The Effects of Knee High Compression Garments and Ice on Exercise Performance and Recovery

By

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Abstract

Introduction: Compression garments (CGs) are becoming increasingly popular in many sports as they are believed to aid performance and recovery. Likewise the use of ice therapy is one of the most used recovery strategies by athletes and sports people. **Purpose:** The purpose of these studies was to examine the effect of CGs on physiological, biomechanical and perceptual measures of performance and recovery after 10 km running; and to assess the combined use of compression and ice on recovery post eccentric exercise. **Method:** Two separate studies were conducted; Phase 1 was a randomised control study in which thirteen recreationally competitive male 10 km runners (Age (median): 26 years (19-48 years), Height: 178 ± 5 cm, Mass: 76.2 ± 6.5 kg, $\dot{V}O_{2Max}$: 50 ± 5 ml.kg^{-1}.min^{-1}) undertook four 10 km runs. The interventions were; CON (no intervention), EX (CGs during run), REC (CGs for 12 hours post run) and EXREC (CGs during and 12 hours post run). During the runs heart rate (HR), rating of perceived exertion (RPE), blood lactate and performance time were measured. Post run (24 hours) creatine kinase (CK), C-reactive protein (CRP), calf girths, and perceived pain were measured. A separate muscle oscillations test was also performed; where participants completed two 30 second runs at 12 km.h^{-1}, wearing CGs (CG) and no CGs (CON). During the runs peak velocity, peak acceleration, average velocity and peak displacement of the calf muscle was measure using a 3D infrared camera system. Phase 2 was a randomised control study in which nine healthy male volunteers (Age (median): 23 years (20-27 years), Height: 178.7 ± 5.3 cm, Mass: 78.2 ± 14.4 kg) completed 3 trials: CON (no intervention), REC (CGs for 12 hours post run) and ICE (ice protocol and CGs for 12 hours post run). Each trial consisted of an eccentric muscle damage protocol followed by a 1 km time trial 48 hours post exercise. Perceptual measures of muscle pain, perceived ability and perceived recovery were measured at 24, 48 and 72 hours post eccentric exercise, with a questionnaire. Muscle damage (CK), calf girths and 1 km performance time were measured 48 hours post run. **Results:** Phase 1; there were no significant differences in 10 km run time, HR, RPE, lactate, CK, CRP, calf girths, perceived pain, peak or average calf muscle velocity, or peak acceleration of calf muscle with any application of CGs compared to the control (p > 0.05). During the muscle oscillation test a significant reduction in calf muscle displacement was found with CGs (p < 0.05). Phase 2; there were no significant differences in 1 km run performance, CK or calf girths, 48 hours post run (p < 0.05). There were inconsistent improvements in muscle pain, perceived recovery and perceived maximum ability in the REC and ICE trials compared to control (p < 0.05). **Conclusion:** Neither CGs nor ice had any physiological effects on performance or recovery. Compression reduced the displacement of the calf muscle during running, which could lead to increased efficiency over longer duration races such as marathons. Compression garments and ice improved some perceptual measures or recovery; however, these results were inconsistent and likely to represent a placebo effect.

Key words: Calf Sleeves, Running, Competition, Perceptual Responses, DOMS

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Abbreviations and Useful Terms

Calf Sleeves	Compression Covering Ankle to Knee
CG	Compression Garment
CGs	Compression Garments
CK	Creatine Kinase
CRP	C-Reactive Protein
Full length tights	Compression Covering Ankle to Hip
Graded	Compression Highest Distally Reducing Proximally
Gradient	Difference between Highest and Lowest Pressure
Graduated	Compression Highest Distally Reducing Proximally
HR	Heart Rate
Knee high CGs	All Compression Ending below the Knee
MD	Muscle Damage
RPE	Rating of Perceived Exertion
Shorts	Compression Covering Hip to Knee
Socks	Compression Covering the Foot up to the Knee
Stockings	Compression Covering the Foot up to Mid Thigh
Thigh high CGs	Compression Covering Ankle to Mid Thigh
Zoned compression	Graduated Compression with Areas of Reduced Pressure for Comfort i.e. the knee.

Chapter 1: General Introduction

Compression garments (CGs) are becoming more popular in many sports, ranging from running and triathlon to mixed martial arts (French et al., 2008). There are many claims about the possible performance benefits of CGs, these include; decreased heart rate during exercise (Dascombe, Hoare, Sear, Reaburn & Scanlan, 2011), increased time to fatigue (Varela-Sanz, Espana, Carr, Boullosa & Esteve-Lanao, 2011), decreased risk of injury (Bernhardt & Anderson, 2005), slower lactate accumulation (Driller & Halson, 2013), and improved performance and power output (Kemmler et al., 2009).

While performance outcomes are the central focus for most athletes and sport scientists, there is also a need for fast recovery in athletes who train or compete multiple times per week, often required to perform consistently without a rest day (Wallace, Slattery & Coutts, 2008). Recovery can be measured in many ways such as; repair of muscle damage, return of maximal force production or maximum performance capability (Jeffrey, 2005). It is possible therefore, that some ergogenic aids may be beneficial in increase recovery and repeat performance, while not affecting maximal fully rest performance. Indeed, there is some evidence that CGs may behave in this way (Duffield, Cannon & King, 2010). Furthermore, compression garments have been linked with; decreased muscle damage, reduced delayed onset muscle soreness (Davies et al., 2009), reduced inflammation (Trenell, Rooney, Sue & Campbell, 2006) and increased maintenance of power (Driller et al., 2013); all of which could be considered markers of recovery. However, while there are many studies supporting the proposed benefits of CGs the evidence remains equivocal, as there are many studies with contradicting findings including studies that have shown no beneficial effects whatsoever (Sperlich et al., 2010). There are also benefits purported that have little evidence to support them; therefore, gaps in knowledge are still evident (Born, Sperlich & Holmberg, 2013).

Another ergogenic aid that is suggested to improve markers of recovery and consequently repeat performance is ice therapy. Ice therapy is used extensively by athletes and recreational sports people for treatment after exercise as it is believed to increase recovery by; reducing muscle damage and inflammation (Bleakley et al. 2012) and reducing post exercise muscle soreness (Oakley, Pardeiro, Powell, Millar & Audrey, 2013). Limited research has been conducted into the combined use of compression and ice together. It has been suggested that this combination could elicit a greater benefit to recovery than either therapy alone (Sloan, Hain & Pownall, 1989).

This thesis describes two studies conducted to investigate the effect of compression and ice application on performance and recovery. The thesis contains seven chapters; Chapter two reviews the current literature surrounding the use of compression garments and ice for performance and recovery. Chapter three describes general methodology used during all testing procedures. Chapter four outlines pilot testing conducted before the main studies were completed. Chapter five outlines phase one: The effect of knee high compression garments on 10 km run performance, and recovery in competitive recreation endurance athletes. Chapter six outlines phase two: the effect of combined compression and ice therapy on recovery after eccentric exercise. Finally, Chapter seven evaluates the findings from both phases in relation to the current literature.

Chapter 2: Literature Review

2.1 Literature Search Strategy

This review aims to examine the current literature relating to the use of CGs and ice therapy, and to evaluate potential benefits and mechanisms of action. Furthermore, the methods used to assess these benefits and mechanisms are discussed. To achieve this, a computer based literature search was performed, ending in June 2015, using three online databases (PubMed, Web of Science and Web of Knowledge). Combinations of the following terms were used: Compression, compression garment, compression clothing, compression stocking, performance, heart rate, blood lactate, perceived exertion, running, endurance, muscle oscillations, blood flow, ice therapy, ice pack, ice bath, cryotherapy, cryo-cuff, cryocompression, cold compression, recovery, EIMD, muscle damage, creatine kinase, inflammation, CRP, DOMS, algometry, muscle soreness and eccentric exercise. The reference lists of obtained articles were examined in order to identify further relevant studies.

2.2 Acute Running Performance

An athlete's performance in a single bout of endurance exercise is influenced by a large number of key factors and confounding variables; however, the main physiological determinants of endurance exercise are: Maximum oxygen consumption (VO_{2Max}), percentage of $\dot{V}O_{2Max}$ at Lactate threshold (LT), and running economy (Bassett & Howley, 2000). While the ability to buffer hydrogen ions can be important in athletic performance, during self paced endurance running this has been shown to be less critical (Creasy, 2008).

$\dot{V}O_{2Max}$

An athlete's $\dot{V}O_{2Max}$ is defined as the highest rate at which oxygen can be taken in and utilized by the body (Bassett & Howley, 2000). This variable is one of the most commonly tested in athletes as a predictor of future performance and a measure of training effects (Noakes, 2000). A long standing debate exists about the limiting factor of maximal oxygen uptake. Specifically, the debate questions whether it is the capability of the muscles to take

in and utilise oxygen (peripheral factors) or the ability of the cardio-pulmonary system to delivery sufficient oxygen to the muscle (Central factors), that is the limiting factor. It is now largely accepted that is healthy individuals performing maximal full body exercise, that central factors limits $\dot{V}O_{2Max}$ (Noakes, 2000). This conclusion was reached largely due to research that augmented the cardio-pulmonary systems ability to deliver oxygen, through blood doping and use of hyperoxic gas; the results of these studies showed a concurrent increase in $\dot{V}O_{2Max}$ that would not have been present if the muscle was the limiting factor (Bassett & Howley, 2000). Moreover, research has shown that the main limiter in the cardiopulmonary system is likely to be cardiac output, more specifically as a consequence of stroke volume (Noakes, 2000). This result is supported by research that has shown that the training induced increases in VO_{2Max} are due to an increase in stroke volume and consequently blood flow to the active muscles (Ekblom, Astrand, Saltin, Stenberg & Wallstrom, 1968; Saltin et al., 1968).

Lactate Threshold

Lactate threshold (LT) indicates the percentage of an athlete's maximum performance that can be sustained for a long period of exercise (Midgley, McNaughton, & Jones, 2007). The percentage of $\dot{V}O_{2Max}$ at LT indicates the amount of oxygen ($\dot{V}O_2$) that is available to the athlete at this sustainable work intensity; sometimes referred to as the performance $\dot{V}O_2$ (Bassett & Howley, 2000). If an athlete's work rate exceeds this level, then reliance on an-aerobic energy pathways will be increase; as will hydrogen ion accumulation and consequently blood lactate concentration (Noakes, 2000). Accumulation of hydrogen ions causes a reduction in cell pH, that interferes with the function of key enzymes, such as phosphofructokinase (PFK) and muscle cross bridging leading to exercise fatigue (Robergs, Ghiasvand & Parker, 2004). Additionally, when exercising above LT the rate of glycolysis is increased, due to changes in cellular charge; this increase in carbohydrate usage can also be a limiting factor during endurance exercise as carbohydrate stores become exhausted (Bassett & Howley, 2000). Unlike $\dot{V}O_{2Max}$, an athlete's lactate threshold is largely governed

peripheral factors; namely by the muscle capillerisation density, number of mitochondria and oxidative enzyme concentrations (Bassett & Howley, 2000); all of which can be increased with training (Midgley et al., 2007).

Running Economy

Running economy refers to an athlete's efficiency at converting the available energy in running speed (Midgley et al., 2007), or more specifically it is the amount of work (distance covered) that can be done per unit for oxygen (Bassett & Howley, 2000). As such, if two athletes have the same maximal oxygen uptake but different running economy, the athlete with the higher economy will have a higher maximum running speed, as they are able to cover more distance (do more work) for the same amount of oxygen delivery (Noakes, 2000). An athlete's running economy and percentage $\dot{V}O_{2max}$ at LT combine to determine the running speed at LT and consequently the maximum sustainable running speed during endurance performance (Figure 1). This maximum sustainable speed has been shown to be the most important and accurate single indicator of endurance running performance (Midgley et al., 2007).

Between-subject variance in running economy is due to a wide range of physiological and biomechanical factors for example: body mass, skeletal structure and running technique. However, the greatest factor affecting an individual's running economy during endurance exercise is their ability to utilise the muscles as an elastic return system, through the stretch shortening cycle (SSC) (Noakes, 2000); this elastic return of energy allows the muscle to produce less torque while maintaining the same power output, therefore increasing efficiency (Paavolainen, Nummela, Rusko & Häkkinen, 1999). The SSC during activities such as walking, hopping and running utilises gravity to lengthen the muscles involved in the movement. Pre-activation of the muscle allows an eccentric contraction to occur during the lengthening phase, which is then followed by a concentric contraction phase (Paavolainen et al., 1999). The pre activation and eccentric phases of the SSC have the effect of storing

elastic energy which is then used to enhance the performance of the muscle during the final concentric phase; when compared to an isolated concentric phase (Komi, 2000). The ability of the muscle to use this stored elastic energy is limited by the: amount of pre activation and stiffening of the muscle, velocity and magnitude of the stretch phase, and the time delay between the eccentric and concentric phases (Paavolainen et al., 1999). Fatigue of the SSC is believed to be a major factor contributing to decreases in running performance during endurance events and in the subsequent muscle damage experienced post exercise (Komi, 2000). The time between eccentric and concentric phases of the muscle movement and consequently ground contact time, have been shown to increase concurrently with a reduction in running economy and maximal performance during the latter stages of 10 km running time trials (Paavlainen et al., 2000). Training interventions and ergogenic aids that could reduce SSC fatigue during exercise could benefit endurance running performance, through increased maintenance of running economy (Noakes, 2000).

Motivation

The three physiological factors discussed above ($\dot{V}O_{2max}$, % $\dot{V}O_{2max}$ at LT and Running economy) have been shown to account for more than 70% of the between-subject variance in long distance running performance (Midgley et al., 2007). However, this physiological model, of the determining factors of endurance exercise performance, fails to acknowledge the role of psychological factors such as motivation. Conscious effort and motivation play a key role in exercise performance; as shown in previous research that has demonstrated performance increases during placebo interventions (Noakes, 2000). Moreover, it has been shown that reduced motivation due to mental fatigue, adversely affected endurance running performance (Marcora, Staiano, & Manning, 2009). Therefore, it is clear that motivation level has a key influence on performance and any model hoping to outline determinants of performance should include motivation (Figure 1); however, due to the complicated interactions of physiological and psychological variables, the mechanisms by which psychological factors affect endurance performance remain unclear (Noakes, 2000).

$\dot{V}O_{2Max}$ | % $\dot{V}O_{2Max}$ at LT

$\dot{V}O_2$ at LT | Running

Speed at

Maximum Sustainable Running Speed

Motivation

Distance Running Performance
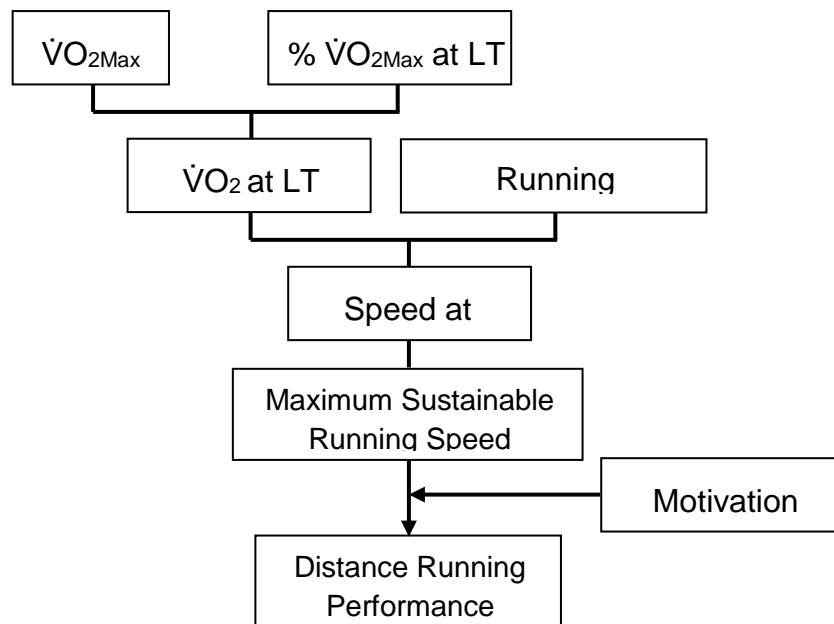
Figure 1: Factors determining endurance running performance. Adapted to include motivation (Bassett & Howley, 2000; Midgley et al., 2007). *LT = Lactate Threshold.*

2.3 Ergogenic Aids to Performance

Ergogenic aids are used extensively by professional athletes and recreational sports people, to aid sport and exercise performance (Ali et al., 2007). These include nutritional aids such as supplements, physical aids such as clothing, and psychological aids such as visualisation and increased motivation (MacRae et al., 2011). Compression garments are now one of the most popular ergonomic aids used for endurance events, such as running and triathlon (Bakken et al., 2011). Despite this, the rationale for their use and evidence for their benefit remains somewhat equivocal (MacRae et al., 2011).

2.3.1 Compression Garments

Compression garments are tight elastic garments, varying from socks to arm sleeves, used to apply compressive force to segments of the body. Compression was originally designed for use in hospitals to aid recovery (Wilkins, Mixter, Stanton & Litter, 1952) by increasing venous blood flow (Lawrence & Kakkar, 1980), decreasing venous stasis (Gandhi & Palmer, 1984) and to prevent thrombosis (O'Donnell & Rosenthal, 1979) in the legs of bed ridden

patients. The thrombosis preventing properties of knee high compressive socks were then utilised by people on long haul flight, to help prevent deep vein thrombosis. The sporting community then began using CGs to aid performance and recovery (Berry & McMurray, 1987), with the use of compression shorts, knee high compression and full leg compression becoming a common sight at running and triathlon events (Creasy, 2008).

2.3.1.1 Compression Garment Type

There are many different types of compression garment used in sport today (Table 1), including upper body, arm sleeves and leg compression. The focus of this review is lower body compression. The different forms of lower body compression are often described by many different names, this combined with the infrequent statement in the literature of the exact area covered by the garment (MacRae et al., 2011), has led to some confusion. For clarity, this review refers to compression garments by the names described in table 1; in the event that it was unclear which type of CG was used in a piece of research, the author's description was used.

Table 1: A summary of compression garment types and descriptions

Description	Area of Body Covered
Upper Body	
Arm sleeves	Arm from the wrist to below shoulder
T shirt	Torso and upper arm above the elbow
Full upper body	Torso and entire arm to the wrist
Lower Body	
Calf Sleeves	Lower leg from the ankle to below the knee
Socks	Foot and lower leg to below the knee
Thigh High	Leg from ankle to the mid thigh
Stockings	Foot and leg to the mid thigh
Shorts	From the knees to the hips
Full length tights	From the ankles to the hips

Description= the term used to describe the compression garment within this thesis

The efficacy and advantages of different types of compression garments have not been studied extensively. Several studies have compared the effect of knee high compression compared with above knee compression on blood flow. Lawrence et al. (1980) found no

difference in venous return when comparing knee high to thigh length or full length compression. They also suggested that below the knee is the most important area to be compressed for increasing blood flow. However, this study was conducted on patients with venous insufficiencies in the supine position; therefore the results may not be transferable to a healthy population (Byrne et al., 2001), while standing or when muscles are actively contracting (Creasy, 2008). No research was identified that evaluated the effect of compression length on any other variable. Consequently the effect of different compression types on the other proposed benefits of CGs remains unclear.

2.3.1.2 Graduated Compression

When testing CGs the definition and measurement of the compression is important. Medical compression and the majority of sport compression claim to provide graduated compression, where the greatest pressure is applied distally and the pressure reduces proximally. The pressure of compression socks and calf sleeves are measured in millimetres of mercury (mmHg) at the ankle and calf. Therefore, a sock labelled 15-20 mmHg is eliciting 20 mmHg at the ankle and 15 mmHg at the calf. Medical compression socks are normally rated around 20-40 mmHg (Hirai, Iwata & Hayakawa, 2002).

Early efficacy research

Stanton et al. (1949) showed that non graduated ankle to knee compression of 20 mmHg increased venous velocity in patients with venous insufficiencies. The first record of graduated compression use was Scurr, Machin and Bailey-King (1977); who showed that graduated stockings (GCS) significantly reduced the incidence of deep vein thrombosis (DVT) in post operative patients. However, Scurr compared the GCS to an untreated control leg, rather than a non -graduated control and this may have influenced the results. Lawrence & Kakkar (1980), compared different ranges of compression gradient and found that 18 mmHg at the ankle and 8 mmHg at the mid thigh was optimum for increasing deep venous blood flow without inhibiting subcutaneous blood flow. They also suggest that the graduation

ensured there was no tourniquet effect and that graduation was critical to the function, contradicting the earlier findings by Stanton. The use of graduated compression garments became widely used in hospitals following a meta-analysis of 12 studies conducted by Wells, Lensing and Hirsh (1994), which concluded that graduated compression significantly decreased post-operative venous thromboemolisms by 68% (p = 0.0001).

Adoption into sport

Despite the limited research supporting graduated over non-graduated compression, it was soon adopted into sport and its use investigated. Berry and Bailey (1990) studied the effects of elastic compression garments on eight healthy males following high-intensity exercise (110 per cent $\dot{V}O_{2max}$) for up to three minutes on a treadmill. There was no significant difference in energy requirement, heart rate (HR) or blood lactate concentration at rest or at 5, 15 or 30 mins post-exercise, when compared to a control. However, Wallace et al. (2008) criticised the study for not having the minimum required compression of 18 mmHg at the ankle and 8 mmHg at the mid thigh needed to encourage venous return (Lawrence et al., 1980). Bringard, Perry and Belluye (2006b) compared CGs to elastic tights and found a reduced energy cost at 12 km.h^{-1}, for both conditions when compared to a loose fitting short. However, Bringard and colleagues did not state the level of compression applied by either garment. Berry et al. (1990) stated that elastic tights did not affect blood lactate, HR or oxygen consumption during cycling and recovery because they do not apply sufficient pressure to enhance venous blood flow. Despite this, no study has been identified that compared graduated compression garments to non-graduated garments of 20 mmHg as shown by Stanton et al. (1949) to increase blood flow.

Graduated vs. non-graduated compression

Despite being identified as an important parameter, it is rare to find an adequate definition of the mechanical properties of the CGs used (MacRae, Cotter & Laing, 2011). Many studies fail to supply a figure for compression (Bringard et al., 2006b), others give single number

compression values making it unclear whether the compression was graduated (Sperlich et al., 2010), or values are presented with no clarification about their origin. Ali, Creasy and Edge (2011) defined the compression used in their study as; control 0 mmHg, low 12-15 mmHg, medium 18-21 mmHg and high 23-32 mmHg. The low and medium CGs resulted in greater maintenance of leg power after endurance exercise compared to the control and high CG trials. However, how they measured the pressure is not explained. It is unknown whether pressure readings were an estimate, based on size of garment or size of leg; or if pressure was measured directly on the participant's leg. Due to wide individual variance in leg sizes and shapes, if a study does not measure compression directly on the participant's leg, the level of compression and gradient being applied can only be estimated and measured pressures frequently differ from the level intended (MacRae et al., 2011). Consequently, results that appear to support the use of graduated compression may not be valid, unless the pressure gradient was measured on the participant's leg.

Recently, Hill, Howatson, van Someren, Leeder and Pedlar (2013) conducted a meta-analysis of 12 compression studies and concluded that CGs are beneficial for recovery; however, analysis did not suggest that the compression should be graduated to give these benefits. Born et al. (2013) conducted a meta-analysis that suggested that CGs may assist athletic performance and recovery in given situation, of the 31 studies analysis by Born et al. (2013), 16 reported the use of graduated compression and 15 did not. Further research is necessary into the efficacy of graduated compression compared to non- graduated compression, and the effect of a pressure gradient on mechanisms of performance and recovery in addition to blood flow.

2.3.2 Mechanisms of Action during Performance

2.3.2.1 Muscle oscillations

Muscle oscillations are the displacement of muscle tissue, caused by acceleration forces, produced when the supporting skeletal structure impacts a surface. For example, the

muscles of the thigh are displaced longitudinally when the feet hit the floor following a jump (Kraemer et al., 1998). Compression shorts have been shown to significantly reduce muscle oscillations compared with loose fitting shorts, when performing countermovement jumps (Doan et al., 2003). Furthermore, when participants were wearing compression shorts, Kraemer et al. (1998) found a significant decrease in muscle oscillations during repeated jumps, using a high speed video system. Similarly, Bakken (2011) used accelerometers placed on the left thigh and found decreased muscle acceleration during running. Borras et al. (2011) evaluated the effects of compression shorts on leg muscle oscillations and showed a significant reduction in thigh muscular displacement in those wearing CGs. Reductions in muscle oscillation have been suggested to give benefits in performance and recovery.

Performance increases found by Kraemer et al. (1998), were explained by increased maintenance of power due to decrease muscle oscillations. It was also suggested that the reduced muscle oscillations allowed for a shorter ground contact (Kraemer et al., 1998), which could increase the efficiency of the SSC and increase running economy (Komi, 2000). This is supported by Doan et al. (2003), who found improved jumping ability was due to reduced muscle oscillation upon ground contact. This could be explained by reduced interruption of neurotransmission and more optimum mechanics of the muscles at a molecular level, with reduction in muscle oscillation (McComas, 1996). These increased mechanics have been suggested to help maintain efficiency of the SSC during fatiguing exercise, which could maintain force output and running economy, which consequently could benefit performance as the bout of exercise continues (Duffield et al, 2008). However, research into muscle oscillations is still very limited and the benefits of reduced muscle oscillations are hypothesised but not proven. In terms of CG use research has shown a trend for thigh musculature to oscillate less with compression shorts; however, a direct link between this and performance has not been established (Bakken, 2011). Furthermore, no

studies have examined muscle oscillations in other muscle groups, or with any other type of CG.

If reduced oscillations were shown in the calf musculature, during running; this would support a possible mechanism by which knee high CGs could aid performance. Further research should explore the link between this stabilisation of the muscle, the force produced, and the effect on exercise efficiency.

2.3.2.2 Blood flow

As described above, CGs were originally developed to augment blood flow; as such the proposed mechanisms and suggested benefits of CGs on blood flow forms a large proportion of the current compression literature (MacRae et al., 2011) and is often quoted as a major benefit of wearing compression by many of the companies who supply the garments for exercise (2XU, 110% Harder, Skins). This has led to a wide range of mechanisms being suggested to explain how CGs may increase blood flow at rest and during exercise.

Myogenic Response

The myogenic response (Bayliss effect) suggests that arteriolar vessels constrict in response to an increase in transmural pressure and dilates in response to a fall in transmural pressure (Bochmann et al., 2005). Transmural pressure is the difference in pressure inside and outside of the vessel. Compression garments exert pressure directly on underlying tissues; this is proposed to increases the pressure outside arterioles, which reduces the transmural pressure (Bochmann et al., 2005). When the transmural pressure is reduced the wall of the arterioles are constricted, causing calcium channels to close. This causes a reduction in contraction force of the smooth muscle in the arterioles' wall. Leading them to dilate and subsequently increase blood-flow (Davies et al., 2009; O'Donnell et al., 1979). Lundvall and Lanne (1989) studied the application to negative pressure (2-50 mmHg) to the forearm of 15 volunteers, they found that the pressure was transmitted almost fully to the tissue below and

that transmural pressure was affected proportionally. Bochmann et al. (2005), found external pressure from made to measure stockings, increased resting perfusion and peak blood flow in the forearm. Maximal flow effect was induced by a pressure of 20 mmHg. Arterial flow significantly increased with CGs from 3.7 ± 0.9 to 8.8 ± 2.0 ml.min^{-1}.100ml^{-1} tissue ($p < 0.001$). The flow increase was consistent for 3 hours of constant CG use and also during simultaneous low intensity hand grips; blood flow returned to normal when CGs were removed.

Venular-Arteriolar Communication

While compression is suggested to cause arterioles to dilate, it is also suggested that veins, which are softer and contain blood at a lower pressure are forced to contract (Bochmann et al., 2005). As a result of the reduced lumen diameter in the veins the blood flow may exert an enhanced shear stress, which could trigger the release of endothelial dilators for example Nitric Oxide. In a process known as venular-arteriolar communication, these dilators may reach neighbouring arteries by diffusion and further reduce arteriol resistance (Hester and Hammer, 2002).

Skin Vasomotor Reflex

Another mechanism by which CGs are suggested to increase blood flow is the skin vasomotor reflex. It has been hypothesised that the application of pressure to the skin surface may activate non-nociceptive skin receptors or proprioceptors in under lying tissue causing an increase in microcirculatory flow (Abraham, Fromy, Merzeau, Jardel & Saumet, 2001). Bochmann et al. (2005), believe that the role of skin vasomotor reflex and venular-arteriolar communication need to be studied further and that the myogenic response is most likely to be responsible for the blood flow increase with compression.

However, none of the above mechanisms are suggested to be reliant on graduation of compression. Indeed, Bochmann et al. (2005) stated that the maximal flow effect was

induced by a pressure of 20 mmHg; there was no suggestion that a pressure gradient was applied, or that one would be necessary to induce this response.

Blood Pooling

When a person stands there is an increase in hydrostatic force of between 80 and 100 mmHg due to gravity (Born et al., 2013). This causes superficial veins to expand and blood to pool in the legs. Agu, Hamilton and Baker (1999) showed that standing increased the concentration of deoxygenated haemoglobin in the calf. CGs were shown to reduce this venous pooling in patients with Chronic venous insufficiencies (CVI) at rest (Hirai et al., 2002). During exercise the skeletal muscle pump works to counter this, using muscle contractions in the lower leg to squeeze blood through the one way valves in the veins. Venous return is also helped by the respiratory pump, cardiac suction, and expansion of the atria due to ventricular contraction (Brooks, Dubouchaud, Brown, Sicurello & Butz, 2001). Agu et al. (1999) found that tip toe exercise reduced deoxygenated blood pooling, but not as much as wearing CGs did during rest. However, Mayberry, Moneta, De Frang and Porter (1991) stated that a rapid increase in venous blood flow and mechanical action of the skeletal muscle pump ensures an adequate supply of blood is returned to the heart to maintain cardiac output during exercise, in healthy individuals. It is therefore unclear if compression affects blood pooling in to healthy people during exercise.

Venous Return

Blood pooling is reduced and venous blood velocity increased by reduction of total venous cross section area (Morris et al., 2004; Stanton et al., 1949). This is achieved through shifting of the blood from superficial veins, that are more susceptible to stretching, to deeper veins (Lawerence et al., 1980) and through reduced lumen size due to the compressive effect on the tissue (Bochmann et al., 2005). Mayrovitz and Sims (2003) found a significant reduction in skin blood perfusion in healthy supine patients, with use of ankle to knee compression. It was concluded that increased venous resistance at the ankle was

responsible for the reduced superficial perfusion. A reduction in lumen size is also hypothesised to help support and increase the function of the one way valves in the leg by allowing them to close properly (Lewis et al., 1976). This deeper blood flow, increased velocity, reduced lumen diameter and supported valves is said to reduce venous stasis, coagulation (Sajid et al., 2006), reflux and stagnant blood behind vein valves (Lewis et al., 1976). This has been shown to reduce chances of thrombogenesis (Lewis et al., 1976; Scurr et al., 2001). A reduction in vein diameter has also been shown to reduce the risk of intimal tears (Sajid et al., 2006) which could help prevent further damage. O'Donnell et al. (1979) found no difference in venous return time with CGs, however there was a reduction in systolic venous pressure. O'Donnell et al. (1979) concluded that this pressure reduction could be beneficial to post phlebitis patients. The above factors, relating to the displacement of blood to deeper veins, have been shown to be beneficial in patients with venous insufficiencies and could reduce the risk of further venous damage during exercise; but limited evidence has been shown for increased venous return in resting supine healthy individuals. However, it is difficult to draw conclusions from studies on resting patients or patients with venous insufficiencies that are applicable to a healthy population (Byrne et al., 2001) during physical activity or exercise (MacRae et al., 2011).

Blood Flow during Exercise

Agu et al. (2004) used near infrared spectroscopy to monitor venous function and calf muscle oxygenation; they found that with CGs total haemoglobin and limb oxygenation was reduced during tip toe exercise and walking. This reduction in blood pooling was greater than when any of these interventions was used on its own. Similarly Ibegbuna, Delis and Nicolaides, (2003), found that graduated CGs significantly improved haemodynamics during walking by reducing residual volume fraction (RVF); this was suggested to indicate an increase in muscle pump function with CGs (Eberhardt and Raffetto, 2005). In contrast, Mayberry et al. (1991) found that neither below knee or above knee CGs significantly improved venous pressure, venous refill or maximum venous pressure. It was concluded

that CGs did not improve deep venous haemodynamics during exercise. However this measurement was performed on a non compressed leg immediately following exercise, therefore the effect the compression had during exercise on the compressed leg is unclear. Bringard et al. (2006a) showed an increase in blood flow induced by CGs caused an increase in oxygen supply to the muscles; It was suggested that this blood flow change could increase metabolite clearance, for example lactate, which would ultimately lead to an increase in performance and reduced energy cost.. However, this was purely hypothetical, as these results were observed at rest. In a meta-analysis positive effect sizes were found for: lactate removal, metabolic clearance and nutrient supply (Born et al., 2013). It was suggested that this may support an improvement in haemodynamics, especially during high intensity training. If these increases are present during high intensity training, it is likely that this mechanism would affect maximal running performance, by increasing the intensity of exercise that could be maintained without hydrogen ion accumulation. However the same meta-analysis found that CGs had no effect on cardiac output, stroke volume, heart rate or performance; which could bring the previous findings in to doubt. Likewise, Dascombe et al. (2011) observed an increase in regional blood flow and a reduction in heart rate; however they did not find an increase in performance or tissue oxygenation with lower body compression. Dascombe concluded that these improvements were trivial for athletes, as they did not correspond to any improvement in endurance running performance.

Despite large volumes of literature, advertising and media coverage surrounding the effects of compression on blood flow, no study has shown CGs to increased blood flow or venous return in healthy participants at exercise intensities matching training or competition (MacRae et al., 2011). The reason for this gap in the current research is largely due to methodological difficulties; the current methods, as described above, to measure blood flow cannot be conducted on moving participants. Additionally, the most common method used to measure blood flow is the measurement of the diameter of major blood vessels and the velocity of the blood passing through them. However, the validity of equating this to total

venous return has been questioned (MacRae et al., 2011). MacRae et al., (2011) suggested that these variables do not necessarily indicate changes in flow volume per unit time. Furthermore, there is also little evidence that blood pooling or blood flow benefits are reliant on pressure gradient; and unless markers of performance or recovery increase concurrently then blood flow increases are irrelevant.

Due to the methodological difficulties described above, it is outside the remit of this research to attempt to measure blood flow during exercise. However, the proposed benefits of increased blood flow to other systems during exercise can be measured, for example: reduced heart rate, reduced lactate and increased performance. If differences in these markers are found with knee high CGs, this would support increased BF as a possible benefit to recreationally trained athletes during endurance running.

2.3.2.3 Heart rate

The measurement of heart rate has been suggested to give an accurate measure of venous return (Baron, Decaux-Jacolot, Edouard, Berdeaux & Samii,1986). It is suggested that the baroreceptors reflex control of heart rate is affected by venous return. This is based on the Frank–Starling law of the heart (Starling's Law), which states that stroke volume increases in response to an increase in the volume of blood filling the heart (end diastolic volume); this increase stroke volume could allow heart rate to decrease while cardiac output is maintained. It is suggested that reduced blood pooling and increased venous return as a result of CG use, may increase the end diastolic volume of the heart and therefore increase stroke volume. As a result previous studies have used HR as an indirect measure of blood flow (Creasy, 2008). However, stroke volume has been shown to be a limiting factor in endurance exercise performance (Bassett & Howley, 2000), therefore it is possible that during hard endurance exercise HR would remain unchanged while cardiac output is increased. Additionally, the use of HR changes during exercise to measure blood flow, fails

to take into account other factors that could affect HR during exercise for example cardiac drift, body temperature or changes in running economy.

While the use of HR as a measure of blood flow during exercise is tenuous; heart rate is a valid measure of intensity of effort (Laukkanen & Virtanen, 1998) and energy expenditure (Strath et al., 2000); therefore, if a lower heart rate can be maintained at a set exercise intensity, or if exercise intensity or performance can be increased without a change in HR, this would support mechanism for increased efficiency and running economy; for example increased blood flow or reduced muscle oscillations. Therefore the current study measured HR during performance as a measure of exercise intensity and when combined with performance results, a measure of running economy.

Varela–Sanz et al. (2011) and Dascombe et al. (2011) showed decreased heart rate during maximal runs, when using knee high and full length CGs respectively. Ali et al. (2007) also found trained athletes had lower heart rates during 10 km time trials when wearing knee high compression. However, these results are conflicted by other studies that found no effect of CGs on HR (Ali et al., 2011; Creasy, 2008; Duffield et al., 2010; Goh, Laursen, Dascombe & Nosaka, 2010). Born et al. (2013) concluded that in healthy subjects it is questionable whether the low area of muscle compressed by knee high CGs has an effects on central circulation. Likewise, MacRae et al. (2011) concluded that submaximal and maximal HR appeared unaffected by compression. These conflicting results bring into question the suggested mechanisms by which CGs may increase physiological efficiency and economy, and suggest that reductions in HR found in previous research may be due to the placebo effect (Born et al., 2013; MacRae et al., 2011).

2.3.2.4 Blood Lactate

Lactate accumulation is the result of hypoxia in the muscle; hypoxia and the associated acidosis (pH decrease) have been found to be limiting factors in maximal exercise (Fitts, 2008). Lactate build up itself is not a limiting factor, as lactate does not cause acidosis but

acts as a hydrogen ion buffer (Lindinger, Kowalchuk & Heigenhauser, 2004; Robergs, Ghiasvand & Parker, 2004). It has also been suggested that lactate does not cause muscle soreness, as was previously hypothesised (Robergs et al., 2004). However lactate can be used as an accurate measure of hypoxia and therefore work intensity. Therefore, reduced lactate accumulation may indicate the capacity for the athlete to work at a higher work rate; this could then lead to a performance increase; furthermore, if lactate accumulation is unchanged but exercise intensity increased, this could lead to an increase in endurance exercise performance (Bassett & Howley, 2000). Lactate and H^+ ions are co-transported out of muscle cells, via the mono-carboxylate transporters (MCT) 1 & 4, to increase the pH of the cells and attenuate acidosis. Lactate can then be converted back into Pyruvate, by muscle cells, when oxygen is available, used by the heart or brain for energy, or can be converted to glucose, through the Cori cycle, in the liver or kidneys. It is proposed that decreased blood pooling and increased blood flow, with the use of CGs, could facilitate greater oxygen delivery to the muscles and greater lactate clearance from the peripheries to the core where it can be converted (Berry et al., 1987; Chatard & Atlaoui, 2004); this reduced production and increased clearance of hydrogen ions at a set intensity and could allow a higher work output and improved performance (Bringard et al., 2006a).

Many studies into the effects of CGs have examined blood lactate levels. Compression was shown to reduced blood lactate concentration during maximal exercise on a bicycle ergometer (Berry & McMurray, 1987). Kemmler et al. (2009) and Chatard and Atlaoui (2004) both found CGs lowered blood lactate levels significantly during maximal running and cycling respectively. Recently, further studies have supported these results (Kraemer et al., 2010: Diller et al., 2013). A contradictory study by Rimaud, Messonnier, Castells, Devillard and Calmels (2010), found increased blood lactate during maximal exercise in eight healthy males using compression socks, with maximum compression of 22 mmHg on the calf and minimum of 12 mmHg at the ankle. However, this compression is opposite to that recommended in other studies (Gandhi & Palmer, 1984; Lawrence & Kakkar, 1980;

O'Donnell et al., 1979) and could created a negative pressure across the one way valves in the veins of the leg, which could cause increased peripheral resistance or venous occlusion. Despite this, MacRae et al. (2011) concluded that there was little conclusive evidence for decreased lactate with CG use.

