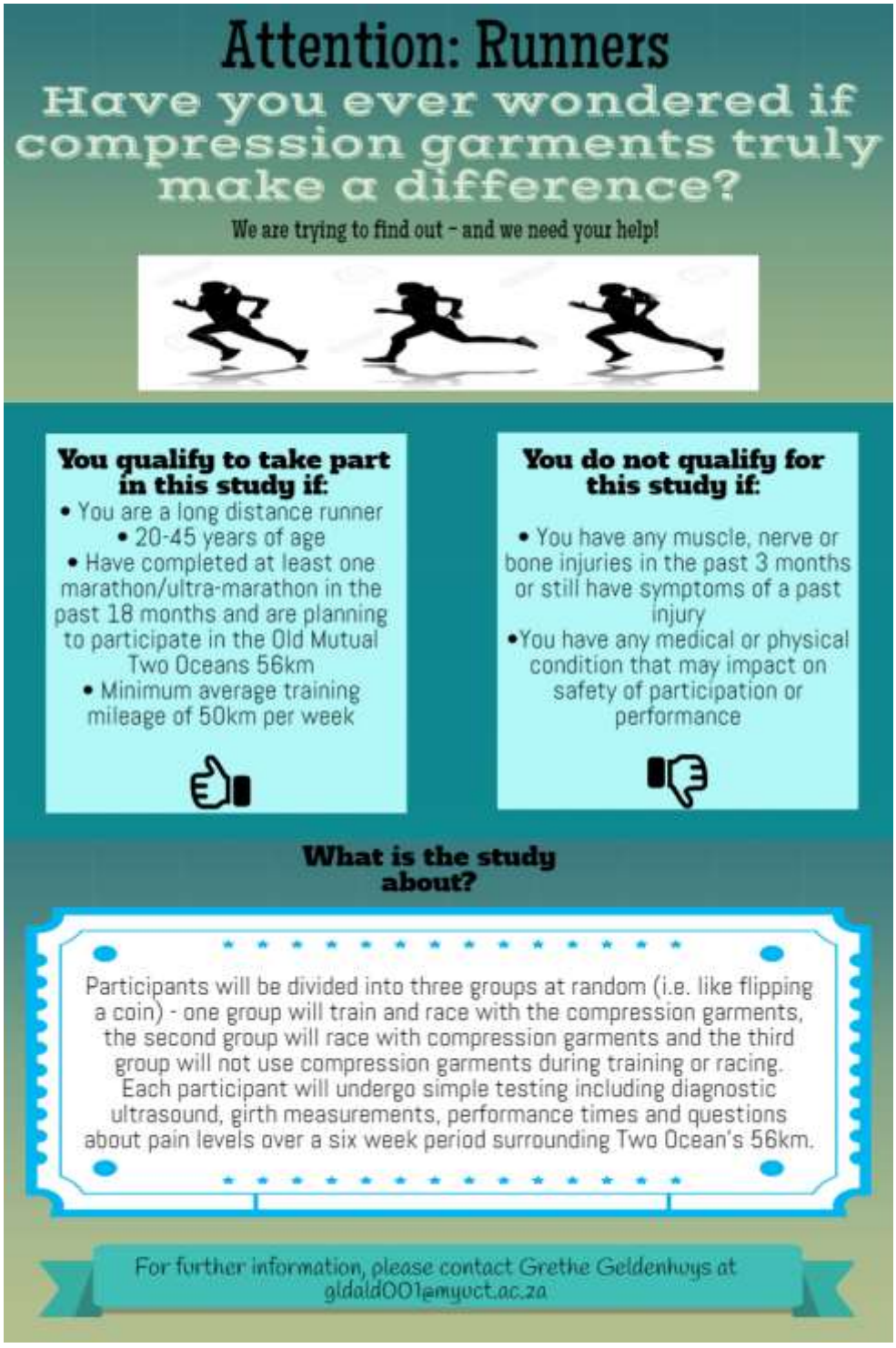
This serves to confirm that the University of Cape Town Human Research Ethics Committee compiles to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2006), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI),and Declaration of Helsinki (2013) guidelines.
The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

Appendix B: Example of recruitment advertisement

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



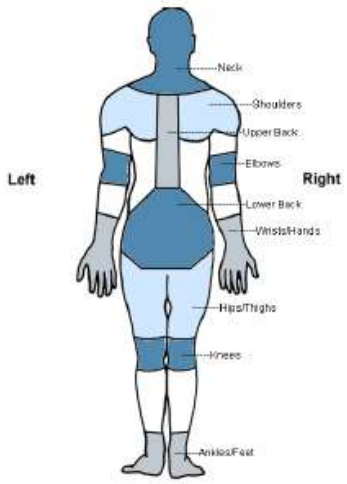
Appendix C: Nordic Musculoskeletal Questionnaire

Musculoskeletal Discomfort Form (Based on the Nordic Questionnaire (Kourinka et al. 1987)) Employee ID:_____

Job/Position: _____ Gender: M F Age: _____ Height: ___ ft.___ in. Weight: _____
How long have you been doing this job? ___years ___ months How many hours do you work each week? _____

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).



Back View

Table: Please answer by putting an "X" in the appropriate box - one "X" for each question. You may be in doubt as to how to answer, but please do your best anyway. Note that column 1 of the questionnaire is to be answered even if you have never had trouble in any part of your body; columns 2 and 3 are to be answered if you answered yes in column 1.

To be answered by everyone		**To be answered by those who have had trouble**			
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?**	
Neck					
☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
Shoulders					
☐ No	☐ Yes, right shoulder ☐ Yes, left shoulder ☐ Yes, both shoulders	☐ No	☐ Yes	☐ No	☐ Yes
Elbows					
☐ No	☐ Yes, right elbow ☐ Yes, left elbow ☐ Yes, both elbows	☐ No	☐ Yes	☐ No	☐ Yes
Wrists/Hands					
☐ No	☐ Yes, right wrist/hand ☐ Yes, left wrist/hand ☐ Yes, both wrists/hands	☐ No	☐ Yes	☐ No	☐ Yes
Upper Back					
☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
Lower Back (small of back)					
☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
One or Both Hips/Thighs					
☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
One or Both Knees					
☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
One or Both Ankles/Feet					
☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes

Appendix D: 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.

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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?	☐	☐

			YES	NO
	Please read the questions below carefully and answer each one honestly: check YES or 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.

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 approved Sept 12 2011 version

Appendix E: 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 are eligible to participate in the research study: "*The impact of below knee compression garments on endurance running performance and lower leg muscular responses in endurance runners",* please complete the following survey.