Given the potential of blood lactate concentration for measuring hypoxia and exercise intensity; lactate accumulation will be measured in the current study during exercise, as a means of testing the potential for performance enhancing mechanisms such as: reduced muscle oscillations, improved oxygen supply or improved haemodynamics.

2.3.3 Efficacy of CGs for performance

Many claims have been made, within the sports community and scientific literature, about the benefits of wearing CGs to increases performance; however, there is limited data available to support these claims (MacRae et al., 2011). Studies have used a varying range of different sports and exercises to examine the effect of compression on performance (Table 1). In moderately trained men, Kemmler et al. (2009) found increases in maximal voluntary running performance and time to fatigue with CGs, compared to wearing normal running socks. Similarly, Varela-Sanz et al. (2011) found an increase in time to fatigue, when running at 105% of 10 km pace, with use of compression socks. However, it could be argued that time to fatigue is not be a valid measure of performance, as there are no races or events of this nature. Therefore, a sport protocol, race or time trial performance would give more ecologically valid results for the athlete's that will be using these garments.

Table 1: A summary of current compression garment research including: garments used, exercise type and findings

Author	Date	Compression	N = ()	Trial	Performance	Musc. Dam.	Inflammation	Musc. Oscill.	DOMS	Lactate	Heart Rate	RPE	Oxygenation	Blood flow	Power Output	Power Maint.	Time-fatigue	Energy Expend
Ali et al.	2007	Knee High	24	10 km road run	↑						↑							
Ali et al.	2010	Stockings	10	40 min treadmill run		∞				∞	∞		∞					
Ali et al.	2011	Knee High	12	10 km run outdoor track	∞												↑	
Berry et al.	1990	Tights	8	110% $\dot{V}O_{2max}$ run						∞	∞		∞					∞
Bakken et al.	2011	Short&Stockings	11	Run to exhaustion	∞	∞		↑			∞							∞
Bernardt et al.	2005	Shorts	13	Jumps and Joint range test	∞										∞			
Boras et al.	2011	Shorts	9	Downhill running		↑	↑		↑									
Born et al	2013	Meta-Analysis of 31 studies			↑	↓	↑		↑	↓	↓		∞		↑	↑	↑	
Bringard et al.	2006a	Knee High	12	Standing and supine									↑	↑				
Bringard et al.	2006b	Full Length	6	Track running									↑	↑				↑
Carling et al.	1995	Arm Sleeves	23	Eccentric arm curls			∞		∞						∞			
Chatard et al.	2004	Knee High	12	5 min maximal cycling						↑	↑						↑	
Connolly et al.	2003	CG DOMS treatment literature review							↑									
Creasy et al.	2008a	Stockings	12	10 km run outdoor track	∞					∞	∞						↑	
Creasy et al.	2008b	Stockings	10	40 min treadmill runs						∞	∞	∞						
Dascombe et al.	2011	Full Length	11	Maximal tests	∞						↑				↑			
Davies et al.	2009	Full Length	11	Drop jumps	∞	↑			↑				∞					
Doan et al.	2003	Shorts	20	Sprints and jumps	∞			↑							↑			
Driller et al.	2013	Full Length	10	2 x 30 min cycling time trial			↑				↑						↑	
Duffield et al.	2008	Full Length	14	Sprints (simulated rugby)	↑	∞									∞			
Duffield et al.	2010	Full Length	11	Sprints and Plyometrics	∞								∞					
French et al.	2008	Full Length	26	Sprints and jumps		∞			∞	∞								
Gill et al.	2005	Full Length	23	Rugby Match					↑									

Table 2: A summary of current compression garment research including: garments used, exercise type and findings cont.

Author	Date	Compression	N = ()	Trial	Performance	Musc. Dam.	Inflammation	Musc. Oscill.	DOMS	Lactate	Heart Rate	RPE	Oxygenation	Blood flow	Power Output	Power Maint.	Time-fatigue	Energy expend
Goh et al.	2010	Shorts	10	20 min treadmill run & to max								↑					↑	
Hill et al.	2013	Meta-analysis of 12 studies				↑			↑								↑	
Higgins et al.	2009	Full Length	10	20m sprints & Jumps	↓													
Jakeman et al.	2010	Full Length	17	10 x 10 plyometric drop jumps		∞			↑								↑	
Kemmler et al.	2009	Knee High	21	Stepwise treadmill test	↑												↑	
Kraemer et al.	1998	Shorts	40	Jumps & 30 min runs				↑								∞	↑	
Kraemer et al.	2001	Arm Sleeves	20	Eccentric arm curls		∞	↑		↑	↑							↑	
Kraemer et al.	2010	Whole body	20	Whole body resistance			↑	↑	↑									
MacRae et al.	2011			Lit review			∞		↑			∞	↑		↑		↑	
Montgonmery et al.	2008a	Full Length	18	2 day basketball tournament			↑		↑									
Montgonmery et al.	2008a	Full Length	18	3 day basketball tournament													↑	
Perry et al.	2008	1 leg Stocking	8	Eccentric walking			↑		↑									
Pruscino et al.	2013		8	Match simulation		∞	∞		∞							∞		
Rimuauld et al.	2010	Stockings	8	Maximal bike tests	∞						∞	∞	∞					
Scanlan et al.	2008	Full Length	12	Max tests and 1h time trials	∞						∞	∞			↑			
Schornstein et al.	2011	Full Length	11	5 kilometre pace to exhaustion							∞	∞	↑				∞	
Sear et al.	2010	Whole body	8	45min non-motorized treadmill	↑													
Sperlich et al	2010	Full body	15	70% V̇O₂ and max runs	∞						∞		↑				∞	
Trenell et al.	2006	1 leg full	11	30 mins downhill walking				↑										
Varela–Sanz et al.	2011	Knee High	16	105% of 10 km pace treadmill	∞						↑		∞				↑	

↑= *Positive effect* , ↓= *Negative effect, ∞= no statistical difference found, Musc. Dam.= muscle damage, Musc. Oscill.= muscle oscillation, DOMS= delayed onset muscle soreness, Lactate= blood lactate concentration, RPE= rating of perceived exertion, Oxygenation= tissue oxygenation, Power Maint.= power maintenance, Energy Expend.= energy expenditure.*

Power exercises such as sprinting and jumping have shown mixed results for performance benefits with CGs. Some studies have found an increase in maximal jump height or power output with full length CGs (Higgins et al., 2009) and compression shorts (Jakeman et al., 2010; Kraemer et al., 1998). It has been hypothesised that mechanisms for improvements in jump height may be; improved warm-up via increased skin temperature and an increase in flexor and extensor torque at the end of range, due to the elasticity of the CGs over the joint (Doan et al., 2003). Born et al. (2013) concluded that the previous evidence showed a positive effect of CGs on performance during single and repeated bouts of power exercises such as sprints and vertical jumping. However, the demands and mechanisms of power exercise are different to those of endurance exercise; therefore, generalisations of performance benefits across exercise types should not be made.

Unlike power exercise, the effect of CGs on performance during endurance exercise is less clear; several studies have looked into long distance running and endurance performance with contradictory results. Ali, Caine and Snow (2007) found that 10 km run time decreased with the use of knee high CGs. This was supported by Sear, Hoare, Scanlan, Abt and Dascombe (2010) who found an increase in distance covered during a maximal 45 min run, wearing whole body compression. However, these results are conflicted by Ali et al. (2011) and Creasy (2008) who found no difference in 10 km running performance with knee high CGs. Scanlan, Dascombe, Reaburn and Osborne (2008) also found no difference in distance covered during a one hour running time trial, when using full length tights. Ali et al. (2001), Creasy (2008) and Scanlan et al., (2008) used highly trained participant's; whereas, Ali et al., (2007) used recreational runners and Sear et al. (2010) trained team sports players who were unaccustomed to the 45 minute continuous running protocol that was tested; therefore, these contradictory results may be due to differences in training status and/or familiarisation with the exercise protocol. Furthermore, a recent meta-analysis concluded that CGs did not affect submaximal or maximal running performance (Born et al., 2013) and inconsistencies in findings prompt further investigation with a moderately trained population.

Limitations of CG performance research

Previous research examining the effect of CGs on exercise performance has demonstrated many conflicting results, making conclusions difficult; indeed, meta-analyses and reviews of literature examining the same variables often reach different conclusions (Born et al., 2013; MacRae et al., 2011). It is possible that these contradictory results are caused by a number of limitations in the methodology and reporting of these studies. Firstly, the type of compression used varies between studies, including: area of the body being covered, amount of pressure applied, and use of a pressure gradient (Born et al., 2013). Results from these studies are often compared despite the differences in muscle mass and joints that are affected. For example, no studies have been identified that supported the use of knee high CGs for reducing muscle oscillation, muscle damage, inflammation, or increasing proprioception. Despite this, many of the proposed benefits have been generalised to the use knee high CGs. Moreover, the characteristics of the garments are often not reported sufficiently for an informed comparison to be made (MacRae et al., 2011). Training status of the populations used in research, may also yield differing results. The majority of the benefits demonstrated with CG use have been demonstrated in untrained individuals and it has been shown that untrained participants are likely to gain a greater benefit from wearing CGs than trained (Creasy, 2008; Kraemer et al., 1998); as trained individuals may have training adaptations that negate the proposed benefits of the CGs (French et al., 2008). Therefore, comparison across training statuses is not advised and the benefits of CGs to these populations should be considered separately. Additionally, research examining performance has used a wide range of modalities and exercise types; that rely of different physiological systems and mechanisms to improve performance (Born et al., 2013). To avoid confusion performance benefits should be assessed separately based on the physiological demands of the exercise being undertaken (MacRae et al., 2011). Furthermore, many of the protocols used are not ecologically valid and care should be taken when generalising these results to real life exercise events.

However, the greatest confounding variable in compression garment research is suggested to be the placebo effect (Born et al., 2013; MacRae et al., 2011). A placebo is a beneficial effect of an intervention or treatment that cannot be attributed to the intervention itself. A placebo effect may improve the positive effect of a treatment when compared to a control simply because the participant believes the intervention will be more effective (Moerman et al., 2002). This psychobiological phenomenon is not fully understood and it is suggested that multiple mechanisms are involved that may differ depending on the conditions and parameters being investigated (Benedetti, Mayberg, Wager, Stohler & Zubieta, 2005). It is suggested that the expectation or conditioning into believing a treatment is effective is enough to stimulate several physiological mechanisms resulting from preceding central nervous system (CNS) alterations, as well as psychological changes (Beedie, 2007; Benedetti et al., 2005). Such systems of the human body affected include the cardiovascular system, respiratory system, pain reception, and motor performance (Pollo et al., 2003). Recently, Ross, Gray & Gill (2014) demonstrated that in a well-trained population of male runners, a placebo injection significantly improved 3km race time by 1.2% with no improvement in the control group. Participants for this study also reported reductions in physical effort with increased motivation and improved recovery. Cycling performance over 10km has also been shown to be positively affected by placebo displaying a limited dose-response relationship between levels of expectancy. In this study by Beedie, Stuart, Coleman & Foad (2006), power increased by 1.3% and 3.1% when participants believed to be administered with 4.5mg/kg or 9mg/kg of caffeine, respectively. In compression research correlations have been shown between a participant's belief in the treatment and subsequent performance (Duffield et al., 2008: Kraemer et al., 1998). Therefore, in laboratory trials it is important to blind participants to the treatment conditions with consideration of the potential placebo response. In practical terms, finding a placebo comparison to some treatments is challenging and it is likely that many individuals are able to determine if they are in a treatment or placebo group (Gibson et al., 2013). Likewise, ensuring a placebo treatment mimics an intervention whilst not exerting its own effects can

be difficult (Enck, Benedetti & Schedlowski, 2008). As such, the implementation of sufficient blinding of trials or placebo trials in compression research has proven difficult. It has been suggested that while double blind, placebo controlled studies are desirable; they are impractical as it is impossible to blind the participants to the compression treatment (Kraemer et al., 2001). In compression research, some studies have attempted to implement a placebo trial with the use of a non compressive garment; however, participants in those studies were consistently able to identify which garments were the most and least compressive (Ali et al., 2011; Creasy, 2008); therefore, it was not a true blind placebo trial. Furthermore non-compressive garments may not be fully inert, as both compressive and non compressive garments present a barrier to heat transfer (Born et al.,2013), which has been suggested to enhance an athlete's warm up and could affect performance (Doan et al., 2003). Likewise, compression as low as 7.8 mmHg has been shown to elicit a physiological response, so even if a placebo garment is not fully non-compressive, other confounding effects may be experienced. These barriers to effective blinding have led researchers to hypothesise that reductions in perceived exertion during exercise may be due to the participants expectations of benefits and therefore psychological effects have resulted in the reported improvements in performance (Born et al., 2013).

The current research was unable to blind participants to the interventions they were receiving. As the perceived comfort of the garment/intervention has been shown to influence the level of placebo effect experienced (Born et al 2013); this research recorded perceived comfort, perceived tightness and pain induced by the garment during each intervention (Ali et al., 2007; Ali et al., 2010; Creasy, 2008), to allow comparison of performance and perception of the intervention.

2.4 Post Exercise Recovery

There are many factors by which recovery can be measured, for example: normalisation of physiological function, muscle damage, muscle soreness, glycogen resynthesis or maximum force production (Jeffreys, 2005). More widely, it could be considered: the ability to meet or exceed the demands of a particular activity (Driller et al., 2013). For many athlete's the demands of subsequent training and performance sessions must be met, often with little time to recovery; as such, it is common for athletes to use ergogenic aids to try and reduce the time needed for recovery.

2.4.1 Exercised Induced Muscle Damage & Inflammation

Following bouts of high intensity or unaccustomed exercise microscopic muscle damage (MD) or exercise induced muscle damage (EIMD) is common. The most widely accepted theory for the initial cause of EIMD is that mechanical force during contraction and loading causes: microscopic tears of the muscle fibres and sarcolemma (Creasy, 2008), alongside Z line streaming within the sarcomere (Armstrong, 1984) and damage of the transverse tubules (Proske et al., 2001). This leads to an imbalance in calcium homeostasis within the muscle cell and to small scale cell necrosis (Cheung, Hume & Maxwell, 2003). This initial damage triggers an acute inflammatory response which further damages the muscle (Stupka et al., 2000). As a result of the inflammatory response, there may also be free radical damage to the muscle, caused by immune cells such as neutrophils (Connolly, Sayers & McHugh, 2003). This increased free radical damage has been connected to a loss of muscle function after exercise-induced muscle damage due to elevated lipid peroxidation (Close, Ashton, Cable, Doran, Maclaren, 2004). Electrical stimulation of fatigued muscle has shown that the post-exercise reductions in maximum force are due to muscle damage, not decreased motivation or muscle recruitment (Clarkson & Hubal, 2002; Davies & White, 1981; Newham, Jones & Clarkson, 1987).

Inflammation and adaption

It is widely believed that to maximize any given exercise performance, the symptoms of EIMD should subside before an athlete competes or exercises at a high intensity again (French et al., 2008). As a result, many recovery strategies attempt to reduce the muscle damage, inflammation and secondary muscle damage experienced post exercise, to help reduce recovery time. This reduction of inflammation post exercise could be beneficial as large increases in reactive oxygen (ROS) and nitrogen (RNS) species may lead to an increased level of cell apoptosis causing immunosuppression, fatigue and underperformance. (Lewis, Howatson, Morton, Hill & Pedlar, 2015). However, muscular fatigue (Helson et al., 2014), inflammatory and low to moderate amounts ROS and RNS play a key role in muscle adaptation to endurance training (Lewis et al., 2015). Therefore, if an intervention reduces inflammation below this level it may also reduce the adaption to exercise that the athlete undergoes. This has raised questions within exercise recovery research about the efficacy of inflammation reduction as a recovery aid in athletes; especially as research examining this area is limited and the results are still inconclusive.

In a study on the effect of ice application following high intensity running, muscle cooling was shown to reduce inflammatory blood markers; however, the intervention also caused a reduction in anabolic hormone levels such as growth hormone and insulin like growth factor (Nemet et al., 2009). Therefore, it was suggesting that the reduction in inflammation could cause or be concurrent with a negative effect on adaptation and future athletic performance (Nemet et al., 2009). Despite this conclusion, long term adaptation was not monitored in this study and therefore the results remain speculative. In contrast, Ice application three times per week during a 3 week training programme was shown to have no negative effect on adaptations when compared to a control (Halson et al., 2014). However the ice protocol used in this study was relatively mild; each intervention was 15 minutes submerged in 15°C water. Whereas, the majority of current studies use interventions of 20 minutes bouts of icing and aim to induce a target skin temperature between 10-15°C. While skin temperature was

not measured in this study, the intervention cannot have induced a skin temperature lower than 15°C. Moreover, Yamane et al. (2002) conducted a study using a 6 week endurance training programme focused on the legs. In this study cold water therapy at 5°C was applied to one leg after each training session, three times per week. The cold water was applied for two 20 minute bouts separated by 30 minutes. The results showed that significant adaptations to the training were three times more frequent in the control leg when compared to the cooled limb. It is possible that the colder temperatures and longer exposure times in this study induced a greater reduction in inflammation than the previous study. These results prompt further research to examine the effect of reduced muscle damage and inflammation on adaptation to exercise, as benefits to short term recovery may not be sufficient to justify the use of an ergogenic aid if long term adaptation is affected. Additionally, the intensity and duration of interventions may need to be adjusted to balance the effect on short term recovery and long term adaptation.

Creatine Kinase

Creatine kinase (CK) is an enzyme found in tissues including; skeletal muscle, cardiac muscle and brain tissue. Creatine kinase catalyses the phosphorylation of adenosine diphosphate to adenosine triphosphate for energy (Apple and Rhodes, 1988). It is released into the blood during muscle damage (Clarkson & Hubal, 2002; Nosaka & Clarkson, 1996). Consequently, CK concentration is used extensively in research as a marker of post exercise muscle damage (Born et al., 2013). Various modes of exercise have been linked with an increase in CK levels. Clarkson and Tremblay (1988) found maximal eccentric forearm exercise produced temporary, repairable muscle damage and raised CK levels. CK levels ordinarily peak between 24-48 hours post exercise (Peterson et al., 2001); this is thought to be due to the delay in the immune and inflammatory response (Nosaka et al., 2008). Despite its regular use in exercise studies, CK has been shown to have high inter and intra subject variability (Connolly et al., 2003); with levels affected by age, race, mass, physical activity and pathological conditions (Brancaccio, Maffulli & Limongelli, 2007).

Additionally, there are individuals who are prone to high or low CK responses; these high and low responders will always have a relatively extreme high or low CK response to the same intensity of exercise, irrespective of the confounding variables listed above (Clarkson, Kearns, Rouzier, Rubin & Thompson, 2006). It should also be noted that serum CK levels are a reflection of both diffusion and clearance, therefore if clearance is increased CK level will decrease giving a false low indication of the level of muscle damage present (Jones, 1985). Likewise, serum CK is also a global measure of all muscle damage in all muscle groups; it is impossible to distinguish from CK results where the muscle damage is or which muscle groups are contributing most heavily (Connolly et al., 2003).

A further consideration when using CK as a blood marker of muscle damage is participant gender. Studies on animals have shown that females experience more muscle damage than males (Amelink & Bar, 1986; Bar, Dressen & Rikken, 1985; Schneider, Correia & Cannon, 1999; Tiidus & Bombardier, 1999). Moreover, Miles, Naukam, Hackney & Clarkson (1999) examined the CK response of non–weight-trained women and men, and found that women showed a greater increase than men after eccentric muscle damage. Serum CK levels have also been shown to be elevated during the second half of the menstrual cycle (Bundey, Crawley, Edwards & Westhead, 1979). Consequently, studies measuring CK levels over a number of weeks may have false elevated results in female subjects.

These weaknesses in serum CK as a marker of muscle damage mean that care must be taken when collecting and interpreting data (Hill et al., 2013). However, despite these limitations, CK concentration is considered to be a valid measure of the severity of post exercise muscle damage in healthy individuals (Brancaccio et al., 2007; Clarkson et al., 2006); and is still used extensively as a marker of EIMD in compression literature (MacRae et al., 2011). Muscle biopsies and MRI are suggested to be the gold standard methods of measuring muscle damage (Connolly et al., 2003; Jones et al.,1985)., however these methods are not possible in the current research therefore creatine kinase will be used, in conjunction with inflammatory markers and muscle pain.

C-Reactive Protein

As suggested above, muscle damage during exercise may cause an acute inflammatory response to occur; as leukocytes and monocytes infiltrate from the bloodstream into muscle tissue degradation may be caused by the release of proteolytic enzymes (Friden & Lieber, 2001). Acute phase proteins, such as C-reactive protein (CRP) are synthesised and released, as part of the acute inflammatory response. Release is from the liver and adipose tissue, when triggered by cytokines; for example interleukin 6 (IL-6). CRP then binds to phosophocholines expressed on the surface of dead or damaged cells and triggers the complement system via C1Q. The complement system leads to destruction of damaged cells via the membrane attack complex, then through chemotaxis, leads to an increased number of in phagocytic cells and subsequently an increase in reactive oxygen species (ROS), which are believed to cause increased muscle cell damage (Connolly et al., 2003). Consequently, the level of serum C-reactive protein is an accurate measure of inflammation, with levels normally peaking around 24 hours after exercise (Strachan, Noakes, Kotzenberg, Nel & de Beer, 1984). Connolly et al. (2003) suggested that CRP may be a more accurate measure of muscle damage that CK. However, as with CK, CRP has some limitations; Serum CRP levels are the sum of total production and clearance and therefore results can be changes in clearance mask increases in diffusion (Jones, 1985). It has also been suggested that as serum CRP is a measure of total diffusion from all muscle groups, that increases in this systemic results post exercise are not proportional to localised increases in the active muscles, as measured with muscle biopsies (Marklund et al., 2013); consequently, a doubling in serum CRP could represent a far greater increase in inflammation in the active muscles.

Muscle Girth

Another method of measuring inflammation is by the measurement of muscle girth before and after exercise. Nosaka and Clarkson (1996), found an increase in upper arm girth with

eccentric muscle damage, and along with CRP suggested girth measurement as an accurate measure of inflammation. Likewise, high reliability of repeated muscle girth measurements have been shown for both intra (Hart, Swanik, & Tierney, 2005) and inter tester results (Soderberg, Ballantyne & Kestel, 1996). However, a measurement can be reliable without being valid (Soderberg et al., 1996) and the majority of the studies that have explored muscle girth use have tested reliability. Doxey (1987), conducted validity testing on muscle girths as a measure of localised inflammation and concluded that while muscle girths are a somewhat inaccurate and insensitive measure, they remain clinically useful. Muscle girths have been used extensively within exercise recovery research (Driller et al., 2013; French et al., 2008; Kraemer et al, 1997; Montgomery et al., 2008); as such muscle girths will be used as an inexpensive and accessible method of monitoring localised inflammation to compliment the CK, CRP and muscle pain results.

2.4.2 Muscle Soreness

Perceived muscle soreness (PMS) is a dull aching pain that makes muscles feel tender and stiff (Creasy, 2008). If there is a delay in the start of muscle pain post exercise, and the pain is accompanied by loss of muscle function, then this is referred to as delayed onset muscle soreness (DOMS) (Clarkson & Tremblay, 1988; Newham et al., 1987). Delayed onset muscle soreness (DOMS) and perceived muscle soreness (PMS) are experienced after bouts of unfamiliar or intense exercise and can be associated with reduced repeat performance. Muscle soreness is commonly experienced most strongly 24 to 72 hours after the exercise (Nosaka, 2008). A correlation has been found between muscle damage and DOMS (Armstrong et al., 1984; Byrnes et al., 1985; Stupka et al., 2000); it is likely that the delay in muscle soreness corresponds to the delay in maximum muscle damage (Nosaka, 2008). Armstrong et al. (1984) suggested that it could take up to 48 hours for the imbalance in calcium ions, caused by structural muscle cell damage, to cause peak cell necrosis. This causes accumulation of intercellular materials and ROS from immune cells in the interstitial space; which stimulates free nerve endings leading to muscle soreness (Armstrong et al.,

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1984). During this time, muscle function is inhibited to ensure further muscle damage is not caused and to allow the muscles time to repair and restore pre-exercise muscle function (Armstrong, Warren & Warren, 1991); this results in a reduction in joint range of motion, maximum voluntary peak torque and the ability of the muscle to absorb shock (Cheung et al., 2003).

Visual analogue scale and Algometry

The two most commonly used methods of measuring muscle pain post exercise are: rating of perceived pain using a visual analogue scale at rest or rating muscle pain while direct pressure is applied to the muscle using a pain algometer (Creasy, 2008). The use of visual analogue scales is the simplest and easiest method of measuring muscle pain in the laboratory and in the field with no specialist equipment needed. However, the use of visual analogue scales has been shown to have a potential for high inter and intra subject variance, (Burnett et al., 2010). These perceived measures have also been shown to be affected by the placebo effect, in trials that have shown equal decreases n muscle pain in placebo and aspirin treated groups (Cook, O'Conner, Eubanks, Smith & Lee, 1997). Despite this, Perceived scales have been shown to have an inter subject reliability of between r = 0.88 to 0.98 (Cook et al., 1997). In an attempt to use a less subjective method of measuring muscle pain, algometry has been used extensively in previous research. Pain algometry is a semi-objective method that uses a force gauge with a 1 cm^2 rubber disk, used to apply pressure (80 N) directly to affect muscle tissue; participants are then asked to rate the pain induced by the pressure. Algometry has been shown to be a valid (Fischer, 1987) and reliable method for quantifying local muscle pain and tenderness (Fischer, 1987; Pontinen, 1998); however, the reliability and validity of results are dependent on the use of standardised methodology and equipment between measurements (Pontinen, 1998). For example, it has been shown that the rate at which the force is applied to the muscle must be consistent to obtain reliable results (Kinser, Sands & Stone, 2009). Additionally, as with all perceived measures, algometry is subject to interference from the placebo effect (Cook et al., 1997). Despite the

weaknesses of these methods they are still useful to measure perceived pain, and both method will be used in the current research to allow comparison of results. Standardised protocols will be used to increase reliability in accordance with previous literature that have used these methods (Creasy, 2008; Kraemer et al., 1997; Prasartwuth, Taylor, & Gandevia, 2005).

2.5 Post-exercise Recovery Strategies

A number of modalities have been investigated in the search for a treatment that may reduce the effects of EIMD or accelerate recovery (Hill et al., 2013). Compression garments and ice have been used individually and in combination for soft tissue injuries for some time (Kowal et al., 1983), as part of the well-known acronym, RICE; representing: rest, ice, compress and elevate (Kraemer et al., 2001). Compression and ice are now two of the most commonly used recovery and regeneration methods among athletes and recreational sports people looking to accelerate recovery post exercise (Mac Auley et al., 2001). As a result of this popularity, products are being commercially produced that allow the combined treatment of ice and compression for athletes in the field (110% Play Harder, Florida, USA). However, despite the common used of these methods for recovery, evidence for their proposed benefits is equivocal (Born et al., 2013; Mac Auley, 2001), and the physiological mechanisms by which they provide any benefits is also unclear (Bleakly et al., 2010, MacRae et al., 2011).

2.5.1 CG's Mechanisms of Action during Recovery

2.5.1.1 Reduction of initial damage during exercise

During endurance running it is suggested that the eccentric component of the SSC may cause structural damage to the muscle cells and consequently an inflammatory response as described above (Noakes, 2000). Paavolainen (1999) showed that both the braking and propulsion phases of the SSC were longer after completion of a 10 km run. Moreover, significant decreases were observed in peak vertical ground reaction forces and muscle

activation during 20 m sprints, post 10 km run (Paavolainen, 1999). These results suggest that repetitive stretch loading during the 10 km run, decreased the capacity of the neuromuscular system to generate force rapidly and to tolerate impact forces (Paavolainen, 1999). This is interruption in contractile function was most likely caused by muscle damage and cellular disturbance as a result of the SSC (Duffield et al., 2008). It is suggested that the use of CGs may be able to attenuate the muscle damage caused during exercise by improving muscle mechanics on a molecular level (McComas, 1996) therefore improving muscle function (Duffield et al., 2008). It is possible that this improvement in muscle function and mechanics is due to reduced muscle oscillations during exercise (Kraemer et al., 1998). Kraemer et al. (1998) showed that CGs reduced the oscillations experienced in the thigh muscles during exercise; this reduction in oscillations was accompanied by increased maintenance of leg power in both trained and untrained individuals. This maintenance of muscle power was suggested to be the consequence of reduced muscle damage as a result of reduced muscle oscillations (Bringard et al., 2006a; Doan et al., 2003; Kraemer et al., 1998). It is hypothesised that reduced initial muscle damage as a result of reduced muscle oscillations, may also reduce the subsequent post-exercise inflammatory response and therefore the secondary damage that would have been caused by immune cells and ROS (Creasy, 2008). These reductions in the magnitude of muscle damage and inflammation experienced could increase recovery time needed between sessions. However, Creasy (2008) warned that this mechanism was only hypothesised and that there was insufficient evidence to support it despite the wide proliferation of it as a suggested mechanism. Since then, further research has supported this mechanism showing reduced muscle oscillations during endurance running (Bakken, 2011); however, no measures of muscle damage or recovery were taken in this study, therefore the link between muscle oscillations and muscle damage remained speculative. However in that same year, a study using 3D cameras and muscle biopsies, showed reduced muscle oscillations and muscle damage in a compressed leg when compared to an uncompressed control leg (Borras et al., 2011). Borras et al. (2011) suggested that this results supported reductions in inflammatory response and

structural sarcomere damage as a result of reduced muscle oscillations during exercise. The current body of research is still insufficient to support the link between reduced muscle oscillations, muscle damage and recovery; therefore more research is required in this area. Additionally, all of the research in this area to date has examined muscle oscillations in the thigh muscle; therefore despite the prevalence of knee high compression use, it is still unclear if this mechanism is applicable to these garments.

2.5.1.2 Reduced inflammation

The use of compression garments during recovery is suggested to reduce the inflammatory response and subsequent muscle damage (MacRae et al., 2011). The external pressure created by compression garments may reduce inflammation in two ways; firstly, by reduction of the intramuscular space available for swelling (French, 2008), and secondly by increasing the hydrostatic pressure outside capillaries; therefore increasing lymphatic drainage (Born et al., 2013). The Starling equation, describes the roles of the hydrostatic and oncotic forces in the movement of fluid across capillary membranes through filtration. The filtration pressure is the hydrostatic pressure in the capillary minus the hydrostatic pressure of the interstitial fluid. This filtration pressure is opposed by the osmotic gradient caused by high concentration of proteins in the plasma in the capillaries compared to the interstitial fluid, which cause a greater oncotic pressure outside the capillary. The interstitial tissue's hydrostatic pressure normally averages 1-2 mmHg and oncotic 25 mmHg (varying from tissue to tissue). This was thought to move fluid into the interstitial space at the arteriolar end of the capillary where filtration pressure exceeds oncotic and into the capillary at the venule end where oncotic exceeds filtration. However, more recent evidence suggests that filtration dominates the full length of the capillary (Levick, 2003). When external compression is applied, it is possible that the filtration pressure could be reduced and therefore net flow out of the capillaries could be reduced or net flow could be directed into the capillaries reducing oedema and inflammation (Born et al., 2013).

In a study on 118 healthy volunteers, using an optical leg volume meter, a mean daily volume increase of the leg of 2.3% in females and 1.6% in males was found. Compression (14 mmHg) reduced this daily increase by 31% and 18%, in males and females respectively. Higher compression (18 mmHg) reduced the daily increase by 37% and 32% in males and female respectively ($p < 0.05$). There was also a reduction in the perception of tiredness and perception of swelling in the legs, when compared to a control (6 mmHg) but there was no difference between the 14 and 18 mmHg conditions (Jonker, de Boer, Ader & Bezemer, 2001). Hirai et al. (2002), found that elastic compression as low as 8 mmHg can prevent oedema in healthy and varicose vein patients. Reductions in post exercise inflammation have been shown, with CG use during recovery (Jonker et al., 2001). This result was supported by further research that reported a reduction in post exercise inflammation with the use of CGs (Borras et al., 2001; Driller et al., 2013). Attenuation of the inflammatory response with CGs has been linked with reduction in post exercise muscle damage (Creasy, 2008), muscle soreness (Bochmann et al., 2005; Davies et al., 2009), recovery time and improved subsequent performance (Kraemer et al., 2001a).

2.5.1.3 Decreased Muscle Soreness

As discussed in the section above, the application of compression may attenuate changes in osmotic pressure post-exercise and reduce the space available for swelling (Ali et al., 2007); subsequently lessening the degree of inflammation, the circulation of inflammatory markers. This reduction in inflammatory markers and consequently the amount of ROS and RNS, is suggested to lower the magnitude of nerve fibre stimulate (Armstrong et al., 1984) and therefore the sensation of pain (Kraemer et al., 2004). Compression has been shown to decrease inflammation post exercise (Boras et al., 2011) and several studies have suggested that CGs can reduce PMS post exercise (Ali et al., 2007; Chatard & Atlaoui, 2004: Connolly et al., 2003; Kraemer et al., 1998). Wearing CGs was found to reduce pain 72-hours post-exercise and restored neuromuscular function at a faster rate than without the garments, after downhill walking (Perrey et al., 2008). More recently, Borras et al. (2011)

found CGs reduced PMS after a 40 minute run test at anaerobic threshold. This is supported by a meta-analysis, which also found that CGs reduced PMS (Hill et al., 2013). As muscle damage is suggested to be the major cause of muscle soreness post exercise (Connolly et al., 2003), muscle soreness can be used as an additional measure of muscle damage and inflammation. However, reductions in perceived muscle damage can increase repeat performance by positively affecting an athlete's perception of recovery and motivation to perform (Hill et al., 2013). Ali et al. (2007) showed that decreases in perceived pain with CGs allowed better performance in subsequent bouts of exercise. Likewise, it has been shown that increased perceived vitality, as a result of decreased muscle soreness, can have a positive effect of an athlete's performance. Therefore, it is likely that perceived muscle soreness as well as being a symptom of previous exercise, is also a determining factor in subsequent bouts (Hill et al., 2013).

2.5.1.4 Increased blood flow

As with performance, augmentations to blood flow are suggested as a mechanism by which CGs improve recovery. There is more evidence for blood flow increases with CGs in healthy people at rest than during exercise; however these results and their effect on recovery are still not conclusive. Bringard, Denis, Belluye and Perrey (2006a) found a significant reduction in blood pooling and an increase in gastrocnemius oxygenation during supine and standing recovery, in 12 trained sports men wearing compression tights, when compared to non-compressive lycra tights and loose shorts at rest. Furthermore, Benko, Kalik and Chetty (1999), found significant increases in peak velocity in femoral vein with thigh length compression. This velocity increase was suggested to be indicative of increased venous return. Benko et al. (1999) also found a significant decrease in popleteal vein diameter. It was suggested that these findings show a decreased risk of venous stasis, intimal tears and venous thrombogenesis in healthy participants. Compression as low as 7.6 mmHg at the ankle to 5.2 at the thigh, was found to attenuate the venous diameter increase experienced during an 8 hour standing protocol (Kraemer et al., 2001). In contrast some studies have

shown that in healthy standing subjects CGs did not reduce vein diameter (Lord & Hamilton, 2004; Mayberry et al., 1991) or increase venous return velocity (Mayberry et al., 1991). It has been suggested that increases in resting blood flow post exercise may aid recovery increasing the removal of metabolites, immune cells and reactive oxygen and nitrogen species; and by increasing the supply of nutrients needed for recovery, for example glucose and proteins (Hill et al., 2013). Additionally, the removal of immune cells, ROS and RNS could reduce the magnitude of muscle soreness experienced (Hill et al., 2013).

2.5.2 Efficacy of CG during Recovery

The results of research examining the effect of CGs on recovery are mixed; making conclusions about their usefulness more difficult. For example, some studies have found that CGs used post exercise can reduce Serum CK concentration (Connolly et al., 2003; Hill et al., 2013) found reductions in CK concentration with CGs post exercise. Likewise, Boras et al. (2011) found reduced muscle damage with CG use, in males after downhill walking. These results support CGs as a mechanism of reducing the muscle damage caused by exercise allowing great maintenance of muscle power and subsequent performance. French et al. (2008) measured post-exercise creatine kinase (CK), myoglobin, range of movement and lower body power as markers of recovery, in healthy males; no significant improvements to any marker of recovery were shown with full length compression tights compared to a control. However, this study used an average compression of 12 mmHg at the calf and 10 mmHg at the thigh, less than the aforementioned suggested minimum pressures (Lawrence & Kakkar, 1980). Therefore, it is possible that this pressure was insufficient to reduce the post exercise inflammatory response. Despite this result, there are several studies that have shown CGs attenuate the loss of performance experienced during repeated jumps (Kraemer et al., 2001; Chatard & Atlaoui, 2004). Ali et al. (2011) also found those wearing CGs maintained leg power after a 10 km time trial. Doan et al. (2003) found no increase in 60 m sprint time in track athletes using compression shorts However, they did find a difference in vertical jump height performance after sprinting in those wearing compression shorts (0.461

m vs. 0.485 m, p = 0.015). Likewise Jakeman, Byrne and Eston (2010), found reduced decrement of jump performance, attenuated loss of strength and reduced muscle soreness with CG use; they therefore concluded that this attenuation of performance decrement supports the mechanism of reduced muscle damage with CGs. Additionally, the ability to maintain power output after a bout of maximal exercise could be very useful for athletes that need to train or compete multiple times per day or week and could lead to reductions in recovery time (Hill et al., 2013). This is supported by others who have shown reductions in recovery time with the use of CGs (Perrey, Bringard, Racinais, Puchaux & Belluye, 2008; Trenell et al., 2006). Gill, Beaven and Cook (2005) undertook a study comparing CGs to passive recovery using no CGs, after rugby matches and found reduced recovery time and decreased muscle damage with CGs. More recently Driller et al. (2013), showed a significant improvement (p < 0.05) in recovery with full length compression; this was evidenced by increased maintenance of power (-0.20% vs. -2.15%) and significant reductions in limb girths (Thigh: 53.2 cm vs. 52.9 cm; Calf: 37.6 cm vs. 37.1 cm) and blood lactate concentration (4 mmol vs. 3 mmol) when compared to a control. There was also moderate, though not significant, effect on perceived soreness in the CG trial. Similarly, Chatard (1998) showed reduced muscle soreness after a 5km run with compression tights when compared to loose running shorts. In contrast to these studies, Pruscino, Halson and Hargreaves (2013) did not find an increase in physiological recovery markers after a hockey match simulation, but did find a decrease in perceived recovery with CGs, measured with a questionnaire; which could translate into an improved repeat performance through psychological benefits. Born et al. (2013) found a small positive effect of compression on recovery of strength and power tasks such as peak leg power, maximal throwing distance and vertical jump height. However, recovery of short sprints ability (10-60 m) was negatively affected by the use of compression clothing. Born et al., also found that compression had a negative effect on levels of creatine kinase. Born concluded that the results show a small improvement in recovery after muscle-damaging exercise protocols; and suggested this was due to enhanced lymphatic outflow, thus reducing post exercise muscle swelling and pain. Furthermore, increased arterial inflow,

venous return, and increased clearance of waste products could potentially enhance the repair process (Hill et al., 2013).

Limitations of CG recovery research

The contrasting results for variables of recovery found in CG research make conclusions hard to reach; indeed two meta-analyses conducted in the same come to different conclusions about the effect of CGs on certain variables, for example CK (Born et al., 2013; Hill et al., 2013). It is likely that the conflicting results are due to limitations and inconsistencies in the methodologies of the current research.

As with performance CG research, the type of CGs, training status of participants and exercise protocols used vary between studies; comparison of these results across conditions may add to the confusion. For example, the majority of studies examining recovery have used full length tights or full body compression (Hill et al., 2013); the research and benefits of which are then generalised and compared to other compression types. No research was identified that has shown reduction in Ck with knee high compression. As knee high CGs are the most commonly used for endurance events (Bakken, 2011), the current research aims to assess whether knee high CGs have the same benefits as other CG types, despite the lower muscle mass being covered. Likewise, the training status of participants greatly affects results. The majority of research into recovery has examined the effects on untrained participant, who may experience higher levels of muscle damage and fatigue (French et al., 2008). Therefore these results may differ greatly from results obtained from an elite or highly trained population (Born et al., 2013); this should be considered when comparing results from such studies. The types of exercise used to induce fatigue, and to assess the effect of CGs on recovery also vary widely. As such the results vary depending on the type, length and intensity of the exercise protocol used (Barnet, 2006). Power exercise has shown more consistent results for attenuation of performance loss, however these types of exercise may benefit for mechanisms such as increased torque around joints due to the elasticity of the

garments (Doan et al., 2008); which other types of exercise such as endurance running may not benefit from. Likewise, it is widely accepted that eccentric contractions cause the highest levels of muscle damage (Cheung et al., 2003; Clarkson & Hubai, 2002; Clarkson & Tremblay, 1988; Friden, Sjostrom & Ekblom, 1983; Nosaka & Clarkson, 1996). Although, most exercise has an element of eccentric contraction involved, there are no sports or races that involve solely eccentric action. Therefore, eccentric muscle damage protocols may be less ecologically valid. Furthermore, Clarkson, Byrnes, McCormick, Turcotte & White (1986) found that muscle damage was caused by all types of muscle action. For chapter 5 of the current research, an ecologically valid protocol was desired to assess performance and recovery benefits for endurance athletes. Maximal 10 km running has been shown to induce significant losses in muscle function (Creasy, 2008) that can take even experienced endurance runners up to 48 hours to recover from. (Gomez et al., 2002). While longer protocols such as half or full marathons would induce greater fatigue, the use of these protocols is not possible in the current study; therefore 10 km time trials will be use in accordance with previous research in this area (Ali et al 2007; Ali et al., 2011). For Chapter 6, fatigue of a specific muscle groups (lower leg) is required, therefore an eccentric muscle damage protocol will be used; as eccentric exercise has been shown to induce the greatest decrements to perceptual and physiological function (Clarkson & Hubai, 2002). As with the performance research, the greatest single limitation to CG research is the lack of blinding of interventions and consequently the placebo effect. None of the studies included in this review of recovery literature, have blinded the participants to the treatments they are receiving; as such the results of recovery measurement, especially perceptual measurements could be greatly affected by the participant's belief and expectation of the outcome (Hill et al., 2013). Unfortunately it was not possible for the current study to blind participants or to include a robust placebo control; Therefore as with the results from previous research, it is important that any positive results be interpreted with the placebo effect in mind.

The time that CGs were applied during recovery also varies from study to study, and is often unreported (Hill et al., 2013). Born et al. (2013) suggests that the recovery benefits of compression clothing were most pronounced when applied for 12-48 hours. However this recommendation was made based on the timings used in studies that found positive results; not based on a comparison of the effects of different timings. No research has been identified that explores the effect of different timings of CG application on recovery. Additionally, the difference between 12 and 48 hours of intervention is very large and either an increase in intervention application time should induce an increase in benefit or this extra intervention is unnecessary. The most commonly used timing for CG application is 12 hours post exercise (French et al., 2008) and this level of intervention has been shown to induce significant recovery benefits (Gill et al., 2005; Jakeman et al 2010); therefore, the current research study used a 12 hour recovery intervention.

2.5.3 Ice Therapy Mechanisms of Action during Recovery

Ice therapy is one of the simplest and oldest therapeutic modality in the treatment of acute soft-tissue injuries, and has been used clinically since the 1940's (Mac Auley, 2001). Ice therapy is now becoming one of the most commonly used recovery aids post exercise. Despite this, the underlying mechanisms by which ice is suggested to benefit recovery are still unclear (Bleakley et al., 2012).

Reduced Inflammation

The most commonly quoted benefit of ice application for recovery is a reduction in inflammation (Yamane et al., 2006). It is suggested that this reduction in inflammation is caused by a number of physiological responses to the reduction in tissue temperature. Firstly, application of ice causes vasoconstriction which limits blood flow to the area (Krityakiarana, Budworn, Khajohnanan, Suramas, & Puritasang, 2014); which reduces the magnitude of post exercise swelling (Lephart & Pincivero, 1999). Karunakara et al. (1999) showed that 20 minutes of ice application caused vasoconstriction and reduced blood flow

for the duration of the ice application; following that intervention, intermittent 10 minute on 10 minute off applications of ice allowed this vasoconstriction to continue for up to an hour. They recommended this protocol as an aid, if reduced blood flow is desired. In addition to causing vasoconstriction and reduced blood flow, applications of ice that reduce skin temperature to below 15°C, are suggested to increased blood vessel permeability and fluid extraction (Mac Auley et al., 2001); which will cause a reduction in oedema and inflammation. This is suggested to reduce inflammation on a cellular level, which may bring about a faster return to functional activity (Sloan et al., 1989). However, increased permeability and fluid extraction has only been shown in animal models as a mechanism by which inflammation is reduced. In a similar way to CGs, the reduction of post exercise inflammation is hypothesised to reduce the concentration of inflammatory cells and ROS (Bleakley et al., 2012); this in turn reduces the amount of secondary muscle damage that occurs and is suggested to reduce the subsequent muscle pain (Ascensao, Leite, Rebelo, Malahaes & Magalhaes, 2014).

Reduced metabolism

In addition to changes in the vascular system, the application of ice is suggested to reduced the metabolic rate of the cells in the treated area (Krityakiarana et al., 2014). By reducing metabolic requirements of the affected area, inflammation and the resulting secondary muscle damage can be prevented or reduced (Karunakara et al., 1999). This reduction in metabolism has traditionally been the reason that ice has been used in the treatment of acute injuries, as a method of reducing inflammation and slowing the metabolism (Bleakley et al., 2012). A 50% reduction in enzyme activity and therefore metabolic demand of muscle tissue has been shown during treatments that reduce the skin temperature to between 10-11°C (Chesterton, Foster & Ross, 2002). However, it is unclear whether this reduction in metabolism reduces the damage done to muscle cells or just delays it; it is also unclear whether or not this mechanism is beneficial to recovery from exercise induced muscle damage (Leader et al., 2012).

Reduced Muscle Soreness

Ice therapy has been shown extensively to elicit an analgesic effect when applied after an acute injury or exercise induced muscle damage (Bleakley et al., 2012). In addition to reducing the amount of muscle damage cause through reduced inflammation, ice is suggested to reduce muscle soreness by slowing nerve impulse transmission (French et al., 2008). This reduction in nerve transmission velocity is suggested to last up to 30 minutes post treatment (Mac Auley et al., 2001), and is suggested to increase pain threshold and consequently reduce perceived DOMS (Karunakara et al., 1999). Analgesic benefits have been shown in ice treatments inducing a skin temperature of 13.6°C, however, to achieve a 10% reduction in nerve transmission a skin temperature below 12.5°C is required (Chesterton, Foster & Ross, 2002).

2.5.4 Efficacy of Ice during Recovery

Much research has examined the effect of icing on post-exercise recovery; during a 3-day basketball tournament, 29 players were assigned into three recovery groups: carbohydrate intake and stretching, cold-water immersion, and compression stockings (mean pressure 18 mmHg). Pre and post-tournament tests (20 m sprints, agility test and vertical jump performance) suggested that cold-water immersion was the best recovery strategy (Montgomery et al., 2008b). Furthermore, Easton and Peters (1999) found reduced stiffness and post exercise damage with the use of ice. Similarly, other researchers have seen a reduced perception of leg soreness and fatigue with ice therapy (Ingram, Dawson, Goodman, Wallman & Beilby, 2009; Rowsell, Coutts, Reaburn & Hill-Haas, 2009). In addition to pain benefits, Gill et al. (2006) compared CK levels, up to 3 days post-match, in rugby players; passive rest showed a 39% recovery in CK levels at 84 hours post exercise when compared to an 85% recovery at 84 hours post exercise with ice therapy. These finding where supported by several studies that have found ice to be a beneficial aid to recovery (French et al., 2008; Lane & Wenger, 2004).

However, Sloan et al. (1989), suggested that while the analgesic effect of Ice application are well documented, there is little scientific evidence for any other benefit. More recently the evidence for the use of ice has continued to be questioned; and together with CGs, there are doubts surrounding their efficacy for recovery. For example, Paddon-Jones & qugley (1997) showed that ice was not effective at reducing DOMS or reducing recovery time. Likewise, Krityakiarana et al. (2014) showed that 20 mins of ice application had no effect on ROM, perceived Pain or maximum voluntary contraction. In fact the control group showed better results. It was suggested that vasoconstriction immediately post exercise could stop the removal of waste products, immune cells and ROS, which may cause negative effects to recovery and DOMS (Krityakiarana et al. (2014). Oakley et al. (2013), used a continuous 20 min post-exercise ice protocol during recovery; the cryotherapy group perceived significantly less pain, using a visual analogue scale, 48-hours after the exercise compared to a control group (3 cm vs. 5.4 cm, p = 0.048). However, there was no difference found in any other variable including: blood CK levels, maximum isometric torque or hamstring length. Guilhem et al. (2013) used four applications of localised air-pulsed cryotherapy (-30°C) for 3 days after strenuous eccentric exercise. They found that while some indicators of muscle damage, including oedema and decreased muscle activity, were delayed; cooling failed to improve long term recovery of muscular performance. This was supported by Tseng et al. (2013), who used cold pack application for 15 minutes at 0, 3, 24, 48 and 72 hours after exercise, they found an increase in blood CK and Myoglobin levels at 48 and 72 hours post exercise and greater perceived fatigue at 71 hours, when compared to a control. It was concluded that cooling of muscles delayed recovery post exercise and actually induced greater total muscle damage. Applying ice may increase short term recovery and reduce muscle soreness, by limiting secondary muscle damage caused by the inflammatory process. However, as suggested previously the effects of reduced inflammation on long term adaptations are still unknown. Reduced inflammation may negatively impact the natural adaptations experienced in response to exercise; by reducing the amount of insulin-like growth factor (IGF-1) released by macrophages during the acute inflammatory response

(Crystal, Townson, Cook & LaRoche, 2013). Leader et al. (2012) conducted a systematic review and meta-analysis (14 studies) on studies examining muscle cooling after exercise. Results showed that ice was effective at reducing DOMS; however the effects of ice on recovery of muscle function was inconclusive. They suggested that acute ice therapy appears to have no negative side effects; although the effect on long term adaptations after chronic use requires further investigation.

The use of ice to reduce blood flow and inflammation is further brought into question by more recent studies that have shown benefits to recovery with interventions such as heat application and exercise; which cause vasodilation and increased blood flow. This is hypothesised to increase the removal of cellular debris and supply cells with the nutrients needed for recovery (Krityakiarana et al., 2014). Indeed, Bleakley et al. (2010) conducted a study that showed that an exercise protocol was more beneficial for recovery than a rest and ice intervention, they also stated that the rationale for cold water immersion and ice therapy in exercise recovery remains unclear.

Limitations of Ice Therapy Research

The confusion and contradictory results in ice therapy literature are at least in part due to a number of limitations. Firstly, there is no evidence based best protocol for recovery or to treat exercise induced muscle damage and inflammation (Chesterton et al., 2002); consequently the wide range of protocols used in the current research makes comparisons between studies difficult (Mac Auley et al., 2001). The current research into ice and recovery has used a number of different ice modalities, for example: wet ice, dry ice and cold water immersion; the type of ice used will affect the temperature induced in the underlying tissue (Chesterton et al., 2002); therefore comparison of results from different modalities may be difficult. Additionally, submersion in water during Cold water immersion and contrast bathing, will elicit a hydrostatic pressure which may act a form of compression (French et al.,2008); this confounding variable is rarely measured, reported or even acknowledged in the majority

of cold water immersion research. In addition to the type of ice used, the area that is affected is often different study to study. The body part that is treated (Karunakara et al., 1999), in combination with the amount of subcutaneous fat in that area (Bleakley et al., 2004) will greatly affect deep tissue temperature that is induced; further complicating the comparison of results. While differences body part and ice modality can be somewhat controlled, by achieving target skin or tissue temperatures; there is also no agreement on the optimal time that cooling should be administered (Chesterton et al., 2002). Chesterton et al. (2002), Suggested that the wide variance in ice application in the current research is due to an incomplete understanding of the physiological responses to cold treatment. It has also been suggested that many of the protocols used are not evidence based (Bleakley et al., 2004), are based on animal models (Bleakley et al., 2006) or the treatment of injuries (Chesterton et al., 2002). Many of the current studies have restricted ice intervention to a maximum of 20 minutes; as application for longer than that can cause localised vasodilation (Karunakara et al., 1999). This is known as the hunting reflex, and is believed to protect tissue from cold damage (Mac Auley et al., 2001). However, even the timing of this response is questioned; with some research suggested longer applications of ice are needed to induce benefits (Weston, Taber, Casagranda & Cornwall, 1994) and other suggesting that the vasoconstriction and dilation alternate between every 10 and 30 minute (Mac Auley et al., 2001). An additional concern that affects the timing of ice application is concerns regarding nerve damage caused by excessive icing, as shown in some studies (KarunKara et al., 1999). As a result of the hunting reflex and concerns of nerve damage intermittent protocols, such as 10 minutes on and 10 minutes off, have become popular. Bleakley et al., 2006, showed that intermittent applications of ice were more effective at reducing DOMS than a continuous protocol. However, despite this there is standardised protocol for intermittent ice application either, with differing timings and numbers of applications between studies. Additionally, there is insufficient evidence to show whether continuous or intermittent protocols are better for any other measure of recovery. Finally, as with compression

research, one of the biggest confounding variables in ice therapy research is the lack of sufficient blinding and placebo controls (Bleakley et al., 2012; Mac Auley et al., 2001). As with compression, placebo trials are hard to design and carry out without the participant's knowing which intervention is the inert treatment. As such, the results of ice research as subject to influence from the expectations of the participants and the placebo effect. It has been suggested that many of the results showing reduced pain more than 30 minutes after completion of the ice intervention, are likely due to the placebo effect (Bleakley et al., 2006).

2.5.5 Combined Compression and Ice Therapy Mechanisms of Action

Compression and ice have been used as part of the well established treatment for soft tissue injuries, RICE; meaning rest, ice, compress, elevate (Yamane et al., 2006). Rice has been widely accepted as a standard treatment for pain and oedema control after injuries and has been suggested to reduce recovery time (Wilkerson & Horn-Kingery, 1993). As such, compression and ice, both individually and combined, have become two of the most commonly used recovery therapies post exercise to increase recovery. Despite this, there is very limited research available to elucidate the benefits of combined ice and compression treatment or to inform of the best protocols to be used.

Combined compression and ice therapy is suggested to work via the same mechanisms as ice therapy, namely: reduced inflammation, reduced muscle damage, reduced metabolic demand, and decreased DOMS due to reduced nerve transmission (Bleakley et al., 2012). The addition of compression is suggested to aid the reduction of inflammation and consequently the secondary muscle damage. Additionally, the pressure from compression has been shown to increase the speed and depth of tissue cooling (Krityakiarana, 2014); this is suggested to be due to increased skin contact with ice which may improve conductivity (Mac Auley et al., 2001), and reduction of the interstitial space allowing better heat transfer between cells (Krityakiarana, 2014). Mac Auley et al. (2001) also suggested that compression may reduce blood flow and limit re-warming of the treated tissue; however, this

hypothesised mechanism contradicts the suggested effects of CGs on blood flow in the current compression literature. Despite this, combined ice and compression therapy has been shown to be more effective at reducing tissue temperature, than ice therapy alone (Mac Auley et al., 2001).

2.5.6 Efficacy of Combined Therapy during Recovery

There is limited evidence for the effect of this combined treatment on recovery. In healthy rested participants, blood flow to the Achilles tendon was shown to decrease by 90% during combined ice and compression therapy (Knobloch et al., 2006). Baseline capillary blood flow was re-established within 20 seconds of cessation. This re-perfusion caused an increase in oxygen saturation of the tendon. While this result partially supports vasoconstriction and reduced blood flow during treatment, it is unknown what effect the re-perfusion and increase in oxygen supply will have on recovery post exercise. Increased lymph drainage and decreased oedema were measured during a 30 minute ice bag treatment combined with 25mmHg pressure, when compared to a control leg (Meeusan et al., 1998). It was also shown in this study that the combined treatment was more effective at increasing lymph flow than either intervention applied on its own. The beneficial effects of the combined treatment to reduce swelling, has been confirmed in several studies (Leegwater, Willems, Brohet, & Nolte, 2012; Shelbourne, Klootwyk & DeCarlo, 1992). Leegwater et al. (2012) also showed the combined treatment to have an analgesic effect, when compared to a control. Sloan et al. (1989) examined the combination of ice therapy (15-20°C, for 20 minutes) and compression (30 mmHg) as a means of reducing inflammation and increasing recovery; it was concluded that the combination treatment may elicit a greater benefit to recovery than either intervention alone. However, this study only showed a trend towards improved recovery and no significant results were shown. Sloan et al. (1989) also highlighted the tendency for blood flow and swelling to return to baseline immediately after the treatment had finished; bringing into question the usefulness of this short term inflammation reduction.

Limitations of Combined Research

Despite its wide use, there is currently a lack of research and evidence to support the use combined ice and compression therapy, and to elucidate the mechanisms by which recovery improvements may be gained (Leader et a, 2012). All the studies discussed about that have examined combined treatment on recovery used patients recovering from acute injury; there were no studies identified that have examined the use of combined treatment on recovery for exercise induced muscle damage. French et al., (2008), highlighted the presence of a hydrostatic pressure during cold water immersion therapy; that they suggested may act to force body fluids upward and inwards which may help to attenuate inflammation. However, this mechanism was only hypothesised and was not measured in that study. Additionally, the majority of cold water immersion and contrast bathing research do not identify this pressure as a confounding variable and as such do not indicate the depth of submersion or the magnitude of the hydrostatic force being applied during the intervention (French et al., 2008). Therefore, the use of cold water immersion therapy research to compliment the current research on combined therapy is not possible. The use of combined therapy also suffers from a lack of a standardised protocol, in the same way as ice therapy. In the few studies conducted the amount of compression, time of application and temperature of the ice differs from study to study; making conclusions about the best practice difficult. Knobloch et al., (2006), suggested that evidence based data on the effects of cryotherapy and compression regarding physiological parameters such as tissue temperature decrease, vasoconstriction and metabolic effect are not currently available; therefore, further research is mandatory. Additionally, as with both treatments individually, research into the combined treatment is subject to influence from the placebo effect, due to difficulties in blinding and administering adequate placebo controls. Additionally, as with both individual treatments, the long term effects of chronic inflammation reduction are not understood and have not yet been investigated, meaning the usefulness of this intervention as a long term recovery aid is questionable for athletes.

2.6 Summary

The sale and use of CGs is increasing in popularity in many different sports, with perceived potential benefits to both performance and recovery; however, the evidence to support the claimed benefits is equivocal. Therefore, this study aims to assess the effect of CGs on performance and recovery and the mechanisms linked to them. Studies have shown beneficial effects of CGs use for performance and recovery in running trials over 40 minutes, likely to be due to the increased time for muscle damage to occur. While a half marathon or marathon may induce more MD, the scale of this study could not support such a protocol. Furthermore, 10 km running is a popular distance for recreationally competitive runners and triathlon competitors; this supports the use of 10 km treadmill time trials as an ecologically valid test of the effects of CGs. There is limited compression research in recreationally competitive athletes; a population that commonly uses CGs as an ergogenic aid. Likewise, there is limited research showing many of the suggested benefits of compression in knee high CGs; the most commonly used type of compression. Therefore, this study will assess the effect of knee high compression on performance and recovery post exercise, in recreationally competitive athletes. There are studies that support the use of CGs during exercise to attenuate the damaging effect on future performance and the use of CGs after exercise to aid recovery, with products on the market specifically design for use during or after exercise. Therefore, it would be useful to examine whether compression should be used during and/or after exercise for maximum benefit. Muscle damage and inflammation are possible causes of DOMS and the subsequent decline in repeat performance; however, CGs have been shown to attenuate these effects. Creatine Kinase as a marker of muscle damage and CRP as a marker of inflammation will be measured along with muscle girths to assess recovery. Furthermore, muscle oscillations are one of the possible causes of muscle damage; therefore, CGs effect on lower leg muscle oscillation will be explored.

Compression and Ice therapy, both individually and combined are two of the most commonly used ergogenic aids during recovery. Ice has been supported by many studies as a recovery strategy from soft tissue injury and exercise induced damage. However, the rationale for using ice and the mechanisms by which benefits may be elicited are still unclear. Despite this, it is believed that ice and compression combined could elicit increased benefits to recovery, based on the commonly used RICE procedure for soft tissue injuries. There is a need for ecologically valid recovery protocols that can be used by athletes and recreational sports people, at home and in the field. 110% Play harder have developed a means of applying compression and ice immediately following exercise. This research will examine the effects of this intervention on recovery post exercise.

2.7 General Aims and Research Questions

Chapter 5

Aims: To assess the effect of knee high compression on: i) acute 10 km running performance and ii) recovery post 10 km run; in competitive recreational endurance athletes. A secondary aim of this research is to test various mechanisms by which CGs are suggested to improve performance and recovery.

To achieve these aims the following research questions will be answered:

1. Does knee high compression use affect maximal 10 km running time trial time, in recreationally competitive endurance athletes?

2. Is a maximal 10 km time trial sufficient to induce perceptual or physiological decrements post exercise, in recreationally trained athletes?

3. Do any of the following CG applications help to attenuate these perceptual of physiological decrements; i) CGs worm during exercise, ii) CGs worm for 12 hours post exercise, or iii) CGs worn both during and for 12 hours post exercise?

Chapter 6

Aim: To assess the effect of compression garments and ice treatment on the perceptual and physiological recovery following a bout of eccentric exercise. As in chapter 5, a secondary aim of this research is to test various mechanisms by which CGs and ice are suggested to improve recovery and subsequent performance.

To achieve these aims the following research questions will be answered:

1. Will eccentric exercise affecting only the lower leg induce perceptual or physiological decrements sufficient to affect subsequent performance?

2. Do CGs or combined CG and ice therapies applied to the lower leg effect perceptual or physiological markers of recovery post eccentric exercise?

Chapter 3: General Methods

3.1 Testing Conditions

3.1.1 Testing and Measurements

To ensure reliability of measurements and control of data; all testing, measurements and analysis was completed by the principle researcher (John Lea); the same equipment was also used throughout the testing and analysis for both chapters 5 and 6.

3.1.2 Laboratory Environment

All testing took place in the Human Performance Laboratory, H260, College Lane campus, University of Hertfordshire. This laboratory was air conditioned and temperature controlled. To ensure consistent testing conditions the temperature, pressure and humidity were recorded from an electrical barometer (Oregon Scientific, Oregon, USA) at the beginning of each testing day (Temperature: 22.1 ± 1.5°C, Pressure: 1004 ± 10 mbar, Humidity: 34.3 ± 5.6%). Before the first trial the treadmill (HP Comos, Quasar, Gemany) was validated for weighted and un-weighted speed (Appendix 3).

3.2 Ethical Approval

Ethical approval was received from the University of Hertfordshire ethics committee, for all procedures used in both of these studies prior to testing commencing.

3.3 Participant Recruitment

A separate cohort was recruited for chapters 5 and 6, based on separate selection criteria (chapters 5.3.1 and 6.3.1). Participants for both phases were recruited using social media, email and word of mouth. Before the initial meeting participants were sent a participant information sheet (Appendix 4 and 12) which gave details of the study design, number of visits and what was expected of the participant. Written informed consent (Appendix 6 and

14) and health questionnaires (Appendix 4 and 12) were received from all participants, before any testing was completed.

3.4 Pre-Testing Instructions

Prior to completion of the first testing session, each participant's was asked to refrain from exercise, alcohol, massages, stretching and supplements for 24-hours, and caffeine for 12 hours prior to the start of each testing session. Participants were also told to keep their routine and preparation before each trial the same.

3.5 Familiarisation Session

All participants completed a preliminary session at least seven days before beginning the first trial. During this session the participants were shown around the laboratory, had the study protocols and tests explained to them, were familiarised with the perceptual scales (RPE and PMS) and were given an opportunity to ask any questions they may have had about the study. If the participant was happy to continue, they were given an opportunity to familiarise themselves with use of a treadmill at low speeds including dismounting the treadmill (HP Comos, Quasar, Germany).

3.6 Anthropometric Measures

3.6.1 Height

Height was measured to the nearest 0.1 cm using a portable Stadiometer (Model 214, Seca, Hamburg, Germany). Height was measured while participants undertook a maximum inhalation, stood bare foot with heels together, with a straight back pushed against the rod, and with the head on the Frankfurt plane.

3.6.2 Mass

Mass was measured to the nearest 0.1 kg using electrical digital scales (Model 780, Seca, Hamburg). Participants wore minimal clothing and were barefoot during measurement.

3.6.3 Calf and Ankle Girth Measurement

Girth measurements were conducted in accordance with the ACSM guidelines (2006). A tension regulated tape (Seca, Hamburg, Germany) was used on the right side of the body, pulled to proper tension without pinching skin to measure girth. Duplicate measurements were taken and the results given were the mean of the two measurements. Where the measurements differed by more than 2 mm a third measurement was taken and the median used. Calf girth measurement was taken at the level of maximum circumference between knee and ankle. Ankle girth measurement was taken at the level of the minimum circumference of the lower leg, superior to the malleoli of the ankle.

3.6.4 Body Fat Percentage

Body fat percentage was established using Tanita scales (Tanita, Illinios, USA) and was carried out in accordance with the manufacturer's instructions. All participants were awake for at least three hours, had not conducted vigorous exercise for at least 12 hours, and had not consumed food or drink for three hours prior to measurement. Duplicate measurements were taken and the results presented were the mean of the two measurements.

3.7 Physiological Measurement

3.7.1 Blood Pressure

Blood pressure (BP) measurements were taken (Omron, Milton Keynes, UK), from the left arm. The cuff was placed on the upper arm with the appropriate mark in line with the brachial artery. Blood pressure measurements were taken in duplicate; the results given are the average (mean) of the two results. If the two results differed by more than 5%, a third measurement was taken and the median result used.

3.7.2 Heart Rate

Resting heart rate (HR) was recorded using a wireless HR monitor (Polar, Finland). Two measurements were taken one minute apart; the mean of the two results was used for data

analysis. If the two results differed by more than 5%, a third measurement was taken and the median result used.

3.7.3 Pain Algometry

Perceived muscle soreness was measured using a pain algometer (Wagner Instruments, Greenwich, Canada) pressed at a force of 80N (Goddard, Karibe, and McNeill, 2004), the degree of muscle soreness was assessed using a 0-10 (0= no pain, 10=unbearable pain) visual analogue scale (Appendix 1). The sites used to assess muscle pain were taken from previous research (Creasy, 2008). The sites were located, and marked with a pen for consistency, using anatomical landmarks as follows: Tibialis anterior, middle of the muscle 10 cm above the proximal aspect of lateral malleolus; Medial head of gastrocnemius, centre of the belly of the muscle; Lateral head of gastrocnemius, centre of the belly of the muscle; Biceps Femoris, 20 cm proximal to popliteal line; Vastus Lateralis, 20 cm above the distal end of lateral aspect of femur; Vastus Medialis, 10 cm above to the distal end of medial aspect of femur. Pain at each site was measured twice and the average taken, if there was a difference in pain rating of more than one unit, then a 3rd measurement was recorded and the median value used.

3.8 Blood Analysis

3.8.1 Blood Lactate and Glucose

To assess blood lactate and glucose levels, whole capillary blood was collected from the finger tip. Prior to each sample, the finger was cleaned using an alcohol wipe. The finger tip was then punctured with a single-use lancet. The first drop of blood was discarded before the samples were collected into 10 ul glass capillary tubes (EKF Diagnostics, Cardiff, Wales). These tubes were placed in Micro-centrifuge tubes with Haemolysing solution (EKF Diagnostics, Cardiff, Wales). The samples were shaken and mixed before being placed in the analyser (EKF Diagnostics, Cardiff, Wales).

3.8.2 Serum Collection

Whole capillary blood was collected, using the standard finger-prick technique, as above (Chapter 3.8.1), into 200ul microvettes, (Sarstedt, Nümbrecht, Germany) with clot activator (Silicate). Samples were placed in a centrifuge (Hyspin 16K, Anachem, Luton, UK) at 10000xg for 5 mins to separate the serum. Serum was separated using a pipette (Gilsons, Middleton, UK) into a pre chilled micro-centrifuge tube and stored at -80°C for batch analysis once all trials were completed

3.8.3 C-Reactive Protein

After calibration according to the manufactures guidelines, samples were analysed using a semi automated spectrophotometer (RS Monza, Randox, Crumlin, Ireland). Serum (50 µL) was mixed with reagent R1 (CP7950, Randox, Crumlin, Ireland) and given 3 minutes to equilibrate. Saline (0.9%, 75 µL) or reagent R2 (75 µL) was then added and the sample was incubated for 15 minutes at 25°C. Following incubation, samples were analysed according to beer-Lambert's law.

3.8.4 Creatine Kinase

After a calibration following the manufactures guidelines, samples were analysed using a semi-automated analyser (RS Monza, Randox, Crumlin, Ireland). Serum (10 µL) was reacted with 500 µL reagent R1 (CK110, Randox, Crumlin, Ireland), the sample was then inverted 10 times and aspirated into the flow cell for analysis. Absorptions were measured at one and four minute intervals, concentrations were calculated according to beer-Lambert's law.

3.9 Trial Garments

3.9.1 Compression Sleeves

The compression used in both chapters 5 and 6 were commercially available graduated ankle to knee sleeves (110% Play Harder, Florida, USA). The CGs were made of 70%

Polypropylene/ 30% Spandex. The sleeves were shaped to be unilateral and fit exclusively to the left or right leg. The compression was available in four sizes; extra small, small, medium and large. The pressure provided by the compression, as reported by the manufacturer, was 45 mmHg at the ankle to 35 mmHg at the base of the knee. The CGs have a double layered construction (mean combined un-stretched thickness 1.69 ± 0.02 mm), to accommodate an ice insert for combined use. The reusable ice inserts (110% Play Harder, Florider, USA; Figure 2) were supplied with the compression garments. The ice inserts were first hydrated by soaking in water until all compartments had expanded to full size. Inserts were frozen at -18 to -20°C, for a minimum of 12 hours prior to use.

3.9.2 Fitting Compression

Once calf girth was determined, the appropriate sized garment for each participant was chosen using the manufactures sizing guide (Appendix 2). Compression was fitted on the lower leg, superior to the malleoli of the ankle and inferior to the Head of fibula and was adjusted to the comfort of the athlete.

3.10 General Statistics

All data was analysed for significance in SPSS (version 18, SPSS, Chicago, USA). Prior to analysis data was checked for normality; due to the sample sizes (n<50) Shapiro-Wilk's tests (p > 0.05) and visual inspections of their histograms were used.

Normally distributed data was analysed to determine any significant difference between groups using: Paired samples T-Tests and one way repeated measures analysis of variance (ANOVA). Mauchly's test for sphericity was conducted with the ANOVAs; where sphericity was breached a Greenhouse-Geisser adjustment was used. Post-hoc tests for pair-wise comparison were conducted to determine the areas of statistical significant. Bonferroni adjustments were performed to reduce the probability of type 1 errors. Parametric data were presented as mean values ± standard deviation (±SD). The coefficient of variation for certain

variables was calculated using the following equation: (SD÷Mean) x 100. Results are presented as a percentage.

The Creatine Kinase data for both chapters 5 and 6 had positively skewed frequency distribution. This data underwent logarithmic transformation, followed by further Shapiro-wilk's testing to confirm normality. As the logarithmically transformed data was normally distributed ($p > 0.05$), repeated measures ANOVAs were conducted as described above.

Data that were found to deviate from normality were assessed using Wilcoxon signed-rank tests (two groups) and Friedman tests (3 or more groups). Post hoc comparisons were carried out using Wilcoxon signed-rank tests, following the Friedman tests, to assess where significance was present. Non-parametric data were reported as median (range).

An α-level of < 0.05 was accepted for statistical significance in all parametric and non-parametric statistical testing.

Chapter 4: Pilot Testing: Ice Therapy Protocol

4.1 Introduction

Ice therapy has been commonly used for recovery in clinical practice since the 1940's (Mac Auley, 2001), and is now established as a key component of treatment for soft tissue injuries (Kowal et al., 1983) and post exercise muscle damage (French et al., 2008). A systematic literature review by Mac Auley (2001) suggests that the optimum temperature range to slow cell metabolism while reducing risks such as cell and nerve damage, is 10-15°C. While the evidence was sufficient to recommend an optimum temperature range, Mac Auley stated that there was insufficient evidence to recommend the optimum timing and frequency of ice application. However it was suggested that an effective technique favoured by some research was an intermittent protocol of: 10 minutes ice, 10 minutes rest at room temperature, followed by a further of 10 minutes ice therapy. This 10 on 10 off intermittent application was confirmed to be more effective at reducing pain, when using ice packs, compared to a 20 minute continuous protocol (Bleakley et al., 2006). Despite this, the confusion in this area continues due to conflicting research demonstrating that continuous icing protocols can also be effective for post exercise recovery (Bailey et al., 2007; Vaile, Halson, Gill & Dawson, 2008).

The research in this thesis (chapter 6) used a commercially available portable ice insert system (110% Play Harder, Florida, USA), designed to allow the combined use of ice and compression in the field. This system could allow easy and convenient treatment for athletes immediately post exercise. However, as this system is designed for field based use, it has certain characteristics that differentiate it from the methods used in previous studies: Firstly, the ice pack had two different sides (Figure 2); one side was a white porous side through which the ice pack was hydrated before use, the second side was a plastic black non porous side. These two surfaces were very different and it was unclear which side of the ice insert should be used inwards (towards the leg), to achieve the desired temperature range.

Additionally, as this system was designed for use in the field, the same ice insert would be used for the entire treatment; consequently using the intermittent protocol may be less effective as it is not possible to re-cool the ice pack between applications. Therefore the purpose of this pilot test was to assess the most effective icing protocol to be used to reach the target skin temperature of 10-15°C, when using this portable ice insert system. The independent variables in this test were: i) ice therapy timing (intermittent vs continuous) and ii) Ice pack orientation (Black side or White Side facing the leg)

Figure 2: 110% Play Harder Ice Inserts (White and Black sides)

4.2 Method

4.2.1 Participants

Six healthy male volunteers (Age (Median): 22 years (20-27 years), Height: 176.7 ± 5.3 cm, Mass: 70.1 ± 3.2 kg, Body fat: 13.7 ± 5.3%) completed this study. All participants completed a minimum of two exercise sessions per week, for 30 mins or more.

4.2.2 Experimental procedures

All testing was completed in the Human Performance Laboratory (Temperature: 21.7 ± 0.3°C, Pressure: 1005 ± 12 mbar, Humidity: 32.3 ± 4.6%), on the University of Hertfordshire campus. Each participant completed four trials, separated by a minimum of 24 hours, in a randomised cross over design. Prior to testing, participants rested for a minimum of 5 minutes in a seated position, during which time written informed consent was collected. The four conditions undertaken were: Continuous 20 minutes ice application with; i) the white side of the ice pack towards the leg (Cont-W) and ii) the black side of the ice pack towards the leg (Cont-B). And intermittent trials consisted of 10 minutes of ice application followed by 10 minutes of rest at room temperature and finally a further 10 minutes of ice application. The intermediate protocol was conducted with: i) the white side of the ice pack towards the leg (Inter-W) and ii) the black side of the ice pack towards the leg (Inter-B). During the breaks in the intermittent protocols the ice pack was placed inside an insulated bag as would be done in the field. The same ice pack was used for the entire intervention. For all trials the participant wore a compression garment (110% Play Harder, Florida, USA) on the right leg, into which the ice pack was inserted. The ice pack sat between the two layers of the garment, therefore the ice insert was not in direct contact with the skin. Skin temperature was recorded every two minutes using an electronic thermometer (1320 Type K, Tes, Taiwan). The thermometer was placed with the sensor located over the belly of the calf musculature, in direct contact with the skin; this was secured using hypo-allergenic tape and the pressure of the compression garment to ensure there was no movement during the

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measurement. Participants remained in the seated position throughout the test, with legs uncrossed and feet flat on the floor. Shoes were worn throughout the procedure.

4.2.3 Data analysis

Mean skin temperature, at each time point during the intervention, was calculated for all groups. Likewise, the average skin temperature (Median and Range) during the 20 minutes of ice application was calculated for each group. Statistical analysis was conducted (as described in chapter 3.10), to assess any differences present between groups in; final (minimum) skin temperature achieved and average skin temperature during the entire intervention.

4.3 Results

The lowest skin temperatures were reached in the trials with the black side of the ice inserts facing the leg. The lowest temperature reached was 11.2°C in the Inter-B trial; the minimum temperature was 0.3°C higher in Cont-B. A statistical analysis of variance (ANOVA) revealed that there was a statistical difference between groups for minimum skin temperature reached ($F_{2, 11}$ = 622, p = 0.001). Bonferroni pairwise comparison showed that both the Inter-B and Cont-B trials reached statistically lower final temperatures than the Inter-w and Cont-W conditions (p < 0.05). However, the difference in final temperature between the Inter-B and Cont-B conditions was not significant (p = 1.00).

The Cont-B trial reached the target temperature range (10-15°C) at 12 minutes; however it took until 14 minutes for the Inter-B trial to reach the target range. From 14 minutes onward the Inter-B group had the lowest temperature of any trial, at every time point until the end of the test (Table 3). The average temperature during the 20 minute ice intervention was calculated for each group. The median temperatures during the interventions were: Cont-W; 17.7°C (30 - 15.5°C), Inter-W; 16.7°C (29.3 - 13.7°C), Cont-B; 15.7°C (29.5 - 11.7°C), and Inter-B; 15.5°C (29.2 – 11.2°C). A Friedman test revealed significance between groups for average skin temperature (X^2_3 = 29.3, p = 0.001). Wilcoxon signed-rank tests showed that, as with minimum temperature, Inter-B and Cont-B had lower average skin temperatures than the Cont-W and Inter-W conditions (p < 0.05): additionally the difference between the Inter-B and Cont-B groups was again not significant (p = 0.58).

Table 3: Skin temperature (°C) during ice therapies (mean ± SD, n = 6)

Time (Mins)	Pre	2	4	6	8	10	Break Temp	12	14	16	18	20
Cont-W Temp (°C)	30 ± 0.9	22.3 ± 0.5	19.5 ± 0.5	18.7 ± 0.5	17.7 ± 0.5	17.7 ± 0.8	-	17.3 ± 1	16.8 ± 1	16.3 ± 1.4	15.7 ± 1.2	15.5 ± 1
Cont-B Temp (°C)	29.5 ± 1	20.3 ± 1.9	18.2 ± 1.2	16.5 ± 1	16.2 ± 1	15.7 ± 0.5	-	14.5 ± 0.8	14.2 ± 1.2	12.8 ± 1	12 ± 0.6	11.5 ± 0.5
Inter-W Temp (°C)	29.3 ± 0.5	20.9 ± 1.7	19 ± 1.8	17.7 ± 1.6	16.7 ± 1.9	16 ± 2	24.2 ± 0.4	17.5 ± 1.2	16.3 ± 1	15.5 ± 0.8	14.7 ± 1.2	13.7 ± 1.2
Inter-B Temp (°C)	29.2 ± 1	19.8 ± 1.3	18 ± 0.9	16.5 ± 1	15.7 ± 0.8	15.2 ± 1.1	21.7 ± 2	15.5 ± 1.9	13.5 ± 1	11.7 ± 0.5	11.5 ± 0.8	11.2 ± 0.8

Pre= skin temperature (°C) under CGs before ice was inserted. Break Temp= skin temperature after 10 minute break at room temperature in intermittent trials only.