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

Do the following statements apply to you?	**Yes**	**No**
1. Are you 20 and 45 years of age?		
2. Have you completed 1 or more marathons or longer distances in the past 18 months?		
3. Is your average weekly training mileage 50km or more?		
4. Have you entered and are you planning to run the Two Oceans Ultra-Marathon in 2017?		
5. Would you be willing to have data collection performed on four occasions (6 weeks and 2-3 days prior to, at the finish line and 2 days following the Two Oceans)?		

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

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

Do the following statements apply to you?	Yes	No
Have you experienced aching, discomfort, pain or abnormal sensations in your legs that necessitated a medical, physiotherapy or health		

professional consultation over the past 3 months?		
Have you been diagnosed and/or received treatment for any injuries or have known damage to your muscles, bones or nerves that that necessitated a medical consultation and/or physiotherapy and/or other health professional in the past 3 months?		
Do you have any previous injuries to your muscles, bones or nerves in your legs that still bothers you (e.g. causes pain regularly) and has required medical attention within the past 3 months?		
Do you suffer from any known medical conditions or complications relating to your nervous system, muscles, skeleton, heart or hormones that would inhibits 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 of the above statements, you may be eligible to participate in this study.

Appendix F: Informed consent

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

Informed Consent Form
Consent to participate in a research study:

A research study to assess the effectiveness of compression socks on ultra-marathon running performance and leg muscles in endurance runners

Dear *participant*

Who is performing the study?
I am a Master's student in the Faculty of Health Sciences, Department of Human Biology, Division of Exercise Science and Sports Medicine, at the University of Cape Town. I am conducting a study to be written up as a mini-dissertation in partial fulfilment of the Master of Science in Sports Physiotherapy Degree. The study will be performed under the supervision of Professor Andrew Bosch.

Purpose and scope of the research
You will have noticed that wearing of compression garments has become very popular among runners. Unfortunately, the research to support the usefulness of this is inconclusive at present. The purpose of this study is to test the effect of compression socks on performance and leg muscles during long distance running.

The study will be performed in runners training for and participating in the Old Mutual Two Ocean's 56km ultramarathon. It will therefore provide valuable information regarding the possible role of compression socks in aiding recovery and improving performance. We hope that this will help with decision-making regarding the continued use of compression garments in the running community.

Who can take part in this study?
To participate in this study, you must:

a) Be entered for the 2017 Two Oceans Ultra
b) Be 20-45 years of age
c) Have completed at least 1 marathon or ultra-marathon in the past 18 months
d) Have a minimum average training distance of 50km per week.

You cannot take part in this study if you:

a) Have had one or more running injuries in the past 3 months or have pain or other symptoms from older injuries
b) Have any medical or physical conditions that may impact on safety or performance
c) Are currently routinely using compression garments and would be unwilling to train and compete with or without compression socks based on which group to which you will be randomly assigned.

What will the study involve?
For this study, if you decide to participate, you will be randomly allocated (i.e. each person has an equal chance of being selected for each group) to one of two groups. If you are allocated to Group 1, you will be required to train for 6 weeks and participate in the 56km race with compression socks that will be provided to you. If you are allocated to Group 2, you will be required to train and participate in the event without compression garments. In this case, you will receive compression socks after the completion of the study.

You will be required to perform four visits for data collection. The first visit will take place 6 weeks before the Two Ocean Ultra-marathon. Basic measurements of your weight and height will be taken as well as measures of the circumference of your legs. An ultrasound scan will also be done to assess your leg muscles. These measurements will be repeated at the second visit 2-3 days before the race along with a questionnaire relating to compression socks usage and your training schedule. In addition, you can choose to participate in another test involving a jumping movement on a force plate. This involves standing with your legs together, then bending at the knees, and jumping as high as you can. Both of these visits will be at the Sport Science Institute of South Africa. At the finish line of the Two Oceans these tests will be repeated along with a questionnaire, with questions on muscle pain levels, food and fluid intake, and muscle recovery strategies. In addition, a jumping test can be completed. The ultrasound scan, circumference measures and questionnaire will finally be repeated at the Sport Science Institute two days after the race. In addition, the jumping test can be completed on a force plate. Information regarding your finish times and race pace will also be accessed from RaceTec, the official timing device for the race.

What will happen to the collected data?
All the information gathered will be kept strictly confidential. It will only to be seen by the researchers and your identity will not be associated with the information that appears in the report. To protect your privacy, we will replace your name with a code on all of the measurements. We will only use this code on information about you. We will do our best to keep the code private. It is however always possible that someone could find out your name but this is very unlikely to happen. Hard copies of data will be locked away and all electronic data will be password protected. Data will be analysed by the researchers to establish if there are any significant difference between the two groups.

Voluntary participation and the right to withdraw
Participation in this study is completely voluntary. In other words it is your personal decision whether you want to take part in the study. If you decide to participate, you are free to withdraw from the study at any point and this decision will not affect you or your current or future health or well-being in any way, or your participation in the race. If you do decide to withdraw, please let us know and we will destroy your information.

Potential risks associated with the research
To date, no negative effects have been reported with the use of compression socks, so the usual running risk profile will remain unchanged (or may be improved by compression socks). None of the measurement procedures poses any known risks.

How will your privacy will be protected?
Your personal information will be kept on a secure computer with hard copies locked in a secure cabinet. It is always possible that someone may find out that you participated in this study. However, it is very unlikely that this will happen and we will do our very best to ensure that it will not.

What happens if I get hurt taking part in this study?
Although there are no risks involved in this study, should you suffer a bodily injury because of taking part in the study, the study is covered by an insurance policy taken out by the University of Cape Town (i.e. the UCT No Fault Insurance Clause).

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 are 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 unauthorised medicine or substances during the study
- Any injury that results from you not following the protocol requirements or the instructions that the study researcher may give you
- An injury that results from negligence on your part

It is important to follow the study researcher's instructions and to report straightaway if you have a side effect from the study procedure.

Potential benefits associated with the research
This research will help us to understand the impact of compression garments on performance in endurance runners as well as the impact on muscles while training for and participating in a long-distance event. This information can be used to aid both individual athletes and health professionals with decision making and advice regarding the use of these garments. If you decide to participate, you will receive cost-free compression garments during (Group 1) or following (Group 2) the study. Please be advised and understand that you will not be paid for your participation in this study.

Return of results
You will receive a report of your test results as well as general findings in the study. This may take approximately 3-6 months.

Questions
Please direct any questions, concerns or comments at myself or my supervisor. You are assured that all inquiries will remain confidential.