4.4 Discussion

The results of this study showed that in both timing conditions the black side of the ice pack was more efficient at cooling the skin to within the target temperature. This increased thermo-conductivity of the black side compared to the white side, was caused by the type of materials used on each side, and a difference in material thickness. The results of this study also demonstrated that the intermittent protocol with the black surface of the ice insert facing the leg (Inter-B) induced the lowest skin temperatures, when compared to all other trials. The Inter-B trial also maintained the lowest average skin temperature throughout the ice intervention when compared to the other trials. However, these results were not statistically significant when compared to Cont-B. Cont-B also reached the target temperature of 10-15°C faster than the Inter-B trial, and was within 0.3°C of its minimum temperature and 0.2°C of the average temperature achieved. While there was no significant difference between these continuous and intermittent trials, previous research has suggested that intermittent protocols are frequently favoured in current ice therapy research (Mac Auley, 2001), and that intermittent protocols are more effective at reducing perceived muscle soreness and DOMS (Bleakley et al., 2006). As a result of this research and the lower average temperatures reached in the Inter-B trial, the intermittent protocol with the black side of the ice insert facing the participant's leg was used in the main study.

A limitation to this study was the small sample size, for more reliable results a greater number of participants would be required, however this information was sufficient to inform a decision in this instance.

4.5 Conclusion

There was statistical difference in surface temperature achieved between the Cont-B and Inter-B trials. As intermittent trials have been shown to be more effective than continuous

trials at reducing DOMS and the Inter-B trial achieved the lowest temperatures; the Inter-B

protocol was used in the main study (chapter 6).

Chapter 5- The effect of knee high compression garments on 10 km run performance, and recovery in competitive recreational endurance athletes

5.1 Introduction

Compression garments are used extensively during and after exercise for the proposed benefits to performance (Bringard et al., 2006b) and recovery (Gill et al., 2006; Jakeman et al., 2010). These proposed benefits make the use of CGs attractive to recreationally competitive athletes who are looking to increase performance, with limited time to train and recover. The use of knee high CGs is a fast growing trend at events such as triathlons and running events, where 10 km is a common run distance (Bakken et al., 2011). However, the recreational athletes taking part in such events are training regularly, three or more times per week; and it is currently still unclear whether CGs will be beneficial to an athlete who is familiar with the exercise (Hill et al., 2014) and has adaptations from training, such as reduced susceptibility to muscle damage (French et al., 2008).

For recreational athletes looking to CGs for improved performance and recovery, it is also unclear what the optimal timings of application are to achieve maximal benefits. It is suggested that the use of compression during exercise as well as improving performance (Ali et al., 2007) may reduce muscle oscillations (Doan et al., 2003) and consequently reduce the muscle damage caused during that exercise (Creasy, 2008); while the use of compression post exercise may reduce inflammation (Davies et al., 2009) and secondary muscle damage caused by immune cells and reactive oxygen species (Bochmann et al., 2005). As a result of this some CG companies market different compression garments to be worn during and after exercise (2XU, Melbourne). Born et al. (2013) suggested that the greatest benefits of CGs seem most pronounced when applied for the recovery process 12 to 48 hours after significant muscle damage inducing exercise. However as the majority of the studies looking into the effects of CGs on recovery administered the compression during

recovery only (Hill et al., 2013) and there are no studies comparing compression use during, after or combined during and after, it is impossible to know the most effective application of compression for recovery. It is possible that the use of CGs both during and after exercise could have an additive effect or even a synergistic effect, although the effect of combined use during and after exercise has not yet been confirmed.

This study compared the effects of compression use: during, after and combined (during and after); on 10 km running performance and post exercise recovery, in competitive recreational endurance athletes.

5.2 Aims and Hypotheses

Aims: 1. To assess the effect of wearing knee high compression garments on muscle oscillations

2.To assess the effect of wearing knee high compression garments on 10 km treadmill time trial performance

3. To assess whether a maximal 10km time trial is sufficient to elicit physiological or perceptual decrements during recovery.

4. To examine the effects of wearing knee high compression garments: i) During exercise, ii) Post exercise for 12 hours, and iii) During exercise and post exercise for 12 hours; on physiological and perceptual recovery

Hypotheses

Hypothesis 1: Muscle oscillations, during running at 12 km.h^{-1}, will be significantly reduced when wearing CGs when compared to a control.

Null hypothesis 1: There will be no statistically significant difference in muscle oscillations between trials. Any differences will be due to chance alone.

Hypothesis 2: The wearing of CGs will significantly decrease 10 km time trial performance time

Null Hypothesis 2: There will be no statistically significant difference in run time when wearing CGs. Any differences will be due to chance alone.

Hypothesis 3: During a maximal 10 km running time trial, the use of CGs will significantly reduce: i) Average heart rate, ii) average blood lactate levels and iii) average RPE scores; when compared to a control.

Null Hypothesis 3: There will be no statistically significant difference between trials in: i) Average heart rate, ii) average blood lactate levels or iii) average RPE scores. Any differences will be due to chance alone.

Hypothesis 4: 24 hours post 10 km running time trial, blood CK levels will be significantly lower when CGs are worn: i) during the exercise, ii) for 12 hours immediately post-exercise and iii) during and for 12 hours post-exercise; when compared to a control.

Null Hypothesis 4: There will be no statistically significant difference in blood CK levels between any trials. Any differences will be due to chance alone.

Hypothesis 5: 24 hours post 10 km running time trial, PMS will be significantly lower when CGs are worn: i) during the exercise, ii) for 12 hours immediately post-exercise and iii) during and for 12 hours post-exercise; when compared to a control.

Null Hypothesis 5: There will be no statistically significant difference in PMS between any trials. Any differences will be due to chance alone.

Hypothesis 6: 24 hours post 10 km running time trial, blood CRP levels will be significantly lower when CGs are worn: i) during the exercise, ii) for 12 hours immediately post-exercise and iii) during and for 12 hours post-exercise; when compared to a control.

Null Hypothesis 6: There will be no statistically significant difference in blood CRP levels between any trials. Any differences will be due to chance alone.

Hypothesis 7: 24 hours post 10 km running time trial, average calf girth will be significantly lower when CGs are worn: i) during the exercise, ii) for 12 hours immediately post-exercise and iii) during and for 12 hours post-exercise; when compared to a control.

Null Hypothesis 7: There will be no statistically significant difference in average calf girth between any trials. Any differences will be due to chance alone.

5.3 Study Methods

5.3.1 Participants

Eighteen healthy male volunteers agreed to participate in this study, with 13 completing all four trials (Age (median): 26 years (19-48 years), Height: 178 ± 5 cm, Mass: 76.2 ± 6.5 kg, Body Fat: 18.6 ± 4.1%, $\dot{V}O_{2Max}$: 50 ± 5 ml.kg^{-1}). Figure 3 shows participant recruitment and attrition for this Chapter.
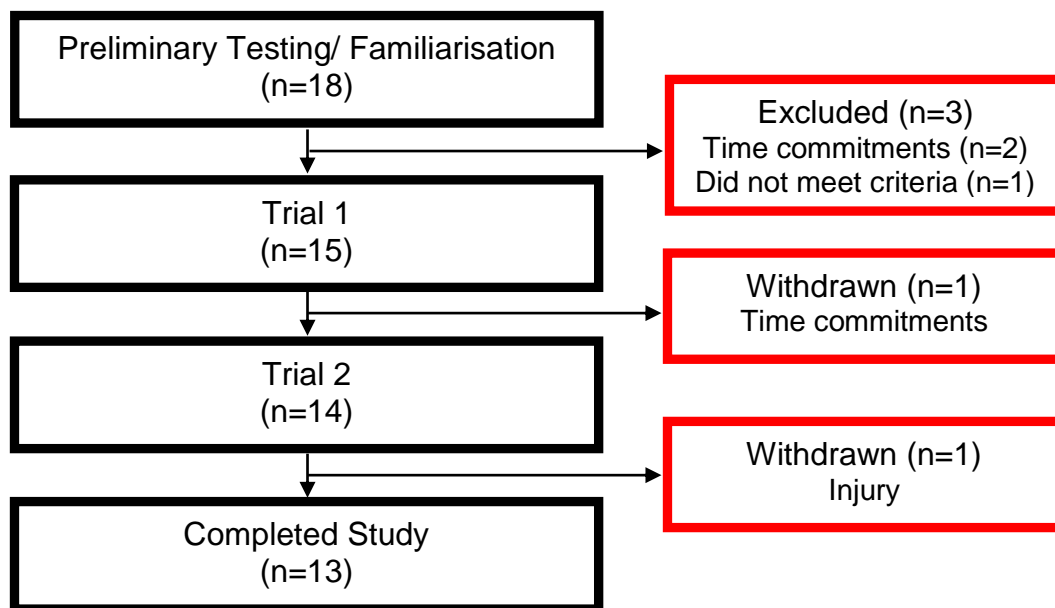
Figure 3: A schematic of participant recruitment and attrition

5.3.1.1 Inclusion Criteria

The participants used in this study were: Healthy males, aged 18-50, able to run 10 km in ≤ 50 mins, trained a minimum of three times per week and had competed in five or more races (≥5 km) in the two years prior to commencing the study.

5.3.1.2 Exclusion Criteria

The excluded criteria for this study were: Participants below 18 or above 50 years of age, any illness, medical issues or injuries preventing completion of a 10 km run, any medication use that makes exercise inadvisable, any issues relating to blood taking or an unwillingness to complete the require protocols.

5.3.2 Study Design

This study was a randomised cross-over design, in which each participant completed four exercise trials: 1. 10 km run wearing loose running shorts providing no compression (CON), 2. 10 km run wearing graduated compression (EX), 3. 10 km run wearing loose running shorts followed by 12 hours wearing graduated compression (REC) and 4. 10 km run wearing graduated compression followed by 12 hours recovery wearing graduated compression (EXREC).

5.3.3 Preliminary Testing

Baseline measurements of height, weight, calf and ankle girth and body fat percentage were recorded (see chapter 4). Perceived muscle soreness (calves, hamstrings and quadriceps) was recorded in two ways; firstly, they were shown a visual analogue scale and asked how much muscle pain they felt at that time; secondly by means of the pain-algometer (see chapter 4).

5.3.3.1 $\dot{V}O_{2Max}$ and Lactate Testing

Participants completed an incremental lactate profile into $\dot{V}O_{2Max}$ test to voluntary exhaustion. The Lactate- $\dot{V}O_{2Max}$ test protocol (Tanner, Nielsen & Allgrove, 2014) consisted of participant running on a 1% gradient treadmill, starting at 2 $km.h^{-1}$ below their 10 mile run pace (or estimated). Each stage was two minutes long. At the end of each stage the participant dismounted the treadmill for a 45 second break. During this break a capillary blood sample was taken for blood lactate and glucose and the treadmill speed was increased 1 $km.h^{-1}$. Once the participant reached 80% of predicted maximum HR no more blood samples were necessary therefore the 45 second breaks between stages were stopped and the protocol became continuous. After a two minutes stage at 16 $km.h^{-1}$, the treadmill gradient was increased by 1%. The test then continued in one minute stages with the gradient increasing by 1% at the end of each stage until volitional exhaustion. During this test oxygen consumption ($ml.min^{-1}$), carbon dioxide excretion ($ml.min^{-1}$) and respiratory

exchange ratio (RER) were recorded using a human respiratory analyser (Metalyser 3B, Cortex, Leipzig, Germany). Heart rate was recorded (Polar, Kempele, Finland) 15 seconds and RPE (Borg, 1973) 10 seconds before the end of each stage. An encouragement schedule (Appendix 7) was followed during the test, so that encouragement was consistent between participants. To ensure a true $\dot{V}O_{2max}$ score was achieved the results must conform to a minimum of three of the following criteria for $\dot{V}O_{2max}$ (BASES, 1997):

1. $\dot{V}O_2$ Plateau –defined as an increase in oxygen uptake of less than 2 ml.kg^{-1}.min^{-1} or 3% with an increase in exercise intensity.
2. A respiratory exchange ratio of 1.15 or above
3. Final heart rate within 10 bpm of maximum. A predicted maximum can be used if true maximum is unknown (220-age)
4. *Rating of perceived exhaustion on the Borg scale (6-20) of 19 or above*

5.3.4 Muscle Oscillation Procedure

Before completing the main study, each participant underwent a separate muscle oscillation measurement via video analysis. This test was completed at least 24 hours before the main study was started. Seven retro-reflective markers were fitted on the right leg and foot of each participant as follows: A. lateral femoral epicondyle; B. Medial femoral epicondyle; C. Belly of the calf muscle on the posterior midline of the leg; D. Shin bone at the same height as the calf marker; E. Lateral malleolus of the ankle; F. Medial malleolus of the ankle; G. Head of the first metatarsal (Figure 4).
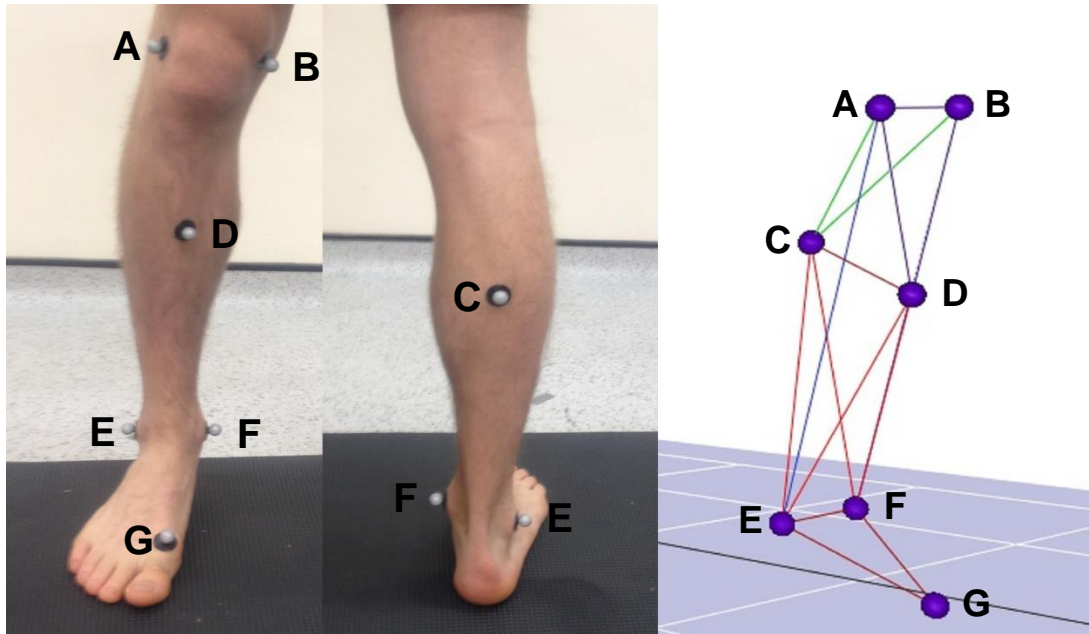
Figure 4: Muscle oscillation marker positions (left & Middle) and computer image (Right)

Following a self-paced five minute warm up, two 1 minute treadmill trials were completed at 12 km.h^{-1}. From a standing start participants increased the speed of the treadmill, at a self selected rate, until the treadmill reached 12 km.h^{-1}. Once at the correct speed and running comfortably the participant gave a verbal signal; following which data was collected for 1 minute. This procedure was completed twice. During one of the trials, knee high compression stocking were worn (COMP), during the other no compression was worn (CON). These trials were completed in a randomised order. The legs were filmed throughout these trials using a 3D infrared motion capture system (Motion analysis, Santa Rosa, USA). The distances between markers were recorded against time. Using the distances between markers C, E and F the longitudinal: displacement, peak velocity and peak acceleration of marker C (calf muscle) was calculated. Displacement against time was plotted; showing one cycle of the running gait, from the point of maximum knee flexion, through heal strike, back to point of maximum knee flexion. The calf muscle movement was in all participants approximately sinusoidal; with two periods of positive net displacement and two periods of negative net displacement per cycle. The two periods of negative displacement were used to calculate average negative velocities of the calf muscle; this allowed comparisons of

velocities associated with heel strike (1st displacement) and velocities of the muscle during normal running gait (2nd displacement) (Figure 5).
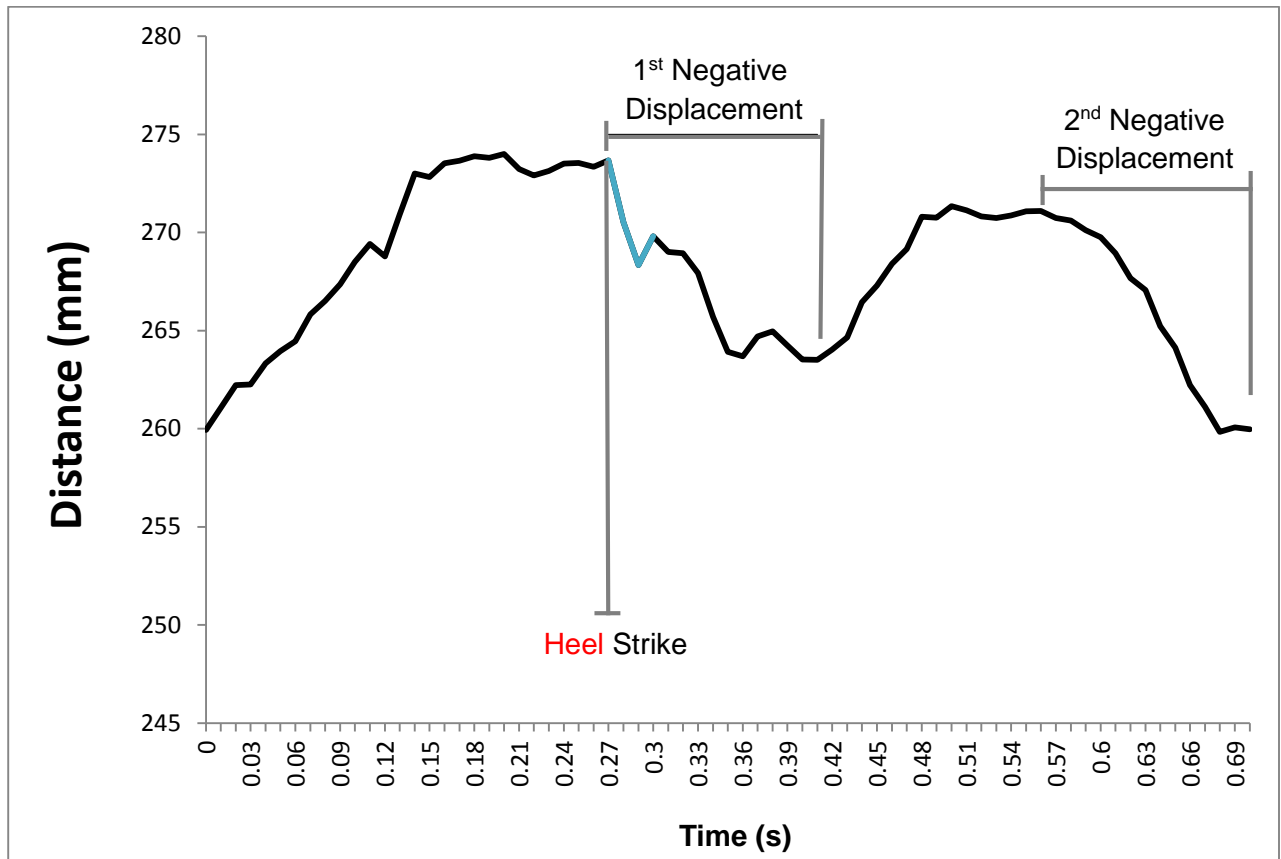
Figure 5: Calf muscle movement (relative to malleoli of the ankle) during running. *Blue line indicates peak muscle oscillation*

5.3.5 Main Trial Procedure

Participants were required to complete four trials (CON, EX, REC & EXREC); each trial consisted of two consecutive days of testing. Where possible, to control for natural variance in physiological markers and performance (Drust, Waterhouse, Atkinson, Edwards & Reilly, 2005), participants were booked in at the same time and on the same days for each trial. On day one of each trial, participants arrived at the laboratory (H260, College Lane, University of Hertfordshire) and completed a 48 hours exercise log (Appendix 8), 24 hour food diary (Appendix 9) and health screen. Participant height, weight and calf girth was recorded and a wireless HR monitor fitted (Polar, Kempele, Finland) to provide an accurate measurement of

HR during exercise (Goodie, Larkin & Schauss, 2000). After the participant had rested for ten minutes, HR and blood pressure measurements were taken. A baseline capillary blood sample was then collected for CK, CRP, lactate and glucose analysis. Participants completing the EX or EXREC trial were fitted with CGs (110% Play Harder, Florida, USA). The participant then complete a self-paced warm up on the treadmill (HP Comos, Quasar, Germany) for five minutes, followed by a maximal 10 km time trial. Rating of perceived exertion (RPE) and HR were recorded at 3 minute intervals during the run and performance time recorded using a stop watch (Fasttime 0, Leicestershire, UK). Blood lactate and glucose were measured during the run at 2.5, 5, 7.5 and 10 km.

An encouragement schedule was used to ensure motivation was consistent between trials and participants (Appendix 10). Participants were allowed to drink water ad-libatum during the run; however, no other drinks or supplements were permitted. During the run, participants were able to see the distance covered, but not speed or performance time. The participants were free to adjust speed their as they wished, but were not informed of their performance times until all trials were completed. After the run, participants were offered a shower and allowed to leave the laboratory, if they were completing the REC or EXREC trials they were fitted with CGs before leaving and instructed to wear them for 12-hours before removing (Gill et al., 2005; French et al., 2008). Following completion of each compression treatment, participants were asked to record, using a visual analogue scale (0-10): Perceived comfort of the garment (0 "very uncomfortable" to 10 "very comfortable"), Perceived tightness (0 "very loose" to 10 "very tight") and perceived pain caused by the garment (0 "no pain" to 10 "very painful").

On visit two, participants arrived at the laboratory 24 hours after the start of day 1. They were told to refrain from exercise, massages, stretching, and supplementation until after day two testing was completed. Participants completed a 24 hours food diary and were asked to rate their PMS and compression garment perceived comfort, using a questionnaire (Appendix 11). After a 10 minute rest, HR and BP were recorded. Following this, PMS was

measured using the pain algometer and a capillary blood sample was taken for later measurement of CK and CRP. Finally, calf girth was measured and the participant was permitted to leave the laboratory. Recovery measurements were collected at 24 hours post exercise as it has been suggested that physiological responses, such as CK, peak within 24 hours after exercise modalities such as running (Jones et al., 1985).

Before each subsequent trial participants were emailed the food diaries they completed for trial 1 (24 hours pre and post run), and were asked to consume the same foods and drinks if possible.

5.4 Results

5.4.1 Muscle Oscillation Results

The data from one participant (participant 4) was removed from analysis for muscle oscillations due to gaps in the data; therefore the muscle oscillation cohort was n=12.

5.4.1.1 Peak Velocity and Peak Acceleration

Peak Velocity

In all cases peak calf muscle velocity was experienced during the first muscle oscillation after heal strike. Median (Range) peak velocity was 0.386 $m.s^{-1}$ (0.203 – 0.865 $m.s^{-1}$) and 0.334 $m.s^{-1}$ (0.212 – 0.627 $m.s^{-1}$), in the CON and COMP trials respectively (Table 4). Wilcoxon signed-rank testing revealed that there was no significant difference in peak velocity between conditions (Z = -0.94, p = 0.18).

Peak Acceleration

The median (range) peak accelerations were 28.658 $m.s^{-2}$ (14.000 – 120.520 $m.s^{-2}$) and 30.043 $m.s^{-2}$ (12.200 – 89.640 $m.s^{-2}$) in the CON and COMP trials respectively (Table 4). Peak acceleration was also experienced during the first oscillation post heal strike. There was no significant difference in calf muscle acceleration between trials, as shown by the wilcoxon signed-rank test results (Z = -0.46, p = 0.33).

Table 4: Peak calf muscle velocity and acceleration during running at 12 $km.h^{-1}$ (Median (Range), n = 12) (p > 0.05).

	Peak Velocity $m.s^{-1}$	Peak Acceleration $m.s^{-2}$
CON	0.386 (0.203-0.865)	28.66 (14.00-120.52)
COMP	0.364 (0.212-0.627)	30.04 (12.20-89.64)

5.4.1.2 Average Negative Velocity

The average velocity of the calf muscle during each period of negative displacement was calculated. A repeated measures ANOVA showed significant differences in average velocity between groups ($F_{1, 43}$ = 17.74, p = 0.001). Post hoc analysis revealed no significant difference in average velocity during the first (1.03 ± 0.46 m.s^{-1}) and second (1.10 ± 0.25 m.s^{-1}) displacement in the CON trial (p = 0.45). There was also no significant difference in average velocity for the first period of negative displacement between the CON and COMP trials (p = 1.00). In the COMP trial the average velocity of the second period (0.51 ± 0.20 m.s^{-1}) of negative displacement was significantly lower than the first period (0.79 ± 0.31 m.s^{-1}, p = 0.001). The second displacement in the COMP trial was also significantly lower that the CON trial (p = 0.002, Figure 6).
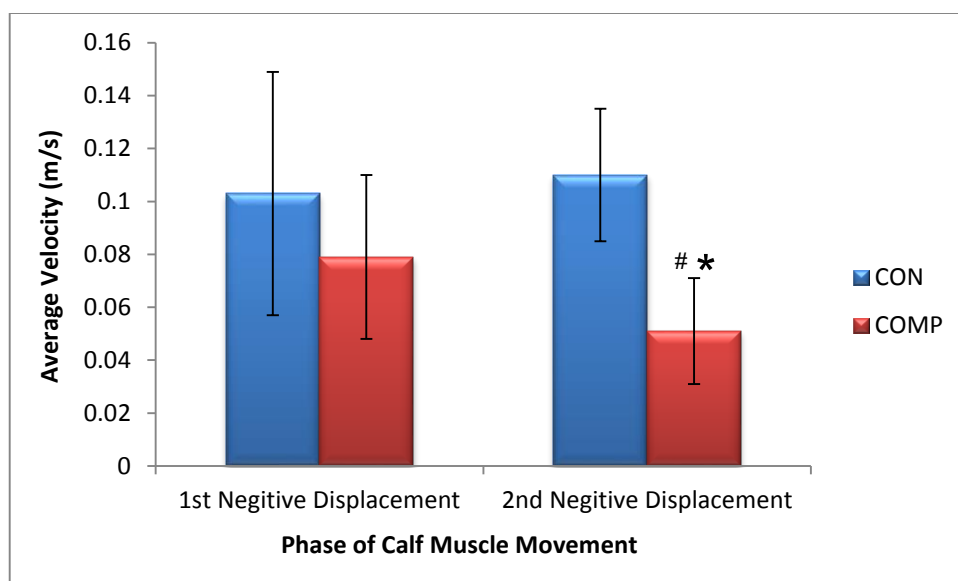
Figure 6: Average calf muscle velocity during negative displacement phases of muscle movement; when running at 12 km.h^{-1} (mean ± SD, n = 12) ∗ *Significant difference when compared to first average velocity in COMP trial (p < 0.05). # Significant difference when compared to second average velocity in CON trial (p < 0.05).*

5.4.1.3 Muscle Displacement

Displacement was calculated for each cycle of calf muscle movement, relative to the malleoli of the ankle. A paired samples T-test revealed a significant decrease (t_{23} = 4.06, p = 0.001) in displacement with the use of CGs (13.28 ± 3.27 mm) compared to the CON trial (17.57 ± 4.36 mm; Figure 7).
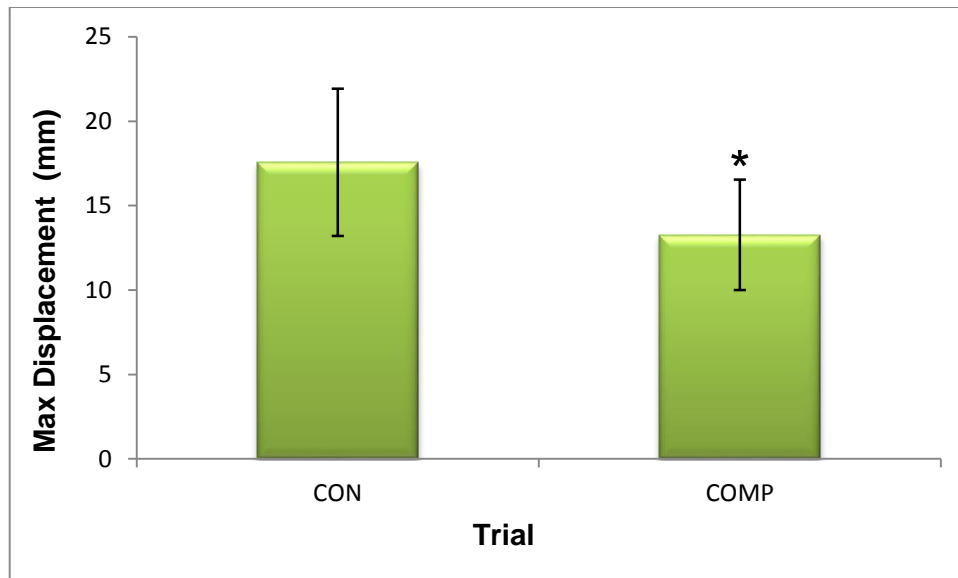
Figure 7: Maximum displacement of calf muscle across a cycle of muscle movement; when running at 12 km.h^{-1} (mean ± SD, n = 12). *Significant difference when compared to CON, p < 0.05).

5.4.2 Ten Kilometer Performance Results

Each participant completed two 10 km runs with no compression (CON & REC) and two runs wearing knee high CGs (EX & EXREC). Therefore for 10 km performance time and physiological response during exercise data, there were two conditions: COMP (wearing compression) and CON (no compression), with two trials in each condition.

5.4.2.1 Performance Time

Ten kilometre run time with the use of CGs (COMP) and without CGs (CON) was compared as a measure of performance. Mean performance time was 46.88 ± 1.76 mins and 47.07 ± 1.94 mins for the CON and COMP conditions respectively (Figure 8). A paired samples t-test showed no significant difference in run time between these conditions (t_{25} = 0.55, p = 0.59).
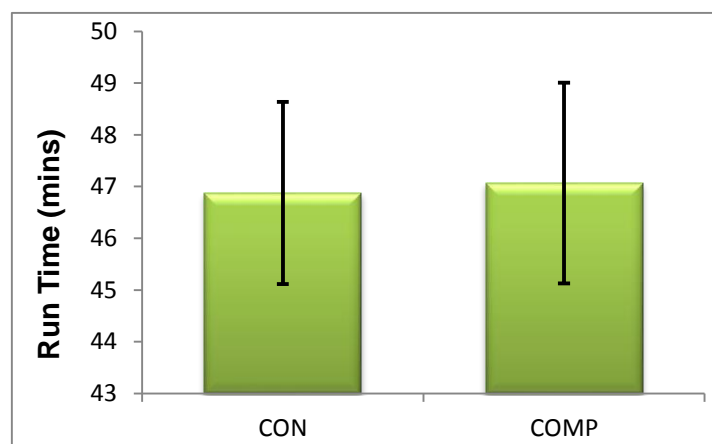
Figure 8: 10 km run time with CG use (COMP) and no compression (CON) (mean ± SD, n = 26).

5.4.2.2 Physiological Responses during Exercise

Paired samples t-tests revealed no significant differences between the CON and COMP trials for: Average HR (t_{25} = 0.92, p = 0.37), RPE (t_{25} = 0.47, p = 0.64), blood lactate (t_{25} = 0.84, p = 0.41), or blood glucose (t_{25} = 1.32, p = 0.13) during the 10 km time trials. The mean results for each variable are shown in Table 5.

Table 5: Heart rate, RPE, lactate and glucose during 10 km run (mean ± SD, n = 26) (p > 0.05).

Trial	Average HR (BPM)	RPE	Lactate (mmol.L^{-1})	Glucose (mmol.L^{-1})
CON	172 ± 6	14 ± 1.4	6.09 ± 1.93	4.34 ± 0.66
COMP	173 ± 8	13 ± 0.1	6.43 ± 0.67	4.47 ± 0.72

5.4.3 Recovery Results

5.4.3.1 Resting and Post Exercise Cardiac Variables

A repeated measures ANOVA showed no significant difference between or within conditions for resting or 24-hours post-exercise HR ($F_{7, 84} = 1.97$, $p = 0.07$). Similarly, there was no difference between or within conditions for pre and 24 hours post Systolic BP ($F_{7, 84.} = 0.49$, $p = 0.84$). Friedman's tests revealed that there was also no significant difference between condition for pre or 24 hours post: diastolic BP ($X^2_7 = 4.8$, $p = 0.68$), or mean arterial pressure ($X^2_7 = 3.97$, $p = 0.783$). Average pre and post results are presented in Table 6.

Table 6: Heart rate, systolic BP (mean ± SD), diastolic BP and mean arterial pressure (median (range)) at rest and 24 hours post 10 km run (n=26, p > 0.05).

	CON	EX	REC	EXREC
Pre-HR (BPM)	58.5 ± 8.5	62.5 ± 7.1	63.6 ± 6.6	60.4 ± 6.2
Post-HR (BPM)	60.2 ± 6.7	64.2 ± 9.1	63.6 ± 8.7	61.3 ± 7.7
Pre-Systol (mmHg)	128 ± 11	126 ± 11	127 ± 14	127 ± 12
Post-Systol (mmHg)	128 ± 13	125 ± 11	127 ± 11	128 ± 11
Pre-Diastol (mmHg)	72 (62-102)	70 (60-101)	67 (59-103)	70 (60-102)
Post-Diastol (mmHg)	68 (55-102)	69 (58-103)	68 (55-99)	69 (50-96)
Pre-MAP (mmHg)	90 (83-118)	89 (81-117)	88 (74-121)	88 (82-118)
Post-MAP (mmHg)	90 (75-120)	86 (77-119)	87 (77-115)	90 (73-115)

Systol = Systolic blood pressure, Diast = Diastolic blood pressure, MAP = Mean arterial pressure.

5.4.3.2 Muscle Damage

Creatine Kinase was measured immediately pre and 24 hours after completion of the 10 km run. The increase in CK 24 hours after exercise relative to baseline in each condition were: CON: 168.93 U/L, EX: 146.17 U/L, REC: 20.77 U/L, and EXREC: 104.75 U/L. Creatine kinase increased by 75.6% in CON compared to a 5% increase in REC; despite this, repeated measures ANOVA testing revealed no significant differences between any trial ($F_{3, 41} = 1.14$, $p = 0.34$). Average pre and post CK results for each condition are presented below (Table 7).

Table 7: Baseline and 24 hours post run CK (Median (Range), n = 13)

Trial	Pre-CK (U/L)	Post-CK (U/L)
CON	160 (75-752)	262 (110-1011)
EX	195 (57-1588)	399 (144-1592)
REC	228 (68-2034)	216 (138-1621)
EXREC	187 (46-1356)	282 (137-1551)

5.4.3.3 Inflammation

C-Reactive Protein

Serum CRP levels were recorded at baseline, before each 10 km time trial, and 24 hours post exercise. The mean CRP levels measured during each trial were: CON; 2.88 ± 1.68 mg.L^{-1} & 3.51 ± 1.43 mg.L^{-1}, EX 2.87 ± 1.38 mg.L^{-1} & 3.00 ± 1.55 mg.L^{-1}, REC 3.03 ± 0.91 mg.L^{-1} & 3.01 ± 1.34 mg.L^{-1}, and EXREC 2.66 ± 1.17 mg.L^{-1} & 3.39 ± 0.57 mg.L^{-1}; baseline and 24 hours post exercise respectively (Figure 9). A repeated measures ANOVA showed that there were no statistically significant differences in CRP levels pre or post exercise within or between any trial ($F_{7, 84}$ = 0.81, p = 0.58).
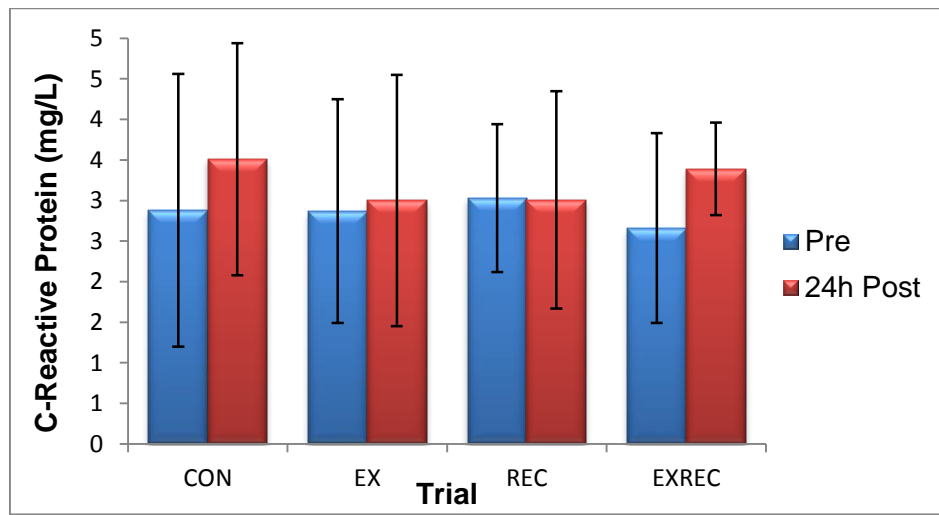
Figure 9: Pre and 24 hours post run serum C-Reactive Protein levels (mean ± SD, n = 13) (p > 0.05).

Calf Girth

As with CRP, repeated measures ANOVA testing revealed no significant differences in calf girth pre or post exercise within or between any trial ($F_{3,\ 43} = 0.65$, $p = 0.61$). The mean (SD) results for calf girth pre and 24 hours post exercise respectively were: CON 36.8 ± 2.2 cm & 36.9 ± 2.2 cm, Ex 36.9 ± 2.3 cm & 36.9 ± 2.2 cm, REC 36.8 ± 2.2 cm & 36.8 ± 2.2 cm, EXREC 37.0 ± 2.4 cm & 36.8 ± 2.3 cm (Figure 10).
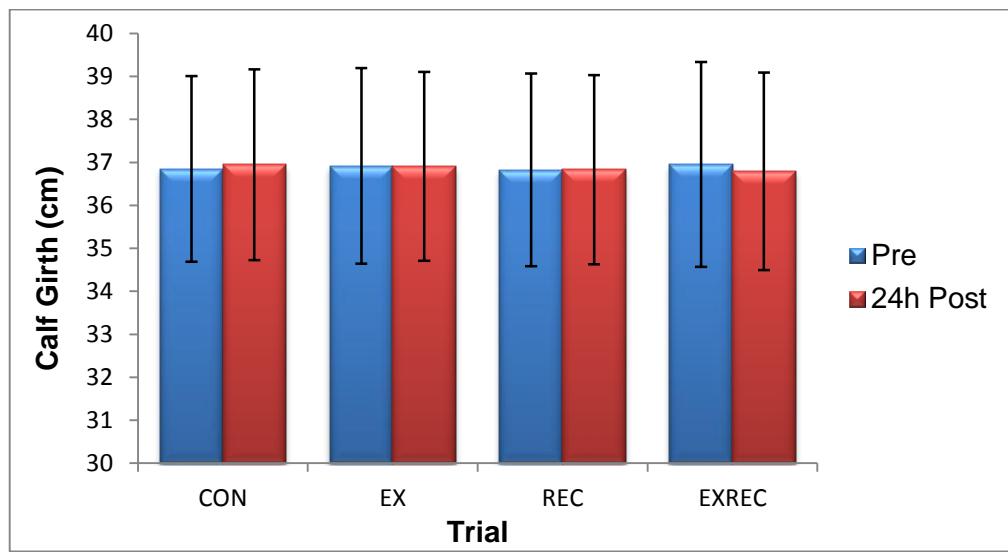
Figure 10: Pre and 24 hours post run calf girth (mean ± SD, n = 13) (p > 0.05).