Yours faithfully
Grethe Geldenhuys
BSc Physiotherapy (UCT)
Email: GLDALD001@myuct.ac.za
Phone: [redacted]
Research Supervisor:
Prof Andrew Bosch
Email: andrew.bosch@uct.ac.za
Phone: [redacted]

If you have any questions or concerns about your rights or welfare as a research participant, you can contact the Human Research Ethics Committee as listed below.

Chairperson of Faculty of Health Sciences Human Research Ethics Committee:
Professor Marc Blockman
Telephone number: 021 406 6492
E-mail address: marc.blockman@uct.ac.za

Informed Consent Signature sheet

I, _____have read the above and am satisfied with my understanding of the study, the possible benefits, risks and alternatives. My questions about the study have been answered. I hereby voluntarily consent to participate in the research study as described.

_____	_____	_____
Signature of Participant	Name (Please Print)	Date
_____	_____	_____
Signature of Investigator	Name (Please Print)	Date

Appendix G: Operational Definitions and protocol

Operational definitions:

Ultrasound imaging

Testing procedure:

Participant must be positioned in prone on a plinth with ankle maintained at 90° plantarflexion by a firm footplate. Participants should be instructed to relax the muscle while ultrasound imaging is performed.

1) Determine aponeuroses and musculotendinous junctions.
2) Find midpoint between musculotendinous junctions and mark clearly.
3) Perform U/S scan here.

Pennation Angle of medial gastrocnemius (degree)	angle formed between the muscle fascicles and the deep aponeurosis
Muscle thickness of medial gastrocnemius (mm)	distance between the superficial and deep aponeuroses

Perform each scan twice and use average values.

Circumference measures

Mid-calf circumference

Testing procedure:

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

Mid-calf measurement (mm)	Measured at widest girth section of calf

Perform each measurement twice and use average.

Ankle circumference

Testing procedure

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

1) Start midway between tibialis anterior tendon and lateral malleolus
2) Move tape medially towards tuberosity of navicular
3) Pull tape upwards across arch and proximal to base of 5th metatarsal
4) Pull tape across tibialis anterior
5) Pull tape around ankle joint to distal tip of medial malleolus
6) Pull tape across the calf/ Achilles tendon
7) Continue with tape to distal tip of lateral malleolus
8) Continue until starting point of measurement

Ankle measurement (mm)	Defined by Figure of 8 method *(Tatro-Adam, et al., 1995)*[103]

Perform each measurement twice and use average.

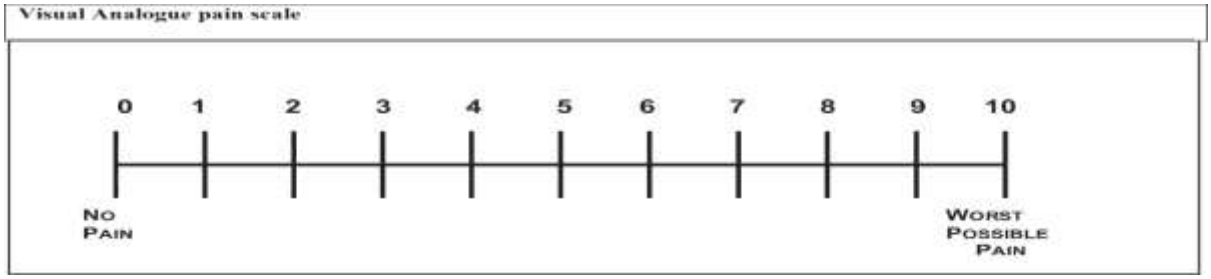
Appendix H: Visit 3 - Adapted Visual Analogue Scale and Self-developed Questionnaire

Name of Participant: _____ Group number: 1 2

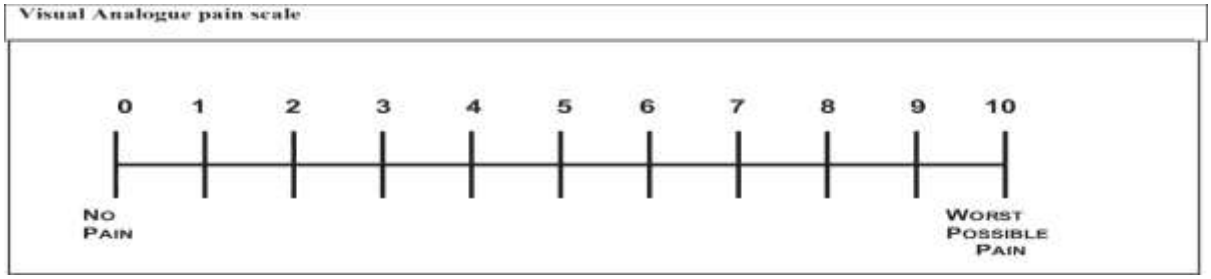
To assess your pain level, please circle the appropriate number.

Adapted Visual Analogue Scale

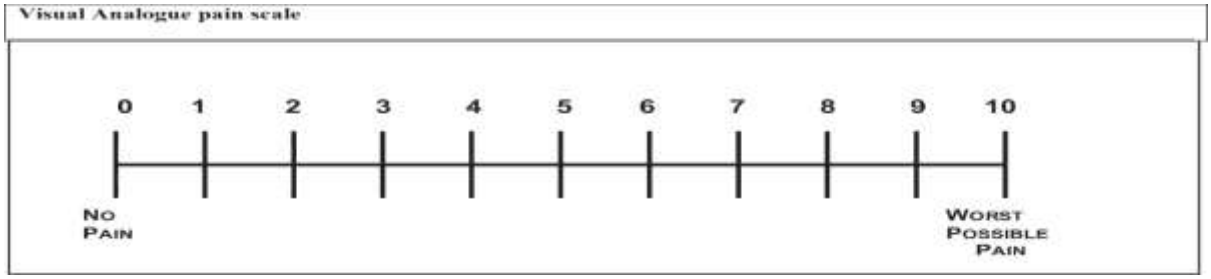
1) While sitting comfortably on a chair, what are your pain levels in the front of your lower leg?



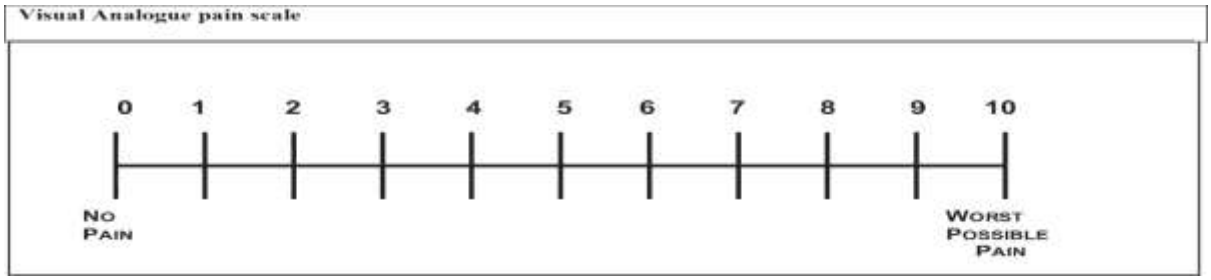
2) While sitting comfortably on a chair, what are your pain levels in the back of your lower leg?



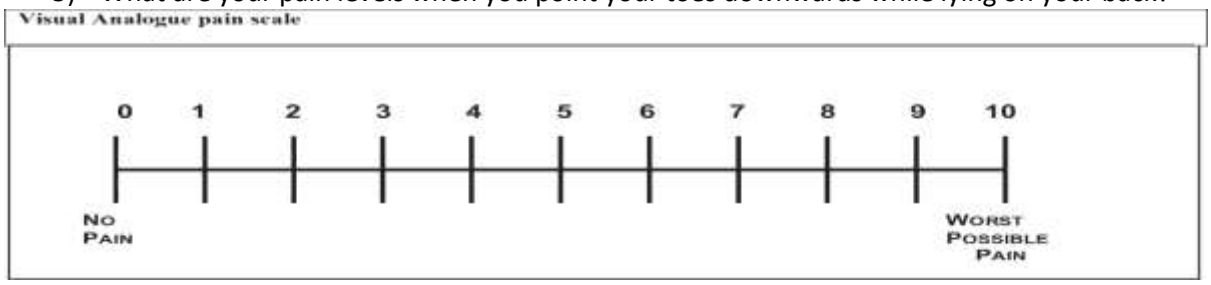
3) While sitting comfortably on a chair, what are your pain levels in the front of your upper leg?



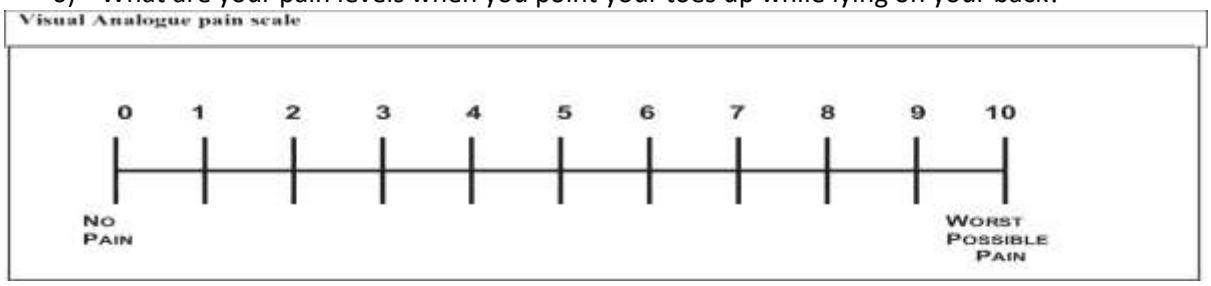
4) While sitting comfortably on a chair, what are your pain levels in the back of your upper leg?



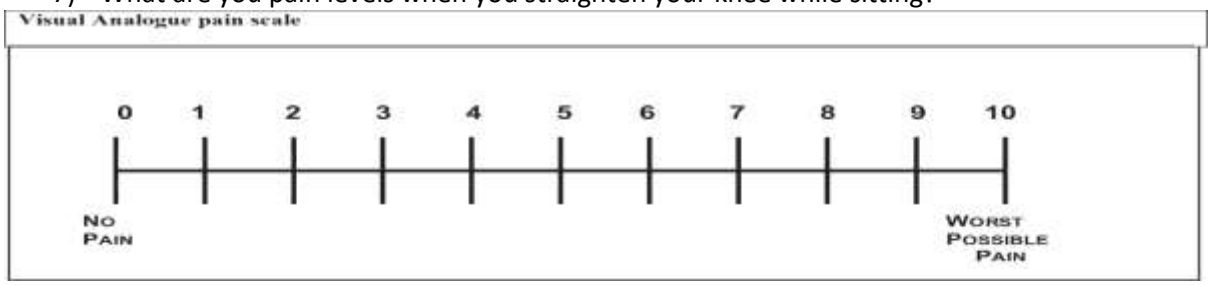
5) What are your pain levels when you point your toes downwards while lying on your back?



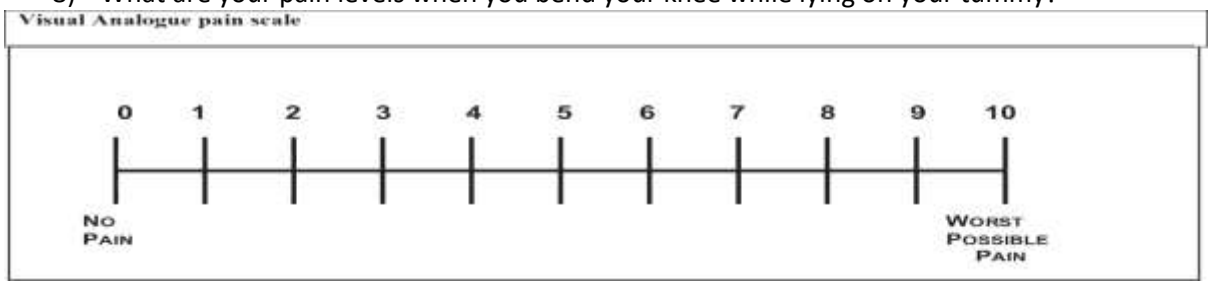
6) What are your pain levels when you point your toes up while lying on your back?



7) What are you pain levels when you straighten your knee while sitting?



8) What are your pain levels when you bend your knee while lying on your tummy?



9) Did you experience any other issues during the race such as a fall or feeling unwell? Please circle the appropriate answer. If yes, please explain further below (Visit 3 only).

YES NO

_____

_____

Records of Nutrition and Fluid Intake

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

Record of recovery strategies

1) Please indicate if any of the following recovery strategies were employed during the last week. Where applicable, indicate when and how frequently the recovery modality was utilised.

Type	Please tick if utilised	Please indicate date(s) of utilisation and frequency
Pain medication		
Anti-inflammatory medication		
Massage		
Stretching		
Ice		
Taping		
Foam rolling		
Nutritional supplements		
Electrical therapy (e.g. ultrasound)		
Other (Please specify)		

Menstrual Cycle (to be completed by females only)

Menstrual Cycle (to be completed by females only)

Participant Code:

1.1) Are you currently menstruating regularly (at least once every one to two months)?