5.4.3.4 Muscle Soreness

Perceived Muscle Soreness Questionnaire

Friedman's testing revealed that there were significant time effect on perceived muscle pain for all muscle groups; Calf (X^2_4 = 15.1, p = 0.005), Quadriceps (X^2_4 = 19.75, p = 0.001), Hamstrings (X^2_4 = 15.92, p = 0.003). Post Hoc Wilcoxon signed rank testing showed that perceived muscle pain for all muscle groups was significantly increased 24 hours post exercise compared to baseline, in all trials (p < 0.05) However, there was no significant difference between trials, for any of the three muscle groups (p > 0.05). Median (Range) pain rating for each muscle group are presented in Table 8.

Algometry Muscle Soreness

Statistical analysis (ANOVA) of algometry measurements revealed significant differences in muscle pain between time points in the quadriceps and hamstrings ($F_{4, 48}$ = 8.62, p = 0.001 & $F_{4, 48}$ = 4.23, p = 0.005; respectively). Similarly Friedman's testing revealed significant difference in muscle pain in the calf (X^2_4 = 12.96, p = 0.011). Post hoc testing showed that 24 hours post exercise pain increased in all trials and all muscle groups (p < 0.05); however there was no significant differences between any trials, for any of three muscle groups. (p > 0.05). Median (Range) calf muscle pain data and Mean (SD) quadriceps and hamstrings data are presented in Table 8.

Table 8: Baseline and 24 hours post exercise perceived muscle pain from visual analogue scales (median (range)) and algometry (mean ± SD, n = 13).

	Base	CON	EX	REC	EXREC
Perceived Pain Questionnaire (/10)					
Calf	0 (0)	1 (0-4)[a]	1 (0-4)[a]	1 (0-6)[a]	1 (0-3)[a]
Quads	0 (0)	1 (0-4)[a]	1 (0-4)[a]	2 (0-6)[a]	1 (0-2)[a]
Hams	0 (0)	2 (0-5)[a]	1 (0-3)[a]	1 (0-5)[a]	1 (0-4)[a]
Algometer Pain Rating (/10)					
Calf	0 (0-3)	2 (0-5)[a]	2 (0-4)[a]	2 (0-4)[a]	2 (0-4)[a]
Quads	2.0 ± 1.2	3.9 ± 1.6[a]	3.2 ± 1.5[a]	3.8 ± 1.6[a]	3.4 ± 1.5[a]
Hams	1.6 ± 1.4	3.2 ± 1.6[a]	2.0 ± 1.4[a]	2.5 ± 1.7[a]	2.2 ± 1.6[a]

Quads = Quadriceps, Hams = Hamstrings.
a. Significant increase compared to baseline (p < 0.05)

5.4.4 Perceived Comfort of Garments

Following each CG treatment participants rated the comfort, tightness and any pain caused by the garment during use. ANOVA testing revealed statistically significant differences between trials in perceived comfort ($F_{2, 24} = 5.71$, $p = 0.009$); while no differences were found for perception of tightness ($F_{2, 24} = 1.84$, $p = 0.181$). The mean (SD) results for perceived tightness for each trial were: EX 6.9 ± 1.1, REC 6.7 ± 1.3, and EXREC 7.1 ± 1.3 (Figure 11). A Friedman's test showed no significant differences between conditions for induced pain ($X^2_2 = 0.667$, $p = 0.717$); the median (range) results for all trials was 0 (0-2). Post hoc analysis revealed a significant reduction in perceived comfort in the EXREC trial (6.8 ± 2.9) compared to EX (7.7 ± 2.3, $p = 0.016$) and REC (7.3 ± 2.5, $p = 0.031$) (Figure 11).
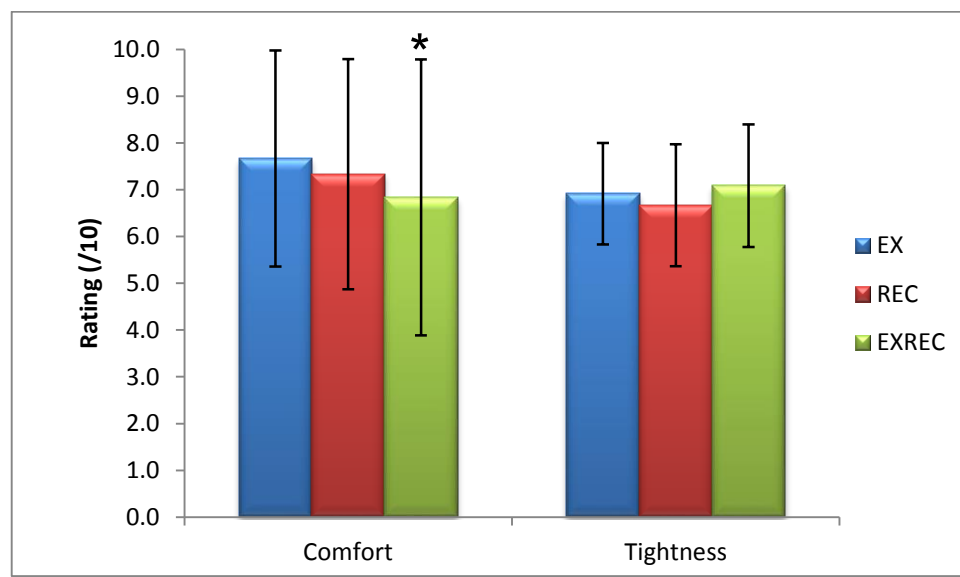
Figure 11: Perceived comfort and tightness induced by compression garments (mean ± SD, n = 13).

* Significant difference when compared to EX and REC trials (p < 0.05).

5.5 Discussion

The aims of this study were to: i) Assess the effect of knee high CGs on muscle oscillations, ii) assess the effect of wearing knee high compression garments on 10 km running performance, iii) determine whether a maximal 10 km time trial was sufficient to elicit physiological or perceptual decrement during recovery, and iv) examine the effects of different application times of knee high CGs on perceptual and physiological recovery. Overall, there was no effect of wearing CGs on performance when compared to a control. Similarly, there was no effect of CGs on muscle pain, muscle damage or inflammation 24 hours post exercise. However, maximum displacement and average velocity of the calf muscle were reduced with CGs when running at $12 km.h^{-1}$.

5.5.1 Muscle Oscillation

The aim of this test was to assess the effect of wearing knee high compression garments on the movement of the calf muscles. Studies to date have measured the velocity, displacement and frequency of muscle movements and refer to all of these as measurement of muscle oscillations. Therefore, it is unclear from the current literature what the key component, or components, of a muscle oscillation are in relation to exercise performance or recovery. This study measured the peak velocity, peak acceleration, average velocity and total displacement of the calf muscle during running at $12 km.h^{-1}$. The results showed no effect of wearing CGs on peak velocity or peak acceleration experienced by the calf muscle, when compared to a non-CG control. However, there was a decrease in total displacement and average downward velocity of the calf muscle with CG use compared to the control.

5.5.1.1 Peak Velocity

The peak velocity of the calf muscle in all observed cases was immediately after foot contact with the ground. The present study showed no significant difference in peak calf muscle velocity with CGs compared to control. This was refuted by Kraemer et al. (1998), who

examined the movement of the thigh musculature upon landing from repeated maximal jumps. They reported a decrease in muscle velocity with the use of CGs and it was suggested that the CGs reduced the velocity to almost zero. This study also showed greater power maintenance between jumps with the use of CGs; it was hypothesised that this was due to a reduction in sarcomere damage, caused by the reduction in muscle oscillations, or in this case a decrease in velocity (Kraemer et al., 1998). The contradictory results found between the current study and Kraemer et al. (1998) are most likely due to the differences in exercise modality and compression type. As the forces during landing from a jump are greater than those experienced during endurance running, it is possible that peak velocities were produced that were able to be attenuated using compression. It is also possible that the muscle groups of the thigh are more susceptible to velocity change, whether due to the size and mass of the muscle, the position on the skeleton or the phase of contraction upon landing. The current study cannot support the findings of Kraemer et al. (1998), as a mechanism by which knee high compression can benefit the calf muscles. There is a lack of research in this area and as such the role of muscle velocity during exercise remains unclear.

5.5.1.2 Peak Acceleration

The peak acceleration of the muscles measured in this study was always experienced during the first muscle oscillation after the foot made contact with the ground. There was no significant difference in acceleration of the calf muscle with or without compression. Only one previous study has measured the acceleration of muscles during oscillation; Bakken (2011) used accelerometers placed under compression shorts, to examine muscle oscillations during 90 minute running. However, they did not report the peak acceleration forces experienced, but instead reported the number of muscle movements in a set period. It was shown in that study that the number of muscle movements was decreased with the use of CGs. Bakken showed a trend towards reduced muscle damage in their study, however this result was non-significant. It is currently unknown whether the magnitude or frequency of

the acceleration forces experience by the muscles during exercise is a cause, or even a key factor in muscle damage, performance or recovery. The current study did not support changes in acceleration as a mechanism of action for calf compression.

5.5.1.4 Average Negative Velocity

During each gait cycle two periods of negative net calf muscle displacement (towards the ankle) were observed; the average velocity during these two periods was calculated and compared. With the use of compression both periods of average negative velocity were decreased, although only the second period was decreased significantly. No previous research has assessed average muscle velocity during exercise. However, as the number of muscle movements per time period remained unchanged; it is concluded that the reductions in average muscle velocity were as a result of reduced muscle displacement. As such any benefits to exercise or recovery would be as a result of the reduced muscle displacement.

5.5.1.4 Total Displacement

There was a significant decrease in total displacement of the calf muscle during each gait cycle with the use of compression garments, compared to the control. This result was supported by all research to date that has measured muscle displacement (Bakken, 2011; Borras et al., 2011; Doan et al., 2003). However, the maximum displacement of the thigh muscles measured in these studies were caused by the force transferred through the muscles upon contact with the floor; in contrast the maximum displacement of the calf muscles found in the current study, was part of the natural movement of the muscle during the running gait, and was unaffected my ground contact. As a result the role of reduced calf muscle displacement during performance and recovery is still unclear. However, research suggests that a reduction in muscle displacement could both increase performance (Born et al., 2013) and decrease recovery time (Hill et al., 2013); the current evidence to support these mechanisms is discussed further in the relevant sections below.

5.5.2 Exercise Performance

This study found no significant difference in 10 km run time with the use of CGs compared to control; therefore, the null hypothesis is accepted. This result supports the findings of several studies that found no difference in running performance with knee high CGs (Ali et al., 2011; Creasy, 2008; Varela–Sanz et al., 2011); and a review of the published literature, which concluded that CGs have little or no effect on performance (MacRae et al., 2011). However, a more recent literature review and meta-analysis showed a positive effect size (ES = 0.15) for performance during endurance exercise (Born et al., 2013). It is likely that these conflicting results are caused by a number of variables: Firstly, the current research examining endurance performance have used a range of different exercise protocols. For example, many studies that have shown benefits to endurance performance have used time to exhaustion protocols (Born et al., 2013; Goh at al., 2011; Higgins et al., 2009; Kemmler et al., 2009; Sear et al., 2010). It could be argued that TTE is not an ecologically valid measurement of performance, as there are no real sports or events that continue indefinitely until exhaustion; it is instead a measure of efficiency, economy and motivation of the athlete, and as such can be heavily influenced by the placebo effect. It has also been shown that TTE results are not as reliable as time trials with a fixed distance (Born et al., 2013). A second confounding variable is the type of compression garment used; many of the positive benefits to endurance exercise have been shown with full length tights or full body compression (Born et al., 2013; Goh at al., 2011; Higgins et al., 2009; Sear et al., 2010). It is likely that mechanisms such as reduced muscle oscillations, that are hypothesised to give more optimum muscle mechanics McComas et al., 1996) that could lead to increased movement economy (Born et al., 2013) and increased performance (Kraemer et al., 1997), would be more effective when applied to a larger muscle mass. While these variables make comparison between studies more difficult, there have been contradictory findings in studies with similar protocols using the same types of compression. Therefore, if is probable that the biggest influencing factor in performance results is the placebo effect (MacRae et al 2011).

This is supported by Born et al. (2013), who showed no differences in maximum oxygen uptake, blood lactate, HR, cardiac output or stroke volume; and therefore concluded that in the absence of physiological benefit the changes in performance were due to the placebo effect, caused by a lack of blinding of interventions.

5.5.2.1 Heart Rate

There was no significant difference in heart rate during exercise with the use of compression compared to the control; consequently the null hypothesis is accepted. These results support the findings of several studies that have found no difference in HR when using CGs (Ali et al., 2011; Creasy, 2008; Duffield et al., 2010; Goh et al., 2010). However, there is conflicting research that has shown a decreased HR with compression use (Ali et al., 2007; Dascombe et al., 2011; Varela–Sanz et al., 2011). The contradictory results found in Ali et al. (2007) can be explained by the use of untrained participants; however, the findings of Dascombe et al., and Varela-sanz et al. were shown in trained athletes. Varela-Sanz et al., showed reduced HR, but no differences in TTE or VO_2 peak. This could imply a placebo effect was responsible for the HR reductions; However, RPE was not different between trails indicating the participants believed they were working equally hard in each trial. Dascombe et al (2011) showed benefits to blood flow, oxygen consumption and HR with CGs, but also showed no differences in maximal performance or TTE. It is clear from these results that any augmentation of the blood flow and reduction in HR were, not sufficient to affect performance; however, these results prompt further investigation to explain the mechanism behind the contradictory findings. Some clarity was achieved when MacRae et al. (2011) concluded that the literature up to that point (July, 2010) showed submaximal and maximal HR was unaffected by compression use; Likewise, Born et al. (2013) showed that CGs had no effect on any cardiac parameter during exercise including: heart rate, cardiac output, cardiac index or stroke volume.

Heart rate was recorded as a measure of exercise intensity and the efficiency of the athlete's performance. The current study also recorded RPE as a measure of perceived intensity; as with HR, no significant difference was found in RPE during the 10 km running, with or without compression. These findings would suggest that knee high compression had no effect on physical effort (Laukkanen & Virtanen, 1998), efficiency, energy expenditure (Strath et al., 2000) or the perceived intensity of effort. These results support the findings from the previous section (Chapter 5.5.2) that increases found in performance in some studies were due to perceptual benefits caused by the placebo effect, and were not due to a physiological benefit.

5.5.2.2 Blood Lactate

This study found no difference in blood lactate during the 10 km run with CGs compared to the control, therefore the null hypothesis was accepted. This result is supported by other research that has shown the same blood lactate response exercise (Ali et al., 2010; Duffield et al., 2010; Scanlan et al., 2008; Sperlich et al., 2010). Despite some conflicting results in elderly athletes (Chatard et al., 2004) and during the first 60 minutes of recovery (Driller et al., 2013); it has been concluded in recent reviews that CGs have no effect blood lactate levels during exercise (Born et al., 2013; MacRae et al., 2011). The current research supports these finding for recreationally trained athletes during maximal 10 km running. Blood lactate levels are caused by and are proportional to muscle hypoxia and acidosis (Lindinger et al., 2004; Robergs et al., 2004); as such lactate levels are affected by the level of exertion, economy of exercise, localised blood flow and oxygen supply to the muscle cells. Therefore, as with HR, the results from the current study do not support any mechanism of increased exercise efficiency, for example blood flow or muscle oscillations as a benefit of knee high CGs for trained individuals during exercise.

5.5.3 Recovery

5.5.3.1 Muscle Soreness

Perceived muscle pain was recorded with a visual analogue scale both with and without use of a pain algometer. Pain increased in the calf, hamstrings or quadriceps in all conditions 24 hours post exercise; however there was no significant difference in 24 hours post-exercise pain in between trials. These results demonstrated that no application of compression (during, after or combined during and after exercise) had any effect on perceived muscle pain when compared to a control (no compression); therefore, the null hypothesis was accepted. While these results are supported by some research (French et al., 2008; Pruscino et al., 2013), the majority of studies examining post exercise muscle soreness have shown CGs to have an effect (Born et al., 2013; Hill et al., 2013; Jakeman et al., 2010; Kraemer et al., 2001; Perry et al., 2008). It has been suggested that CGs are able to reduce exercise induced muscle damage and consequently muscle pain (Kraemer et al., 1997); by reducing muscle oscillations and optimising the of muscle mechanics, for example increased cross bridge overlap (McComas et al., 1996). However, there is insufficient evidence to support these mechanisms and therefore they remain speculation. Additionally, as this study found no difference in muscle damage, there was no physiological reason why CGs would have lowered muscle pain. As discussed in Chapter 2, a limitation to the current research into CGs is that participants are not blinded to the intervention and may have preconceived expectations of what CGs will do; therefore, this study supports suggestions that the findings of reduced perception of pain in the current research may predominately be due to the placebo effect (MacRae et al., 2011).

5.5.3.2 Exercise Induced Muscle Damage and Inflammation

There were no significant differences in CK, CRP or Calf girth measurements post exercise in any trials. These results would suggest that the maximal 10km run used in this study was insufficient to elicit significant muscle damage or inflammation, in a recreationally competitive

population. These results are supported by previous research that has shown CGs to have no effect on creatine kinase, in trained individuals (Ali et al., 2010; Bakken, 2011; Duffield et al., 2010; Pruscino et al., 2013). It is suggested that trained individuals gain adaptations to training that protect the muscles from repeat damage; therefore physiological responses to exercise, such as muscle damage and inflammation, would be expected to be reduced when compared to untrained individuals (French et al., 2008). However, as was shown in previous research (chapter 2), the CK and CRP data collected during this study suffered from high inter test variance (Brancaccio et al., 2007). This variance in the data could cause a result to be not statistically different, despite the presence of localised muscle damage (Creasy, 2008). The significant increase in perceived muscle soreness demonstrated in this study could support this idea, as the major cause of muscle soreness post exercise is believed to be muscle damage and the associated inflammatory response (Clarkson & Hubal, 2002). However, in the absence of muscle damage or inflammation marker increases, this result is inconclusive.

Some research, in contrast to the findings of the current study, has shown a reduction in CK and CRP, with CGs. However, these studies use eccentric loading protocols (Borras et al., 2011; Davies et al, 2009; Kraemer et al., 2001), unfamiliar exercise (Duffield et al., 2007) or heavy contact sport (Gill et al, 2005). Indeed, a recent meta-analysis found that wearing CGs reduced CK levels (Hill et al., 2013). Of the seven studies analysed, three suggested that CGs had a positive effect; all three of those studies used eccentric exercise protocols. It is probably that unfamiliar and eccentric protocols will elicit greater muscle damage (French 2008); consequently, these results are irrelevant to endurance exercise and generalisation of results from one exercise modality to another is not valid. Additionally, all research demonstrating positive results for CK or muscle damage have used full length tight or full body compression (Davies et al, 2009; Duffield et al., 2007; Gill et al, 2005; Hill et al., 2013); no studies were identified that have demonstrated reduced CK or muscle damage with knee high CG use.

A suggested mechanism by which CGs may reduce muscle damage, inflammation and consequently recovery time after endurance exercise, is by reduced muscle oscillations (Bakken, 2011; Borras et al., 2011; Doan et al., 2003). Findings from the current study support reductions in muscle displacement during running; however, as the 10 km protocol used was insufficient to induce a significant increase in muscle damage or inflammatory markers, the current findings cannot support this mechanism in trained individuals using knee high compression.

To further assess whether knee high CGs are able to attenuate muscle damage and inflammation in trained athletes during ecologically valid exercise protocols, longer duration races for example marathons or ultra-marathons (Benigni et al., 2001) could be used. Additionally, more specific and sensitive methods of muscle damage and inflammation measurement could be used for example muscle biopsies (Borras et al., 2011) or MRI (Clarkson & Hubal, 2002).

5.6 Conclusion

The peak velocity and peak acceleration of the calf muscle when running at 12 km.h^{-1} were unchanged with the use of compression, whereas total displacement of the calf muscle was reduced. This increased stabilisation of the muscle has been hypothesised to increase running economy, decrease muscle damage and increase recovery. However, these mechanisms are speculative as there is insufficient evidence to support them. The current study found that compression use had no effect on 10 km performance, heart rate, RPE or blood lactate concentration during exercise. When considered together with other research findings, these results suggest that any performance improvements in trained individuals undertaking familiar exercise, wearing knee high compression are likely to be due to a placebo effect. The 10 km protocol was sufficient to induce significant increases in perceived muscle pain in all trials; however, there were no differences between the trials; proving that CGs were ineffective. Therefore, reductions in perceived muscle pain in previous studies are

also likely due to the placebo effect. There was no difference in muscle damage or inflammation after the 10 km time trials; participant familiarisation with the exercise and high variation in the data likely contributed to the lack of significant change. No studies were identified that showed reductions in CK or CRP with the use of knee high compression. It is likely that CGs compressing a larger muscle mass could have a greater effect to some variables of performance and recovery; therefore, results from such garments should not be generalised to knee high CGs.

Chapter 6- The effect of combined knee high compression and ice therapy on recovery after eccentric exercise

6.1 Introduction

There are many different recovery strategies used after exercise to allow the participant to perform again in the minimum time possible. These strategies include fluid and carbohydrate replacement (Burke, Kiens & Ivy, 2004), stretching (Cheung et al., 2003), contrast bathing (Gill et al., 2006), cold water therapy (Bleakley et al., 2006) and compression garments (Montgomery et al., 2008b). Recently ice therapy and compression garments have become increasing popular (Montgomery et al., 2008b). Compression garments have been shown to improve the recovery of strength and power (Hill et al., 2013), reduce muscle pain (Chatard & Atlaoui, 2004) and reduce muscle damage post exercise (Davies et al., 2009). Likewise it has been shown that ice can increase recovery, decrease muscle pain (Swenson, sward, Karlson, 1996) and decrease muscle damage (Bailey et al., 2007). Both Ice and CGs have also been shown to provide improvements in perceptual markers of recovery (French et al., 2008). These perceptual benefits have in certain cases been sufficient to improve repeat performance independent of any physiological changes (Hill et al., 2013; Pruscino et al., 2013). However despite these findings and the wide use of these strategies, there are many conflicting results that make the evidence for their use equivocal (Bleakley et al., 2010; MacRae et al., 2011).

Rest, ice, compression and elevation (RICE) are routinely used as a combined treatment for sports injuries such as strains and sprains (Clanton and Coupe, 1998). Sloan et al. (1989), examined the combination of ice therapy and compression as a means of increasing recovery post exercise. They used 30 mmHg of compression and a temperature of 15-20°C, for 20 minutes, and suggested this combination may elicit a greater benefit to recovery than either intervention alone. Despite this, there is a lack of understanding about the collective effects of these treatments on muscle damage and recovery post exercise (Trenell 2007).

This is possibly due to a lack of available methods by which an athlete could administer combined therapies without improvising such as completing an ice bath treatment while wearing CGs. Furthermore there are logistical limitations to combining treatments in the field; while compression treatments are easily transported and used immediately following training and competitions, ice therapies are often limited to use at home or at a training centre; due to the difficulties with storing and transporting ice to an event. In response to these limitations,110% Play Harder have developed a portable system for applying combined compression and ice therapy immediately post exercise in the field or at any other time as required by the athlete. This study examined the use of this portable compression and ice therapy system after exercise.

6.1.1 Exercise Protocol

In the previous study (chapter 5), the maximal 10 km time trial did not cause significant increases in blood CK levels. Eccentric exercise has been shown to cause more muscle damage and perceived muscle soreness than exercises using concentric or isometric movements (Cheung et al., 2003; Clarkson & Hubai, 2002); therefore an eccentric protocol was utilised in this study. However, as discussed previously (Chapter 2.8.1) a limitation of serum CK, as a means of measuring muscle damage, is that it is impossible to distinguish which muscle groups are damaged and contributing to the CK levels, or to ascertain the magnitude to which a specific muscle group is damaged (Jones et al., 1985). As the CGs used in this study were knee high and therefore would only apply compression to the musculature of the lower leg, it was important to ensure that any muscle damage, or reductions in muscle damage, were measured in the treated muscle groups. Consequently, previously used protocols such as downhill walking (Boras et al., 2011) and squatting (French et al., 2008) could not be used, as the larger muscles of the upper leg would also be targeted (French et al., 2008); instead an eccentric exercise protocol was employed to target the musculature of the lower leg only. While such an eccentric protocol may not be considered ecologically valid for athletes participating in the majority of sports; it was used to

test the mechanisms by which perceptual and physiological recovery of the lower leg musculature could be improved. If benefits were found with this type of exercise it could indicate mechanism by which ecologically valid modes of exercise could be affected.

6.2 Aims and Hypotheses

Aims:

1. To assess the effect of compression garments and ice treatment on physiological and perceptual recovery after eccentric exercise

2. To test various mechanisms by which CGs and ice are suggested to improve recovery and subsequent performance.

Hypotheses:

Hypothesis 1: Within 72 hours post-exercise, perceived recovery will be significantly increased when: i) CGs are worn for 12 hours post exercise and ii) CGs are worn for 12 hours and ice therapy is administered immediately post-exercise; when compared to a control.

Null Hypothesis 1: There will be no statistically significant difference in perceived recovery between any trials. Any differences will be due to chance alone.

Hypothesis 2: Within 72 hours post-exercise, PMS will be significantly increased when: i) CGs are worn for 12 hours post exercise and ii) CGs are worn for 12 hours and ice therapy is administered immediately post-exercise; when compared to a control.

Null Hypothesis 2: There will be no statistically significant difference in PMS between any trials. Any differences will be due to chance alone.

Hypothesis 3: 48 hours post-exercise, blood CK levels will be significantly increased when: i) CGs are worn for 12 hours post exercise and ii) CGs are worn for 12 hours and ice therapy is administered immediately post-exercise; when compared to a control.

Null Hypothesis 3: There will be no statistically significant difference in blood CK levels between any trials. Any differences will be due to chance alone.

Hypothesis 4: 48 hours post-exercise, 1 km time trial performance will be significantly increased when: i) CGs are worn for 12 hours post exercise and ii) CGs are worn for 12 hours and ice therapy is administered immediately post-exercise; when compared to a control.

Null Hypothesis 4: There will be no statistically significant difference in 1 km time trial performance between any trials. Any differences will be due to chance alone.

6.3 Study Methods

6.3.1 Participants

Eleven healthy male volunteers agreed to participate in this study, with 9 completing all three trials (Age (median): 23 years (20-27 years), Height: 178.7 ± 5.3 cm, Mass: 78.2 ± 14.4 kg, Body Fat: 16.2 ± 8.4%). Figure 12 shows participant recruitment and attrition for this chapter.
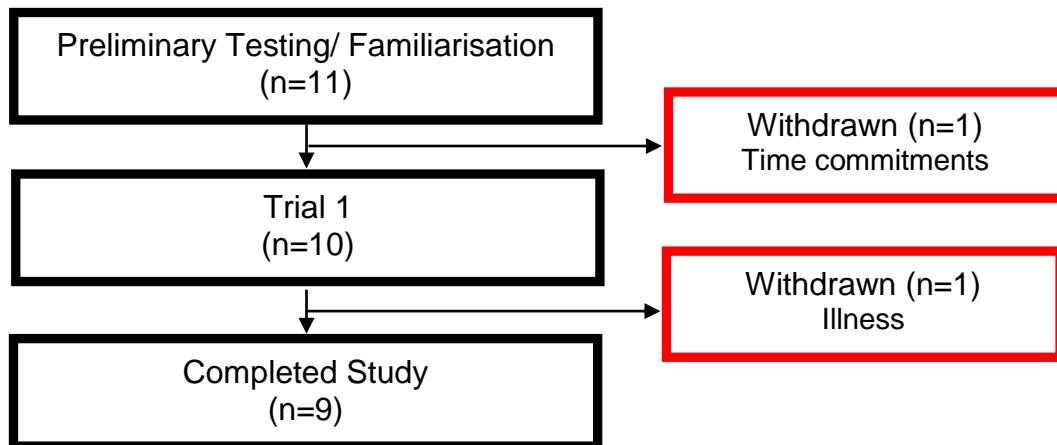
Figure 12: A schematic of participant recruitment and attrition

6.3.1.1 Inclusion Criteria

The participants used in this study were: Healthy males, aged 18-50, undertook a minimum of two exercise sessions per week, for 30 mins or more and were able to complete a maximal 1 km run.

6.3.1.2 Exclusion Criteria

The excluded criteria for this study were: Participants below 18 or above 50 years of age, any illness, medical issues or injuries preventing completion of the exercise protocols, any medication use that makes exercise inadvisable, any issues relating to blood taking or an unwillingness to complete the require protocols.

6.3.2 Study Design

This study was a randomised cross-over design, in which each participant completed three exercise trials: 1) eccentric muscle damage followed by recovery with no intervention (CON),

2) eccentric muscle damage followed by 12 hours wearing graded compression (COMP), 3) eccentric muscle damage followed by 12 hours wearing graded compression and surface icing for 20 minutes post exercise (ICE) .

6.3.3 Preliminary Testing

Baseline measurements were recorded including height, mass and body fat percentage (chapter 4). Following a self-paced five minute warm up, participants then completed a 1km time trial on a treadmill, starting from stationary. During the run, participants were able to see distance covered, but they were not able to see speed or performance time. The participants were free to adjust speed according to how they felt. An encouragement schedule was used to ensure motivation was consistent between trials and participants (Appendix 15).

6.3.4 Main Trial Proceedure

Each trial consisted of four consecutive days; the first day was the eccentric exercise day followed by three days (up to 72 hours post exercise) of recovery measurements. Recovery was monitored for 72 hours post exercise, as this has been shown to be the time period during which peak muscle soreness (Nosaka et al., 2008) and CK Levels (Peterson et al., 2001) occur. Where possible the start of day 1 of each trial was at the same time, on the same day of the week. The procedure during each trial was as follows:

On day one participants arrived at the laboratory (H260, College Lane, University of Hertfordshire) and completed a 24 hour exercise log (Appendix 16), 24 hour food diary (Appendix 17) and health screen (Appendix 13). Participant height and weight were recorded. The participant was then asked to rest for a minimum of five minutes, during which time they were asked to fill out the first section of the recovery questionnaire (Appendix 18); including, perceived muscle pain, perceived maximum ability, feeling scale rating and felt arousal level (Creasy, 2008; Pruscino et al., 2013). Baseline calf circumference, PMS (algometry) and CK samples were then collected. The pain algometer was applied to the Tibialis anterior, lateral and medial heads of the gastrocnemius as in chapter 4, this ensured

that both heads of the gastrocnemius and the soleus were targeted with the algometer. The participant then completed a lower body eccentric exercise protocol, focusing on the gastrocnemius and soleus muscles.

The protocol consisted of a five minute warm up of skipping, participants unable to skip with a rope were asked to complete the movement without one. Participants then completed two minutes of walking on the treadmill at 5.5 km.h^{-1}. A 1 km time trial was then completed following the same protocol as the baseline run. After a break of three minutes the participants then completed the eccentric exercise protocol. This started with straight leg calf raises. Fifteen repetitions were completed on the right leg immediately followed by fifteen repetitions on the left leg, this constituted one set. This exercise was continued for 3 sets after which the participant was allowed a 2 minute break. Following the break the same protocol was completed with bent leg calf raises. The bent leg raises aimed to target the soleus muscle. Participants were show an image (Appendix 19) of the degree of leg bend required to ensure consistency. The straight and bent leg calf raises were conducted in time with a metronome (Qwik Time, Quartz Metronome, Camarillo, USA) to ensure all repetitions had a 2 second concentric phase, a 3 second eccentric phase with a 1 second pause at the end of the eccentric phase. During the final repetition of the final set RPE was recorded. The eccentric portion of this exercise protocol took approximately 30 minutes to complete; this was designed to produce a similar workload to previous protocols that: used 30 minutes of downhill walking to induce significant muscle soreness (Trenell at al., 2007; Perry et al., 2008) and reductions in maximal voluntary contraction (Perry et al., 2008), and 100 eccentric bicep contractions used to induce significant CK increases (Kraemer et al., 2001). Drinking water was allowed during the session; however, no energy drinks or supplements were allowed.

After the exercise participants completing the CON trial were allowed to leave, participants completing the COMP trial were fitted with CGs and then allowed to leave and participants in the ICE trial were fitted with CGs and undertook an icing protocol before leaving. The ice

protocol consisted of inserting ice packs (110% Play Harder, Florider, USA) into the compression garments on both legs, with the black side facing the participant. The icing protocol was 30 minutes long in total; ice was applied for 10 minutes then removed and placed in an insulating bag for 10 minutes, then re-applied for a further 10 minutes. Skin temperature was monitored (1320 Type K, Tes, Taiwan) throughout the protocol. The thermometer was placed with the sensor located over the belly of the calf musculature, in direct contact with the skin; this was secured using hypo-allergenic tape and the pressure of the compression garment to ensure there was no movement during the measurement. Participants remained in the seated position, with legs uncrossed and feet flat on the floor, throughout the ice protocol. Shoes were worn throughout the procedure. Temperature was recorded every 5 minutes; the protocol was discontinued if the surface temperature dropped below 10°C. During both COMP and ICE participants wore the CGs for 12-hours before removing (Gill et al., 2005; French et al., 2008).

On day two, 24 hours post exercise participants filled out section two of the recovery questionnaire. On day three, 48 hours post eccentric exercise participants returned to the laboratory and filled out section three of the recovery questionnaire. Calf girth, PMS (Algometer) and CK were measured and they completed a maximal 1 km time trial under the same conditions as the previous runs. Participants were not informed of their performance times until all trials were completed. On day four, 72 hours post exercise participants filled in section four of the recovery questionnaire.

Before each subsequent trial participants were emailed the food diaries that they completed for trial 1 (24 hours pre and 72 hours post exercise), and were asked to consume the same foods and drinks if possible.

6.4 Results

6.4.1 Interventions

Participants rated the perceived exertion of the last repetition of the calf exercise for each trial. Friedman's testing showed there was no significant difference ($X^2_2 = 2.00$, $p = 0.368$) in RPE between trials (Median (Range); CON: 19 (18-20), COMP: 19 (18-20), ICE: 19 (18-20)).

During the ice intervention skin temperature was measured; the mean skin temperature after the 30 minute intervention was 11.9 ± 1.2°C. In all 9 cases skin temperature reduced to within the target 10-15°C range (Figure 13).
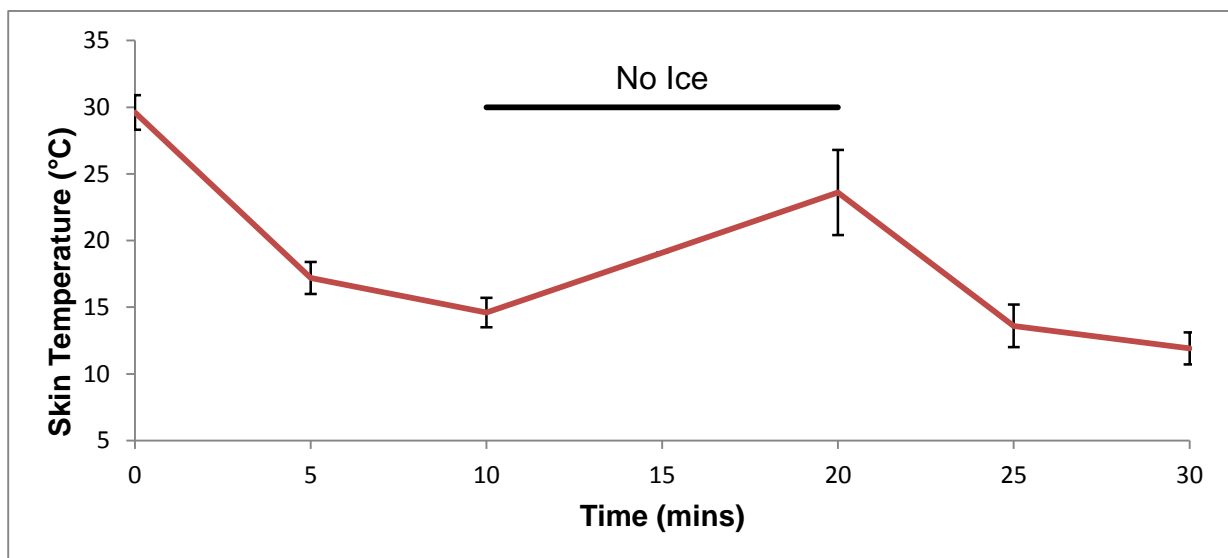
Figure 13: Skin temperature measurement during icing protocol (mean ± SD, n = 9).

6.4.2 Repeat Performance

One Kilometre run times were compared to a baseline run recorded when no strenuous exercise had been conducted. The means ± SD for each condition were: Baseline 3.82 ± 0.49 mins, CON 3.94 ± 0.44 mins, COMP 4.05 ± 0.51, and ICE 3.89 ± 0.38 (Figure 14). A repeated measures ANOVA showed no significant difference between any trial for 1 km run time ($F_{3, 24} = 1.75$, $p = 0.184$).
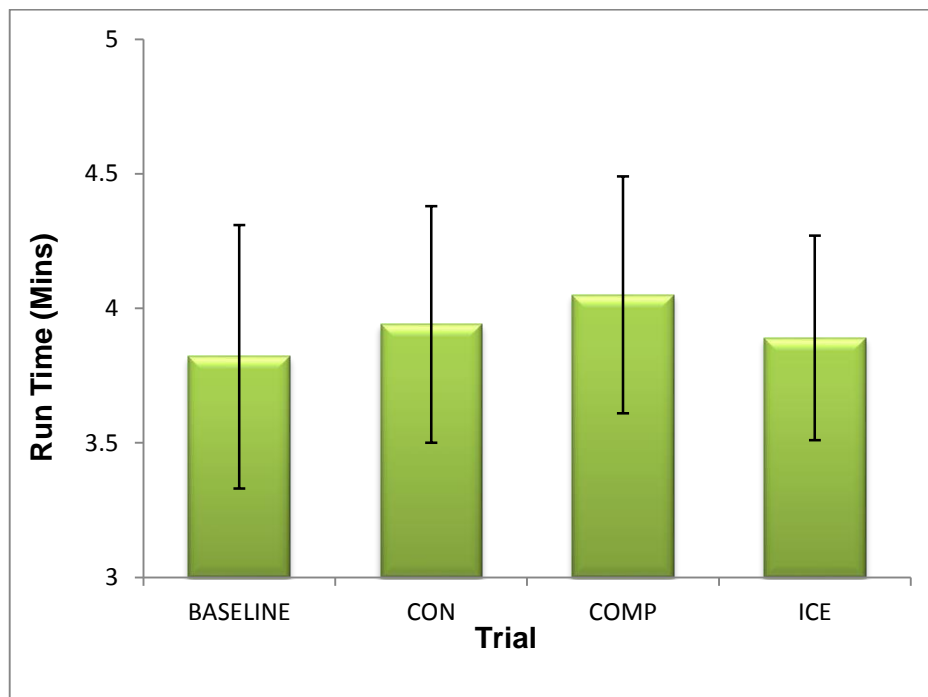
Figure 14: 1 km run time at baseline and 48 hours post calf exercise (CON, COMP & ICE). (mean ± SD, n = 9) (p > 0.05).