YES	NO	Prefer not to answer

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

_____

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

_____

2.1) Are you currently taking a contraceptive pill?

YES	NO	Prefer not to answer

2.2) If yes, please indicate brand name.

_____

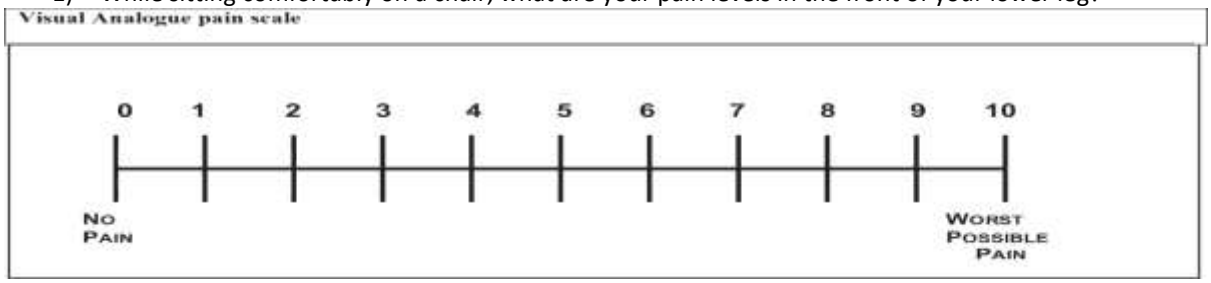
Appendix I: Visit 4 - Adapted Visual Analogue Scale and Self-developed Questionnaire

Name of Participant: _____ Group number: 1 2

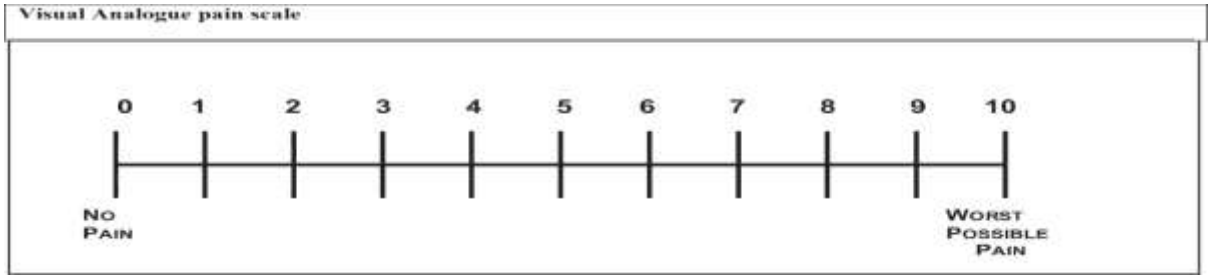
To assess your pain level, please circle the appropriate number.

Adapted Visual Analogue Scale

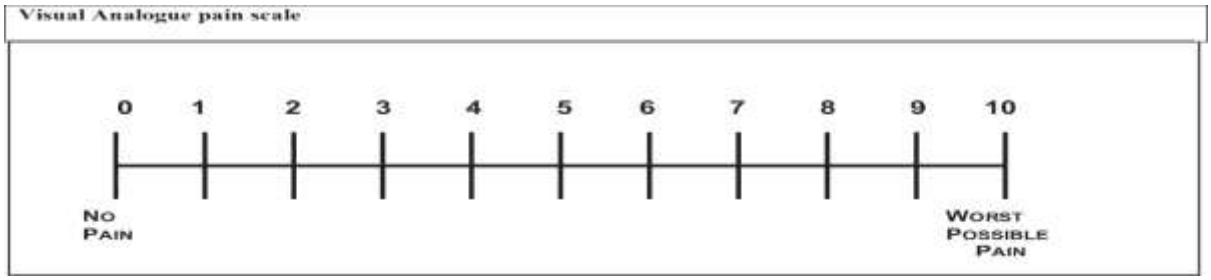
1) While sitting comfortably on a chair, what are your pain levels in the front of your lower leg?



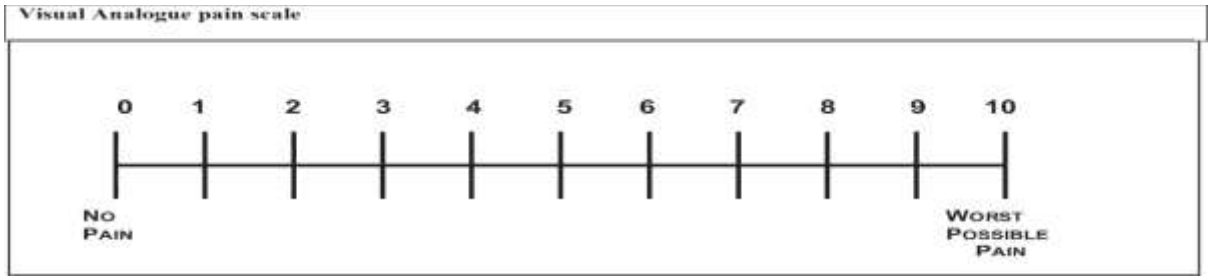
2) While sitting comfortably on a chair, what are your pain levels in the back of your lower leg?



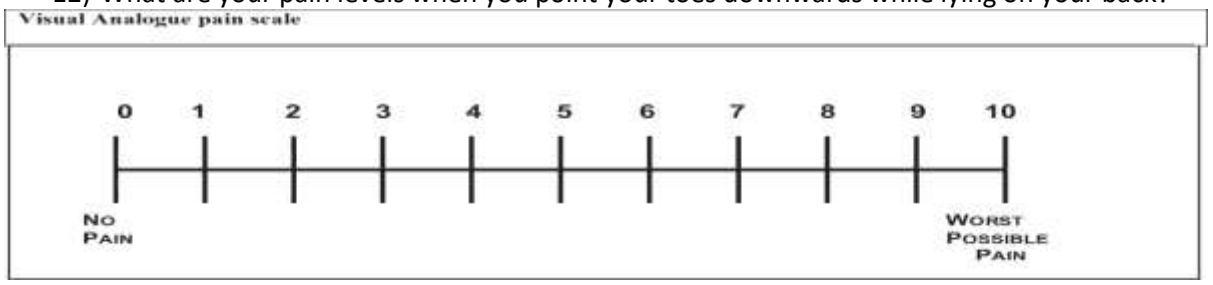
10) While sitting comfortably on a chair, what are your pain levels in the front of your upper leg?