6.4.3 Muscle Damage and Inflammation

Creatine Kinase was measure pre and 48 hours post eccentric exercise as a marker of muscle damage. Repeated measures ANOVAs showed no significant differences between any groups for CK ($F_{2, 18}$ = 1.15, p = 0.34). Median (Range) pre and post exercise CK results for each condition are presented in Table 9.

Table 9: Serum CK levels at baseline and 24 hours post calf exercise (Median (range), n = 9) (p > 0.05).

Trial	Pre-CK (U/L)	Post-CK (U/L)
CON	151 (77-364)	232 (103-822)
COMP	169 (63-394)	136 (83-1269)
ICE	127 (61-181)	182 (83-1163)

Calf girths were measured pre and 48 hours post eccentric exercise as a measure of local inflammation. The mean ± SD results for each condition were: CON 37.4 ± 2.9 cm & 37.6 ± 2.9 cm, COMP 37.4 ± 2.9 & 37.6 ± 2.8, and ICE 27.2 ± 2.8 & 37.3 ± 2.6; pre and 48 hours post respectively (Figure 15). A repeated measure ANOVA revealed no significant differences in calf girth between any condition ($F_{5, 40}$ = 2.32, p = 0.61).
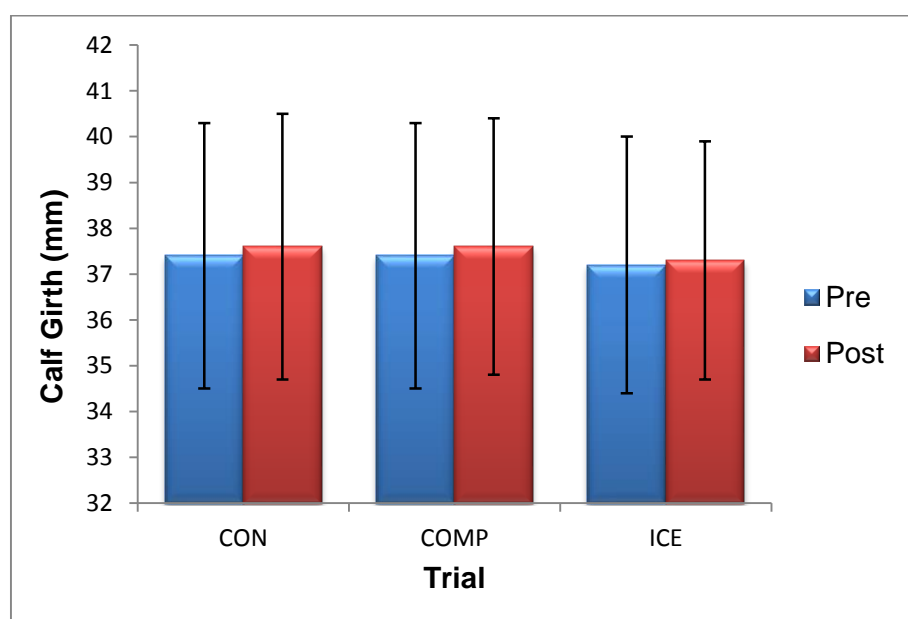
Figure 15: Pre and 48 hours post exercise calf girth (mean ± SD, n = 9) (p > 0.05).

6.4.4 Perceived Muscle Pain; Algometry

Friedman's testing revealed significant differences between conditions for perceived Tibialis anterior pain (X^2_5 = 15.22, p = 0.009). Wilcoxon signed rank tests showed: Tibialis anterior pain was significantly increased after the eccentric muscle damage protocol when compared to the pre measure (p = 0.016), in the CON trial. Post ICE pain was significantly lower (p = 0.031) when compared to post CON pain. There were no other significant differences, in Tibialis anterior pain, between groups (p > 0.05, Table 10). A repeated measures ANOVA also revealed significant differences in perceived calf pain between conditions ($F_{5, 40}$ = 12.71, p = 0.001). Post hoc testing showed an increase (p = 0.012) in post exercise calf muscle soreness in CON when compared to baseline. There were no other significant differences between groups (p > 0.05, Table 10).

Table 10: Pre and 48 hours post exercise algometry pain of the Tibialis anterior (Median (Range)) and Calf muscles (mean ± SD, n = 9).

	CON	COMP	ICE
	Tibialis Anterior		
Pre	0 (0-5)	0 (0-2)	0 (0-4)
Post	1 (0-6)[a]	1 (0-4)	0 (0-3)[b]
	Calf		
Pre	2.7 ± 1.7	2.4 ± 0.8	2.4 ± 1.5
Post	5.4 ± 1.4[c]	4.9 ± 2.2	3.8 ± 1.8

a. Significant difference when compared to Tibialis Anterior pre CON trial (p < 0.05)
b. Significant difference when compared to post CON (p < 0.05)
c. Significant difference when compared to Calf pre CON trial (p < 0.05)

6.4.5 Perceived Muscle Pain; Questionnaire

Perceived muscle pain in the Tibialis anterior, Calf, Hamstrings and Quadriceps was measured using a questionnaire with visual analogue scales (0-10); at baseline, 24, 48 and 72 hours post eccentric exercise.

Tibialis Anterior

Twenty four hours perceived pain of the Tibialis anterior, increased in all trials (CON: 1.3, COMP: 1.2, ICE: 0.5) compared to baseline (Table 11). Friedman's testing revealed significance between groups (X^2_{11} = 30.2, p = 0.001). Wilcoxon post hoc testing showed that the increase in COMP was significant (p = 0.031) but not in CON (p > 0.05). However the coefficient of variation for these pain data were COMP: 106% compared to CON: 121% (Table 11). The increase in Tibialis anterior pain experience in ICE was also non-significant (p = 0.063). Perceived pain was significantly lower at 72 hours compared to 24 hours in both ICE and COMP (p = 0.031). In contrast the 72 hours CON pain rating was not significantly different to 24 hours (p = 0.188).

Calf

Friedman's tests also showed significance between groups for perceived calf muscle pain (X^2_{11} = 58.5, p = 0.001). Wilcoxon signed rank tests revealed that: Pain was significantly increased in CON at 24 (p = 0.002), 48 (p = 0.002) and 72 hours (p = 0.004), compared to baseline (Table 11); however the 72 hours pain was significantly lower (p = 0.023) than the 48 hours rating. Similarly for COMP, 24 (p = 0.004), 48 (p = 0.008) and 72 hours (p = 0.016) pain ratings were significantly increased. For ICE, 24 (p = 0.016) and 48 hours (p = 0.008) pain was significantly increased compared to baseline; however 72 hours pain was not significantly increased (p = 0.125), and was significantly lower than both the 24 (p = 0.016) and 48 hours (p = 0.008) ratings. ICE pain ratings were significantly lower than CON at all time points (24: p = 0.016, 48: p = 0.023, 72 hours: p = 0.016). There was also a trend at all

time points for lower pain in COMP compared to CON, however this was not significant (24: p = 0.068, 48: p = 0.076, 72 hours: p = 0.156) (Table 6).

Hamstrings and Quadriceps

Friedman's analysis was carried out on the perceived pain data for the Hamstrings and Quadriceps; There were no significant differences in perceived muscle pain for either muscle group, between any trials or time points (Hamstrings: X^2_{11} = 11.92, p = 0.37; Quadriceps X^2_{11} = 15.2, p = 0.27) (Table 11).

Table 11: Perceived muscle pain from visual analogue scale (median (range), n = 9)

Trial	Baseline	24 Hours	48 Hours	72 Hours
		Tibialis Anterior		
CON	0 (0-1)	1 (0-5)	1 (0-6)	0 (0-5)
COMP	0 (0-1)	1 (0-4)[a]	0 (0-4)	0 (0-1)[b]
ICE	0 (0-1)	1 (0-1)	0 (0-1)	0 (0)[b]
		Calf		
CON	0 (0-0)	5 (1-7)[a]	6 (1-9)[a]	3 (0-7)[a,c]
COMP	0 (0-0)	2 (0-6)[a]	2 (0-6)[a]	3 (0-4)[a]
ICE	0 (0-1)	2 (0-6)[a,d]	1 (1-7)[a,d]	1 (0-5)[b,c,d]
		Hamstrings		
CON	0 (0-2)	0 (0-3)	0 (0-4)	0 (0-2)
COMP	0 (0-4)	0 (0-5)	0 (0-5)	0 (0-2)
ICE	0 (0-3)	0 (0-6)	0 (0-5)	0 (0-2)
		Quadriceps		
CON	0 (0)	1 (0-4)	1 (0-5)	0 (0-3)
COMP	0 (0)	0 (0-3)	0 (0-4)	0 (0-2)
ICE	0 (0-1)	1 (0-4)	0 (0-1)	0 (0-1)

a. Significant increase compared to baseline (p < 0.05)
b. Significant reduction compared to 24 hours result (p < 0.05)
c. Significantly reduction compared to 48 hours result (p < 0.05)
d. Significantly lower compared CON trial at same time point (p < 0.05)

6.4.6 Perceptual Measures of Recovery

Perceptual measures of recovery were taken at baseline, 24, 48 and 72 hours, using a recovery questionnaire with visual analogue scales (0-10).

Perceived Maximum Ability

A Friedman's test showed significant differences between conditions for perceived maximum ability (X^2_{11} = 37.74, p = 0.001). Post hoc testing revealed that: In all trials perceived maximum ability was reduced at 24 hours (CON: p = 0.008, COMP: p = 0.047, ICE: p = 0.047; Table 12). In CON 48 hours perceived ability was also significantly reduced (p = 0.016) compared to baseline; however, 72 hours ability was significantly increased when compared to 24 (p = 0.037) and 48 hours (p = 0.039). Likewise in ICE, 72 hours ability was significantly increased compared to 24 (p = 0.016) and 48 hours (p = 0.016). In the COMP trial perceived ability increased significantly at 48 (p = 0.016) and 72 hours (p = 0.047) compared to 24 hours. The 48 hours rating was also significantly higher in COMP compared to CON (p = 0.012); there were also non-significant trends at 24 (p = 0.055) and 72 hours (p = 0.09) for COMP ability to be higher than CON. Likewise, there were non-significant trends at 24 (p = 0.055) and 48 hours (p = 0.063) for ICE ability to be higher than CON (Table 12).

Perceived Recovery

Significant differences were revealed between groups for perceived recovery during Friedman testing (X^2_{11} = 42.98, p = 0.001). Wilcoxon signed rank tests showed perceived recovery in CON was significantly lower at all time points (24, 48 & 72 hours: p = 0.008) compared to baseline; however, the 72 hours rating of recovery was significantly increased (p = 0.016) compared to 48 hours. COMP recovery at 24 hours was significantly lower than baseline (p = 0.004); but then significantly improved by 72 hours (p = 0.008). There was a non significant trend at 48 hours for COMP to be more recovered than CON (p = 0.068). Both 24 (p = 0.004) and 48 hours (p = 0.008) ICE ratings were significantly lower than

baseline. 72 hours ICE perceived recovery was significantly improved compared to 24 (p = 0.027) and 48 hours (p = 0.043); and there was also a trend for 72 hours ICE to be greater than 72 hours CON (p = 0.078), however this trend was non-significant. Conversely, 48 hours ICE was significantly increased (p = 0.016) when compared to CON (Table 12).

Sleep and Feeling scale

Friedman's tests revealed no statistical differences between any trials or time points for sleep (X^2_{11} = 5.75, p = 0.89) or feeling scale ratings (X^2_{11} = 14.12, p = 0.227) (Table 12).

Felt arousal

Friedman's testing showed significant differences between groups for felt arousal (X^2_{11} = 20.17, p = 0.43). Wilcoxon signed rank testing revealed that: Felt arousal in ICE was significantly increased at 72 hours compared to baseline (p = 0.031); there was also a non significant trend for increased arousal at 72 hours in COMP compared to baseline (p = 0.063). 72 hours arousal in COMP was significantly higher (p = 0.047) than CON; there was a trend for 72 hours arousal to also be higher in ICE than CON (p = 0.063), however this was not significant (Table 12).

Perceptions of Interventions

Compression garment comfort was rated by each participant after use (COMP, 7.1 ± 2.4; ICE, 7.2 ± 2.0). A paired t-test revealed there was no significant difference in CG comfort between trials (t_8 = 0.263, p = 0.799). Participants also rated how effective they felt the ice protocol had been in aiding recovery and reducing muscle pain, at 24 hours post exercise; the mean rating out of 10 was 8.3 ± 1.2.

Table 12: Perceived maximum performance, sleep, recovery, feeling scale and felt arousal (median (range), n = 9)

Trial	Baseline	24 Hours	48 Hours	72 Hours
	Perceived Maximum Performance Ability			
CON	90 (80-100)	70 (50-90)[a]	60 (30-100)[a]	80 (40-100)[b,c]
COMP	90 (70-100)	80(60-90)[a]	90 (70-100)[b,d]	100 (70-100)[b]
ICE	90 (80-100)	80 (60-90)[a]	80 (60-90)	90 (70-100)[b,c]
	Sleep			
CON	8 (4-10)	8 (4-10)	9 (3-10)	8 (6-10)
COMP	9 (4-10)	9 (4-10)	9 (5-10)	8 (6-10)
ICE	8 (5-10)	8 (4-10)	8 (5-10)	9 (6-10)
	Perceived Recovery			
CON	10 (7-10)	5 (1-9)[a]	5 (1-10)[a]	7 (2-10)[a,c]
COMP	10 (7-10)	7 (0-10)[a]	9 (0-10)	8 (6-10)[b]
ICE	10 (7-10)	7 (2-10)[a]	7 (4-10)[a,d]	8 (6-10)[b,c]
	Feeling Scale			
CON	3 (-1-5)	3 (-2-5)	3 (-3-4)	3 (1-5)
COMP	3 (0-5)	3 (2-4)	4 (2-4)	4 (2-5)
ICE	2 (1-5)	3 (1-4)	3 (1-4)	4 (2-5)
	Felt Arousal			
CON	4 (2-5)	4 (3-5)	4 (1-6)	4 (3-5)
COMP	4 (2-6)	4 (3-6)	5 (2-6)	5 (4-6)[e]
ICE	4 (2-6)	4 (3-5)	4 (3-5)	4 (4-6)[a]

a. Significantly lower than at baseline (p < 0.05).
b. Significantly higher than 24 hours (p < 0.05).
c. Significantly higher than 48 hours (p < 0.05).
d. Significantly higher than 48 hours CON (p < 0.05).
e. Significantly higher than at 72 hours CON (p < 0.05).

6.5 Discussion

The aims of this study were: to assess the effect of compression garments and ice treatment on perceptual and physiological measures of recovery, and to test various mechanisms by which CGs and ice are suggested to improve recovery and subsequent performance. This study found significant reductions in perceived pain in the ICE trial compared to the control. There were also increases in perceived recovery and perceived maximum performance ability at certain time points in the COMP and ICE trials. However, there were no significant differences in running performance, muscle damage or calf girths 48-hours after eccentric exercise compared to baseline.

6.5.1 Perceptual Measures of Recovery

Perceived maximum ability was significantly lower in all trials 24-hours post exercise compared to baseline. The COMP trial recovered by 48 hours; while after both CON and ICE it took 72 hours for perceived maximum ability to increase significantly from the 24 hours result. After 48 hours perceived ability was significantly higher in the COMP trial compared to CON. Furthermore, perceived maximum ability 72 hours post exercise in CON was still significantly lower than baseline, but this was not the case after COMP or ICE.

Perceived recovery was significantly less in all trials 24 hours after the eccentric exercise when compared to baseline. At 48 hours post exercise the ICE trial participants perceived themselves to be significantly more recovered than after the CON trial; the COMP trial showed a trend towards this result. Felt arousal was also significantly lower at 72 hours in the CON trial when compared to the COMP trial.

These results suggest that CGs and ice treatments during recovery can give an increased perception of recovery and maximum ability. However, these results are limited to certain time points within certain trials and the results for perceived recovery and perceived maximum ability do not seem to support one another. MacRae et al. (2011) suggested that

the subjective nature of perceived variables and high inter-subject variance make reliable findings difficult to achieve; despite this, they concluded that the overall effect of CGs on perceptual ratings of recovery tended to be better or at least no worse. Kraemer et al. (2010) showed increases in some psychological measures of recovery with the use of full body compression. However these benefits were accompanied by improvements to some physiological variables and performance measures; the results of the current study showed improvements in perceptual measures and not in any physiological or biological variables. Similarly, Pruscino et al. (2013), found psychological benefits of CG use to recovery with no physiological effects. It has been proposed that reduced voluntary muscle activation may contribute to the reduced muscle strength seen after eccentric exercise even when muscle damage is not present (Hill et al., 2013). Hill et al., (2013) went on to suggest that interventions such as CGs may increase recovery in two ways: Firstly, they may attenuate the physiological effect of the exercise; secondly, they may increase restoration of central factors that may result in increased voluntary activation, irrespective of physical changes. This is supported by the findings of Duffield et al. (2007), who found that an increased feeling of vitality was concurrent with increases in repeat performance, in the intervention trials. Likewise the current study observed increases in felt arousal in the treatment conditions but not in the control; which correspond to other increases in perceptual variables. Results from previous studies and reviews suggest that perceived variables of recovery are affected by the lack of blinding of interventions and participant expectations of results; causing perceptual results to be affected by the placebo effect. Kraemer et al. (1998) compared the use of two compression garments to a loose fitting gym short; they asked participants to rate the perceived benefit of each intervention, and found that increases in repeated jump performance, matched the expected benefit as rated by the participant. Any benefit to recovery or repeat performance, whether caused by a placebo effect or otherwise, is nonetheless a benefit (MacRae et al., 2011). However, if the only benefits of CGs are due to the placebo effect, then there is no need for graduated compression, zoning, development of new weave types and materials, or the production of garments that can cost in excess of

£150; as these benefits could be delivered by any tight fitting garments. Furthermore if, as was shown in this study, the improvements to perceptual variables do not cause improved repeat performance, then this is of no benefit to the athlete.

6.5.2 Muscle Soreness

The algometry pain rating for the Tibialis anterior was significantly higher 48 hours after the eccentric exercise when compared to baseline, in the control group; however, there was no significant increase in pain in the COMP or ICE trials. The 48-hours post exercise pain rating was also significantly lower in the ICE trial than in CON. Perceived soreness in the Tibialis anterior, as rated in the questionnaire, significantly decreased by 72 hours in both the COMP and ICE trials. However, at 72 hours pain remained elevated in the control group. In the calf, algometry pain at 48 hours was significantly increased in the control trial but not in the COMP and ICE trials. In the questionnaire calf pain was significantly increased at all-time points when compared to baseline, except the 72 hours ICE result; the ICE trials pain ratings were also significantly lower than the control at all-time points except baseline. The COMP group showed a non-significant trend towards reduced perceived pain at all-time points except baseline when compared to the control.

These results show that the use of CGs and compression plus ice gave reductions in pain perception compared to the control (no intervention). This result is supported by many of the previous studies that have examined CGs effect on pain (Born et al., 2013; Hill et al., 2013; Jakeman et al., 2010; Kraemer et al., 2001; Perry et al., 2008). Many studies that have examined the effect of ice on post exercise muscle pain have also found beneficial results (Easton and Peters, 1999; Lane and Wenger, 2004; Rowsell et al., 2009). The use of ice has been shown to reduce nerve conduction which is suggested to explain the reduced muscle soreness found in many studies (MacAuley, 2001). However, in the current study reductions in muscle soreness were present for up to 72 hours when compared to the control. As the ice therapy was only administered on day 1, immediately post exercise, it is unlikely that

nerve conduction could be the mechanism by which pain was affected over such a long time period, without repeat ice treatments. Additionally pain reductions were experienced in the COMP group who would not have benefitted from a reduction in nerve conduction. Therefore it is unlikely that nerve conduction is the mechanism by which these pain reductions were achieved.

The current study found no difference in muscle damage or inflammation 48-hours post exercise, which would suggest there was no physiological cause for the reduced muscle pain. Previous research has suggested that there is a psychological effect of CGs on recovery and performance often independent of blood or other physiological markers that indicated any effect (Pruscino et al., 2013). MacRae et al. (2011), suggested that reduced perception of pain seen after wearing CGs is likely to be due to the placebo effect. Likewise, in a study looking at ice therapy; a group that received 20 minutes of cryotherapy perceived significantly less pain 48 hours after the exercise, when compared to a control. However there was no difference found in any other variable including: blood CK levels, maximum isometric torque or hamstring length (Oakley et al., 2013). Furthermore, Leader et al. (2012) conducted a meta-analysis that showed ice was effective at reducing DOMS; however, the effects of ice on recovery of muscle function were inconclusive. It has been suggested in recent research that ice may delay markers of post exercise fatigue; for example muscle damage, inflammation and decreased muscle activity, rather than reducing them (Tseng et al., 2013). It is unlikely that this is the case in the current study, with combined CGs and ice, as the data showed that muscle soreness peaked in all groups at 48 hours irrespective of the intervention received; with reductions in the peak muscle pain in the COMP and ICE trials when compared to CON. This would suggest that the reductions in perceived pain were caused by a dampening of physiological or perceptual responses to exercise rather than a delay in those responses.

Both CGs and ice have been shown to have beneficial effects on pain perception; however as these effects are often shown independent of a physiological benefit, it is most likely that

these perceptual benefits are the result of the placebo effect. It currently remains unclear whether the perceptual benefits of knee high compression and ice are sufficient to cause an improvement in recovery. Further research is required to explore the effect of CGs and ice on long term adaptations, as presently the positive psychological effects of these treatments are not sufficient to justify their use, especially if they may have negative effects on training adaptations and future performance.

6.5.3 Repeat Performance

No significant difference was found in any trial for 1 km run time 24 hours after the eccentric exercise, when compared to baseline. These results may indicate that the exercise was not sufficient to induce enough fatigue to hinder performance. However, the average RPE for the eccentric calf exercise was over 19, which implies it was close to maximal and eccentric exercise has been shown to be the most effective form of exercise to decrease muscle function (Carling et al., 1995; Kraemer et al., 2001) and increase muscle soreness (Davies et al., 2009). The participants in the current study also reported increases in muscle soreness and reductions in perceived ability, which would imply the exercise was fatiguing, however this was not sufficient to impact the subsequent running performance. It is possibly that as the calf musculature is not greatly involved in the major movements of the legs during running, for example flexion and extension of the hips and knee, athletes are able to ignore any discomfort in the calf caused by the eccentric exercise. Therefore, it may be concluded that fatigue of the calf muscles alone is not sufficient to significantly affect performance of dynamic movements involving the whole body or lower body. If this study had employed performance testing specific to the calf musculature at 48 hours post eccentric exercise, for example maximal voluntary contractions (Perry et al., 2008), there may have been a significant reduction in performance, caused either by reduced motivation (Hill et al., 2013) or structural damage to the muscle fibres (Clarkson and Hubal, 2002).

Previous studies that have observed significant differences in repeat performance have used protocols that have fatigued the larger muscle groups in the legs, for example: two 30 minute maximal cycling bouts (Driller et al., 2013), maximum repeated jump performance (Jakeman et al., 2010), rugby match simulation including sprints and jumps (Gill et al., 2005) and repeated sprints and jumps (French et al., 2008). All of these studies also used full length compression tights, which compress the larger muscle groups of the lower body. However, despite this treatment affecting a larger muscle mass, some studies were still unable to show a statically difference to recovery compared to a control (French et al., 2008). Born et al. (2013) found a small positive effect of compression on recovery of strength and power tasks (ES = 0.10); such as peak leg power, maximal distance throwing and vertical jump height. Born and colleagues concluded that CGs provide a small improvement in recovery after muscle-damaging exercise protocols; and suggested this was due to enhanced lymphatic outflow, thus reducing post exercise muscle swelling and pain. Hill et al. (2013), found moderate reductions in decrement to strength and power and a reduction in CK, when compression was worn during or during and after intense exercise. However, there were no studies identified that have used exercise protocols or compression that only affect the calf musculature. Therefore, it is still unclear whether knee high compression garments are able to have a major effect on repeat exercise performance in most sports.

6.5.4 Muscle Damage

Creatine kinase was measured pre and 48-hours post eccentric exercise. There was no significantly difference in any trial after 48 hours compared to baseline, and there was no difference between groups at either time point. A significant rise in serum CK post exercise would be an indication that the exercise had caused an increase in muscle damage (Brancaccio et al., 2007). As a significant increase in CK was not found either; i) the eccentric exercise protocol did not induce muscle damage in the calf or ii) CK was not a sensitive enough measure to pick up the muscle damage that was present.

As suggested above, it may be that the eccentric protocol was not sufficient to induce significant muscle damage, this would be supported by the results that there was no decrement to run performance 48-hours post exercise. It is possible that the calf muscles are resilient to muscle damage due to the higher frequency of eccentric loading in normal movements, when compared to the muscles of the upper leg. However, the average RPE was greater than 19 during the calf exercise, indicating that the exercise was near maximal and eccentric exercise has been shown to be the most effective form of exercise at causing muscle damage (Cheung et al., 2003; Clarkson & Hubal, 2002; Clarkson & Tremblay, 1988; Friden et al., 1983; Nosaka & Clarkson, 1996). Furthermore as shown in the previous section there were significant increase in muscle pain, this suggest that some muscle damage was present. Therefore it may be that there was some localised muscle damage but, that damage was not able to be measured using CK. The CK data from the current study showed high inter and intra subject variance similar to the results shown in previous studies (Creasy, 2008). This high variance together with the small size of the muscle area affected by the exercise may have made a significant serum CK result impossible, even if muscle damage was present. The current research that have shown CGs to have an effect on CK have used protocols that engage all major muscle groups of the legs; for example, maximal repeated jump performance (Jakeman et al., 2010), drop jumps (Davies et al., 2009), sprints and jumps (Duffield et al., 2007; French et al., 2008; Gill et al., 2005) and whole body resistance training (Kraemer et al., 2010). No studies were found that have shown CK increases with calf exercise alone or that identified reduced CK with knee high CG use.

It is possible that if a more muscle specific method of measuring muscle damage or muscle function was used, that any localised muscle damage to the calf could be measured. For example previous research has used maximal voluntary contraction (MVC) to measure muscle damage. Perry et al. (2008) conducted a study during which participants had one leg treated with CGs and the other acted as a control. Serum CK measurements were not used

as it would have been impossible to distinguish between legs. Instead MVCs were used in each leg to compare muscle function to baseline. A more specific method of measuring localised muscle damage may have yielded more valid results; however, as repeat performance was unaffected, any muscle damage present was insufficient to affect recovery. Therefore it remains unclear whether reduced muscle damage is a mechanism by which knee CGs and ice therapy may improve recovery; although the results from this study may suggest it is unlikely.

6.5.5 Inflammatory Response to Exercise

There was no significant difference in calf girth 48-hours post-exercise in any group compared to baseline. As there was not a significant amount of muscle damage caused by the eccentric exercise, it would follow that there would not be a large inflammatory response. However, it is a possibility that the method used to measure inflammation was not sensitive enough. As discussed in chapter 2.8.2, although muscle girths are used in many studies (Driller et al., 2013: French et al., 2008) as a convenient measure of localised swelling, this measurement is not sensitive enough to identify inflammation on a cellular level. Furthermore, perhaps there was localised inflammation that this method was unable to measure. This was supported by the increase in post exercise muscle soreness seen in all trials suggested to be caused by ROS released by immune cells during the inflammatory response (Armstrong et al., 1984). However as CK was not significantly increased and repeat performance was unaffected, it would suggested that any localised inflammation that may have been present was not enough to affect recovery.

It is also possible that the eccentric protocol was not sufficient to elicit a significant amount of inflammation in the calf muscles, because these muscles are more accustomed to eccentric movements, than the muscle of the upper leg, and therefore have adapted to make them more resilient to subsequent muscle damage and inflammation (French et al., 2008). The majority of studies looking at post exercise inflammation have used exercise protocols

affecting the thigh muscles; for example, downhill walking (Borras et al., 2011; Trenell et al., 2006). Only one study was identified that measured inflammation directly in the calves (Driller et al., 2013). This study measured thigh and calf muscle girths immediately post maximal cycling exercise and then again after a 60 minute recovery protocol. While the effect in the thigh musculature was far greater than in calf, both showed a decrease in girth after the 60 minute recovery with CGs. However, inflammation as a result of exercise induced muscle damage has been shown to peak between 24 and 48 hours post-exercise (Strachan et al., 1984). Therefore, it is likely that the differences in muscle girths measured in this study were due to a decrease in superficial blood pooling rather than inflammation caused by exercise induced muscle damage.

It has also been suggested that CGs have no effect on muscle circumferences and that girth measurement does not correlate to muscle pain (MacRae et al., 2011). Therefore, the role of knee high compression and ice therapies in the reduction of inflammation remains unclear. To allow further exploration into this mechanism, a more sensitive method of inflammation measurement is required, to assess local cellular inflammation in the affected muscle, for example muscle biopsies (Clarkson and Hubal, 2002).

6.6 Conclusion

The maximal eccentric exercise caused significant increases in perceived pain and reductions in perceived ability and recovery. However the exercise did not cause a significant increase in serum CK or inflammation markers; and despite increases in post exercise calf muscle pain, repeat performance was unaffected. Both CGs and compression with ice had positive effects on the perception of: pain, recovery and maximum ability post eccentric exercise. However, as these perceptual benefits were not accompanied by any physiological improvements, the placebo effect was most likely the cause. Furthermore, as the benefits to the perceptual responses to exercise did not affect repeat performance in the current study; it is still unclear whether these perceptual differences are of benefit to an athlete's performance. Further research is required to examine the role of muscle damage and inflammation as mechanisms for increased recovery when using knee high CGs and ice as the current literature is equivocal regarding treatments affecting the lower leg.

Chapter 7: Discussion

7.1 General Discussion

The aims of these studies were: to explore the effect of different applications of knee high CGs on physiological, biomechanical and perceptual measures of athletic performance and recovery (chapter 5); and to examine the effect of knee high CG and ice therapy on recovery after eccentric damage of the calf (chapter 6). Chapter 5 showed a reduction in muscle displacement with CG use however no differences were found in performance. However, it was concluded that the 10 km time trial used was not sufficient to induce a measurable amount of muscle damage or inflammation, in the recreationally trained athletes used. Chapter 6 showed improvements in perceptual responses following eccentric exercise, with CGs and combined CG and ice treatment. However, the eccentric exercise did not elicit a physiological response and no differences were measured in repeat 1 km running performance. Therefore, the perceptual responses measured in chapter 6 were most likely elicited by the placebo effect. Therefore, the current studies were unable to support the use of CGs and ice for performance or recovery.

7.1.1 Exercise Performance

This study found no differences in 10 km performance time, heart rate, RPE or blood lactate concentration with CGs. It has been suggested that increased venous return and blood flow with CG use can reduce HR and increase metabolite removal (Creasy 2008); although because neither HR or blood lactate concentration were affected and performance time remained the same, the results of this study do not support increased blood flow as a benefit of knee high CGs during exercise, in trained individuals. This is possibly because the skeletal muscle pump surpasses any possible effect on blood flow provided by CGs (Bringard et al., 2006a). It has also been suggested that CGs can increase muscle oxygenation (Driller et al., 2013) or increase economy of oxygen use (Bringard et al., 2006b) during exercise. If CGs have an effect on oxygen usage, then hypoxia should be reduced

when compared to exercise of the same intensity without CGs. This study has shown that both exercise intensity (run time, HR and RPE) and hypoxia (lactate) remained constant with and without CGs. Therefore, this study found no evidence to support the mechanism of increased oxygen uptake; and this mechanism has now been largely discounted in recent research in trained individuals (Ali et al., 2010; Bernhardt et al., 2005; Born et al., 2013).

Despite there being no performance improvement found in this study (chapter 5), results of the muscle oscillation test showed reduced muscular displacement. Perhaps it is possible that over a longer event for example a marathon or ultra-marathon this stabilisation of the muscle could increase running economy and potentially improve performance or reduce effort. Further research is necessary to explore the role of reduced muscle oscillations, with knee high CGs, on running economy over longer events.

7.1.2 Exercise Recovery

In Chapter 6, markers of perceived recovery, including pain, showed some improvements. However, there were also contradictions; for example, perceived maximum ability showed benefits with compression but not with ice, while perceived recovery showed improvements with ice but not with compression. This is common as subjective measurements have been shown to have a potential for high variance, which may affect reliability of results (Burnett et al., 2010). The ability of CGs to affect perceived recovery was further questioned by the results of chapter 5; which showed increases in muscle pain in all groups 24 hours post exercise, and application of compression did not affect post exercise pain levels. Furthermore, while improvements in perceived recovery were measured (chapter 6), no corresponding improvements in repeat performance were experienced in any trial. Measurement of recovery through physiological variables (muscle damage and inflammation) was complicated in the current studies, by high variance and low reliability of the data. Chapter 5 used a form of ecologically valid exercise (10 km run), that was familiar to the recreationally trained athletes. This combined with adaptations to training within those

athletes (Clarkson & Hubal, 2002), likely made any increases in muscle damage or inflammation too small to be measure with the markers used. Chapter 6 also showed no increases muscle damage or inflammation post exercise. Unlike the exercise in chapter 5, the eccentric exercise used was not familiar to the participants; however, due to the indiscriminate nature of the makers used, a focused exercise protocol was necessary to avoid muscle damage of the larger muscles of the legs. This meant that established methods of inducing eccentric muscle damage and inflammation, such as downhill walking could not be used. A more sensitive and specific measurement tool, for example muscle biopsies (Borras et al., 2011), may be needed to show differences in these variables with knee high compression, especially when in a trained population. Despite this, the consensus of the previous research is that CGs and ice have a positive effect on perceived pain and recovery (Leader et al., 2012; Hill et al., 2013). However, research is subject to a lack of placebo controls and due to the lack of placebo controls and the absence of physiological benefits with the use of knee high CGs and ice; it is concluded that the psychological benefits of CGs and ice were caused by the placebo effect. Additionally, any recovery interventions that are shown to reduce muscle damage or inflammation require further research to examine the effects on long term adaptations to exercise, to ensure there are no deleterious effects.

7.2 Limitations

There were a number of limitations that affected these studies: As with all previous studies examining CGs, the participants were not blinded to the trial they were participating in or the intervention they were receiving. There was also no placebo interventions as placebo trials for this type of study are very hard to design and conduct. In previous studies, non-compressive garments have been used; However, compression as low as 7.6 mmHg has been shown to elicit a physiological response in healthy participants when standing (Kraemer et al., 2001) and participants can consistently identify low compressive and non-

compressive garment (Ali et al., 2011; Creasy, 2008). The use of a deception placebo, for example mock ultrasound, could be useful in future studies to overcome this problem.

High variance in CK and CRP results made it difficult to find statistically significant differences between groups; this effect could have been reduced if larger cohorts were tested, if untrained participants were used or if more specific and sensitive measurements were used, for example muscle biopsies. Furthermore, measures of maximal voluntary contractions and maximum countermovement jump heights could have been used to show any reduction in force production post exercise. Reduced force is considered to be one of the most valid and reliable indirect measures of exercise induced muscle damage in humans (Clarkson & Hubal, 2002).

When measuring muscle oscillations with CG use, the retro-reflective marker on the belly of the calf muscle was stuck on top of the compression garment. It is unknown the effect that that might have on the results collected, although it is possible that movement of the muscle could be missed through the compression. Previous research that has examined muscle oscillation using high speed cameras has also suffered from this limitation (Borras et al., 2011; Doan et al., 2003; Kraemer et al., 1997). Unfortunately, due to time constraints, it was not possible to do a validation or reliability test on the camera system before data collection, although calibration was performed. Future research could work to address some of these issues concerning validation.

In chapter 6, participants were required to complete a second 1 km run 48 hours after the eccentric muscle damage. This second run was undertaken at this time to limit the number of visits the participants made to laboratory and reduce dropout. While this run may have influenced the 72 hours measures of perceived recovery and pain, this was conducted by all participants in all trials therefore the comparison of the 72 hours data was still valid. Furthermore, the recovery questionnaire was not validated, however many of the questions used were taken from previous studies on the effect of compression garments on recovery

and the cross over design of the study allowed the variance in each participant's perceptions to be assessed.

Finally, the pressure elicited by the compression used in these studies was 45 mmHg at the ankle and 35 mmHg at the base of the knee, as measured on a static body form by the manufacturer. This level of compression is above that recommended by Lawrence and Kakkar (1980) for augmenting blood flow; however, no research has been conducted to show the effect of different levels of compression on any other variable during exercise. In chapter 6, the compression delivered by the garment was also likely to be increased when the ice insert was placed between the two layers of the garment; due to greater stretching of the outer layer, this increased pressure could be a confounding variable and may affect the results of such an intervention. In future research, it would be useful to measure the pressure of the garments on each individual, during each intervention, in an attempt to keep within the recommended range and more accurately report the pressure provided by the garments for comparison with other research.

7.3 Conclusion

Knee high CGs had no effect on 10 km running performance, HR, RPE, lactate, muscle damage, inflammation or perceived pain. It is possible that reduced muscular displacement, as found in chapter 5, could increase running efficiency and decrease muscle damage over longer events; however, the current study was unable to present results to support this hypothesis. The use of CGs and CGs with ice elicited decreases in perceived muscle pain and increases in perceived recovery; however, these benefits were mixed and contradictory and were not accompanied by any physiological benefits or benefits to repeat performance. Therefore, it was concluded that the psychological benefits of ice and compression found in this study and others was most likely caused by the placebo effect. Further research is necessary to explore whether knee high compression is able to exert an effect on any markers of performance or recovery beyond the placebo effect; in both trained and untrained

individuals. This will require testing procedures that incorporate placebo trials and sufficient

blinding of the participant, possibly utilising a deception placebo.

Chapter 8: References

Abraham, P., Fromy, B., Merzeau, S., Jardel, A., & Saumet, J. L. (2001). Dynamics of local pressure-induced cutaneous vasodilation in the human hand. *Microvascular Research, 61*(1), 122-129.

ACSM's Guidelines for Exercise Testing and Prescription (2006). 7 ed: Philadelphia: Lippincott. Williams & Wilkins.

Agu, O., Hamilton, G., & Baker, D. (1999). Graduated compression stockings in the prevention of venous thromboembolism. *British Journal of Surgery, 86*(8), 992-1004.

Ali, A. Caine, M. P., & Snow, B. G. (2007). Graduated compression stockings: physiological and perceptual responses during and after exercise. *Journal of Sports Sciences, 25*(5), 413-419.

Ali, A., Creasy, R. H., & Edge, J. A. (2010). Physiological effects of wearing graduated compression stockings during running. *European Journal of Applied Physiology, 109*(6), 1017-1025

Ali, A., Creasy, R. H., & Edge, J. A. (2011). The effect of graduated compression stockings on running performance. *Journal of Strength and Conditioning Research, 25*(5),1385-92.

Amelink, G. J., & Bar, P. R. (1986). Exercise-induced muscle protein leakage in the rat: Effects of hormonal manipulation. *Journal of Neurological Science, 76*(1), 61–68.

Apple, F. S., & Rhodes, M. (1988). Enzymatic estimation of skeletal muscle damage by analysis of changes in serum creatine kinase. *Journal of Applied Physiology, 65*(6), 1598-2600.

Armstrong, R. B. (1984). Mechanisms of exercise-induced delayed onset muscular soreness: a brief review. *Journal of Medical Science and Sports Exercise, 16*(1), 529 538.

Armstrong, R. B., Warren, G. L. & Warren, J. A. (1991). Mechanisms of exercise-induced muscle fibre injury. *Sports Medicine, 12*(1), 184-207.

Ascensao, A., Leite, M., Rebelo, A. N., Magalhäes, S., & Magalhäes, J. (2011). Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. *Journal of Sports Sciences, 29*(3), 217-225.