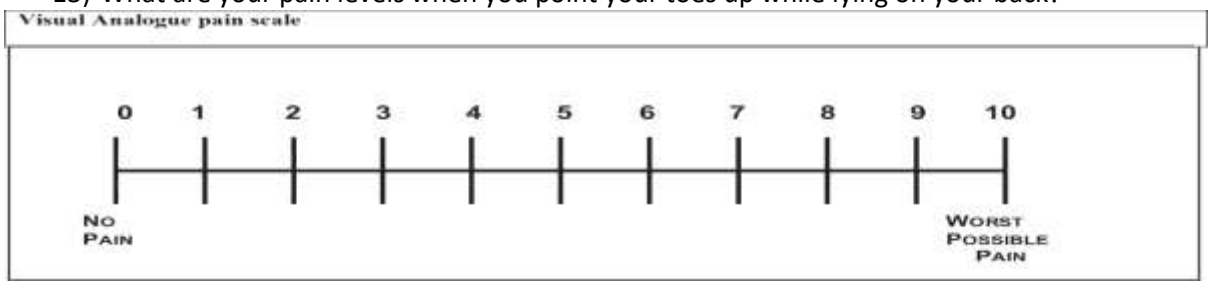
11) While sitting comfortably on a chair, what are your pain levels in the back of your upper leg?



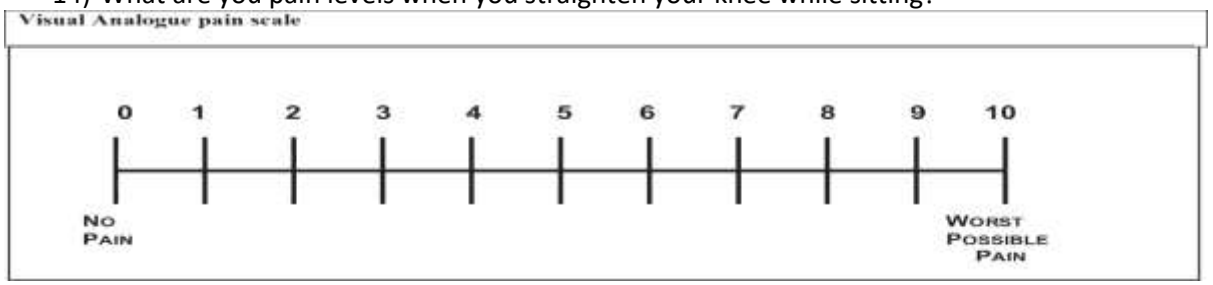
12) What are your pain levels when you point your toes downwards while lying on your back?



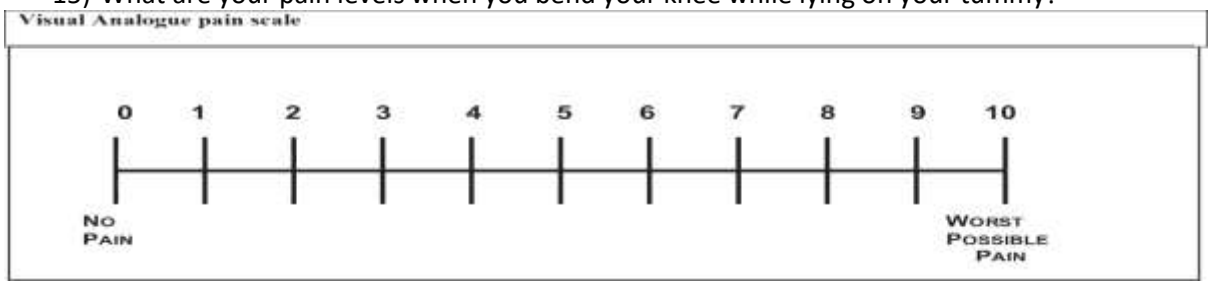
13) What are your pain levels when you point your toes up while lying on your back?



14) What are you pain levels when you straighten your knee while sitting?



15) What are your pain levels when you bend your knee while lying on your tummy?



Record of recovery strategies

Please indicate if any of the following recovery strategies were employed over the past two days. Where applicable, indicate when and how frequently the recovery modality was utilised.

Type	Please tick if utilised	Please indicate date(s) of utilisation and frequency
Pain medication		
Anti-inflammatory medication		
Massage		
Stretching		
Ice		
Taping		
Foam rolling		
Nutritional supplements		
Electrical therapy (e.g. ultrasound)		
Other (Please specify)		

Appendix J: Training history questionnaire

Training and compression garment usage records

Please tick the appropriate answers:

1) Please select all of 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 of 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.

2) Please select the number of runs you generally performed per week over the past 6 weeks.

	0
	1
	2
	3
	4
	6
	7
	8
	More than 8

3) Please select the approximate average range of mileage you performed per week over the past 6 weeks.

	0-49km
	50-60km
	60-70km
	70-80km
	80-90km
	90-100km
	More than 100km

4) Do you perform any other training in addition to running regularly every week?

YES NO

If yes, please indicate the type and frequency.

Type:	Participation:		Frequency:
Strength training (e.g. weight training, crossfit)	YES	NO	
Flexibility Training (e.g. stretch classes, yoga)	YES	NO	
Cycling	YES	NO	
Swimming	YES	NO	
Team sports (e.g. football, cricket, tennis, netball)	YES	NO	
Skill specific training (e.g. agility classes, balance training)	YES	NO	

Other (Please specify) _____ _____	YES	NO	

Appendix K: Summary of Data Collection

Visit 1	Initial Baseline Data Collection
Time	6 weeks prior to event
Location	Division of Exercise Science and Sports Medicine (ESSM), Department of Human Biology, University of Cape Town (UCT), Sport Science Institute South Africa (SSISA)
Outcome measures	• Height, weight (BMI) • Pre-race medial gastrocnemius pennation angles and muscle thickness • Pre-race mid-calf and figure-of-8 ankle circumference
Duration	Approximately 30 minutes per participant

Visit 2	Second Baseline Data Collection
Time	2-3 days prior to event
Location	ESSM, SSISA
Outcome measures	• Pre-race mid-calf and figure of 8 ankle circumference • Pre-race medial gastrocnemius pennation angles and muscle thickness • Tapering baseline countermovement jump (CMJ)
Duration	Approximately 15-20 minutes per participant

Visit 3	Event Data Collection
Time	During and at the finish line of the event
Location	Old Mutual Two Oceans Marathon finish line at the Green Mile, University of Cape Town
Outcome measures	• Immediately post-race mid-calf and figure of 8 ankle circumference • Immediately post-race VAS pain ratings • RaceTec finish times and split at 42km (average race pace) • Immediately post-race CMJ
Duration	Approximately 10 minutes per participant

Visit 4	Post-Event Data Collection
Time	2 days following the race
Location	ESSM, SSISA
Outcome measures	• 2 days post-race medial gastrocnemius pennation angles and muscle thickness • 2 days post-race mid-calf and figure of 8 ankle circumference • 2 days post-race VAS pain ratings • 2 days post-race CMJ
Duration	Approximately 15-20 minutes per participant

Appendix L: Individual Results Template

Provisional Individual Results For Mr XY

Descriptive measures:		
	Measurment:	**Intepretation:**
Baseline weight:		
Baseline height:		
Baseline body mass index:		(normal range: 18.5-25.0; Please note that this does not discriminate between lean tissue and adipose/fat tissue, therefore higher ranges may be normal in athletes due to higher muscle bulk).
Tapering baseline weight:		
Immediately post-race weight:		
2 days post-race weight:		
Circumference measures:		
Ankle measures:		
6 weeks baseline:		
Tapering baseline:		
Immediately post-race:		
2 days post-race:		
Mid-calf measures:		
6 weeks baseline:		
Tapering baseline:		
Immediately post-race:		
2 days post-race:		
Ultrasound measures:		
6 weeks baseline:		**Disclaimer: Please note measures were taken specifically for research purposes and should not be considered diagnostic i.e. it does not replace the need for a radiography report if there are concerns regarding calf complaints/injuries.*
Tapering baseline:		
2 days post-race:		
Countermovement jump test:		
Tapering baseline jump height:		
Immediately post-race jump height:		
2 days post-race jump height:		
Average Race pace:		
To 42km:		
Final 14 km:		
Over-all race pace:		

Appendix M: Data Capturing

Name of Participant: _____ Group number: 1 2

To be completed by examiner:

1) Personal Best Marathon Time (past 18 months):_____
   a) Calculated average pace:_____
   b) If unavailable, use ultra-marathon time:_____

2) Anthropometric information
   a) Height (cm) :_____
   b) Weight (kg) :_____
   c) Calculated BMI :_____

3) Ultrasound imaging

	Visit 1	Visit 2	Visit 3	Visit 4
Pennation angle (º)				
Muscle thickness *(mm)*				

4) Circumference measures

	Visit 1	Visit 2	Visit 3	Visit 4
Mid-calf Circumference *(cm)*				
Figure of 8 ankle circumference *(cm)*				

5) RaceTec timing results
   a) Time to 42km:_____
   b) Time to 56km:_____
   c) Calculated race pace:
      -Over-all: _____
      -First 75%:_____
      -Final 25%:_____

Appendix M: Timing of Data Collection

Example of proposed timing schedule for first data collection

Visit 1

Number	Name of Participant	Group Number	Date & Time	Completed
1	X Y	1	2 March 8:00	X
2	B N	1	2 March 8:30	
3		1		
4		1		
5		1		
6		1		
7		1		
8		1		
9		1		
10		1		
11		1		
12		1		
13		1		
14		1		
15		2		
16		2		
17		2		
18		2		
19		2		
20		2		
21		2		
22		2		
23		2		
24		2		
25		2		
26		2		
27		2		
28		2		
29		3		
30		3		
31		3		
32		3		
33		3		
34		3		
35		3		
36		3		
37		3		
38		3		
39		3		
40		3		
41		3		
42		3		

Appendix N: Example of follow up email correspondence during recruitment

Follow up email following initial interest

Dear Potential Participant

Thank you to everyone who indicated an interest in the research study.

Please find attached an informed consent form which contains further information regarding the study procedure and regulations. If anything is unclear or if you have any questions regarding this, please do not hesitate to ask. If you decide to participate, you will be asked to complete the bottom section of the form at the first data collection session (see below). Please note that participation is voluntary and if you should decide at a later stage that you no longer wish to participate, you will be free to do so. We do ask, however, that you carefully look at the schedule below and consider in advance if you would be able to attend the data collection sessions. This will occur on four occasions:

Duration	Dates	Locations
Visit 1 (Approximately 20-30 min)	Between 2-5 March 2017	Sport Science Institute of South Africa, Newlands
Visit 2 (Approximately 15 minutes)	Between 12-14 April 2017	Sport Science Institute of South Africa, Newlands
Visit 3 (Approximately 5-10min)	15 April 2017	Medical tent, finish line of Old Mutual Two Oceans
Visit 4 (Approximately 10-15min)	17 April 2017	Sport Science Institute of South Africa, Newlands

If you would like to participate, please answer the questions on the screening tool (attached), which will help to determine if you meet the preliminary inclusion and exclusion criteria. Further screening will be performed at the first data collection session (visit 1). If you would be willing and able to participate, please let us know by the 20th of February. After this date or once we have reached our maximum capacity for the study, we will unfortunately no longer be able to include further participants.

We look forward to hearing from you!

Yours sincerely
Grethe Geldenhuys

**If you would like to opt out of receiving further correspondence regarding the research study, please let me know so I can remove you from the mailing list.*

Example of email correspondence regarding for Visit 1

Dear Participant

Thank you for your willingness to commit to the study. Based on the preliminary criteria, you are eligible to participate. This will be verified with further screening during your first visit.

The first visit will take place at the Sport Science Institute of South Africa. Further details have been attached. In addition, a time schedule is included. Please select and send through three possible slots (e.g 8:00 on 2nd of March; 18:15 on 3rd of March, etc) when you would be available to come in for data collection. We will then do our best to accommodate you in one of these slots. A confirmation email with the time of your appointment will be sent.

If you have any further questions, please let me know.

Please send your responses to gldald001@myuct.ac.za.

Kind regards

Grethe

*A map with directions to the Sport Science Institute of South Africa is also attached.

VISIT 1

Location:

Physiology Lab 3, Second floor, Sport Science Institute of South Africa
Address: *Boundary Road, Newlands, Cape Town, 7725*

Duration and description:
The first visit will take approximately of 30 minutes. It will involve screening questionnaires, height and weight measurements, an ultrasound imaging scan of your calves and leg circumference measures.
Please come in comfortable clothing and preferably in shorts to expose the calf for ultrasound imaging and circumference measures.

Parking
Please note that there is secure parking available at the Sport Science Institute of South Africa. Please sign in at security at the Visitors section.