Bailey, D. M., Erith, S. J., Griffin, P. J., Dowson, A., Brewer, D. S., Gant, N., & Williams, C. (2007). Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *Journal of Sports Sciences, 25*(11), 1163-1170.

Bakken, B. (2011). The influence of lower body compression clothing on markers of running economy during submaximal treadmill running (Doctoral dissertation, Montana State University-Bozeman, College of Education, Health & Human Development).

Bar, P. R., Dressen, M., & Rikken, B. (1985). Muscle protein leakage after strenuous exercise: Sex and chronological differences. *Journal of Neuroscience, 22*(1), 288-290.

Baron, J. F., Decaux-Jacolot, A., Edouard, A., Berdeaux, A., & Samii, K. (1986). Influence of venous return on baroreflex control of heart rate during lumbar epidural anesthesia in humans. *Anesthesiology, 64*(2), 188-193.

Bassett, D. R., & Howley, E. T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine and science in sports and exercise, 32*(1), 70-84.

Beedie, C. J., Stuart, E. M., Coleman, D. A., & Foad, A. J. (2006). Placebo effects of caffeine on cycling performance. *Medicine and Science in Sports and Exercise*, *38*(12), 2159-2164.

Benedetti, F., Mayberg, H. S., Wager, T. D., Stohler, C. S., & Zubieta, J. K. (2005). Neurobiological mechanisms of the placebo effect. *The Journal of Neuroscience*, *25*(45), 10390-10402.

Benko, T., Kalik, I. & Chetty, M. N. (1999). The physiological effect of graded compression stockings on blood flow in the lower limb: an assessment with colour doppler ultrasound. *Phlebology, 14*(1), 17-20.

Bernhardt, S., & Anderson, T. (2005). Influence of moderate prophylactic compression on sport performance. *Journal of Strength and Conditioning Research, 19*(2), 292-297.

Berry, M. J., & Bailey, S. P. (1990). The effects of elastic tights on the post-exercise response. *Canadian Journal of Sports Science, 15*(1), 244–8.

Berry, M. J., & McMurray, R. G. (1987). Effects of graduated compression stockings on blood lactate following an exhaustive bout of exercise. *American Journal of Physical Medicine & Rehabilitation, 66*(3), 121-132.

Bleakley, C., McDonough, S., Gardner, E., Baxter, D. G., Hopkins, T. J., Davison, G. W., & Costa, M. T. (2012). Cold-water immersion (cryotherapy) for preventing and treating muscle soreness after exercise. *Sao Paulo Medical Journal, 130*(5), 348-348.

Bleakley, C. M., McDonough, S. M., & MacAuley, D. C. (2006). Cryotherapy for acute ankle sprains: a randomised controlled study of two different icing protocols. *British Journal of Sports Medicine, 40*(8), 700-705.

Bleakley, C. M., O'Connor, S. R., Tully, M. A., Rocke, L. G., MacAuley, D. C., Bradbury, I., Keegan, S., & McDonough, S. M. (2010). Effect of accelerated rehabilitation on function after ankle sprain: randomised controlled trial. *BMJ, 340.*

Bochmann, R. P., Seibel, W., Haase, E., Hietschold, V., Rödel, H., & Deussen, A. (2005). External compression increases forearm perfusion. *Journal of Applied Physiology, 99*(6), 2337-2344.

Born, D. P., Sperlich, B., & Holmberg, H. C. (2013). Bringing light into the dark: effects of compression clothing on performance and recovery. *International Journal of Sports Physiology and Performance, 8*(1), 4-8.

Borràs, X., Balius, X., Drobnic, F., Til, L., Turmo, A., & Valle, J. (2011). Effects of lower body compression garment in muscle oscillation and tissular injury during intense exercise. *ISBS-Conference Proceedings Archive, 1*(1).

Bottoms, L., Buscombe, R., & Nicholettos, A. (2014). The placebo and nocebo effects on peak minute power during incremental arm crank ergometry.*European Journal of Sport Science, 14*(4), 362-367.

Bringard, A., Denis, R., Belluye, N., & Perrey, S. (2006). Effects of compression tights on calf muscle oxygenation and venous pooling during quiet rest in supine and standing position. *Journal of Sports Medicine and Physical Fitness, 46*(4), 548.

Brancaccio, P., Maffulli, N., & Limongelli, F. M. (2007). Creatine kinase monitoring in sport medicine. *British medical bulletin, 81*(1), 209-230.

Bringard, A., Perrey, S., & Belluye, N. (2006). Aerobic energy cost and sensation responses during submaximal running exercise – Positive effects of wearing compression tights. *International Journal of Sports Medicine, 27*(1), 373–378.

Brooks, G. A., Dubouchaud, H., Brown, M., Sicurello, J. P., & Butz, C. E. (1998). Role of mitochondrial lactate dehydrogenase and lactate oxidation in the intracellular lactate shuttle. *Journal of Applied Physiology, 96*(3), 1129-1134.

Bundey, S., Crawley, J. M., Edwards, J. H., & Westhead, R. A. (1979). Serum creatine kinase levels in pubertal, mature, pregnant, and postmenopausal women. *Journal of medical genetics, 16*(2), 117-121.

Byrnes, W. C., Clarkson, P. M., White, J. S., Hsieh, S. S., Frykman, P. N., & Maughan, R. (1985). Delayed onset muscle soreness following repeated bouts of downhill running. *Journal of Applied Physiology, 59*(1), 710-715.

Carling, J., Francis, K., & Lorish, C. (1995). The effects of continuous external compression on delayed-onset muscle soreness (DOMS). *International Journal of Rehabilitation Health, 1*(1), 223–235.

Chatard, J. C. & Atlaoui, D. (2004). Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. *European Journal of Applied Physiology, 93*(3), 347–352.

Chesterton, L. S., Foster, N. E., & Ross, L. (2002). Skin temperature response to cryotherapy. *Archives of Physical Medicine and Rehabilitation*, *83*(4), 543-549.

Cheung, K., Hume, P. A., & Maxwell, L. (2003). Delayed onset muscle soreness: Treatment strategies and performance factors. *Journal of Sports Medicine, 33*(2), 145 - 164.

Clanton, T.O. & Coupe, K.J. (1998) Hamstring strains in athletes: diagnosis and treatment. *Journal of the American Academy of Orthopaedic Surgeons, 6*(1), 237-248.

Clarkson, P. M., & Hubal, M. J. (2002). Exercise-induced muscle damage in humans. *American Journal of Physiology, 81*(1), 52–69.

Clarkson, P. M., Kearns, A. K., Rouzier, P., Rubin, R., & Thompson, P. D. (2006). Serum creatine kinase levels and renal function measures in exertional muscle damage. *Journal of Sports and Exercise Science, 38*(4), 623–627.

Clarkson, P. M., Byrnes, W. C., McCormick, K. M., Turcotte, L. P., & White, J. S. (1986). Muscle soreness and serum creatine kinase activity following isometric, eccentric, and concentric exercise. *International Journal of Sports Medicine, 7*(03), 152-155.

Clarkson, P. M. & Tremblay, I. (1988). Exercise induced muscle damage, repair, and adaptation in humans. *Journal of Applied Physiology, 65*(1), 1-6.

Close, G. L., Ashton, T., Cable, T., Doran, D., & MacLaren, D. P. (2004). Eccentric exercise, isokinetic muscle torque and delayed onset muscle soreness: the role of reactive oxygen species. *European Journal of Applied Physiology, 91*(5-6), 615-621.

Connolly, D. A. J., Sayers, S. P., & McHugh, M. P. (2003). Treatment and Prevention of Delayed Onset Muscle Soreness, *Journal of Strength and Conditioning Research, 17*(1), 197-208.

Cook, D. B., O'Connor, P. J., Eubanks, S. A., Smith, J. C., & Lee, M. I. N. G. (1997). Naturally occurring muscle pain during exercise: assessment and experimental evidence. *Medicine and science in sports and exercise*, *29*(8), 999-1012.

Creasy, R. (2008). Performance, physiological, and perceptual effects of wearing graduated compression stockings during running. Master's thesis.

Crystal, N. J., Townson, D. H., Cook, S. B., & LaRoche, D. P. (2013). Effect of cryotherapy on muscle recovery and inflammation following a bout of damaging exercise. *European Journal of Applied Physiology, 113*(10), 2577-2586.

Dalen, J. E. (2002). Pulmonary embolism: what have we learned since Virchow? Natural history, pathophysiology, and diagnosis. *CHEST Journal, 122*(4), 1440-1456.

Dascombe, B. J., Hoare, T. K., Sear, J. A., Reaburn, P. R., & Scanlan, A. T. (2011). The effects of wearing undersized lower-body compression garments on endurance running performance. *Journal of Applied Physiology, 6*(1), 82-85.

Davies, C. T. M., & White, M. J. (1981). Muscle weakness following eccentric work in man. *European Journal of Physiology, 392*(2), 168-171.

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

Doan, B. K., Kwon, Y. H., Newton, R. U., Shim, J., Popper, E., Rogers, R. A., Bolt, L. R., Robertson, M., & Kraemer, W. J. (2003). Evaluation of a lower-body compression garment. *Journal of Sports Sciences, 21*(4), 601–610.

Doxey, G. E. (1987). Assessing quadriceps femoris muscle bulk with girth measurements in subjects with patellofemoral pain. *Journal of Orthopaedic & Sports Physical Therapy, 9*(5), 177-183.

Driller, M. W., & Halson, S. L. (2013). The effects of lower-body compression garments on recovery between exercise bouts in highly-trained cyclists. *Journal of Science and Cycling, 2*(1), 45-50.

Drust, B., Waterhouse, J., Atkinson, G., Edwards, B., & Reilly, T. (2005). Circadian rhythms in sports performance-an update. *Chronobiology international, 22*(1), 21-44.

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

Duffield, R., Edge, J., Merrells, R., Hawke, E., Barnes, M., Simcock, D., & Gill, N. (2008). The effects of compression garments on intermittent exercise performance and recovery

on consecutive days. *International Journal of Sports Physiology Performance, 3*(4), 454-468.

Duffield, R., & Portus, M. (2007). Comparison of three types of full-body compression garments on throwing and repeat-sprint performance in cricket players. *British Journal of Sports Medicine, 41*(7), 409-414.

Eberhardt, R. T., & Raffetto, J. D. (2005). Chronic venous insufficiency. *Circulation, 111*(18), 2398-2409.

Ekblom, B., Astrand, P. O. Saltin, B. Stenberg, J. & Wallstrom, B. (1968). Effect of training on circulatory response to exercise. *Journal of Applied Physiology, 24*, 518 –528.

Enck, P., Benedetti, F., & Schedlowski, M. (2008). New insights into the placebo and nocebo responses. *Neuron, 59*(2), 195-206.

Fischer, A. A. (1987). Pressure algometry over normal muscles. Standard values, validity and reproducibility of pressure threshold. *Pain, 30*(1), 115-126.

Fitts, R. H. (2008). The cross-bridge cycle and skeletal muscle fatigue. *Journal of Applied Physiology, 104*(2), 551-558.

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

Friden, J., Sjostrom, M., & Ekblom, B. (1983). Myofibrillar damage following intense eccentric exercise in man. *International Journal of sports medicine, 4*(3), 170-176.

Fridén, J., & Lieber, R. L. (2001). Eccentric exercise-induced injuries to contractile and cytoskeletal muscle fibre components. *Acta Physiologica Scandinavica, 171*(3), 321-326.

Gandhi, D. B., & Palmar, J. R. (1984). Clinical comparison of elastic supports for venous diseases of the lower limb. *Postgraduate Medical Journal, 60*(703), 349–352.

Gibson, N., White, J., Neish, M., & Murray, A. (2013). Effect of ischemic preconditioning on land based sprinting in team sport athletes. *International Journal of Sport Physiology and Performance*, *8*, 671-676.

Gill, N. D., Beaven, C. M., & Cook, C. (2006). Effectiveness of post match recovery strategies in rugby players. *British Journal of Sports Medicine, 40*(1), 260-263.

Goddard, G., Karibe, H., & McNeill, C. (2004). Reproducibility of visual analog scale (VAS) pain scores to mechanical pressure. *The Journal of Craniomandibular Practice, 22*(3), 250-256.

Goh, S. S., Laursen, P. B., Dascombe, B., & Nosaka, K. (2010). Effect of lower body compression garments on submaximal and maximal running performance in cold (10°C) and hot (32°C) environments. *Journal of Applied Physiology, 23*(6), 1786-1794.

Gomez, A. L., Radzwich, R. J., Denegar, C. R., Volek, J. S., Rubin, M. R., Bush, J. A., Doan, B. K. & Kraemer, W. J. (2002). The effects of a 10-kilometer run on muscle strength and power. *The Journal of Strength & Conditioning Research*,*16*(2), 184-191.

Goodie, J. L., Larkin, K. T., & Schauss, S. (2000). Validation of Polar heart rate monitor for assessing heart rate during physical and mental stress. *Journal of Psychophysiology, 14*(3), 159-164.

Guilhem, G., Hug, F., Couturier, A., Regnault, S., Bournat, L., Filliard, J. R., & Dorel, S. (2013). Effects of air-pulsed cryotherapy on neuromuscular recovery subsequent to exercise-induced muscle damage. *The American journal of sports medicine, 41*(1), 1942 1951.

Halson, S. L., Bartram, J., West, N., Stephens, J., Argus, C. K., Driller, M. W. & Martin, D. T. (2014). Does hydrotherapy help or hinder adaptation to training in competitive cyclists. *Medicine and science in sports and exercise*, *46*(8), 1631-1639.

Hart, J. M., Swanik, C. B., & Tierney, R. T. (2005). Effects of sport massage on limb girth and discomfort associated with eccentric exercise. *Journal of athletic training*, *40*(3), 181.

Hester, R. L., & Hammer, L. W. (2002). Venular-arteriolar communication in the regulation of blood flow. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 282*(5), 1280-1285.

Higgins, T., Naughton, G. A., & Burgess, D. (2009). Effects of wearing compression garments on physiological and performance measures in a simulated game-specific circuit for netball. *Journal of Science and Medicine in Sport, 12*(1), 223-226.

Hill, J., Howatson, G., Van Someren, K., Leeder, J., & Pedlar, C. (2013). Compression garments and recovery from exercise-induced muscle damage: a meta-analysis. *British Journal of Sports Medicine*, bjsports-2013.

Hirai, M., Iwata, H., & Hayakawa, N. (2002). Effect of elastic compression stockings in patients with varicose veins and healthy controls measured by strain gauge plethysmography. *Skin Research and Technology, 8*(1), 236–239.

Ibegbuna, V., Delis, K. T., & Nicolaides, A. N. (2003). Effect of elastic compression stockings on venous hemodynamics during walking. *Journal of Vascular Surgery, 37*(1), 420–425.

Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science and Medicine in Sport, 12*(3), 417-421.

Jakeman, J. R., Byrne, C., & Eston, R. G. (2010). Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. *European Journal of Applied Physiology, 109*(1), 1137–1144.

Jeffreys, I. (2005). A multidimensional approach to enhancing recovery. *Strength & Conditioning Journal, 27*(5), 78-85.

Jonker, M. J., de Boer, E. M., Ader, H. J., & Bezemer, P. D. (2001). The Oedema-protective effect of lycra support stockings. *Journal of dermatology, 203*(1), 294-298.

Karunakara, R. G., Lephart, S. M., & Pincivero, D. M. (1999). Changes in forearm blood flow during single and intermittent cold application. *Journal of Orthopaedic & Sports Physical Therapy, 29*(3), 177-180.

Kemmler, W., vonStengel, S., Kockritz, C., Mayhew, J., Wassermann, A., & Zapf, J. (2009). Effect of compression stockings on running performance in men runners. *Journal of Strength and Conditioning Research, 23*(1), 101–105.

Kinser, A. M., Sands, W. A., & Stone, M. H. (2009). Reliability and validity of a pressure algometer. *The Journal of Strength & Conditioning Research, 23*(1), 312-314.

Knobloch, K., Grasemann, R., Jagodzinski, M., Richter, M., Zeichen, J., & Krettek, C. (2006). Changes of Achilles midportion tendon microcirculation after repetitive simultaneous cryotherapy and compression using a Cryo/Cuff. *The American journal of sports medicine, 34*(12), 1953-1959.

Komi, P.V. (2000). Stretch–shortening cycle: a powerful model to study normal and fatigued muscle. *Journal of Biomechanics,* 33(1), 1197–1206.

Kraemer, W. J., & Bush, J. A. (1998). Influence of compression garment on repetitive power output production before and after different types of muscle fatigue. *Journal of Sports Medicine, Training and Rehabilitation, 8*(1), 163–184.

Kraemer, W. J., Bush, J. A., Wickham, R. B., Denegar, C. R., Gómez, A. L., Gotshalk, L. A. Duncan, N. D., Volek, J. S., Putukian, M., & Sebastianelli, W. J. (2001). Influence of compression therapy on symptoms following soft tissue injury from maximal eccentric exercise. *Journal of Orthopaedic & Sports Physical Therapy, 31*(6), 282-290

Kraemer, W.J., Flanagan, S.d., Comstock, B.A., Fragala, M.S., Earp, J.E., Dunn-Lewis, C., Ho, J., Thomas, G. A., Solomon-Hill, G., Penwell, Z. R., Powell, M. D., Wolf, M. R., Volek, J. S., Denegar, C. R., & Maresh, C. M. (2010). Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. *Journal of Strength and Conditioning Research, 24*, 804-814.

Krityakiarana, W., Budworn, J., Khajohnanan, C., Suramas, N., & Puritasang, W. (2014). Effect of ice bag, dynamic stretching and combined treatments on the prevention and treatment of delay onset muscle soreness. *International Journal of Physiotherapy Research*, *2*(6), 799-805.

Lane, K. N., & Wenger, H. A. (2004). Effect of selected recovery conditions on performance of repeated bouts of intermittent cycling separated by 24 hours. *The Journal of Strength & Conditioning Research, 18*(4), 855-860.

Laukkanen, R., & Virtanen, P. (1998). Heart rate monitors - state of the art. *Journal of Sports Sciences, 16*(1), 3-7.

Lawrence, D., & Kakkar, V. V. (1980). Graduated, static, external compression of the lower limb: a physiological assessment. *The British Journal of Surgery, 67*(2), 119–121.

Leeder, J., Gissane, C., van Someren, K., Gregson, W., & Howatson, G. (2011). Cold water immersion and recovery from strenuous exercise: a meta-analysis. *British Journal of Sports medicine, 46*(4), 233-240.

Leegwater, N. C., Willems, J. H., Brohet, R., & Nolte, P. A. (2012). Cryocompression therapy after elective arthroplasty of the hip. *Hip International: The Journal of Clinical and Experimental Research on Hip Pathology and Therapy.*

Levick, J. R. (2003). An Introduction to Cardiovascular Physiology Arnold.London, UK.

Levine, B. D., Stray-Gundersen, J. (1997). Living high-training low. Effect of moderate altitude acclimatization with low altitude training on performance. *Journal of applied Physiology. 83*(1): 102-112.

Lewis, C. E., Antoine, J., Meuller, C., Talbot, W.A., Swaroop, R., & Edwards, W. S. (1976). Elastic compression in the prevention of venous stasis. *American Journal of Surgery 132*(1), 739-743.

Lindinger, M. I., Kowalchuk, J. M., & Heigenhauser, G. J. F. (2005). Applying physicochemical principles to skeletal muscle acid-base status. *American Journal of Physiology-Regulatory Integrative and Comparative Physiology, 289*(3), 891-894.

Lewis, N. A., Howatson, G., Morton, K., Hill, J., & Pedlar, C. R. (2015). Alterations in redox homeostasis in the elite endurance athlete. *Sports Medicine, 45*(3), 379-409.

Lord, R. S., & Hamilton, D. (2004). Graduated compression stockings (20− 30 mmHG) do not compress leg veins in the standing position. *ANZ Journal of Surgery, 74*(7), 581-585.

Lundvall, J. & Lanne, T. (1989). Transmission of externally applied negative pressure to the underlying tissue: a study on the upper arm of man. *Acta Physiologica Scandinavica, 136*(3), 403– 409.

Mac Auley, D. C. (2001). Ice therapy: how good is the evidence?. *International Journal of Sports Medicine, 22*(05), 379-384.

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

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology*, *106*(3), 857-864.

Marklund, P., Mattsson, C. M., Wåhlin-Larsson, B., Ponsot, E., Lindvall, B., Lindvall, L., Ekblom, B. & Kadi, F. (2013). Extensive inflammatory cell infiltration in human skeletal muscle in response to an ultraendurance exercise bout in experienced athletes. *Journal of Applied Physiology, 114*(1), 66-72.

Mayberry, J. C., Moneta, G. L., De Frang, R. D., & Porter, J. M. (1991). The influence of elastic compression stockings on deep venous hemodynamics. *Journal of Vascular Surgery, 13*(1), 91-100.

Mayrovitz, H. N., & Sims, N. (2003). Effects of ankle-to-knee external pressures on skin blood perfusion under and distal to compression. *Advances in Skin & Wound Care, 16*(4), 198-202.

McComas, A. J. (1996). Skeletal muscle: form and function. Champaign, IL: Human Kinetics.

Midgley, A. W., McNaughton, L. R., & Jones, A. M. (2007). Training to enhance the physiological determinants of long-distance running performance. *Sports Medicine, 37*(10), 857-880.

Miles, M. P., Naukam, R. J., Hackney, A. C., & Clarkson, P. M. (1999). Blood leukocyte and glutamine fluctuations after eccentric exercise. *International Journal of Sports Medicine, 20*(1), 322–327.

Moaerman, D. E. & Jonas, W. B. (2002). Deconstruction the placebo effect and finding the meaning response. *Annals of Internal Medicine. 136*(6): 471-476.

Montgomery, P. G., Pyne, D. B., Cox, A. J., Hopkins, W. G., Minahan, C. L., & Hunt, P. H. (2008). Muscle damage, inflammation, and recovery interventions during a 3-day basketball tournament. *European Journal of Sport Science, 8*(5), 241-250.

Montgomery, P. G., Pyne. D. B., Hopkins, W. G., Dorman, J.C., Cook, K., & Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Science, 26*(11), 1135–1145.

Nemet, D., Meckel, Y., Bar-Sela, S., Zaldivar, F., Cooper, D. M., & Eliakim, A. (2009). Effect of local cold-pack application on systemic anabolic and inflammatory response to sprint interval training: a prospective comparative trial. *European Journal of Applied Physiology*, *107*(4), 411-417.

Newham, D. J., Jones, D. A., & Clarkson, P. M. (1987). Repeated high-force eccentric exercise: effects of muscle pain and damage. *Journal of Applied Physiology, 63*(1), 1381-1386.

Noakes, T. D. (2000). Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scandinavian Journal of Medicine and Science in Sports*, *10*(3), 123-145.

Nosaka, K. K. (2008). Muscle soreness and damage and the repeated Bout Effect. P.M.Tiidus (Ed.), Skeletal Muscle Damage and Repair. Champaign, IL, USA, Human Kinetics

Nosaka, K. K., & Clarkson, P. M. (1996). Changes in indicators of inflammation after eccentric exercise of the elbow flexors. *Medicine and Science in Sport and Exercise, 28*(8), 953-961.

Oakley, E. T., Pardeiro, R. B., Powell, J. W., & Millar, A. L. (2013). The effects of multiple daily applications of ice to the hamstrings on biochemical measures, signs, and

symptoms associated with exercise-induced muscle damage. *The Journal of Strength & Conditioning Research, 27*(10), 2743-2751.

O'Donnell, T. F. Jr., & Rosenthal, D. A. (1979). Effect of elastic compression on venous hemodynamic in postphlebitic limbs. *The Journal of the American Medical Association, 242*(25), 2766–2768.

Paavolainen, L., Nummela, A., Rusko, H. & Häkkinen, K. (1999). Neuromuscular characteristics and fatigue during 10 km running. *International Journal of Sports Medicine, 20*(1), 516–521.

Paddon-Jones, D. J. & Quigley, B. M. (1997) Effects of cryotherapy on muscle soreness and strength following eccentric exercise. *International Journal of Sports Medicine, 18*, 588-593.

Petersen, E. W., Ostrowski, K., Ibfelt, T., Richelle, M., Offord, E., Halkjær-Kristensen, J., & Pedersen, B. K. (2001). Effect of vitamin supplementation on cytokine response and on muscle damage after strenuous exercise. American *Journal of Physiology-Cell Physiology, 280*(6), 1570-1575.

Perrey, S., Bringard, A., Racinais, S., Puchaux, K., & Belluye, N. (2008). Graduated Compression Stockings and Delayed Onset Muscle Soreness. *The Engineering of Sport 7*(1), 547-554.

Pollo, A., Vighetti, S., Rainero, I., & Benedetti, F. (2003). Placebo analgesia and the heart. *Pain, 102*(1), 125-133. Pollo, A., Vighetti, S., Rainero, I., & Benedetti, F. (2003). Placebo analgesia and the heart. *Pain, 102*(1), 125-133.

Pöntinen, P. J. (1998). Reliability, validity, reproducibility of algometry in diagnosis of active and latent tender spots and trigger points. *Journal of Musculoskelatal Pain, 6*(1), 61-71.

Prasartwuth, O., Taylor, J. L., & Gandevia, S. C. (2005). Maximal force, voluntary activation and muscle soreness after eccentric damage to human elbow flexor muscles. *The Journal of Physiology*, *567*(1), 337-348.

Proske, U. & Morgan, D. L. (2001). Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptations and clinical applications. *Journal of Physiology. 537*, 333-345.

Pruscino, C. L., Halson, S., & Hargreaves, M. (2013). Effects of compression garments on recovery following intermittent exercise. *European Journal of Applied Physiology,113*(1), 1585-1596.

Rimaud, D., Messonnier, L., Castells, J., Devillard, X., & Calmels, P. (2010). Effects of compression stockings during exercise and recovery on blood lactate kinetics. *European Journal of Applied Physiology, 110*(1), 425–433.

Robergs, R. A., Ghiasvand, F., & Parker, D. (2004). Biochemistry of exercise-induced metabolic acidosis. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *287*(3), 502-516.

Ross, R., Gray, C. M., & Gill, J. M. (2014). The effects of an injected placebo on endurance running performance. *Medicine and science in sports and exercise, 47*(8),1672-1681.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences, 27*(6), 565-573.

Sajid, M. S., Tai, N. R. M., Goli, G., Morris, R. W., Baker, D. M., & Hamilton, G. (2006). Knee versus thigh length graduated compression stockings for prevention of deep venous thrombosis: a systematic review. *European Journal of Vascular and Endovascular Surgery, 32*(6), 730-736.

Saltin, B., Blomquist, B., Mitchell, J. H., Johnson, R. L. Wildenthal, K. & Chapman. C. B. (1968). Response to submaximal and maximal exercise after bed rest and after training. *Circulation, 38*(7),1–78.

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

Schneider, B. S., Correia, L. A., & Cannon, J. G. (1999). Sex differences in leukocyte invasion in injured murine skeletal muscle. *Research Nurse Health, 22*(2), 243–251.

Scurr, J. H., Ibrahim, S. Z., Faber, R. G., & Le Quesne, L. P. (1977). The efficacy of graduated compression stockings in the prevention of deep vein thrombosis. *British Journal of Surgery, 64*(5), 371-373.

Sear, J. A., Hoare, T. K., Scanlan, A.T., Abt, G. A., & Dascombe, B. J. (2010). The effects of whole-body compression garments on prolonged high-intensity intermittent exercise. *Journal of Strength Conditioning Research, 24*(7), 1901-1910.

Shelbourne, K. D., Klootwyk, T. E. & DeCarlo, M. S. (1992). Update on accelerated rehabilitation after anterior cruciate ligament reconstruction. *Journal of Orthopaedic & Sports Physical Therapy*, *15*(6), 303-308.

Sloan, J. P., Hain, R., & Pownall, R. (1989). Clinical benefits of early cold therapy in accident and emergency following ankle sprain. *Archives of Emergency Medicine, 6*(1), 1-6.

Soderberg, G. L., Ballantyne, B. T., & Kestel, L. L. (1996). Reliability of lower extremity girth measurements after anterior cruciate ligament reconstruction. *Physiotherapy Research International, 1*(1), 7-16.

Sperlich, B., Haegele, M., Krüger, M., Schiffer, T., Holmberg, H. C., & Mester, J. (2010). Cardio-respiratory and metabolic responses to different levels of compression during submaximal exercise. *Journal of Sports Sciences, 28*(6), 609-614.

Stanton, J. R., Freis, E. D., & Wilkins, R. W. (1949). The acceleration of linear flow in the deep veins of the lower extremity of man by local compression. Journal of Clinical Investigation, 28(3), 553.

Strachan, A. F., Noakes, T. D., Kotzenberg, G., Nel, A. E., & De Beer, F. C. (1984). C reactive protein concentrations during long distance running. British Medical Journal (Clinical research ed.), 289(6454), 1249.

Strath, S. J., Swartz, A. M., Bassett, D. R., O'Brien, W. L. Jr., King, G. A., & Ainsworth, B. E. (2000). Evaluation of heart rate as a method for assessing moderate intensity physical activity. Medical Journal of Science, Sports and Exercise, 32(9), 465-470.

Stupka, N., Lowther, S., Chorneyko, K., Bourgeois, J. M., Hogben, C., & Tarnopolsky, M. A. (2000). Gender differences in muscle inflammation after eccentric exercise. Journal of Applied Physiology, 89(6), 2325-2332.

Swenson, C., Swärd, L., & Karlsson, J. (1996). Cryotherapy in sports medicine.Scandinavian Journal of Medicine & Science in Sports, 6(4), 193-200.

Tanner, A. V., Nielsen, B. V., & Allgrove, J. (2014). Salivary and plasma cortisol and testosterone responses to interval and tempo runs and a bodyweight-only circuit session in endurance-trained men. *Journal of sports sciences*, *32*(7), 680-689.

Tiidus, P. M., & Bombardier, E. (1999). Oestrogen attenuates post-exercise myeloperoxidase activity in skeletal muscle of male rats. Journal of Applied Physiology Scandinavia, 166(1), 85–90.
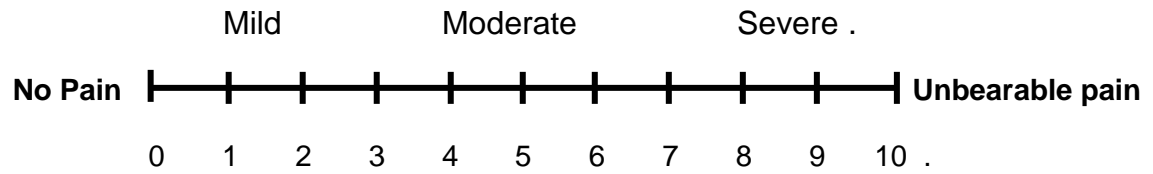
Trenell, M.I., Rooney, K.B., Sue, C.M., & Campbell, H.T., (2006). Compression garments and recovery from eccentric exercise. Journal of Sports Science and Medicine, 5, 106 114.

Tseng, C. Y., Lee, J. P., Tsai, Y. S., Lee, S. D., Kao, C. L., Liu, T. C., Harris, M. B., & Kuo, C. H. (2013). Topical cooling (icing) delays recovery from eccentric exercise-induced muscle damage. The Journal of Strength & Conditioning Research, 27(5), 1354-1361.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Medicine, 29*(07), 539-544.

Varela-Sanz, A., Espana, J., Carr, N., Boullosa, D. A., & Esteve-Lanao, J. (2011). Effects of gradual-elastic compression stockings on running economy, kinematics and performance in runners. *Journal of Strength and Conditioning Research, 25*(10), 2902-2910.

Wallace, L., Slattery, K., & Coutts, A. (2008). Compression garments: Do they influence athletic performance and recovery? *Australian Sport commission, 28*(4), 645-648.

Wells, P. S., Lensing, A. W., & Hirsh, J. (1994). Graduated compression stockings in the prevention of postoperative venous thromboembolism: a meta-analysis. *Archives of Internal Medicine, 154*(1), 67-72.

Weston, M., Taber, C., Casagranda, L. & Cornwall, M. (1994). Changes in local blood volume during cold gel pack application to traumatized ankle. *Journal of Orthop Sports Phys Ther., 19*, 197-199.

Wilkerson, G. B., & Horn-Kingery, H. M. (1993). Treatment of the inversion ankle sprain: comparison of different modes of compression and cryotherapy. *Journal of Orthopaedic & Sports Physical Therapy, 17*(5), 240-246.

Wilkins, R. W., Mixter Jr, G., Stanton, J. R., & Litter, J. (1952). Elastic stockings in the prevention of pulmonary embolism: a preliminary report. *New England Journal of Medicine*, *246*(10), 360-364.

Yamane, M., Teruya, H., Nakano, M., Ogai, R., Ohnishi, N., & Kosaka, M. (2006). Post - exercise leg and forearm flexor muscle cooling in humans attenuates endurance and resistance training effects on muscle performance and on circulatory adaptation. *European Journal of Applied Physiology*, *96*(5), 572-580.

Yanagisawa, O., Miyanaga, Y., Shiraki, H., Shimojo, H., Mukai, N., Niitsu, M., & Itai, Y. (2003). The effects of various therapeutic measures on shoulder range of motion and cross-sectional areas of rotator cuff muscles after baseball pitching. *The Journal of Sports Medicine and Physical Fitness, 43*(3), 356-366.

Chapter 9: Appendices

Appendix 1: Visual Analogue Scale Pain

Please rate your current pain:

	Mild	Moderate	Severe .	
No Pain	├─────┼────┼────┼────┼────┼────┼────┼────┼────┤			**Unbearable pain**
	0 1 2 3 4 5 6 7 8 9 10 .			

Appendix 2: 110% Play Harder Size Guide

MEASURING INSTRUCTIONS: Sizing is important for optimal performance and the most comfortable fit. Find the size that's right for you by measuring the specified body part (un-flexed) outlined below. If you are between sizes or have a mixture of measurements that don't quite match up, we recommend favoring the larger size.

SIZE	1	2	3	4	5	6	7
UNISEX	XS	S	M	L	XL	XXL	
CALF (IN)	<12	12-13.5	13.5-15	15-16.5	16.5-18	18-20	

DOUBLE-LIFE CALF SLEEVES
Measure the calf circumference at he widest part.

QUESTIONS ON SIZING? HIT US UP.
INFO@PLAYHARDER.COM
P: 800.507.6971

THIS SIZE CHART IS OUR SUGGESTED GUIDELINE BUT EVERY SHAPE IS UNIQUE. ALWAYS FAVOR YOUR COMFORT OVER THE SUGGESTED MEASUREMENTS.

110%
PLAY HARDER.

Appendix 3: Treadmill Speed Validation

Displayed Speed (km.h^{-1})	Belt Length (mm)	Actual Speed Un-Weighted (km.h^{-1})	Actual Speed Weighted (km.h^{-1})
8	3750	8	8
9	3750	9.01	8.91
10	3750	9.92	9.9
11	3750	10.97	10.91
12	3750	11.9	11.9
13	3750	12.99	12.97
14	3750	13.96	13.85
15	3750	14.98	14.85
16	3750	15.9	15.88

Appendix 4: Participant Information Sheet – Chapter 5

FORM EC6: PARTICIPANT INFORMATION SHEET

Title of Research

The effect of compression garments on 10 km run performance, muscle damage and post exercise recovery in competitive endurance athletes

Introduction

You are being invited to take part in a research study. Before you decide whether to do so, it is important that you understand the research that is being done and what your involvement will include. Please take the time to read the following information carefully and discuss it with others if you wish. Do not hesitate to ask us anything that is not clear or for any further information you would like to help you make your decision. Please do take your time to decide whether or not you wish to take part. Thank you for reading this.

What is the purpose of this study?

There is a need for fast recovery in athletes who compete or train multiple times per week, often required to perform consistently without a rest day (Wallace et al., 2008). The use of compression garments (CGs) in sport is becoming more popular, as they are believed to aid performance and recovery (French et al., 2008). There are many claims made and many mechanisms suggested for how CGs increase performance and recovery. This study aims to investigate whether Compression garments have an effect on 10 km running performance, muscle damage and recovery.

Project Aims: 1. To assess the effect of compression garments on performance
2. To compare the effects of administering compression on muscle damage and recovery:
    i. During exercise
    ii. Post exercise for 12 hours
    iii. During exercise and post exercise for 12 hours
3. To assess the effect of compression on Inflammation
4. To assess the effect of compression on muscle oscillations

Do I have to take part?

It is completely up to you whether or not you decide to take part in this study. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. Agreeing to join the study does not mean that you have to complete it. You are free to withdraw at any stage without giving a reason. A decision to withdraw at any time, or a decision not to take part at all, will not affect the rest of the treatment/care that you receive.

What will happen to me if I take part?

If you decide to take part in this study, you will be involved in it for approximately 5 weeks.

The first thing to happen will be a familiarisation session and $\dot{V}O_{2Max}$ testing. This will involve you coming to the laboratory where you will be shown around, have the study explained to you and will fill out a health screen and consent form. You will be given an opportunity to

familiarize yourself with running on a treadmill at low speeds including dismounting the treadmill. You will then complete two 1 minute runs at 12 km.h^{-1}, with a break in-between. During one of the runs you will wear compression and during the other no compression, the order in which you will do this will be random. While you run a 3D camera system will film 3 small dots attached to one of your legs. You will then complete a lactate threshold into $\dot{V}O_{2Max}$ test, that will give us a measurement of your aerobic fitness. This test will involve you starting at 2 km.h^{-1} less than your 16 km.h^{-1} pace (or estimated if unknown), every two minutes the speed will increase by 1 km.h^{-1}. After two minutes at 16 km.h^{-1} the gradient will increase by 1 degree every minute. You will be asked to run until exhaustion.

Following the familiarisation session, you will be asked to return to the laboratory to complete four trials, preferable over 4 consecutive weeks. During these visits you will complete four 10 km running trials in a randomised order. The four trials will be: no compression used (Con), compression used during the run (Ex), compression used for 12 hours after the run (Rec) and compression during the run and for 12 hours post run (Exrec).

Each trial will consist of two days: On day one you will complete a self-paced maximal 10 km run on a treadmill. During the run; heart rate, lactate, RPE and performance time will be measured. On day two, 24 hours post run, muscle damage (Creatine kinase) and inflammation (C-reactive protein) will be measured, using a small finger prick blood test, calf muscle girths, measured using a tape measure, and muscle soreness will be measured using a verbal feedback based on a pain scale. Below is a guide for each day

Day 1

Meet at the laboratory
Fill out health screen, food diary and training diary
Change into appropriate clothing for assigned trial and apply heart rate monitor
Complete warm up (5 mins)
Complete a self paced maximal 10 km time trial
Return home (estimated time 1.5 hours)

Day 2

Return to laboratory (24 hours post run)
Complete remainder of food and training diary
Have heart rate and Blood pressure measured
Have a finger prick blood test
Muscle girths measured
Give a perceived muscle soreness rating
Return home (estimated time 30 mins)

Participants should come to each visit prepared with comfortable running shorts, T shirt and running shoes.

What are the possible disadvantages, risks or side effects of taking part?

All the tests and exercises used in this study are safe and have been used and researched in previous studies. Participants will have all test procedures explained before starting to ensure all procedures are performed correctly. All tests will be conducted following the university guidelines.

Maximal/race pace 10 km running may cause muscle soreness and stiffness. Maximal exercise can cause energy depletion, light headedness and in extreme circumstances

fainting. All participants should be accustomed to these affect as they have participated in a minimum of five races in the past two years and train a minimum of three times per week. Any feelings of light headedness should be reported to the researcher immediately.

What are the possible benefits of taking part?

You will receive a free running $\dot{V}O_{2Max}$ test and results. You could experience benefits from completing the 10 km runs, as with any exercise programme. You will get a free trial of knee high compression stockings. You will also receive experience of participating in a research study and will be allowed to view the results after the study is finished.

How will my taking part in this study be kept confidential?

The information that is obtained during the study will follow ethical and legal practice and handled in strict confidence. The information obtained, however, will be used for statistical analysis with your right to privacy retained. All information will be anonymised; that is, all figures and numbers will not be traceable to you and personal details will be removed. All data you provide will be stored on a password protected computer.

What will happen to the results of the research study?

If you agree to take part, your results will be stored on a password protected computer and disk drive, with your name and other details removed. All paper data will be locked in a filing cabinet in a room which will be locked when it is not being occupied by a member of the research team at University of Hertfordshire. The data may be published in a scientific journal. In publication of results it will not be possible to identify individual participants. All personal data will be destroyed upon completion of the study.

Who has reviewed this study?

This research study has been reviewed by an independent Research Ethics Committee, to protect your interests. This study has been reviewed and given a favourable opinion by the Hertfordshire University Ethics Committee. The study design and suitability has been discussed with Dr. Amy Tanner and Ms. Lindsy Kass

Who can I contact if I have any questions?

If you would like further information or would like to discuss any details personally, please get in touch with me, in writing, by phone or by email:

John Lea
G104a, CP Snow building
College Lane Campus
University of Hertfordshire
AL10 9AB
John_lea87@hotmail.com

Although we hope it is not the case, if you have any complaints or concerns about any aspect of the way you have been approached or treated during the course of this study, please write to the University Secretary and Registrar.

Thank you very much for reading this information and giving consideration to taking part in this study.

Appendix 5: Health Screen – Chapter 5

UNIVERSITY OF HERTFORDSHIRE   **Researcher: John Lea**
SCHOOL OF LIFE SCIENCE

HEALTH SCREEN 2

Title of Project: The Affects of Compression Clothing on Performance, Muscle Damage, Power and Fatigue in Male 10 km Runners

Subject Name:

It is important when having volunteered as subject for this study, and having read the briefing sheet for subjects that you answer the following questions. Please do not answer any questions if you consider them intrusive.

1)   Do you suffer from high blood pressure, or any heart problems?

Yes	No

2)   Do you often get dizzy, or do you know that you have low blood pressure?

Yes	No

3)   When and what did you last eat?

4)   Are you under the influence of alcohol or any other psycho-active substance?

Yes	No

5)   Have you had a cold or flu in the last two weeks?

Yes	No

6)   Are you suffering from any musculo-skeletal injury?

Yes	No

7)   Are you currently taking any medication (over the counter, or prescription)?

Yes	No

(you do not need to answer "Yes" if you are only taking oral contraceptives, or if you are an asthmatic with an inhaler available)

8)   Do you, or have you suffered from any blood related disorders, or have you any issues related to blood taking?

Yes	No

9)   Have you ever been told that you should not exercise?

Yes	No

10)   Do you feel fully fit, and eager to act as subject?

Yes	No

11)   Is there any reason, not stated above, why you cannot take part as a subject in this practical?

Yes	No

Signature……………………………………………..   Date:

Checked by (Name):   Date:

Appendix 6: Consent Form – Chapter 5

University of Hertfordshire

CONSENT FORM FOR STUDIES INVOLVING HUMAN PARTICIPANTS

I, the undersigned *[please give your name here, in BLOCK CAPITALS]*

……….

of *[please give contact details here, sufficient to enable the investigator to get in touch with you, such as a postal or email address]*

…..……………………………………………………………………………………………………… ..

hereby freely agree to take part in the study entitled:

The effect of compression garments on 10 km run performance, muscle damage and post exercise recovery in competitive endurance athletes

1 I confirm that I have been given a Participant Information Sheet (a copy of which is attached to this form) giving particulars of the study, including its aim(s), methods and design, the names and contact details of key people and, as appropriate, the risks and potential benefits, and any plans for follow-up studies that might involve further approaches to participants. I have been given details of my involvement in the study. I have been told that in the event of any significant change to the aim(s) or design of the study I will be informed, and asked to renew my consent to participate in it.

2 I have been assured that I may withdraw from the study at any time without disadvantage or having to give a reason.

3 I have been given information about the risks of my suffering harm or adverse effects.   I have been told about the aftercare and support that will be offered to me in the event of this happening, and I have been assured that all such aftercare or support would be provided at no cost to myself.

4 I have been told how information relating to me (data obtained in the course of the study, and data provided by me about myself) will be handled: how it will be kept secure, who will have access to it, and how it will or may be used.

5 I have been told what will be done if the study reveals that I have a medical condition which may have existed prior to the study, which I may or may not have been aware of, and which could affect the present or future health of myself or others. If this happens, I will be told about the condition in an appropriate manner and advised on follow-up action I should take.   Information about the condition will be passed to my GP, and I may no longer be allowed to take part in the study.

6 I have been told that I may at some time in the future be contacted again in connection with this or another study.

Signature of
participant……………………………………………………………………………Date…………………………..

Signature of (principal) investigator………………………………………………… Date………………………

Name of (principal) investigator *[in BLOCK CAPITALS please]*

……...

Appendix 7: $\dot{V}O_{2Max}$ Verbal Encouragement Schedule

Start of test: Do you feel ok "name"?
Are you ready to start?
Starting at "speed"
We will start in 3, 2, 1, go.

End of first stage: Dismount the treadmill in 3, 2, 1, Now.

Lactate Threshold Stages (repeated for each stage)

Start of stage: Going up to "speed"
Back on the treadmill in 3, 2, 1, Go
2 minutes at this speed "name"

1min into stage: That's half way through this stage, one minute left

End of stage: Dismount the treadmill in 3, 2, 1, Now.

$\dot{V}O_{2Max}$ Stages

Before 1st stage: This will be the last blood test. No more stops now, so you can focus on the max test. Give everything you've got. Let's get the best result we can.

Stages ≤16 km.h⁻¹ on 1% gradient (repeated for each stage)

Start of stage: Speed going up to "new speed" in 3, 2, 1
2 minutes at this speed "name"
keep going, you're doing really well

1min into stage: That's half way through this stage, one minute left

1.5min into stage: 30 seconds left of this stage, keep pushing.

Stages 16 km.h⁻¹ on >1% gradient (repeated for each stage)

Start of stage: Gradient is going up by 1% in 3, 2, 1
1 minute at this gradient "name"
keep going, you're doing really well

30secs into stage: That's half way through this stage, 30 seconds left
Keep Pushing
Give everything you've got

Appendix 8: Exercise Log – Chapter 5

Please list all physical activity performed.

Day -2 (48-24 hours before run)	Day -1 (24 hours before 10 km run)	10 km Run day (24 hours after 10 km run)

Appendix 9: Food diary – Chapter 5

Please list all the food and drink you have consumed for the 24 hours prior to this testing session. Quantity or weight of the food should be included where possible.

24 Hours Before10 km Run	24 Hours After 10 km Run
Breakfast	Breakfast
Snacks	Snacks
Lunch	Lunch
Snacks	Snacks
Dinner	Dinner
Snacks	Snacks

Appendix 10: 10 km Verbal Encouragement Schedule

Start of test
Do you feel ok "name"?
Are you ready to start?
We will start in 3, 2, 1, go. (Simulate race start)

1 km That's the first kilometre done you're doing well. Find your rhythm now.

2.5 km You're a quarter of the way now "name", keep it up you're doing great

3 km You're doing good "name"

4 km You're doing great, find your pace.

5 km That's half way, let's keep up this pace.

6 km You're doing great "name" keep going.

7.5 km That's 7.5 k, "name", three quarters done. Let's win this race

8 km Only 2 km left "name"

9 km Last kilometre now "name" let's finish strong. Let's win this race

9.5 km Come on "name" 500m left. Strong finish. Win this race.

9.7 km Last 300m "name", nearly there, finish strong. You can win this.

9.8 km 200m left "name", keep going. Win the race.

9.9 km Last 100m "name", go to the finish. Keep going. Finish strong

Appendix 11: Perceived Comfort of Compression Garments

GCS Comfort, Tightness & Pain Scales

For each of the statements below please point to the number that best describes how you feel.

1. Rate 1-10, the comfort of the sock.

   1   2   3   4   5   6   7   8   9   10

    Very   Very
Uncomfortable   Comfortable

2. Rate 1-10, the tightness of the sock.

   1   2   3   4   5   6   7   8   9   10

Very   Very
Slack   Tight

3. Rate 1-10, the pain induced by the sock.

   1   2   3   4   5   6   7   8   9   10

 No   Very
Pain   Painful

FORM EC6: PARTICIPANT INFORMATION SHEET

Title of Research

The effect of combined compression and ice therapy on recovery after eccentric exercise

Introduction

You are being invited to take part in a research study. Before you decide whether to do so, it is important that you understand the research that is being done and what your involvement will include. Please take the time to read the following information carefully and discuss it with others if you wish. Do not hesitate to ask us anything that is not clear or for any further information you would like to help you make your decision. Please do take your time to decide whether or not you wish to take part. Thank you for reading this.

What is the purpose of this study?

There is a need for fast recovery in athletes who compete or train multiple times per week, often required to perform consistently without a rest day (Wallace et al., 2008). The use of compression garments (CGs) in sport is becoming more popular, as they are believed to aid recovery (French et al., 2008). Ice is also used extensively to aid recovery after exercise. For most athletes the application of pressure and ice together is difficult and requires expensive equipment or homemade solution, such as ice bathing whilst wearing compression garments. Likewise, the application of effective reliable combined ice compression treatment in the field is, for most, not possible. There are now CGs available, with pockets for the application of ice built in to them (110% Harder, Canada). These pockets allow the combined treatment at home and in the field, with consistent graduated compression and safe ice application.

This study aims to investigate whether compression alone or compression and ice treatment combined, have an effect on the rate of recovery experienced after exercise.

Study Aims: 1. To assess the effect of compression on recovery
                 2. To assess the effect of combined compression and ice treatment on recovery

Do I have to take part?

It is completely up to you whether or not you decide to take part in this study. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. Agreeing to join the study does not mean that you have to complete it. You are free to withdraw at any stage without giving a reason. A decision to withdraw at any time, or a decision not to take part at all, will not affect the rest of the treatment/care that you receive.

What will happen to me if I take part?

If you decide to take part you will first come in for a familiarisation and baseline session. This session will be at least seven days before you begin the first trial. During this session you will be shown around the laboratory, will have the study protocols and tests explained to you, will be familiarised with the perceptual scales (Perceived effort and Muscle soreness) and will be given an opportunity to ask any questions you may have about the study. You will then fill out a health screen and consent form. Baseline measurements will then be recorded including height, weight and body fat percentage. You will then be given an opportunity to familiarise yourself with the use of a treadmill at low speeds including dismounting the treadmill. Following a self paced five minute warm up, you will then complete a 1 km time trial. During the run, you will be able to see distance covered, but not speed or performance time.

Each trial will consist of four consecutive days, where possible you will be booked in to start day 1 of each trial at the same time on the same day of the week. You will be asked to keep your routine and preparation the same before each trial and will be asked to refrain from exercise, caffeine and supplements for 24 hours before each trial. On day one you will arrive at the laboratory (G111 or H260, College Lane, University of Hertfordshire) and will fill out an exercise log, food diary and a health screen. After a rest of a minimum of five minutes, a baseline finger prick blood sample will be collected. This sample involves a small prick on the finger no needles are used; the sample will be used to measure Creatine Kinase (CK), a marker of muscle damage. You will then complete a lower body eccentric exercise protocol focusing on the lower leg including: skipping (without rope if you cannot skip), hopping, calf raises and small bench jumps. You will be allowed to drink water during the session however no energy drinks or supplements will be allowed. After the exercise participants completing the control trial (CON) trial will be allowed to leave. If you are completing the compression trial (COMP) you will have CGs fitted then will leave and if you are in the ice trial (ICE), you will be fitted with CGs, will undertake a 20 minute icing protocol then you will leave. On the COMP and ICE trials you will be asked to wear the CGs for 12-hours before removing.

On day two, 24 hours post exercise; you will fill out a questionnaire about recovery and muscle soreness, in your own home. You will not be required to return to the laboratory on day two.

On day three, 48 hours post exercise you will return to the laboratory, fill out the recovery and muscle soreness questionnaire, will have a finger prick blood sample for muscle damage and will complete a maximal 1 km time trial. You will not be informed of your performance times until all trials are completed. After the run you will be allowed to leave the laboratory.

On day four, 72 hours post exercise you will fill out the last of the recovery questionnaire, at home. You will not be required to attend the laboratory on day four.

You should come to each visit with comfortable running shorts, T shirt and Trainers.

What are the possible disadvantages, risks or side effects of taking part?

All the tests and exercises used in this study are safe and have been used and researched in previous studies. Participants will have all test procedures explained before starting to ensure all procedures are performed correctly. All tests will be conducted following the university guidelines.

Exercise can cause energy depletion, light headedness and in extreme circumstances fainting. The exercise in this study is short and therefore is unlikely to elicit any of these responses. Also all participants should be accustomed to these affect as they train a minimum of two times per week. Any feelings of light headedness should be reported to the researcher immediately. It is likely that the leg exercises with cause some muscle soreness of the calves; this is normal and should not cause alarm. If you think any pain or discomfort believed to be more than muscle soreness should be reported to the researcher.

Finger prick blood sampling can cause a slight bruised feeling on the side of the finger; the sample will not be taken from the part of the finger used to type or text message. When the finger is pricked a small sharp pinch sensation can be felt, but often it is painless.

What are the possible benefits of taking part?

You will get a free trial of a new brand of knee high compression stockings, and the ability to use ice with those stockings. You will receive experience of participating in a research study and will be allowed to view the results after the study is finished, which may give you an idea of your fitness level.

You may receive benefits to fitness and leg strength, from the exercise undertaken.

How will my taking part in this study be kept confidential?

The information that is obtained during the study will follow ethical and legal practice and handled in strict confidence. The information obtained, however, will be used for statistical analysis with your right to privacy retained. All information will be anonymised; that is, all figures and numbers will not be traceable to you and personal details will be removed. All data you provide will be stored on a password protected computer.

What will happen to the results of the research study?

If you agree to take part, your results will be stored on a password protected computer and disk drive, with your name and other details removed. All paper data will be locked in a filing cabinet in a room which will be locked when it is not being occupied by a member of the research team at University of Hertfordshire. The data may be published in a scientific journal. In publication of results it will not be possible to identify individual participants. All personal data will be destroyed upon completion of the study.

Who has reviewed this study?

This research study has been reviewed by an independent Research Ethics Committee, to protect your interests. This study has been reviewed and given a favorable opinion by the Hertfordshire University Ethics Committee. The study design and suitability has been discussed with Dr. Amy Tanner and Ms. Lindsy Kass

Who can I contact if I have any questions?

If you would like further information or would like to discuss any details personally, please get in touch with me, in writing, or by email:

John Lea
G104a
CP Snow building
College Lane Campus
University of Hertfordshire
AL10 9AB

John_lea87@hotmail.com

Although we hope it is not the case, if you have any complaints or concerns about any aspect of the way you have been approached or treated during the course of this study, please write to the University Secretary and Registrar.

Thank you very much for reading this information and giving consideration to taking part in this study.

Appendix 13: Health Screen – Chapter 6

UNIVERSITY OF HERTFORDSHIRE   **Researcher: John Lea**
SCHOOL OF LIFE SCIENCE

HEALTH SCREEN 2

Title of Project: The Affects of Compression Clothing on Performance, Muscle Damage, Power and Fatigue in Male 10 km Runners

Subject Name:

It is important when having volunteered as subject for this study, and having read the briefing sheet for subjects that you answer the following questions. Please do not answer any questions if you consider them intrusive.

12)   Do you suffer from high blood pressure, or any heart problems?

Yes	No

13)   Do you often get dizzy, or do you know that you have low blood pressure?

Yes	No

14)   When and what did you last eat?

15)   Are you under the influence of alcohol or any other psycho-active substance?

Yes	No

16)   Have you had a cold or flu in the last two weeks?

Yes	No

17)   Are you suffering from any musculo-skeletal injury?

Yes	No

18)   Are you currently taking any medication (over the counter, or prescription)?

Yes	No

(you do not need to answer "Yes" if you are only taking oral contraceptives, or if you are an asthmatic with an inhaler available)

19)   Do you, or have you suffered from any blood related disorders, or have you any issues related to blood taking?

Yes	No

20)   Have you ever been told that you should not exercise?

Yes	No

21)   Do you feel fully fit, and eager to act as subject?

Yes	No

22)   Is there any reason, not stated above, why you cannot take part as a subject in this practical?

Yes	No

Signature……………………………………………..   Date:

Checked by (Name):   Date:

Appendix 14: Consent Form – Chapter 6

University of Hertfordshire

CONSENT FORM FOR STUDIES INVOLVING HUMAN PARTICIPANTS

I, the undersigned *[please give your name here, in BLOCK CAPITALS]*

…….

of *[please give contact details here, sufficient to enable the investigator to get in touch with you, such as a postal or email address]*

…..…………………………………………………………………………………………………… ..

hereby freely agree to take part in the study entitled:

The effect of combined knee high compression and ice therapy on recovery after eccentric exercise

1 I confirm that I have been given a Participant Information Sheet (a copy of which is attached to this form) giving particulars of the study, including its aim(s), methods and design, the names and contact details of key people and, as appropriate, the risks and potential benefits, and any plans for follow-up studies that might involve further approaches to participants.   I have been given details of my involvement in the study. I have been told that in the event of any significant change to the aim(s) or design of the study I will be informed, and asked to renew my consent to participate in it.

2 I have been assured that I may withdraw from the study at any time without disadvantage or having to give a reason.

3 I have been given information about the risks of my suffering harm or adverse effects.   I have been told about the aftercare and support that will be offered to me in the event of this happening, and I have been assured that all such aftercare or support would be provided at no cost to myself.

4 I have been told how information relating to me (data obtained in the course of the study, and data provided by me about myself) will be handled: how it will be kept secure, who will have access to it, and how it will or may be used.

5 I have been told what will be done if the study reveals that I have a medical condition which may have existed prior to the study, which I may or may not have been aware of, and which could affect the present or future health of myself or others. If this happens, I will be told about the condition in an appropriate manner and advised on follow-up action I should take.   Information about the condition will be passed to my GP, and I may no longer be allowed to take part in the study.

6 I have been told that I may at some time in the future be contacted again in connection with this or another study.

Signature of
participant……………………………………………………………………………Date………………………….

Signature of (principal) investigator…………………………………………………… Date…………………………

Name of (principal) investigator *[in BLOCK CAPITALS please]*

………...

Appendix 15: 1 km Time Trial Verbal Encouragement Schedule

Start of test
Do you feel ok "name"?
Are you ready to start?
So this is 1 km as fast as you can.
We will start in 3, 2, 1, go. (Simulate race start)

250m Good "name", Keep going as quick as you can.

500m That's half way, you're doing great. Keep pushing.

600m 400 m to go. Last lap of the track. Give it everything you've got.

800m Last 200 m. Come on "name" Let's go, as fast as you can now.

900m Last 100 m "name". Everything you've got now.

Appendix 16: Exercise Log – Chapter 6

Please list all physical activity performed.

24 Hours Pre Eccentric Exercise	0-24 Hours Post Eccentric Exercise	24-48 Hours Post Eccentric Exercise

Appendix 17: Food diary – Chapter 6

Please list all the food and drink you have consumed for the 24 hours prior to this testing session. Quantity or weight of the food should be included where possible.

24 Hours Pre Eccentric Exercise	24-48 Hours Post Eccentric Exercise
Breakfast	Breakfast
Snacks	Snacks
Lunch	Lunch
Snacks	Snacks
Dinner	Dinner
Snacks	Snacks

Appendix 18: Chapter 6- Recovery Questionnaire

<u>Day -1:</u> Please fill out this page for the last 24 hours

<u>Pain</u>
Please rate the pain in your Tib Ant, calf, Hamstrings and Quadriceps
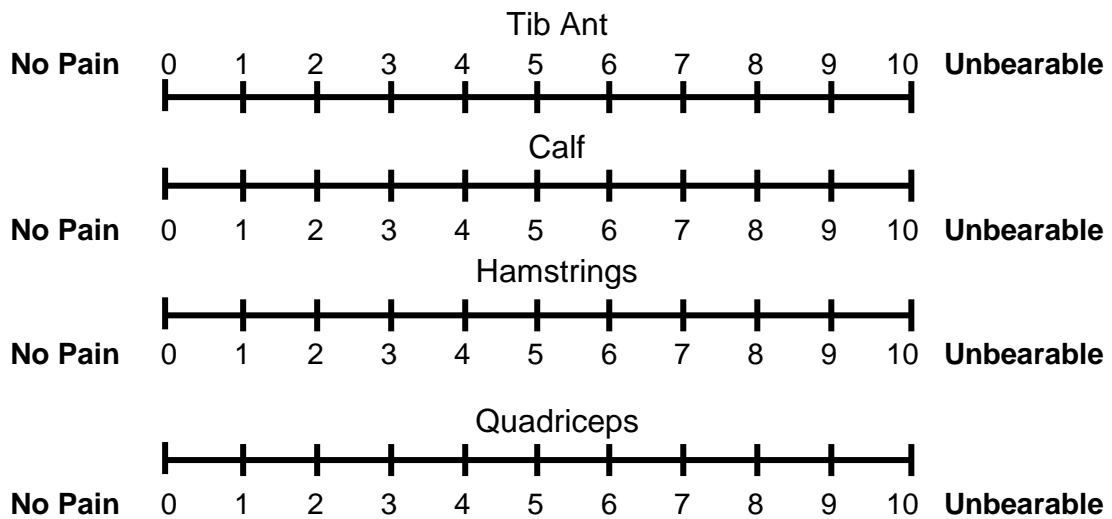
Tib Ant

No Pain   0   1   2   3   4   5   6   7   8   9   10   **Unbearable**

Calf

No Pain   0   1   2   3   4   5   6   7   8   9   10   **Unbearable**

Hamstrings

No Pain   0   1   2   3   4   5   6   7   8   9   10   **Unbearable**

Quadriceps

No Pain   0   1   2   3   4   5   6   7   8   9   10   **Unbearable**

<u>Max performance</u>
Please rate at what percentage of you maximum you think you could perform now

Unable   0   10   20   30   40   50   60   70   80   90   100%   **maximum**

<u>Sleep</u>
Please rate your last night sleep out of 10

No Sleep   0   1   2   3   4   5   6   7   8   9   10   **Deep/undisturbed**

<u>Recovery</u>
Please rate how well you think you have recovered since the exercise

Unrecovered   0   1   2   3   4   5   6   7   8   9   10   **Recovered**

Feeling Scale

+5   Very Good

+4

+3   Good

+2

+1   Fairly Good

0   Neutral

-1   Fairly Bad

-2

-3   Bad

-4

-5   Very Bad

Felt Arousal

Please rate your arousal (motivation) since the exercise

| 0 | 1 | 2 | 3 | 4 | 5 | 6 |
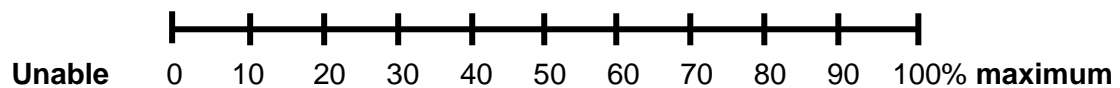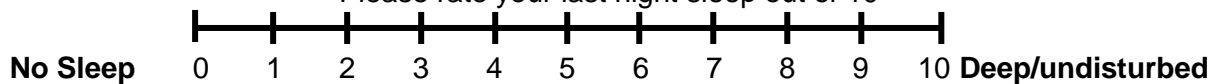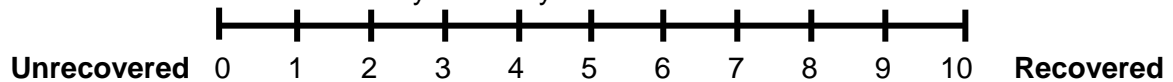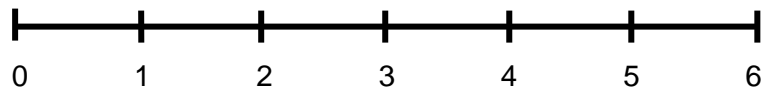
Perceived Comfort

If you have worn compression please rate out of 10 how comfortable you found them

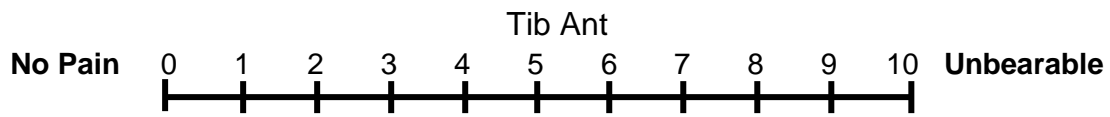**Unbearable** 0 1 2 3 4 5 6 7 8 9 10 **Total Comfort**
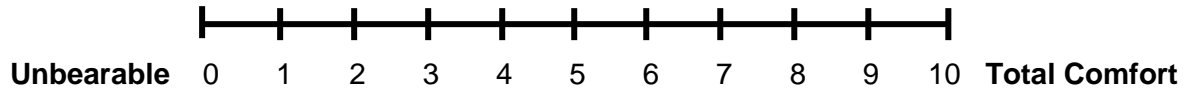
If you completed the ice protocol please rate out of 10 how effective you thought it was
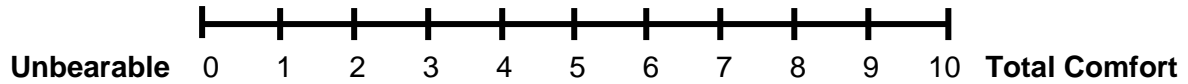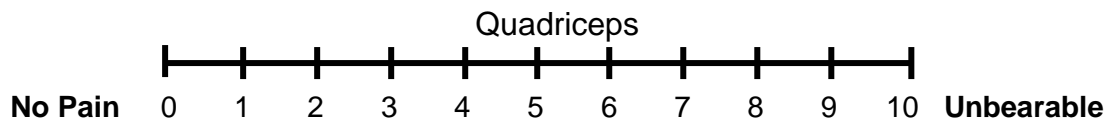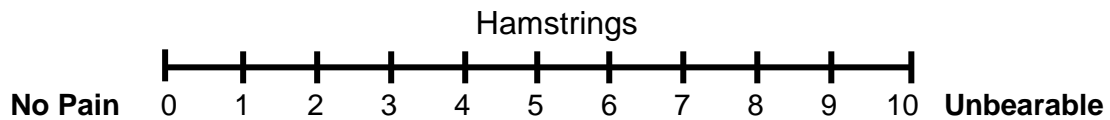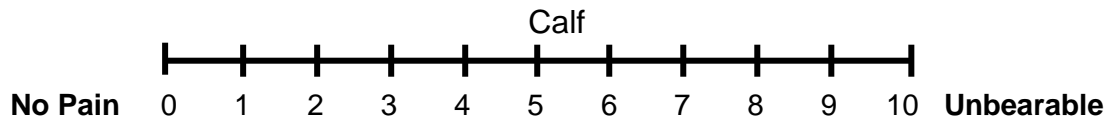
Unbearable 0 1 2 3 4 5 6 7 8 9 10 **Total Comfort**

Pain

Please rate the pain in your Tib Ant, calf, Hamstrings and Quadriceps

Tib Ant
No Pain 0 1 2 3 4 5 6 7 8 9 10 **Unbearable**

Calf
No Pain 0 1 2 3 4 5 6 7 8 9 10 **Unbearable**

Hamstrings
No Pain 0 1 2 3 4 5 6 7 8 9 10 **Unbearable**

Quadriceps
No Pain 0 1 2 3 4 5 6 7 8 9 10 **Unbearable**

Max performance

Please rate at what percentage of you maximum you think you could perform now

Unable 0 10 20 30 40 50 60 70 80 90 100% **maximum**

Sleep

Please rate your last night sleep out of 10

No Sleep 0 1 2 3 4 5 6 7 8 9 10 **Deep/undisturbed**

Recovery

Please rate how well you think you have recovered since the exercise

Unrecovered 0 1 2 3 4 5 6 7 8 9 10 **Recovered**

Feeling Scale

+5   Very Good

+4

+3   Good

+2

+1   Fairly Good

0   Neutral

-1   Fairly Bad

-2

-3   Bad

-4

-5   Very Bad

Felt Arousal

Please rate your arousal (motivation) since the exercise

```
├───┼───┼───┼───┼───┼───┤
0   1   2   3   4   5   6
```
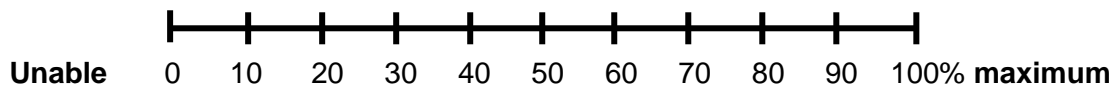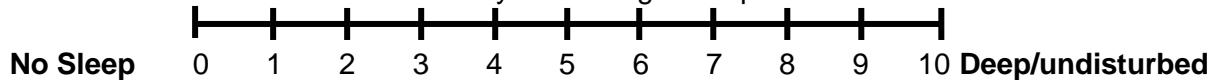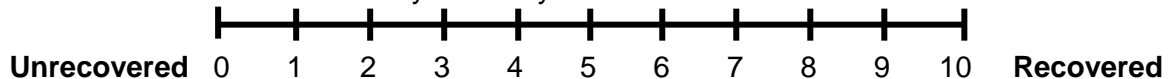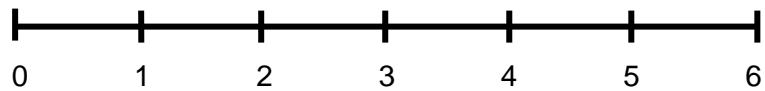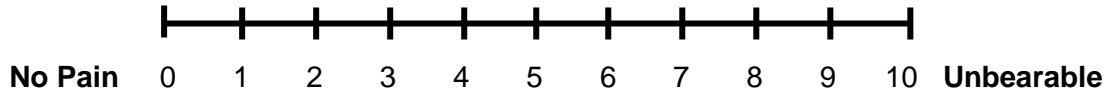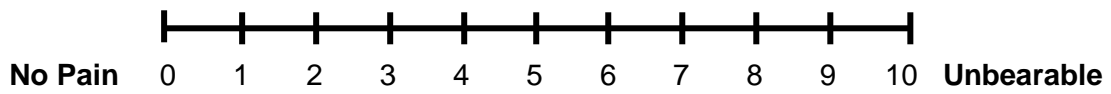
Please fill out this page 48 hours after run

Pain

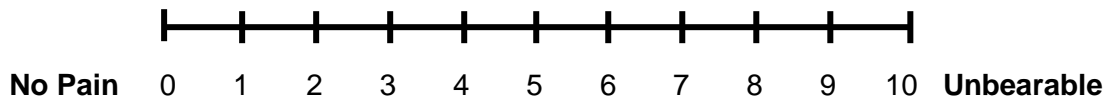Please rate the pain in your Tib Ant, Calf, Hamstrings and Quadriceps

Tib Ant

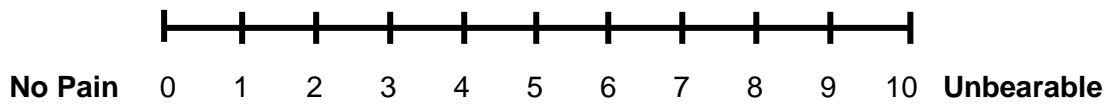**No Pain**   0   1   2   3   4   5   6   7   8   9   10   **Unbearable**

Calf

No Pain   0   1   2   3   4   5   6   7   8   9   10   **Unbearable**

Hamstrings

No Pain   0   1   2   3   4   5   6   7   8   9   10   **Unbearable**

Quadriceps

No Pain   0   1   2   3   4   5   6   7   8   9   10   **Unbearable**

Max performance
Please rate at what percentage of you maximum you think you could perform now

Unable   0   10   20   30   40   50   60   70   80   90   100%   **maximum**

Sleep
Please rate your last night sleep out of 10

No Sleep   0   1   2   3   4   5   6   7   8   9   10   **Deep/undisturbed**

Recovery
Please rate how well you think you have recovered since the exercise

Unrecovered   0   1   2   3   4   5   6   7   8   9   10   **Recovered**
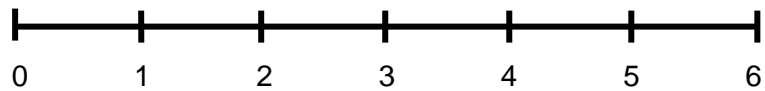
Feeling Scale

+5   Very Good

+4

+3   Good

+2

+1   Fairly Good

0   Neutral

-1   Fairly Bad

-2

-3   Bad

-4

-5   Very Bad

Felt Arousal

Please rate your arousal (motivation) since the exercise

```
├───────┼───────┼───────┼───────┼───────┼───────┤
0       1       2       3       4       5       6
```
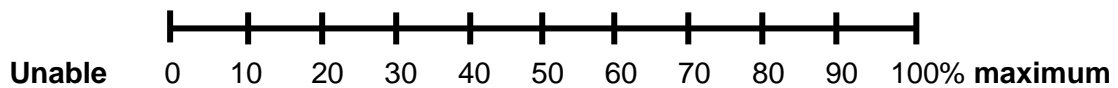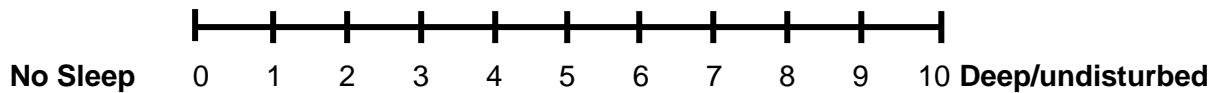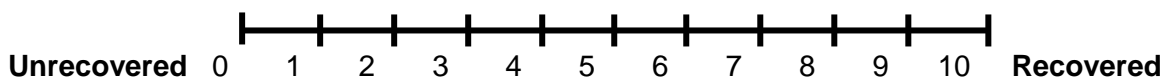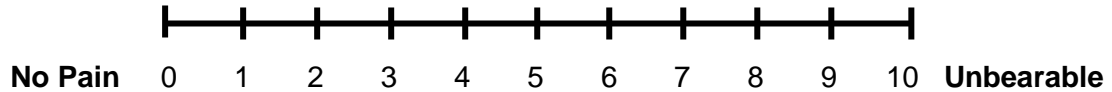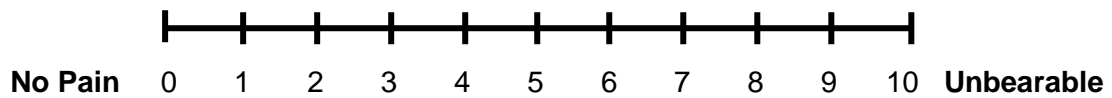
Please fill out this page 72 hours after run

Pain

Please rate the pain in your Tib Ant, Calf, Hamstrings and Quadriceps
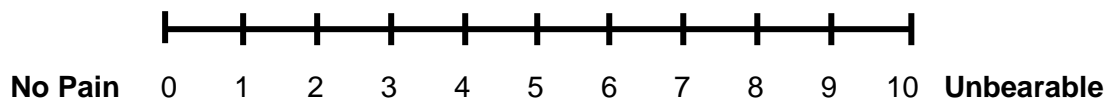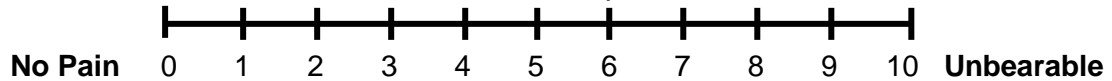
Tib Ant

No Pain 0   1   2   3   4   5   6   7   8   9   10 **Unbearable**

Calf

No Pain 0   1   2   3   4   5   6   7   8   9   10 **Unbearable**

Hamstrings

No Pain 0   1   2   3   4   5   6   7   8   9   10 **Unbearable**

Quadriceps

No Pain 0   1   2   3   4   5   6   7   8   9   10 **Unbearable**

Max performance

Please rate at what percentage of you maximum you think you could perform now

Unable 0   10   20   30   40   50   60   70   80   90   100% **maximum**

Sleep

Please rate your last night sleep out of 10

No Sleep 0   1   2   3   4   5   6   7   8   9   10 **Deep/undisturbed**

Recovery

Please rate how well you think you have recovered since the exercise

Unrecovered 0   1   2   3   4   5   6   7   8   9   10 **Recovered**
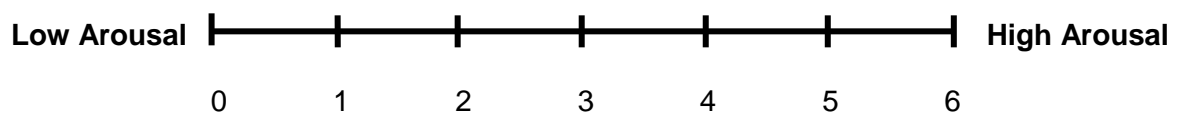
Feeling Scale

+5   Very Good

+4

+3   Good

+2

+1   Fairly Good

0   Neutral

-1   Fairly Bad

-2

-3   Bad

-4

-5   Very Bad

Felt Arousal

Please rate your arousal (motivation) since the exercise

Low Arousal ├──────┼──────┼──────┼──────┼──────┼──────┤ **High Arousal**

0   1   2   3   4   5   6
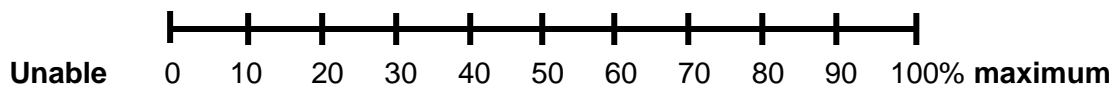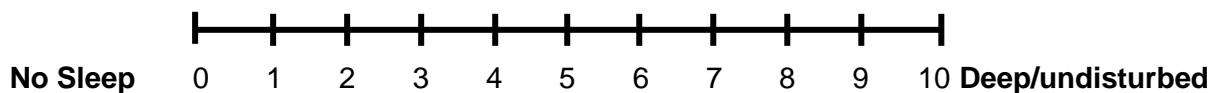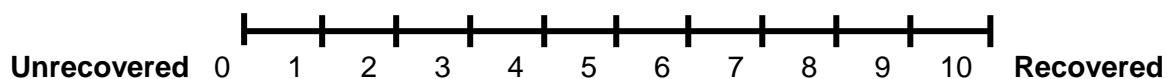
Appendix 19: Example of Bent Leg Calf Raise Angle

Appendix 20: Ankle to Calf Ratios

Compression size, ankle girth, calf girth, and ankle to calf circumference ratio for participant in chapters 5 and 6 combined (mean ± SD, n = 22).

Participant	Compression Size	Ankle Girth (mm)	Calf Girth (mm)	Ankle-Calf Ratio
1	2	20.5	34.5	1.68
2	2	20.4	34.7	1.70
3	2	20.4	34.7	1.70
4	2	20.4	34.7	1.70
5	2	19.3	34.2	1.77
6	2	19.2	34.6	1.80
7	3	23.4	35.5	1.52
8	3	23	35.5	1.54
9	3	22.3	36.5	1.64
10	3	22.3	36.8	1.65
11	3	22.7	37.6	1.66
12	3	21.3	35.6	1.67
13	3	21.5	36.5	1.70
14	3	21.4	36.8	1.72
15	3	21.5	38.1	1.77
16	3	21.1	38.1	1.81
17	4	25	40	1.60
18	4	24.2	41.4	1.71
19	4	22.1	38.4	1.74
20	4	23.1	40.4	1.75
21	4	22.9	40.5	1.77
22	4	23.7	42.5	1.79