Time table:

2 March (Thursday)	3 March (Friday)	4 March (Saturday)	5 March (Sunday)
7:30	7:30	7:30	7:30
8:00	8:00	8:00	8:00
8:30	8:30	8:30	8:30
9:00	9:00	9:00	9:00
9:30	9:30	9:30	9:30
10:00	10:00	10:00	10:00

10:30	10:30	10:30	10:30
11:00	11:00	11:00	11:00
11:30	11:30	11:30	11:30
12:00	12:00	12:00	12:00
12:30	12:30	12:30	12:30
13:15	13:15	13:15	13:15
13:45	13:45	13:45	13:45
14:15	14:15	14:15	14:15
14:45	14:45	14:45	14:45
15:15	15:15	15:15	15:15
15:45	15:45	15:45	15:45
16:15	16:15	16:15	16:15
16:45	16:45	16:45	16:45
17:15	17:15	17:15	17:15
17:45	17:45	17:45	17:45
18:15	18:15	18:15	18:15

Available slots:___; Unavailable slots:___

Please provide a possible time slots when you would be available for data collection. Please note that we operate on a first come, first serve basis with the allocation of time slots. You will receive a confirmation email of your allocated time slot in due course.

We kindly request that you arrive 10 minutes before the start of your time slot to allow for timely data collection of each participant.

We look forward to seeing you there!

Example of email correspondence prior to visit 2-4

Dear participant

I hope this email finds you well.

Thank you to each one of you who performed the baseline testing and has become involved in the study. Your participation is greatly appreciated.

Just a reminder that the next visit (visit 2) will take place on the 12-14 April at the Sport Science Institute of South Africa. The venue will be at the Biomechanics lab on the first floor. The third visit will be at the medical tent following completion of the OMTOM 56km and the fourth and final visit will take place on Monday the 17th of April, again at the Biomechanics Lab, Sport Science Institute of South Africa. Further information regarding the data collection sessions as well as a time schedule for visit 2 has been attached. Please could you send through three possible time slots and I will do my best to accommodate each one of you in one of these slots.

Furthermore, there is also the opportunity to add an additional test courtesy of a visiting masters student from the University of Jyväskylä in Finland. For those who are interested and willing, following a repeat of the ultrasound and circumference measure testing as previously, an additional test to estimate muscle power by means of a simple jumping movement on a force plate can be performed at the next three visits. There are minimal risks associated with this test. This may add approximately 10-15minutes to the duration of testing at each visit. As with the other testing, this is completely voluntary and all the same principles apply. You can indicate on the day of testing if you would be willing to take part in this additional test without affecting participation in any of the other tests.

Please let me know if you have experienced any issues related to either using or not using the compression garments or if you have any other questions. In addition, could everyone in group 2 (that is, those of you who were asked to run without compression garments) please send me your shoe size as we will be providing a pair of compression socks to you once the study is completed.

In addition, we kindly request that runners try to refrain from using other recovery modalities (such as pain or anti-inflammatory medication, massage, foam rolling, stretching classes, electrotherapy modalities and so forth) as this may impact on results. However, if it is utilised, we ask that a record is kept and disclosed to the researcher at your discretion.

All the best with the final weeks of training!

Kind regards

Grethe

VISIT 2

Location and directions to venue:

Biomechanics Lab, First floor, Sport Science Institute of South Africa
Address: *Boundary Road, Newlands, Cape Town, 7725*

Upon arrival at the Sport Science Institute of SA, please sign in at reception. Walk straight through the cafeteria to the lifts/stairs to go up to the first floor. Walk across the blue floor to the Biomechanics Lab on the left hand side.

Duration and description:
The second visit will take approximately of 15 minutes.

It will involve an ultrasound imaging scan of your calves and leg circumference measures.

Please come dressed in shorts to expose the calf for ultrasound imaging and circumference measures.

Parking
Please note that there is secure parking available at the Sport Science Institute of South Africa. Please sign in at security at the Visitors section.

Time table:

12 April (Wednesday)	13 April (Thursday)	14 April (Friday)
7:30	7:30	7:30
7:50	7:50	7:50
8:10	8:10	8:10
8:30	8:30	8:30
8:50	8:50	8:50
9:10	9:10	9:10
9:30	9:30	9:30
9:50	9:50	9:50
10:10	10:10	10:10
10:30	10:30	10:30
10:50	10:50	10:50
11:10	11:10	11:10
11:30	11:30	11:30
11:50	11:50	11:50
12:10	12:10	12:10
12:30	12:30	12:30
12:50	12:50	12:50
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14:10	14:10	14:10
14:30	14:30	14:30
14:50	14:50	14:50
15:10	15:10	15:10
15:30	15:30	15:30
15:50	15:50	15:50
16:10	16:10	16:10

16:30	16:30	16:30
16:50	16:50	16:50
17:10	17:10	
17:30	17:30	
17:50	17:50	
18:10	18:10	

Available slots:___; Unavailable slots:___

Please provide 3 possible time slots when you would be available for data collection. Please note that we operate on a first come, first serve basis with the allocation of time slots. You will receive a confirmation email of your allocated time slot in due course.

We kindly request that you arrive a few minutes before the start of your time slot to allow for timely data collection of each participant.

Visit 3

Location:

Medical tent at the finish line of the Old Mutual Two Oceans, Green Mile, University of Cape Town.

Duration and description:
The third visit will take approximately 5 minutes. It will involve leg circumference measures and a questionnaire.

At this visit, we will ask you to confirm the time slot for the final data collection. As we will need to test a large volume of individuals in a limited period of time for the fourth and final visit, we kindly request that you keep strictly to the time schedule. A guide for the time schedule can be found below. If you have special requests for times, please let me know in advance.

VISIT 4

Location:

Biomechanics Lab, First floor, Sport Science Institute of South Africa
Address: *Boundary Road, Newlands, Cape Town, 7725*

Upon arrival at the Sport Science Institute of SA, please sign in at reception. Walk straight through the cafeteria to the lifts/stairs to go up to the first floor. Walk across the blue floor to the Biomechanics Lab on the left hand side.

Duration and description:
The final visit will take approximately of 10-15 minutes.

It will involve an ultrasound imaging scan of your calves and leg circumference measures and a questionnaire. You will receive the questionnaire after completing your race. We kindly request that you complete this questionnaire shortly before coming in for your data collection to allow us to perform testing within the time frames.

Parking
Please note that there is secure parking available at the Sport Science Institute of South Africa. Please sign in at security at the Visitors section.

Time table:

17 April (Monday)
6:45
7:00
7:15
7:30
7:45
8:00
8:15
8:30
8:45
9:00
9:15
9:30
9:45

10:00	
10:15	
10:30	
10:45	
11:00	
11:15	
11:30	
11:45	
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16:00	
16:15	
16:30	
16:45	
17:00	
17:15	
17:30	
17:45	
18:00	
18:15	
18:30	
18:45	
19:00	

Available slots:; Unavailable slots: