EFFECTS OF COMPRESSION GARMENTS ON RECOVERY FROM INTERMITTENT EXERCISE

CATHRYN PRUSCINO

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Department of Physiology

The University of Melbourne

ABSTRACT

Purpose: To examine the effects of wearing compression garments for 24 h post-exercise on the biochemical, physical and perceived recovery of highly-trained athletes. **Method:** Eight field hockey players completed a match-simulation exercise protocol on two occasions separated by 4 wks after which lower-limb compression garments (CG) or loose pants (CON) were worn for 24 h. Blood was collected pre-exercise and 1, 24 and 48 h post-exercise for IL-6, IL-1β, TNF-α, CRP and CK. Blood lactate was monitored throughout exercise and for 30 min after. A 5 counter-movement jump (5CMJ) and squat jump (SJ) were performed and perceived soreness rated at pre-exercise and 1, 24 and 48 h post-exercise. Perceived recovery was assessed post-exercise using a questionnaire related to exercise readiness. Repeated measures ANOVA was used to assess changes in blood, perceptual and physical responses to recovery. **Results:** CK and CRP were significantly elevated 24 h post-exercise in both conditions ($p<0.05$). No significant differences were observed for TNF-α, IL1-β, IL-6 between treatments ($p>0.05$). Power and force production in the 5CMJ was reduced and perceived soreness was highest at 1 h post-exercise ($p<0.05$). Perceived recovery was lowest at 1 h post exercise in both conditions ($p<0.01$), whilst overall, perceived recovery was greater when CG were worn ($p<0.005$). **Conclusion:** None of the blood or physical markers of recovery indicate any benefit of wearing compression garments post-exercise. However, muscle soreness and perceived recovery indicators suggest a psychological benefit may exist.

DECLARATION

This is to certify that this thesis comprises only my original work towards the masters. Due acknowledgement has been made in the text to all other material used. This thesis is 16,075 words in length, exclusive of tables, maps, bibliographies and appendices.

Cathryn Pruscino

PREFACE

The following article was published from data obtained in this thesis and is included at Appendix H:

Pruscino, C.L., Halson, S., & Hargreaves, M. (2013). Effects of Compression Garments on Recovery following Intermittent Exercise. *Eur J Appl Physiol,*113:1585-1596.

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To my husband Sandy, although this is not the biggest hurdle I've overcome, it's yet another milestone which could not have been achieved without your extraordinary support. You're the rock on which we all lean. Thank you for making this possible.

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CHAPTER 1

INTRODUCTION

For elite athletes, full recovery from training and competition is important for optimal physiological adaptation and performance. The training of an athlete is generally the primary focus in elite athlete preparation, however, the athlete generally spends more time recovering than they do in training or competition (Bishop, Jones, & Woods, 2008). In order for the exercise-induced adaptations to occur, the body must adequately repair the damage and promote recovery from high-intensity exercise to ultimately improve training capacity and athletic performance.

As such, there is a growing body of research investigating the efficacy of various recovery techniques in mitigating the effects of exercise-induced muscle damage (EIMD) and thereby, optimising recovery from high-intensity exercise (Bishop, et al., 2008; Cheung, Hume, & Maxwell, 2003; Connolly, Sayers, & McHugh, 2003; Howatson & van Someren, 2008; McIntyre, Reid, & McKenzie, 1995). The effects of EIMD are well characterised in the literature and are seen as a limiting factor in athletic performance and improvement. Whilst not all training or competition carried out by elite athletes elicits EIMD, a strategy which may accelerate the recovery from the symptoms associated with EIMD is thought to be beneficial for optimal performance.

A range of recovery modalities has been utilised by the athletic population in an attempt to enhance the recovery from EIMD in order to return the athlete to training sooner. Compression garments are one of the strategies now commonly employed by elite athletes

during recovery from competition and training. The benefits of compression garments on the heamodynamics of the lower limb include reduced arterial blood flow, increased venous outflow and venous return, leading to greater ventricular filling and cardiac output. The improved fluid movement along the lower limb assists in the prevention of interstitial fluid accumulation and tissue oedema, whilst potentially promoting the local clearance of inflammatory mediators.

In the medical profession, the benefit of using medical grade compression garments for patients with venous insufficiency is well established (Holford, 1976; Sigel, Edelstein, Felix, & Memhardt, 1973; Sigel, Edelstein, & Savitch, 1975). Previous studies have provided evidence of a reduction in the distension of the deep veins of the calf and a reduction in the incidence of deep vein thrombosis in post-operative patients (Coleridge Smith, Hasty, & Scurr, 1991; Holford, 1976). Furthermore, some research has found that medical grade compression garments have a positive effect on blood flow in patients with normal venous systems (Sigel, et al., 1973; Sigel, et al., 1975), however, findings to the contrary also exist in the literature (Macklon & Greer, 1995; Stein et al., 2010).

The improvement in blood flow characteristics in the lower extremities of post-operative patients has been the rationale for use of compression garments in the treatment of medical conditions and, as such, their adaptation by the sporting fraternity stems from this. There is a general belief in the sporting world that compression garments worn in the post-exercise period may enhance the time course of repair by accelerating the recovery response to acute inflammation and reducing delayed onset muscle soreness. A growing body of research investigating the physical, biochemical and performance effects of using commercially-available compression garments post-exercise has attempted to determine the effectiveness of

this as a recovery strategy (Berry & McMurray, 1987; Davies, Thompson, & Cooper, 2009; Duffield, Cannon, & King, 2010; French et al., 2008; Kraemer et al., 2001; Kraemer et al., 2010; Montgomery, Pyne, Hopkins, et al., 2008; Trenell, Rooney, Sue, & Thompson, 2006). However, whether compression garments worn following exercise, improve the time course of the recovery process or mitigate the effects of EIMD for the elite athlete, is still unclear.

The main reasons for this include the differences in type and pressure characteristics of the compression garments utilised, as well as the variation in the training status of the subjects and the exercise regimens used within the current body of research. Furthermore, much of the research examining the effect of compression garments on exercise recovery employs exercise regimens known to incur EIMD, for which recovery can be easily measured and monitored. However, for elite athletes, the eccentric resistance exercise regimen traditionally used to elicit muscle damage, may not reflect the extent of typical damage incurred during training or competition. As such, the recovery from this type of exercise may not be specific to the training recovery required for their sport (Bishop, et al., 2008).

The purpose of this study was to investigate the efficacy of lower-body compression garments following high-intensity, intermittent exercise on the recovery of highly-trained team-sport athletes. By simulating the specific demands of team sports, our aim was to conduct a controlled study to test the hypothesis that wearing compression garments after intermittent exercise provides a benefit to the recovery process, as measured by a number of novel biomarkers and the recovery of symptoms commonly associated with EIMD.

CHAPTER 2

REVIEW OF LITERATURE

2.1 EXERCISE-INDUCED MUSCLE DAMAGE

Exercise-induced muscle damage (EIMD) is generally categorised by reduced muscle function, muscle stiffness, swelling, and delayed-onset muscle soreness, thought to be caused by a range of mechanical and biochemical incidents during exercise (McIntyre, et al., 1995; Tee, Bosch, & Lambert, 2007). The symptoms of EIMD are most evident 24-48 h, and can persist for up to 10 days, after the cessation of high intensity exercise, particularly eccentric in nature (Connolly, et al., 2003; McIntyre, et al., 1995).

During eccentric muscle contractions, as the muscle lengthens the number of attached cross-bridges decreases and, therefore, the mechanical stress tolerated by each fibre is much higher than during concentric actions (Tee, et al., 2007). Eccentric contractions result in higher levels of force even though fewer muscle fibres are recruited, and as a consequence, there is greater evidence of muscle damage following eccentric compared with concentric or isometric contractions (McCully & Faulkner, 1985). The greater mechanical stress on each individual muscle fibre causes damage to the contractile components of the muscle tissue, particularly at the z-line (Cheung, et al., 2003; Howatson & van Someren, 2008; McIntyre, et al., 1995).

Localised disruption of the contractile components and damage to the cell membranes of muscle fibres often cause leakage of muscle proteins, such as CK, into the blood (Cheung, et al., 2003). The structural damage to the cell membrane is also believed responsible for the

loss of calcium homeostasis following eccentric exercise, causing increased intracellular calcium levels, resulting in degeneration of the muscle fibre (Armstrong, Warren, & Warren, 1991; Koh, 2008; Sayers & Hubal, 2008; Tee, et al., 2007).

2.1.1 Inflammatory Response

In response to structural damage to the muscle cell, the inflammatory process plays a central role in promoting the movement of fluid, plasma proteins and leucocytes into the damaged tissues (McIntyre, et al., 1995). The inflammatory-mediated increase in blood flow brings about swelling at the damage site which is often associated with pain and discomfort (Connolly, et al., 2003). Neutrophils and macrophages are central in the inflammatory response and tend to accumulate in skeletal muscle in the hours and days after injury (McIntyre, et al., 1995; Pizza, 2008). It is possible that these inflammatory cells are responsible for stimulating the production of a complex range of cytokines which play varying roles in the inflammatory response (McIntyre, et al., 1995; Pedersen, Ostrowski, Rohde, & Bruunsgaard, 1998; Pizza, 2008). The production of cytokines is triggered locally at the site of inflammation and is part of the acute phase inflammatory response (Ostrowski, Rohde, Asp, Schjerling, & Pedersen, 1999). Neutrophil concentrations peak in damaged tissue 1-4 hours after injury (Pedersen, et al., 1998) which is thought to initiate the production of cytokines such as TNF-α and IL-1β (McIntyre, et al., 1995). These cytokines are pro-inflammatory and may actually delay muscle regeneration by decreasing the growth of regenerating myofibres (Pizza, 2008). The presence of TNF-α and IL-1β is thought to trigger the release of IL-6, which is restorative rather than pro-inflammatory in nature (McIntyre, et al., 1995; Pedersen, et al., 1998). Macrophage accumulation within the injured tissue occurs when neutrophil concentrations are in decline and is thought to be involved in the removal of necrotic tissue in order to prepare the area for repair (McIntyre, et al., 1995; Pizza, 2008).

Macrophages may also be responsible for triggering the production of IL-6 which promotes the growth of regenerating myofibres and therefore, regeneration and repair (Pizza, 2008). The presence of IL-6, in turn, is thought to promote synthesis of C-reactive protein (CRP) (Pedersen, et al., 1998), a marker of systemic inflammation and tissue damage (Malm et al., 2004).

The time course and magnitude of the cytokine response to EIMD and eventual repair, is generally dependent on the type, duration and intensity of the eccentric exercise performed (Sayers & Hubal, 2008).

2.1.2 Markers of Exercise-Induced Muscle Damage

Given the mechanical stress placed on the individual muscle fibres during eccentric exercise and the damage to the contractile properties and membranes of the muscle cell, there are a number of markers that are commonly used to indicate that muscle damage has occurred. Typical markers of muscle damage are generally accepted as including a loss of muscle function as well as the presence of muscle-specific proteins such as creatine kinase (CK) and inflammatory cytokines (Nosaka, 2008). Other biomarkers, although not specifically examined in this study, such as troponin, myoglobin and lactate dehydrogenase (LDH), are also elevated following tissue damage (Sayers & Hubal, 2008). Delayed-onset muscle soreness (DOMS) and reduced range of movement often accompany these markers following bouts of eccentric exercise, however, whether DOMS is directly related to damage to the muscle itself is questionable (Malm, et al., 2004; Nosaka, Newton, & Sacco, 2002).

2.1.2.1 Muscle Function

Reduced muscle function after exercise is a consequence and commonly used indictor of EIMD, particularly following eccentric exercise (Sayers & Hubal, 2008). This is largely due to damage to the contractile properties of the individual muscle fibres sustained during eccentric exercise. Furthermore, damage to the cell membranes and subsequent increase in intracellular calcium levels, results in degeneration of the muscle fibre causing impairment of excitation–contraction coupling and muscle function (Armstrong, et al., 1991; Koh, 2008; Sayers & Hubal, 2008; Tee, et al., 2007).

It is generally accepted that the larger the decrement in muscle strength following exercise, the greater the extent of the muscle damage (Nosaka, 2008). As such, strength loss following eccentric exercise is one of the most commonly used indirect markers of muscle damage (Armstrong, et al., 1991; Sayers & Hubal, 2008).

The magnitude of strength loss after exercise is dependent on the type and intensity of the exercise performed. Strength losses of 10-30% are common following downhill running or eccentric cycling, losses of 30-50% generally follow moderately intensive exercise protocols and losses of 50-70% are sustained from intense protocols (Sayers & Hubal, 2008). Depending on the extent of the injury, the reduction of muscle strength may persist for up to 10 days (Armstrong, et al., 1991).

Maximal isometric strength is often used to measure changes in muscle strength after eccentric exercise (Nosaka, 2008) and is regarded as a valid and reliable measure for this purpose (Armstrong, et al., 1991). However in more applied settings, counter movement jumps (CMJ) have been used to assess the recovery of muscle function post-exercise (French,

et al., 2008; K. Petersen, Bugge Hansen, Aagaard, & Madsen, 2007). The specific variables which may be monitored during repeated CMJ include flight time, peak force, relative force, peak power, relative power and mean power, all of which have been shown to be reliable measures (CV<10%) in team sport athletes (Cormack, Newton, McGuigan, & Doyle, 2008).

Following a resistance exercise challenge, leg power was assessed using a single CMJ and a repeat CMJ for 15 s where maximal jump height was emphasised (French, et al., 2008). In the single CMJ, leg power was found to be 8.5% lower 48 h after exercise compared with pre-exercise values, however, the repeat CMJ test showed no change from baseline performance (French, et al., 2008). Thirty minutes after a marathon race, maximum isometric voluntary contractions of plantar flexion and knee extension were 17% and 22% lower, respectively, whilst CMJ power was decreased by 13% in the same subjects. Both plantar flexion and CMJ power remained depressed for up to 5 days, suggesting a prolonged suppression of function muscle power following marathon running (K. Petersen, et al., 2007).

2.1.2.2 CK Concentration

CK is an enzyme which facilitates the reversible conversion of ADP and phosphocreatine to regenerate adenosine triphosphate (ATP) when energy is required. Three isoenzymes of CK exist within the cells of skeletal muscle and the brain (CK-MM, CK-MB, CK-BB). In addition, two isoenzymes of CK exist in the mitochondria (non-sarcomeric and sarcomeric) and facilitate the formation of phospho-creatine from mitochondrial ATP. Circulating levels of CK are made up largely of the CK-MM isoenzyme provided by the skeletal muscle (Brancaccio, Maffulli, & Limongelli, 2007). Resting levels of CK are highly variable and are influenced by gender, age, race, training status and climatic conditions (Brancaccio, et al., 2007).

Increased circulating concentrations of CK following exercise, generally indicates a leakage of this intracellular protein from the cell into the bloodstream due to a disturbance of the skeletal muscle cell membrane (Brancaccio, et al., 2007; Sayers & Hubal, 2008). This is generally evident following high-intensity exercise involving eccentric muscular contractions. As such, CK concentration in the blood is commonly used as a marker of muscle damage following exercise (Jamurtus et al., 2005; Nosaka, et al., 2002; Ostrowski, Rohde, Zacho, Asp, & Pedersen, 1998; Sayers & Hubal, 2008; Thompson, Nicholas, & Williams, 1999).

CK activity may peak in the blood anywhere from 24h to 5d post-exercise depending on the type of exercise performed, with endurance-based eccentric exercise producing a more rapid appearance and high-force eccentric exercise producing slower and more prolonged peaks (Sayers & Hubal, 2008). The magnitude of the elevation in circulating CK following eccentric exercise appears to be influenced by the specific muscle group exercised with mean CK values for elbow flexor of 5440±850 IU/L, knee extensor yielding 1080±370 IU/L and downhill running inducing 550±200 IU/L (G. L. Warren & Palubinskas, 2008). The increase in post-exercise CK values is further influenced by a range factors, including gender and training status (Brancaccio, et al., 2007). Females generally show lower resting and post-exercise values of serum CK levels than males, whilst athletes have higher resting levels than sedentary subjects (Brancaccio, et al., 2007). However, the post-exercise elevation of CK in trained subjects is lower than in untrained subjects (H. Vincent & Vincent, 1997) possibly due to neural adaptation and the repeated bout effect (Howatson, van Someren, & Hortobagyi, 2007). Furthermore, performing exercise in colder weather results in higher serum CK increases compared with the same exercise in warmer conditions (Brancaccio, et al., 2007).

There is, however, substantial variation in the levels of CK within the blood even amongst similarly trained-individuals (Sayers & Hubal, 2008). Low responders exhibit low variability of CK levels with exercise, whilst high responders exhibit higher values and greater changes with exercise (Brancaccio, et al., 2007). This may in part be due to the fact that the blood levels of CK reflect not only their release from the cell but also their clearance from the circulation by the lymphatic system (Sayers & Hubal, 2008; G. Warren, Lowe, & Armstrong, 1999). As such, differences in clearance rates may vary the individual post-exercise response (Sayers & Hubal, 2008) and contribute to the dissociation between its time course of appearance in the blood and the histological assessment of muscle damage (Sayers & Hubal, 2008; G. Warren, et al., 1999). Therefore, although elevated CK activity following exercise represents a disruption to the cell membrane and therefore damage to the muscle cell, care should be taken when associating it with the magnitude of the damage sustained and the time course of change in other markers of muscle damage.

2.1.2.3 Cytokines and C-Reactive Protein

The appearance of cytokines in the blood suggests that the acute-phase inflammatory response has been initiated and is thought to reflect the magnitude of the muscle damage that has occurred (Pedersen, et al., 1998).

Previous research has identified an increase in circulating concentrations of cytokines following marathon running (Ostrowski, et al., 1999; Ostrowski, et al., 1998). A 2.3-fold increase in TNF-α, a 2.1-fold increase in IL-1β and a 128-fold increase in IL-6 was reported within 10 min of completion of the marathon race (Ostrowski, et al., 1999). Further research investigating distance running protocols identified distance related increases in CRP concentrations after 5 races of varying durations (15-88km) (Strachan, Noakes, Kotzenberg,

Nel, & De Beer, 1984). Regardless of the distance run, the time course of CRP elevation was the same, peaking 24 h after each race (Strachan, et al., 1984). However, the greater the total distance run, the greater the magnitude of the elevation of CRP at 24 h post-exercise. Only following the event of longest duration, the 88 km running race, were significantly elevated CRP concentrations evident immediately post-race (Strachan, et al., 1984).

Maximal eccentric resistance training has also been shown to produce an increase in circulating cytokines post-exercise. Following single arm, high force, maximal eccentric elbow flexor actions (3x15 sets), IL-6 concentration peaked 8 h after exercise with an almost 2-fold elevation above resting conditions (Miles et al., 2007). Similarly, maximal isometric force production using elbow flexion produced a 1.5 fold elevation of IL-6 above resting levels at 8 h post-exercise, however, there was no significant change in CRP concentrations (Miles, Pearson, Andring, Kidd, & Volpe, 2007).

An elevation of cytokines has also been reported following a game of soccer (Ispirlidis et al., 2008) and basketball (Montgomery, Pyne, Cox, et al., 2008). Following basketball match-play, IL-6 concentrations were 3-4 fold higher immediately post-match and remained above resting levels at 6h post (Montgomery, Pyne, Cox, et al., 2008). Intense, intermittent exercise during soccer match-play, resulted in an immediate post-match elevation of IL-1β, whilst IL-6 increased 4-fold also immediately post-match (Ispirlidis, et al., 2008). The peak in IL-6 following a soccer match preceded the peak in CRP which is in line with previous findings (Malm et al., 2000).

As such, previous research has shown that different types of exercise will bring about an increase in the levels of circulating cytokines following exercise. This is thought to indicate

that an inflammatory response has occurred, however, it should be considered that the production of some cytokines may play roles other than purely inflammatory mediators during exercise and in the post-exercise period. For example, IL-6 is thought to be involved in substrate delivery during exercise through its ability to induce lipolysis and fat oxidation and through its involvement in glucose homeostasis (A. Petersen & Pedersen, 2005). As such, aside from its role in inflammation, the increase in IL-6 post-exercise may be part of a normal biological exercise-mediated response. In line with this, baseline levels of CRP and IL-6 have both been found to be influenced by the diet, with low-fat, high-carbohydrate diets found to illicit an increase in circulating levels of these inflammatory mediators (Kasim-Karakas, Tsodikov, Singh, & Jialal, 2006).

With regards to the exercise response, although the extensive role of cytokines may not yet be completely understood, it is clear that the magnitude of the cytokine response varies with different types of exercise. It is thought that eccentric exercise with an endurance component will result in a more robust cytokine response, however, the duration of the response may be shorter than when high-force eccentric exercise is performed (Sayers & Hubal, 2008).

2.1.2.4 Delayed-Onset Muscle Soreness

DOMS is generally associated with EIMD, however, the degree of DOMS does not necessarily reflect the magnitude of the damage sustained (Nosaka, et al., 2002). Malm et al. (2004) found that DOMS was related to markers of inflammation found in the epimysium following strenuous downhill running, suggesting that DOMS is more closely related to connective tissue damage rather than damage to the muscle itself.

Damage to the connective tissue surrounding the muscles may influence the extensibility and elasticity of the muscle potentially affecting the overall range of movement around the joint. In addition, damage to the connective tissue causes discomfort when the muscle is contracted, stretched or massaged (Cheung, et al., 2003; Nosaka, et al., 2002).

From a purely psychological perspective, the presence of discomfort or pain as characterised by DOMS, may significantly alter an individual's perception of their ability to perform optimally. Previous research found that when cyclists ingested acetaminophen (paracetamol) prior to a 16km time trial (TT), participants cycled at a higher mean power with higher blood lactate concentration and heart rate and no associated increase in perceived exertion or pain compared to placebo conditions. Completion time of the TT was significantly faster when the perception of pain was regulated (Mauger, Jones, & Williams, 2010).

As such, by moderating the perception of pain and lessening its negative impact on physiological and motor function, an individual's psychological approach to subsequent exercise bouts and their ability to perform may be improved (Mauger, et al., 2010).

Whilst DOMS does not technically reflect muscle damage, it indicates that damage has occurred in the associated tissue and as such, plays a vital role in the overall physical and psychological recovery process.

2.1.3 Recovery From Exercise

The symptoms commonly experienced following EIMD have a profound effect on an athlete's ability to adhere to a training program or perform optimally during subsequent exercise (Howatson & van Someren, 2008). Given the structural and biochemical damage and the internal disruptions to homeostasis of the injured cells, physiological recovery and repair

of muscle fibres can take 5-10 days following high-intensity eccentric exercise (Armstrong, et al., 1991; Connolly, et al., 2003).

The recovery of these symptoms associated with EIMD may suggest improved readiness for exercise (Bishop, et al., 2008). The restoration of muscle function and homeostasis at the cellular level are important physiological and biochemical factors, whilst the presence or dissipation of DOMS following exercise may be a strong psychological determinant of exercise readiness.

In an attempt to accelerate the natural physiological response of the body and enable an athlete to return to full training or competition sooner, a range of recovery strategies is often put in place following high-intensity exercise. These strategies include nutrition and hydration strategies, contrast water therapy, cold water immersion, compression therapy, cryotheraphy, massage, stretching and exercise techniques, to name a few. Numerous studies have examined these strategies to assess their efficacy in reducing the symptoms of EIMD and accelerating the recovery of the athlete in order to return to full training or competition. The focus of the present study is on the use of compression garments and their impact on the recovery process following high-intensity exercise.

2.2 COMPRESSION GARMENTS

Compression garments are widely used in general medicine to improve circulation in immobile or post-operative patients (Holford, 1976; Horner, Fernandes e Fernandes, & Nicolaides, 1980). Furthermore, compression therapy is widely used in sports medicine to reduce oedema and improve recovery from injuries sustained during exercise including acute muscle sprains, strains and more severe muscle tears. More recently, compression therapy

using commercially-available compression garments, has been used as a recovery strategy following intense exercise. The premise behind their use, in this instance, appears largely related to the benefit of compression on the promotion of blood flow.

2.2.1 Compression Garments and Blood Flow

Early research by Sigel et al. (1973) provided evidence of an improvement of blood flow velocity in the lower leg using elastic compression stockings during inactive recumbency in subjects with normal venous systems. It was suggested that the blood flow velocity was improved due to the reduction of the deep venous bed, which thereby lead to an improved venous return to the heart and a reduction of stasis in the lower extremities of the immobile subjects (Sigel, et al., 1973).

Further work carried out by this group, identified that the optimal type of compression for reducing venous stasis was compression which offered a graduated reduction in the force that was applied (Sigel, et al., 1975). That is, compression garments that applied a force of 18 mmHg at the ankle reducing to 8 mmHg at the thigh, increased average femoral blood flow velocity by 38.4%, significantly greater than that achieved when uniform compression was applied (Sigel, et al., 1975).

Such garments have since been proven to significantly reduce the incidence of deep vein thrombosis in post-operative patients (Holford, 1976) due to the improved flow velocity and reduction of stasis in the lower extremities. Furthermore, graduated lower body compression garments have been found to enhance the venous haemodynamics in patients with deep venous insufficiency (1976; Horner, et al., 1980; Ibeguna, Delis, & Nicolaides, 1997; Zajkowski et al., 2002).

These findings have generally been of most value to the inactive, recumbent population of hospitalised patients for the prevention of deep venous thrombosis. However, the fact that the benefits of wearing lower body compression garments on circulation were initially reported in patients with normal venous systems (Sigel, et al., 1973), offers support for their use by the healthy population.

2.2.2 Compression Garments and Recovery from Exercise

In recent years, sports compression garments have been heavily promoted to athletes for use during or after exercise with claims that they facilitate lactate removal, reduce muscle soreness and enhance muscular function. The potential benefits of an improved haemodynamic response with the use of sports compression garments during recovery are numerous. A reduction in stasis of the lower limbs may reduce the risk of oedema whilst improved venous flow velocity and return of venous blood to the heart may enhance the removal of metabolic waste generated during exercise. If arterial flow were improved this may result in better delivery of oxygen and nutrients to damaged cells and a have a beneficial effect on the biochemical environment of the muscle and the physiological restoration of muscle fibres following high-intensity exercise.

To this date there has been no research, to my knowledge, examining the effects of sports compression garments on the lower leg haemodynamics of healthy athletic subjects. However, there has been a range of studies investigating the use of these garments on the symptoms of EIMD in the post-exercise recovery period (Table 2.1). The findings relating to the efficacy of such garments as a viable recovery strategy, however, are mixed.

Trenell et al. (2006) investigated the metabolic recovery from EIMD and reported an increased intracellular phosphodiester (PDE) concentration inside the muscle following compression, potentially indicating increased skeletal muscle membrane turnover and therefore an accelerated inflammatory response. Other authors have reported reduced post-exercise blood lactate concentration (Berry & McMurray, 1987), an enhanced recovery of force production, reduced CK concentrations and decreased soreness in the days following exercise (Kraemer, et al., 2001) when wearing compression garments in the recovery period. However, the use of compression garments following resistance exercise (French, et al., 2008) or a simulated basketball tournament (Montgomery, Pyne, Hopkins, et al., 2008) has been found to provide minimal and sometimes harmful effects on the recovery process using subsequent exercise tests as performance markers (Table 2.1).

2.2.3 Compression Garment Characteristics

The mixed results of previous research may partly be due to the range of exercise regimens employed, the differences in training status of the subjects utilised and the diverse characteristics of the compression garments investigated (Table 2.1).

The varied characteristics of compression garments give rise to their unique qualities and influence their overall effectiveness. The degree of compression applied by the garment and the specific compression characteristics (graduated or even) are important if the optimum increase in venous flow is to be achieved (Sigel, et al., 1975). Furthermore, the type of compression garment worn (full length tights, socks and shorts) may impact their specific influence on the haemodynamics of the lower limb.

2.2.3.1. Compression Garment Type

Different types of garments have been used within the literature to assess the effectiveness of compression on the recovery from various forms of exercise. The commercial garments utilised vary by manufacturer, each with their own fabric composition and pressure characteristics. Furthermore, many of these garments vary according to the area of the skin or limb to which they apply a compressive force.

Research investigating the benefits of compression following maximal eccentric upper arm exercise utilised a compressive arm sleeve which extended from the arm pit to just below the elbow (Kraemer, et al., 2001). The arm sleeve was found to promote recovery of force, improve range of movement at the elbow and reduce soreness and swelling compared to when no sleeve was worn (Kraemer, et al., 2001). Other research investigating the use of a full-body compression suit reported a reduction in CK concentration and improvements in upper body strength parameters following a whole-body heavy resistance exercise protocol (Kraemer, et al., 2010).

A range of studies has also focused on lower body garments. Compression stockings to the knee were found to have no effect on oxygen consumption, heart rates and lactate concentrations in the 30 min post-exercise period (Berry & McMurray, 1987). A full length lower body garment had no effect on muscle function, mid-thigh girth and muscle soreness following a drop-jump exercise protocol, however, produced significantly slower sprint times over 5 m compared with control conditions (Davies, et al., 2009). Two further studies utilising full-length lower body garments also resulted in delayed sprint recovery when compression garments were worn after a resistance exercise protocol (French, et al., 2008) or a competitive basketball tournament (Montgomery, Pyne, Hopkins, et al., 2008).

Table 2.1: Previous research investigating the post-exercise use of compression garments for recovery purposes.

Reference	Subject Training Status	Compression Garment type	Garment Pressure	Duration of wear	Exercise Stimulus	Changes in EIMD markers/Biochemical markers/Performance with CG v Control
Berry & McMurray (1987)	Fit college students	Compression sock to knee	Ankle 18 mmHg; Calf 8 mmHg	During exercise & 1h- post	Treadmill ramp test to exhaustion	↓ Blood lactate at 15min post-exercise No difference in max VO_2, time to exhaustion
Kraemer et al. (2001)	Untrained females	Arm sleeve	10 mmHg	5 d	2x50 arm curl incl. max eccentric & isometric curls	↓ CK concentration, ↓ Loss of elbow motion, ↓ Soreness, ↓ Swelling, ↑Recovery of force No differences in serum cortisol, LDH
Trenell et al. (2006)	Recreational athletes	Skins, single-leg, full-length, lower body	Calf 17±2 mmHg; Thigh 10±2 mmHg	48 h	30min downhill walking	↑ Skeletal muscle PDE 1h post-exercise No differences in PCr/Pi, magnesium, phosphomonoester
French et al. (2008)	Strength-trained	Skins, full-length, lower body	Calf 12 mmHg; Thigh 10mmHg	12 h	Whole body resistance exercise protocol	↑ 30m sprint time (2% slower than baseline) No difference in soreness, CK, myoglobin, joint flexibility or ROM,
Montgomery, Pyne, Hopkins (2008)	State level Basketballers	LineBreak, full-length, lower body	Not measured	Approx 18 h	3-day basketball tournament (1 full game per day)	↑ 20m sprint time (3.2% slower than baseline), ↓Soreness, Better maintenance of basketball line drill performance and vertical jump performance No difference in thigh girth, sit and reach
Duffield et al. (2008)	1st division U21 rugby players	Skins, full-length, lower body	Not measured	During match & 15h post-match	2-day simulated tournament (1 game per day)	↓Soreness, ↑ skin temp No difference in repeated sprint test, peak power, lactate, CK, HR, core temp, BM
Davies, Thompson & Cooper (2009)	University netballers and basketballers	LineBreak, full-length, lower body	Not measured	48 h	5x20 plyometric drop jumps	↑ 5m sprint time (8% slower than baseline), ↓Soreness, ↓ CK concentration for females only No differences between treatments in 10m and 20m sprint tests, LDH, thigh girth, CMJ, 5-0-5 agility test
Duffield, Cannon & King (2010)	Moderately trained club & regional rugby players	Slazenger, full length lower body	Not measured	24 h	20m sprint +10x deep squat bounds per min (10min)	↓Aspartate transaminase (AST), ↓Soreness No difference in HR, RPE, pH, CK, C-RP
Kraemer et al. (2010)	Resistance-trained	UnderArmour, whole body suit	Not measured	24 h	Heavy resistance exercise protocol	↓ CK concentration, ↓Soreness, ↓Swelling, ↑Bench press throw No difference for CMJ, Squat jump, mood state

With regards to garment type, whilst the upper body garments appear to provide the greatest benefit in reducing the symptoms commonly associated with EIMD, it should be noted that this may in part be specifically associated with the unique biochemical response of the musculature of the upper body (G. L. Warren & Palubinskas, 2008). For lower body garments, so far there does not appear to be consensus within the literature of a clear benefit on the time course of the recovery process or in reducing the symptoms commonly associated with EIMD.

2.2.3.2. Pressure Characteristics

Further compounding the uncertainty surrounding the compression research is the variation in pressure characteristics of the garments investigated. The haemodynamic efficacy of a compression garment depends mainly on the amount of compression applied, the elasticity of the materials used (Partsch et al., 2006) and the graduation of the garment along the limb (Sigel, et al., 1975). Few of the studies mentioned above, utilised the same type or brand of garment, and pressure characteristics were sometimes stated (based on manufacturers information), but rarely measured. Furthermore, whether the pressure characteristics are maintained whilst being worn is also questionable. Only one study measured garment pressure over the course of the study period reporting a slight reduction in calf compression (1 mmHg) and no change in thigh compression after 48h of wear compared to baseline values (Trenell, et al., 2006). As such, given the varied and limited information available, it is difficult to ascertain the accuracy of the pressure applied by the sports garments examined and the ultimate impact this has on the research outcomes.

Within the medical profession, consensus for the measurement and evaluation of compression garments has been reached and previously outlined (Partsch, et al., 2006). When clinical and experimental outcomes of compression treatments are to be evaluated, it is recommended that the interface pressure be measured in order to determine its hemodynamic efficacy (Partsch, et al., 2006).

Manufacturers of both medical and sports compression products often disclose the pressure characteristics of their garments, however, the techniques used for fitting these garments to their respective populations vary significantly. Medical grade compression garments are custom-fit to suit the individual patient. That is, the ankle, calf and thigh circumference of each individual patient are taken into consideration when determining sizing, to ensure accurate and well-fitting stockings are provided (Venosan, 2009). The fitting of commercially-available sports compression tights, however, is generally determined by the subject's height and body mass (2XU, 2009; Skins, 2012). Whilst the later is an easy means for distribution of a commercial product to the general population, it is questionable whether the pressure characteristics of the garments would be preserved across a wide range of anthropometric profiles. Given the diversity in the body composition of different athletes and within the wider community, it would be fair to suggest that the variability in ankle, calf and thigh circumference may greatly influence the pressure application offered by different garments at these important sites.

A homogenous group of subjects used to assess any form of commercially-available sports compression garment will likely present less variation in the pressure characteristics and therefore, overall blood flow response, to the compression applied.

Well-trained subjects from similar activity backgrounds will likely provide this and may reduce, but not remove, the potential variation in the pressure characteristics offered by a commercially-available compression garment. Only two previous studies have utilised the effect of commercially-available compression garments on such a group of subjects, however, neither of these studies measured the pressure interface between the garment and the skin (Davies, et al., 2009; Montgomery, Pyne, Hopkins, et al., 2008).

2.2.3.3. Post-Exercise Use

The way that compression garments are used in the post-exercise period also varies depending on how soon they are put on after exercise and the length of time that they are worn.

The optimal duration of time that a garment might be worn post-exercise for any benefit to be achieved, is unknown. The current body of research investigating the recovery of exercise using compression varies in the duration of wear from 1 h (Berry & McMurray, 1987) to 5 days (Kraemer, et al., 2001) post-exercise. There does not appear to be any indication that a shorter or longer wear period offers a different response.

The only research which appears to have monitored the effect on blood flow velocity of the different durations of applied compression, was reported by Sigel et al. (Sigel, et al., 1973). Regardless of whether the stockings were worn on the lower extremities for 30 min or 3 h, the increased flow velocity continued to persist for 30 minutes after the release of compression. The authors were careful to emphasise however, that the

experiments were performed during inactive recumbency and as such the conclusions could not be applied to any other body positions or during exercise (Sigel, et al., 1973). This suggests that, when evaluating the effects of compression on the haemodynamics of the lower leg, the body position and activity status of the subject may be more important than the duration of time that the compressive force is applied.

2.2.4 Compression Therapy for the Elite Athlete

There are a range of physiological, biochemical and perceptual markers which may be used to assess the impact of the damage sustained on the body during exercise and its subsequent recovery. The optimal recovery process for any given type of exercise is likely unique to the specific damage and fatigue incurred and will vary depending on how familiar the exercise is to the individual. Trained and un-trained participants are very different physiologically and psychologically and will respond differently when exposed to the same exercise stimulus (Brancaccio, et al., 2007) and as such, caution must be applied when transferring results between groups (Bishop, et al., 2008).

For elite athletes, an acceleration of the muscle repair process, even for minor episodes of muscle damage, is advantageous in their capacity to return to competition or training at the earliest opportunity. Compression garment use in the post-exercise period is thought to augment recovery from EIMD by improving venous return to the heart and minimising swelling at the site of damage, however, there is no specific evidence to support this in this population. Whilst various types of garments have been shown to reduce some of the symptoms associated with EIMD, that which is most commonly used within the athletic population appears to be the full-length lower body compression garment. The effect of this type of garment on the recovery of

sport-specific competition using highly-trained athletes has only been investigated once before with minimal benefit reported (Montgomery, Pyne, Hopkins, et al., 2008).

Given the varying types of compression garments investigated, the lack of clarity with regards to the pressure characteristics and the significant variation with regards to training status of subjects in the bulk of previous research in this area, the benefit of using compression garments post-exercise for the highly-trained population remains unclear.

The present study aimed to investigate the efficacy of wearing commercially available, full-length, lower body compression garments for 24 h following intense, intermittent-exercise. By measuring the interface pressure of the garment against the skin, and utilising an exercise protocol specific to the demands of intermittent team sport, we were able to specifically monitor the post-exercise course of recovery in highly-trained athletes. A range of physiological, biochemical and perceptual markers were used to test the hypothesis that there would be a beneficial effect of wearing lower body compression garments on recovery following intense, intermittent-exercise.

CHAPTER 3

METHODS AND PROCEDURES

3.1 OVERVIEW OF STUDY DESIGN

Eight field hockey players completed two 3-day trials in a randomised, cross-over design. The two trials were separated by 4 wks. On day one of each trial, subjects performed a match-simulation exercise protocol, called the Loughborough intermittent shuttle test (LIST), incorporating five 15 min exercise bouts, interspersed by 3 min of rest. Upon completion of exercise and after obtaining the 4 min post-exercise blood lactate sample, either lower-limb compression garments (CG) or loose pants (CON) were worn for 24 h. Venous blood was collected from each subject pre-exercise and at 1, 24 and 48 h post-exercise for IL-6, IL-1β, TNF-α, CRP, whilst capillary blood was collected at the same time points for CK analysis. Blood lactate, heart rate (HR) and rating of perceived exertion (RPE) was monitored at the end of each 15min exercise bout and blood lactate samples were collected at 4, 8, 12, 20 and 30 min post-exercise. At pre-exercise and 1, 24 and 48 h post-exercise, subjects collected body mass, performed a 5-repetition counter-movement jump (5CMJ) and squat jump (SJ) and rated their perceived muscle soreness (RPS). Each subject's perceived recovery was rated at 1, 24 and 48 h post-exercise using a questionnaire related to exercise readiness. The experimental design and study timeline is summarised in Figure 3.1.

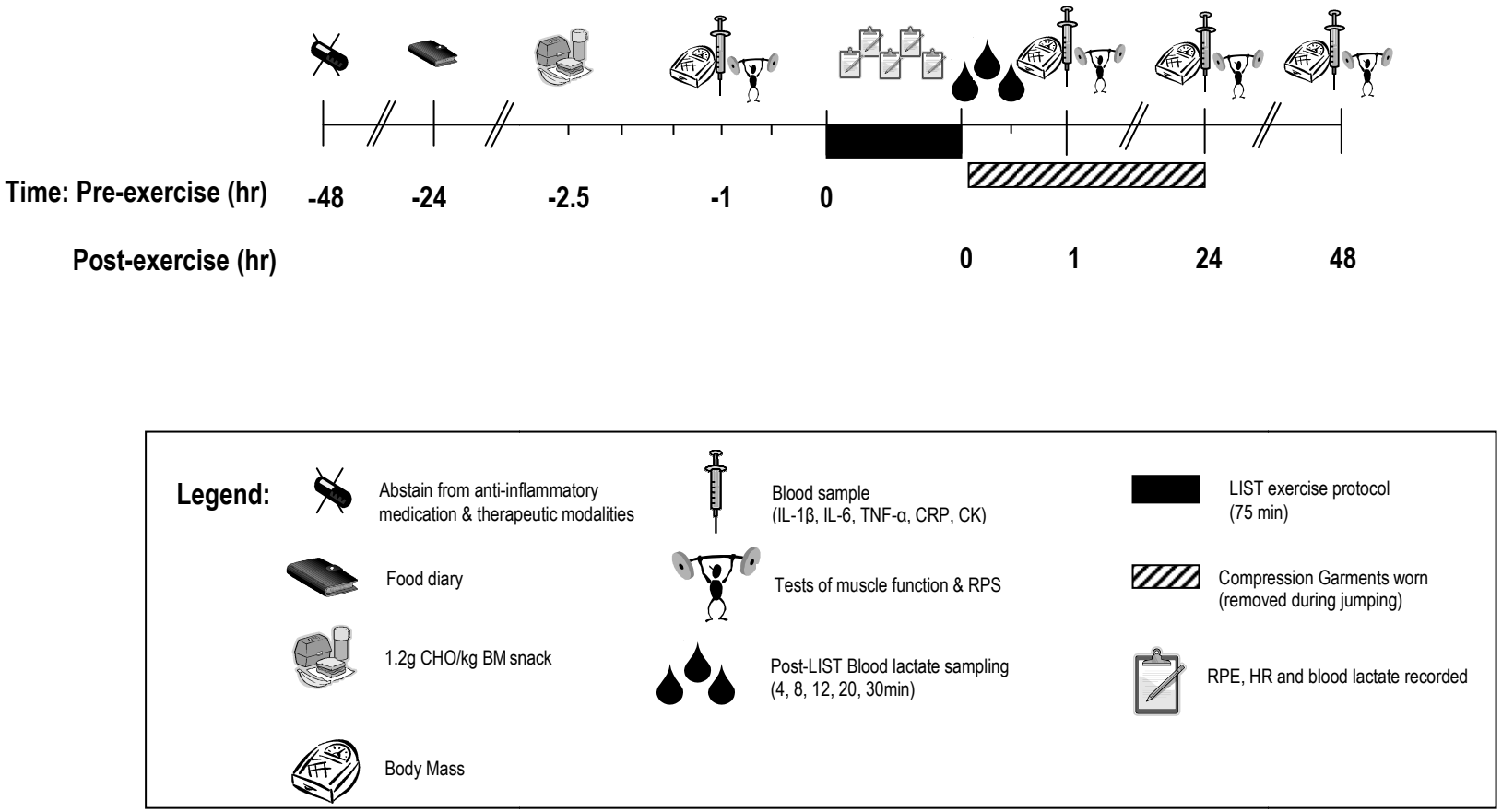

Figure 3.1: Experimental design and study timeline.

3.2 SUBJECTS

Eight highly-trained male hockey players, who competed at either national or international level, volunteered to participate in this investigation (n=8). Subjects were recruited from the Victorian Institute of Sport Men's Hockey program and their characteristics are described in Table 3.1. Prior to commencing the study, all participants were informed of the requirements, risks and benefits of the investigation and written informed consent (Appendix A) was obtained from each. All subjects were provided with an information sheet outlining the study procedures (Appendix B) and were required to complete a medical questionnaire (Appendix C) prior to participation in the study, to screen for any contraindications associated with maximal exercise testing. Approval for the procedures of the study was granted by the University of Melbourne Human Research Ethics Committee.

3.2.1 Subject Instructions

Following recruitment into the study, subjects were asked to follow simple study guidelines pertaining to: 1) food and fluid intake; 2) restrictions on exercise intensity prior to each trial; 3) instructions on the use of the compression garments; 4) restrictions on the use of medications; 5) restrictions on the temperature of showers and; 6) restrictions on the use of other recovery modalities during the study period (Appendix D).

Subject	Age (yrs)	Body Mass (kg)	Height (cm)	Sum of 7 Skinfolds (mm)	Pred. VO_2 max ($ml.kg.min^{-1}$)	Waist girth (cm)
1	25.1	70.0	171.0	46.2	60	82.0
2	21.6	93.5	191.9	74.9	58	84.5
3	19.2	72.3	179.3	74.2	62	77.5
4	20.6	78.8	181.1	37.5	62	82.5
5	19.3	70.4	176.3	71.6	54	80.5
6	19.9	72.6	178.8	80.2	62	78.0
7	23.9	104.4	193.5	109.7	54	91.4
8	25.8	60.9	169.0	65.3	61	77.0
Mean	**22±2**	**77.9±13.9**	**180.1±8.0**	**70.0±19.8**	**59±3**	**81.7±4.7**

Table 3.1 Physiological characteristics of subjects (n=8). Mean values are ± SD.

3.2.1.1 Nutrition, Hydration and Exercise Controls

A study pack containing sports drinks, a urine container, a food pack and a food diary was delivered to each subject prior to the commencement of each trial. The food pack contained hydration fluids for the night before each trial and a normalised breakfast pack for the morning of the trial which aimed to deliver 1.2g CHO.kg BM^{-1}. This was to ensure that subjects arrived at each testing session in a similar state of hydration, and carbohydrate availability would not be a limiting factor to their physiological response.

In addition, food diaries were kept by each athlete in the 24 h prior to the start of the first trial and throughout the 3 day trial period. These diaries were copied and handed back to the subjects in order for them to replicate this food intake regimen prior to the subsequent trial to ensure that pre-exercise glycogen stores were similar between the two trials.

Subjects were restricted from performing high intensity exercise in the 24 h prior to each trial to reduce the likelihood that subjects would present with muscular fatigue or damage prior to commencing the exercise protocol.

3.2.1.2 Compression Garment Guidelines

Subjects were asked to wear the compression garments provided for 24 h following completion of the exercise protocol. They were permitted to remove the garments for showering purposes, however, they were asked that the garment was not removed for longer than 30 min in total within the 24 h period during each trial. This was to ensure that the garments remained on for as close to 24 h as possible and reduce any potential differences between subjects with regards to the duration of wear during the recovery period.

3.2.1.3 Medication & Recovery Restrictions

In the days prior to each trial and throughout the study period, subjects were asked to refrain from taking anti-inflammatory medication (aspirin, ibuprofen). They were also asked to limit the water temperature and duration of showers and refrain from using the following therapeutic modalities: ice therapy, ice baths, contrast water therapy, cold water immersion, heat, massage therapy, stretching. The reasons for these restrictions are that these medications and strategies have previously been outlined as being potentially advantageous to the recovery process in the prevention and treatment of either EIMD or DOMS (Cheung, et al.,

2003; Connolly, et al., 2003; Howatson & van Someren, 2008). Given that this study ran over several days, these guidelines were put in place to ensure that compression was the only recovery strategy that varied during this period.

3.3 PRE-TEST PROCEDURE

3.3.1 Determination of Exercise Intensity

The LIST protocol, used in the present study, includes intermittent walking, jogging at 55%VO_{2max}, cruising at 95% VO_{2max} and sprinting at maximal running speeds (Nicholas, Nuttall, & Williams, 2000). As such, initial indication of the aerobic capacity of each subject was required prior to testing in order to determine the appropriate speeds for the intermittent protocol. At least 7 days prior to the commencement of the study and in accordance with procedures previously recommended (Nicholas, et al., 2000), the predicted VO_{2max} of each subject was ascertained (Table 3.1) using a progressive multistage shuttle running test (Ramsbottom, Brewer, & Williams, 1988). This running test is part of the routine fitness testing battery for this group of subjects and as such, was familiar to all.

The progressive multistage shuttle running test is performed in an indoor gymnasium and involves running back and forth between two lines situated 20 m apart whilst keeping in time with audio beeps. The running speed increases 0.14 $m.s^{-1}$ each minute at which point the start of a new level begins. As the levels progress, subjects must run progressively faster to keep up with the beep. They are instructed to continue until they are no longer able to reach the line on the corresponding beep. The level before which they are no longer able to meet the beep is recorded as their final score with each level having a corresponding VO_{2max} value. This value is recorded as their predicted VO_{2max}. The correlation between the predicted

VO_{2max} determined by the progressive multistage shuttle running test and the directly determined VO_{2max} as measured by a treadmill ramp test to exhaustion, has been reported as r = 0.92 (SEE 3.5 $ml.kg^{-1}.min^{-1}$) (Ramsbottom, et al., 1988).

Following completion of the multistage shuttle running test, subjects were grouped according to their predicted VO_{2max} scores. Subjects with a predicted VO_{2max} in the range 53-57 $ml.kg.min^{-1}$ were assigned the 55 $ml.kg.min^{-1}$ LIST protocol and those in the range 57-62 $ml.kg.min^{-1}$ were assigned the 60$ml.kg.min^{-1}$ LIST protocol to perform during the study period. As such, the running speeds required of subjects during testing, were suitable to the aerobic fitness level of each individual.

3.3.2 Test Familiarisation

Prior to commencement of the study, each subject participated in a familiarisation session for the tests of muscle function to be performed. Each subject was coached on the specific techniques required for performing both the 5CMJ and the SJ test which would be used to assess muscle function throughout the recovery period.

3.3.3 Garment Fitting

Subjects were measured for height, body mass and waist girth (Table 3.1) prior to commencing the study, to assist the process of fitting the compression garments, as required by the manufacturer. A representative of the garment manufacturer was present during the garment fitting process to provide advice on fitting and to ensure sizing was appropriate. Subjects were fitted into a comfortable size garment, smaller than that outlined on the packaging, which was in line with manufacturer's recommendations.

3.3.4 Pressure Interface Monitoring

Separate to testing, the interface pressure between the compression garment and the skin was monitored for each subject using a portable interface pressure monitor (Talley SD500 Digital Skin Pressure Evaluator, Talley Medical, Miami, USA). This interface pressure measurement system has previously been assessed against other portable systems for the evaluation of compression garments, and was found to produce reliable results at the ankle and calf (global error <3 mmHg) with good repeatability (CV 2-3.5%) (Flaud, Bassez, & Counord, 2010).

Measurements were recorded at three sites on the lower limb, at the minimal ankle, maximal calf and maximal thigh sites, according to international recommendations (Partsch, et al., 2006). Subjects were measured, in the standing position, using a 2.8 cm pressure sensor positioned at each of the three designated sites. The pressure sensor was attached to the hand held pressure evaluator via a jack plug and air connector. The sensor was slowly inflated and then deflated whilst the pressure (mmHg) between two surfaces was displayed on the digital screen. The interface point was indicated by visual and auditory signals.

3.4 EXPERIMENTAL PROCEDURE

Data was collected during two 3 day trial periods separated by 4 weeks. The 3 day trial procedure is outlined in Figure 3.1. On the first morning of each trial, subjects were required to collect a urine sample on waking for analysis of urine specific gravity (Usg) to assess the hydration status of each subject. At 2.5 h prior to the commencement of exercise, subjects consumed a normalised snack which delivered 1.2g CHO.kg BM^{-1}.

Subjects arrived at the testing venue at the same time on both trials. Upon arrival, subjects had body mass (BM) measured and were then required to rest seated for 15 min before a

baseline venous blood sample was obtained for later analysis of IL1-β, IL-6, TNF-α and CRP, and, a baseline capillary sample was obtained for CK analysis. This blood collection procedure was repeated at 1, 24 and 48 h post-exercise (Fig 1).

Following baseline blood measurements, subjects moved to the indoor gymnasium (24.6 ± 1.1 deg C, 51.4 ± 6.1 %RH) where they completed a standard warm-up consisting of low intensity stationary bike, running drills, 30 m run throughs increasing in intensity and box jumps. This warm-up was repeated prior to each set of muscle function tests and a maximum of 5 min rest was allowed before commencing the jumps.

3.4.1 Tests of Muscle Function

A 5CMJ and a SJ were performed by each subject at baseline, 1, 24 and 48 h post-exercise to monitor the effect of fatigue and recovery on lower-body force and power production.

A repeated counter movement jump was used instead of a single counter movement jump due to the potential for unique high or low scores in a single effort jump test and the likelihood that the measurement of repeated efforts may be more reliable (Hopkins, Schabort, & Hawley, 2001). It has previously been suggested that the 5CMJ is suitable for assessing the training and performance of elite athletes (Cormack, et al., 2008) with good overall reliability for peak power and peak force (CV 4.4% and 3.3%, respectively).

For the 5CMJ, subjects were instructed to exert maximal effort for 5 consecutive jumps, without a pause between them. The counter-movement enabled activation of the stretch-shortening cycle to measure explosive leg extension.

According to previous recommendations for the SJ (Sheppard & Doyle, 2008), subjects were required to begin from a 90 degree squat position which was briefly held prior to jumping vertically as high as possible. The brief isometric hold prior to the jump is intended to prevent counter movement activity and thereby remove the contribution of the stretch-shortening cycle. As such, the SJ is a strength measure of the concentric-only action of the muscles of the lower leg (Sheppard & Doyle, 2008).

All jumps were performed with a lightweight pole placed across the subject's shoulders to remove any contribution of the arms and to provide attachment for a linear position transducer. The linear position transducer was attached to the centre of the lightweight pole in line with the spine of the subject and was connected to computer software (Balllistic Measurement System, Fitness Technology, Adelaide, Australia) which measured the vertical displacement of each jump.

Using the vertical displacement along with the measured time data and body mass of each subject, the computer program is able to calculate a range of performance variables including peak force and peak power. The vertical displacement (d) over the time (t) taken to perform the jump was used to determine velocity (v) of the movement ($v=d/t$). The change in velocity across the time taken to produce the movement determines the acceleration ($a=\Delta v/\Delta t$) of the movement and using this value along with the measured mass of the subject, the applied force may be determined ($F=ma$). Power is determined using the calculated values for force and velocity ($P=f.v$). The use of a linear position transducer has previously been found to be reliable and acceptable for identifying deficiencies in muscular function (Hansen, Cronin, & Newton, 2011a, 2011b) and to ensure compliance in SJ (Sheppard & Doyle, 2008).

Wearing compression garments during jumping has previously been reported to improve mean force and power production over a 10 counter-movement jump test (Kraemer et al., 1996) and a single maximal vertical jump (Doan et al., 2003) and as such, compression garments were removed prior to jumping in the present study.

The warm-up procedures described above preceded the tests of muscle function on each occasion. The participants performed each jump test at least twice or until force and power values no longer increased. This method has previously been used to ensure that maximum values are recorded (Doan, et al., 2003). For the 5CMJ, an average of the five peak force and peak power values was calculated for each set of jumps and the highest average value is reported as the 5CMJ mean force and 5CMJ mean power, respectively. For the SJ, the peak force for each jump was recorded and reported as SJ peak force.

3.4.2 Rating of Perceived Soreness

An adapted visual analogue scale (Mattacola, Perrin, Gansneder, Allen, & Mickey, 1997) was used to measure the RPS that subjects experienced during muscle function testing. Immediately following the 5CMJ and SJ, RPS was measured on an 11 point scale (Appendix E) which had anchors at either end indicating no soreness (0) and extreme soreness (10). Subjects were asked to point to the marker along the line which best indicated their soreness during jumping. Each marker on the line corresponded to a value between 0 and 10 and the corresponding value was recorded for each subject at each time point. Subjects reported their RPS following each set of muscle function tests at baseline, 1, 24 and 48 h post-exercise.

3.4.3 LIST Exercise Protocol

Once all baseline measures had been collected, subjects commenced the exercise protocol. The LIST exercise protocol was developed to simulate the intermittent nature of sports such as soccer and field hockey (Nicholas, et al., 2000). It was selected for the current study specifically for this reason, as well as its proven ability to elicit muscle damage and muscle soreness (Thompson, et al., 1999). Exercise was performed on an indoor running track in moderate conditions (24.8 ± 1.1 deg C; 51.4 ± 6.1% RH). Subjects wore comfortable training gear during the exercise protocol.

The LIST is made up of variable speed running, jogging and walking and was developed to simulate the intermittent nature of sports such as soccer and field hockey (Nicholas, et al., 2000). The intermittent exercise bouts are 15 min in duration, interspersed by 3 min rest periods, and include walking, jogging at 55%VO_{2max}, cruising at 95% VO_{2max} and sprinting at maximal running speeds up and back on a 20 m course with markers at 0, 10, 15 and 20 m. Audio cues from a CD indicated when each activity would occur and regulated the speed of each sub-maximal lap. The activity order within each 15 min exercise bout was of a repetitive nature and five bouts were performed in total (75 min of exercise) to replicate the duration of a field hockey match. The LIST protocol has been previously outlined in detail (Thompson, et al., 1999).

At the conclusion of each 15 min exercise block, average HR and rating of RPE was recorded and subjects ingested 2 $ml.kg^{-1}$ BM plain water from clearly labelled, individually prepared drink bottles. At the start of each rest period and after 4, 8, 12, 20 and 30 min of recovery from the LIST, capillary blood samples were obtained from the earlobe of each subject for blood lactate analysis.

3.4.4 Post-exercise procedure

Upon completion of the LIST and after obtaining the 4 min post-exercise capillary blood lactate sample, subjects changed into either a full length, lower limb compression garment (CG; 2XU Compression, Australia) or loose tracksuit pants (CON). The subjects were randomly assigned to the two treatments over two trials in a crossover research design and were blinded to their order of treatment up until completion of the first LIST protocol.

During the CG trial, compression tights were worn for a 24 h post-exercise period and were only allowed to be removed for bathing and during jumping for muscle function testing. The CG were applied for the 24 h post-exercise period as this is a normal recovery period for team-sport athletes during a tournament situation. Hockey matches are often scheduled daily throughout the National Hockey League competition and as such, athletes must recover within 24 h to be ready for the next match. This is a highly demanding schedule over a one to two week competition, during which, EIMD and fatigue progressively accumulate.

In the hour after completion of the LIST, subjects rested in a seated position. At 1 h post-exercise, subjects had venous and capillary blood samples collected and then repeated the standard warm-up, tests of muscle function and RPS protocols. Subjects were then free to leave the testing venue and returned to the lab at 24 and 48 h post-exercise to repeat the blood collection, warm-up, tests of muscle function and RPS procedures.

3.4.5 Perceived Recovery and Readiness for Exercise

Following exercise and whilst resting seated prior to blood collection at the 1, 24 and 48 h time points, participants were given a post-exercise questionnaire (Appendix F). They were asked to respond to the following statement to assess their perceived recovery: “I feel well

recovered and physically ready to perform at my best in a match right now". The participants responded using a scale ranging from strong disagreement (1) to strong agreement (5), with descriptors in between. The post-exercise questionnaire was designed to assess each subject's perceived recovery from exercise and hence, their perceived readiness for subsequent exercise.

3.5 URINALYSIS

Urine samples were analysed for Usg to assess the hydration status of each subject prior to exercise.

3.5.1 Urine Specific Gravity

Urine specific gravity was analysed using a hand-held optical refractometer (Atago, URC-Ne, Japan), providing an index of urine density and hence, hydration status. The refractometer was calibrated with distilled water to 1.000 on the optical Usg scale. Following this, a sample of urine was placed on the refractometer and its density displayed. Usg scores were given in the range 1.000 to 1.050. Subjects are considered in a state of minimal dehydration when the Usg falls below 1.020 (Casa et al., 2000).

3.6 BLOOD ANALYSIS

Venous blood was analysed for inflammatory mediators IL1-β, IL-6, TNF-α and CRP. Capillary blood was analysed for CK and lactate.

3.6.1. IL1-β, IL-6, TNF-α and CRP Analysis

Whole blood (5-6 ml) was collected from the arm into a plastic syringe, immediately transferred into blood collection tubes containing the anti-coagulant EDTA and centrifuged

for 10 min at 1000 xg. The plasma was separated into four clearly labelled storage tubes and frozen (-80 deg C) until analysis.

IL1-β, IL-6 and TNF-α were analysed using a standard analysis kit (Human High Sensitivity Multiplex panel, Millipore, USA) following procedures outlined in the High Sensitivity Human Cytokine LINCOplex kit guide (Cat. #HSCYTO-60SK).

CRP was analysed using a separate analysis kit (Human Cardiovascular Disease Panel 2, Millipore, USA) and procedures outlined in the Human Cardiovascular Disease (CVD) Panel 2 (Acute-Phase Proteins) LINCOplex kit guide where adhered to (Cat. HCVD2-67BK).

The reliability (%CV) of measuring each analyte using these kits was reported in the assay guides (3.11% IL1-β; 3.51% IL-6; 3.49% TNF-α; 8.0% CRP).

The sensitivity (minimum detectable concentration) of the kits was also reported in the assay guides (0.06 pg/mL IL1-β; 0.10 pg/mL IL-6; 0.05 pg/mL TNF-α; 6 pg/mL CRP).

3.6.1.1 Radioimmunoassay procedure: IL1-β, IL-6 and TNF-α

Assay guidelines for specimen collection and storage were closely adhered to as were the preparation of the reagents for the immunoassay. The following immunoassay procedures were conducted in conjunction with a specialist laboratory technician according to the assay guidelines (High Sensitivity Human Cytokine LINCOplex kit 96 Well Plate Assay Cat. #HSCYTO-60SK).

The filter plate was pre-wet by pipetting 200 µL of 1X wash buffer into each well of the

microtiter plate, then sealed and mixed on a plate shaker for 10 minutes at room temperature (20-25°C). Wash buffer was then removed by vacuum. The bead bottle was sonicated for 30 seconds, vortexed for 1 minute and then 25 µL of the mixed beads were added to each well. Liquid was removed from the wells by vacuum without inverting the plate. Any excess liquid was removed from the bottom of the plate by blotting on paper towel.

50 µL of lincoplex assay buffer was added to the 0 standard (background). 50 µL of lincoplex assay buffer was added to the sample wells. 50 µL of each standard or control was added to the appropriate wells. 50 µL of matrix solution was added to the background, standards, and control wells (the serum matrix provided with the kit was used as the matrix solution). 50 µL of sample was added into the sample wells after centrifuging the samples to remove any precipitates or denatured proteins. The plate was then sealed and covered with aluminium foil, and incubated with agitation on a plate shaker overnight at 4°C.

Fluid was then gently removed by vacuum being careful not to invert the plate. The plate was washed twice with 200 µL/well of wash buffer, removing the wash buffer by vacuum filtration after each wash. Excess wash buffer was removed from the bottom of the plate by blotting on a paper towel.

50 µL of detection antibody cocktail was added into each well once it had warmed to room temperature. Plate was then sealed, covered with aluminium foil, and allowed to incubate with agitation on a plate shaker for 1h at room temperature (20-25°C). 50 µL Streptavidin-Phycoerythrin was added to each well containing the 50 µL of detection antibody cocktail. The plate was then sealed, covered with aluminium foil, and incubated with agitation on a plate shaker for 30 min at room temperature (20-25°C).

All contents were gently removed by vacuum being careful not to invert the plate. The plate was washed twice with 200 µL/well wash buffer, removing wash buffer by vacuum filtration after each wash. Excess buffer on the bottom of the plate was wiped with a tissue.

100 µL of sheath fluid was added to all wells then the plate was covered with aluminium foil and the beads were resuspended on a plate shaker for 5 minutes. Following this, the plate was read immediately on the Luminex Instrument. Data were evaluated by the laboratory technicians.

3.6.1.2 Radioimmunoassay procedure: CRP

Assay guidelines for specimen collection and storage were closely adhered to as were the preparation of the reagents for the immunoassay. The following immunoassay procedures were conducted in conjunction with a specialist laboratory technician according to the assay guidelines (Human Cardiovascular Disease Panel 2 (Acute-Phase Proteins) LINCOplex kit 96 Well Plate Assay Cat. HCVD2-67BK).

The filter plate was pre-wet by pipetting 200 µL of 1X wash buffer into each well of the microtiter plate, after which the plate was sealed with and agitated on a plate shaker for 10 min at room temperature. Wash buffer was then removed by vacuum, being careful not to invert the plate. Excess wash buffer was removed from the bottom of the plate using a paper towel.

25 µL of assay buffer was added to the 0 standard (background).25 µL of assay buffer was added to the sample wells.25 µL of each standard was added into the appropriate wells.

25 µL of sample was added into the appropriate wells. 25 µL of assay buffer was added to the background, standards, and control wells as the matrix solution and sample diluent. The bead mix bottle was vortexed and 25 µL of mixed beads was added to each well. The bead suspension was shaken intermittently to avoid settling.

The plate was sealed, covered with aluminium foil, and incubated with vigorous agitation on a plate shaker for 1 h at room temperature. After this, fluid was gently removed by vacuum filtration being careful not to invert the plate. The plate was washed twice with 200 µL/well of wash buffer, removing wash buffer by vacuum filtration between each wash. Excess wash buffer was removed from the bottom of the plate using paper towel.

25 µL of detection antibody cocktail was added into each well, after it was allowed to warm to room temperature. The plate was then sealed, covered with aluminium foil, and incubated with vigorous agitation on a plate shaker at room temperature for 30 minutes.
25 µL sStreptavidin-Phycoerythrin was added to each well containing the 25 µL of detection antibody cocktail. The plate was then sealed, covered with aluminium foil, and incubate with agitation on a plate shaker for 30 minutes at room temperature.

All contents were gently removed by vacuum, being careful not to invert the plate. The plate was then washed twice with 200 µL/well wash buffer, removing wash buffer by vacuum filtration between each wash. Excess buffer on the bottom of was wiped with a tissue.
100 µL of sheath fluid was added to all wells then the plate was covered with aluminium foil and the beads were resuspended by shaking on a plate shaker for 5 minutes. The plate was then immediately run on the Luminex Instrument. The data were evaluated by the laboratory technician.

3.6.2. CK Analysis

A capillary blood sample was collected from the fingertip of each subject for CK analysis at baseline, 1h, 24h and 48h post-exercise. 32µl of blood was collected into a lithium-heparinised capillary tube then transferred to the Reflotron CK test strip and immediately analysed using a Reflotron Plus diagnostic device (Roche Diagnostics, Basel, Switzerland).

3.6.3. Lactate Analysis

A capillary blood sample was collected from the earlobe of each subject for analysis of blood lactate concentration immediately following completion of each exercise bout of the LIST protocol and throughout the 30 min post-exercise period. A portable lactate analyser (Lactate Pro, Arkray, Japan) was used for determination of blood lactate concentration. The Lactate Pro has previously been shown to be an accurate and reliable portable analyser for blood lactate concentration (Tanner, Fuller, & Ross, 2010).

3.7 STATISTICAL ANALYSIS

Two-way analysis of variance (ANOVA) with repeated measures (treatment x time) was used to determine differences between the two treatments with regards to blood and muscle function parameters.

When ANOVA revealed a significant interaction, a Tukey's honestly significant difference (HSD) post-hoc test was used to establish where the differences occurred. Tukey's HSD was calculated according to the methods set out in Vincent & Weir (2012).

Where appropriate, a Student's t-test was used to compare differences between two means and Spearman's rank order correlation (ρ) was used when examining relationships between perceptual variables.

Statistical analysis was carried out using IBM SPSS Statistics (Version 19.0). Statistical significance is reported when $P < 0.05$. All data are expressed as means ± standard deviation (SD).

CHAPTER 4

RESULTS

4.1 Pre-Exercise Variables

There was no significant difference in baseline BM at the commencement of each trial (CG 78.0 ± 13.6 kg; CON 77.6 ± 12.7kg, $p>0.05$). There was no difference in Usg at the start of each trial (CG 1.019 ± 0.008; CON 1.019 ± 0.005, $p>0.05$) and as such, baseline hydration status of the participants was the same on each occasion.

4.2 Garment Pressure Characteristics

The interface pressure between the lower body compression garment and the skin was measured at three sites on the lower limb (Figure 4.1). There was a significant difference between the pressure exerted by the compression garment at the ankle and the calf ($p<0.01$), ankle and thigh ($p<0.01$), but not between the calf and thigh ($p>0.05$). The garments provided greater pressure at the ankle than at the thigh, rather than uniform pressure along the length of the limb, and therefore can be categorized as a graduated compression garment.

4.3 LIST response

All subjects, except one, performed five bouts of the LIST exercise protocol (75 min total) on both occasions. One subject was physically unable to commence the fifth bout of exercise in his first trial, and therefore completed only four bouts (60 min total) on both occasions. Following completion of his fourth exercise bout, timelines and procedures for this subject were the same as all other subjects.

The physiological response of each subject was monitored at the conclusion of each 15 min bout of the LIST exercise protocol and are shown in Table 4.1. A main effect for time was found for RPE across the five bouts ($p<0.01$) with RPE increasing as exercise duration increased. There were no differences between the two treatments in the blood lactate concentration ($p>0.05$), average HR ($p>0.05$), or RPE ($p>0.05$) throughout the LIST protocol. As such, prior to commencing either CG or CON, it appears that the physiological stress of the exercise protocol was similar in both trials.

4.4 Post-Exercise Blood Lactate

Table 4.2 shows the blood lactate concentration of subjects from 0-30 min post-exercise under both conditions. No differences were observed between trials for post-exercise blood lactate concentration ($p>0.05$).

4.5 Cytokines and CRP

No significant differences were observed for TNF-α or IL-1β or IL-6 between the two treatments ($p>0.05$, Fig. 4.2).

The CRP response revealed a significant interaction ($p=0.030$, Figure 4.2) and post-hoc analysis identified a difference between the two treatments only at baseline. A main effect for time ($p=0.001$) also confirmed that CRP was significantly higher at 24 h post-exercise than all other time points. For CG, CRP at 24h was higher than baseline, 1h and 48h ($p<0.01$), whilst for CON, CRP at 24h was higher than at 48h ($p<0.05$).

4.6 CK

A main effect for time identified that CK concentration was significantly elevated in the post-exercise period in both CG and CON ($p=0.001$, Figure 4.3), however, there were no differences in the concentration of CK when comparing CG with CON ($p>0.05$). CK values peaked 24 h after the completion of exercise at which time they were higher than all other time points ($p<0.05$) indicating that the LIST protocol successfully induced some muscle damage, however, the leakage of CK into the blood, appears to have been similar between trials regardless of the recovery technique used.

4.7 Tests of Muscle Function

A significant interaction ($p=0.039$) and a main effect for time ($p=0.002$) were observed for mean power production during the 5CMJ (Table 4.3). Power production had decreased significantly ($p<0.05$) by 1h after exercise in both trials and was significantly higher at 48h compared with 1h and 24h post-exercise ($p<0.01$). The post-hoc analysis following the significant interaction, revealed a difference between CG and CON only at 48h post-exercise ($p<0.05$), however, the magnitude of the difference between treatments at this time point (158w) and that which was observed across time within each treatment, were generally smaller than the typical error associated with this test (210w intraday, 278w interday) (Cormack, et al., 2008).

For mean force in the 5CMJ, a significant time effect ($p<0.05$) confirmed that mean force production was significantly lower at 1h post-exercise than at baseline, 24h and 48h under both conditions, and the difference was generally greater than the typical error (69N) associated with this parameter (Cormack, et al., 2008).

There were no significant differences observed between trials for mean force or mean power output in the SJ (Table 4.3).

4.8 Perceived Recovery and Readiness for Exercise

The perceived recovery of subjects following exercise is shown in Figure 4.4. Although no interaction effect was observed ($p>0.05$), significant main effects for both treatment ($p=0.005$) and time ($p=0.001$) were found. At 1 h after the end of exercise in both CG and CON, subjects disagreed with the notion that they were "well recovered" and "ready to perform at their best". They felt significantly less recovered at 1h ($p<0.05$) compared with 24h and 48h post-exercise. Given the treatment main effect, averaged across all time points it is evident that perceived recovery was reported as superior when CG were worn. Individual data show that after wearing CG for 48 h, six out of eight subjects strongly agreed they were "ready to perform at their best", compared to one out of eight for CON.

4.9 Rating of Perceived Soreness

Rating of perceived muscle soreness in the post-exercise period is displayed in Figure 4.4 (0=no soreness; 10=extreme soreness). There was no significant interaction effect, however, the main effect for time was $p=0.003$ as perceived soreness was higher at 1 h post-exercise in both conditions compared to all other time points ($p<0.05$). There was a trend for a treatment main effect ($p=0.053$) with soreness reported to be less in the CG versus control condition averaged over all recovery time points.

4.10 Relationship Between Perceptual Markers

To establish the relationship between the two perceptual markers, a correlation was performed between RPS and perceived recovery using data from both trials combined. A

negative correlation between the two markers was observed across each time point (1h, ρ= -0.50, p=0.05; 24h, ρ= -0.51, p<0.05 48h, ρ= -0.51, p<0.05), suggesting that in general, recovery and readiness for exercise was greater when there was less muscle soreness. However, the magnitude of each correlation is considered low, according to Vincent and Weir (2012). The correlation co-efficients reported indicate that, on average, perceived recovery and perceived soreness have only 26% common variance. The remaining 74% of the variance is unexplained and not accounted for by the common factors between the two perceptual markers (W. Vincent & Weir, 2012). As such, the subjects' perceived recovery and readiness for exercise is influenced by factors other than simply muscle soreness.

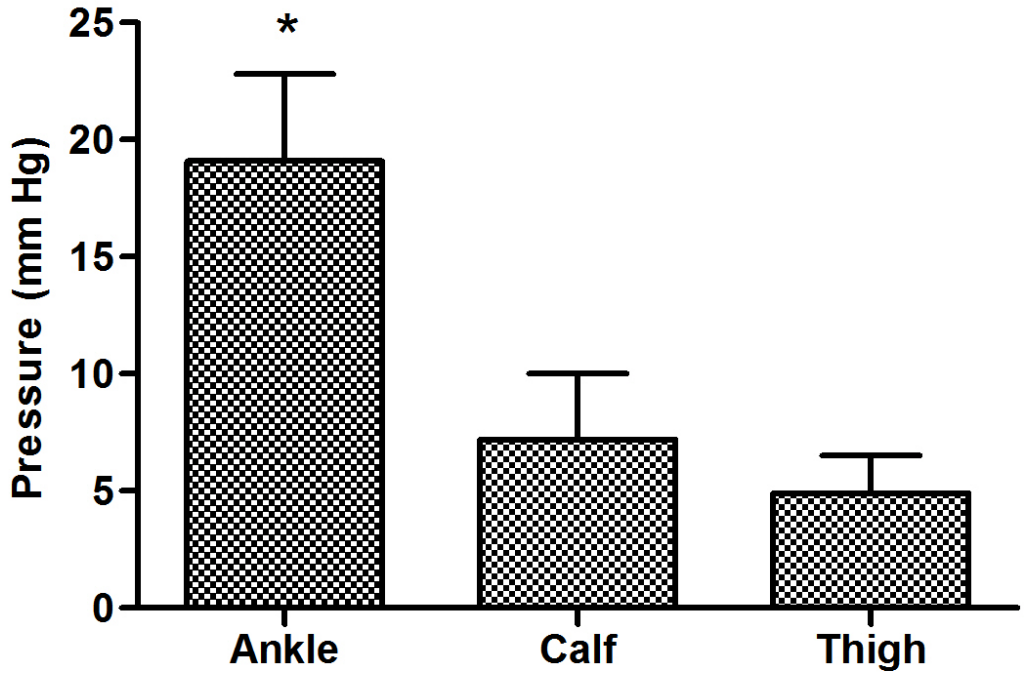

Figure 4.1. Pressure interface between the compression garment and the skin at 3 sites of the lower limb. *Significantly different to calf and thigh (P<0.01). Values are mean ± SD

Table 4.1. Average HR, blood lactate concentration and RPE recorded at the conclusion of each 15 min exercise bout performed during the LIST protocol.

	Average HR (bpm)					Blood Lactate concentration (mmol.l-1)					RPE (6-20)				
LIST	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
CG	163(11)	166(10)	166(11)	166(9)	167(10)	2.6 (0.9)	2.9(1.5)	2.8 (1.7)	2.7(1.2)	2.7(1.2)	11(2)	13(2)	14(2)	15(2)	15(1)
CON	161(12)	165(15)	166(10)	165(8)	167(10)	2.9(1.1)	2.8(0.8)	2.7(0.7)	2.6(0.6)	2.6(0.8)	12(2)	13(1)	14(1)	14(2)	14(1)

Note that one subject completed only four exercise bouts on both occasions and as such, for bouts 1-4, n=8 and for bout 5, n=7. No significant differences were observed between treatments for any variables monitored throughout the LIST. All values are means (SD).

Table 4.2. Blood lactate concentration in the 30 min following exercise (n=8). CG were worn from 4 min post-exercise until 24 h post-exercise. Values are presented as means (SD).

	0 min	**4 min**	**8 min**	**12 min**	**20 min**	**30min**
CG	2.9 (1.4)	2.4 (0.8)	2.0 (0.7)	1.6 (0.6)	1.3 (0.5)	1.0 (0.2)
CON	2.7 (0.7)	1.8 (0.6)	1.5 (0.5)	1.3 (0.4)	1.0 (0.2)	0.9 (0.1)

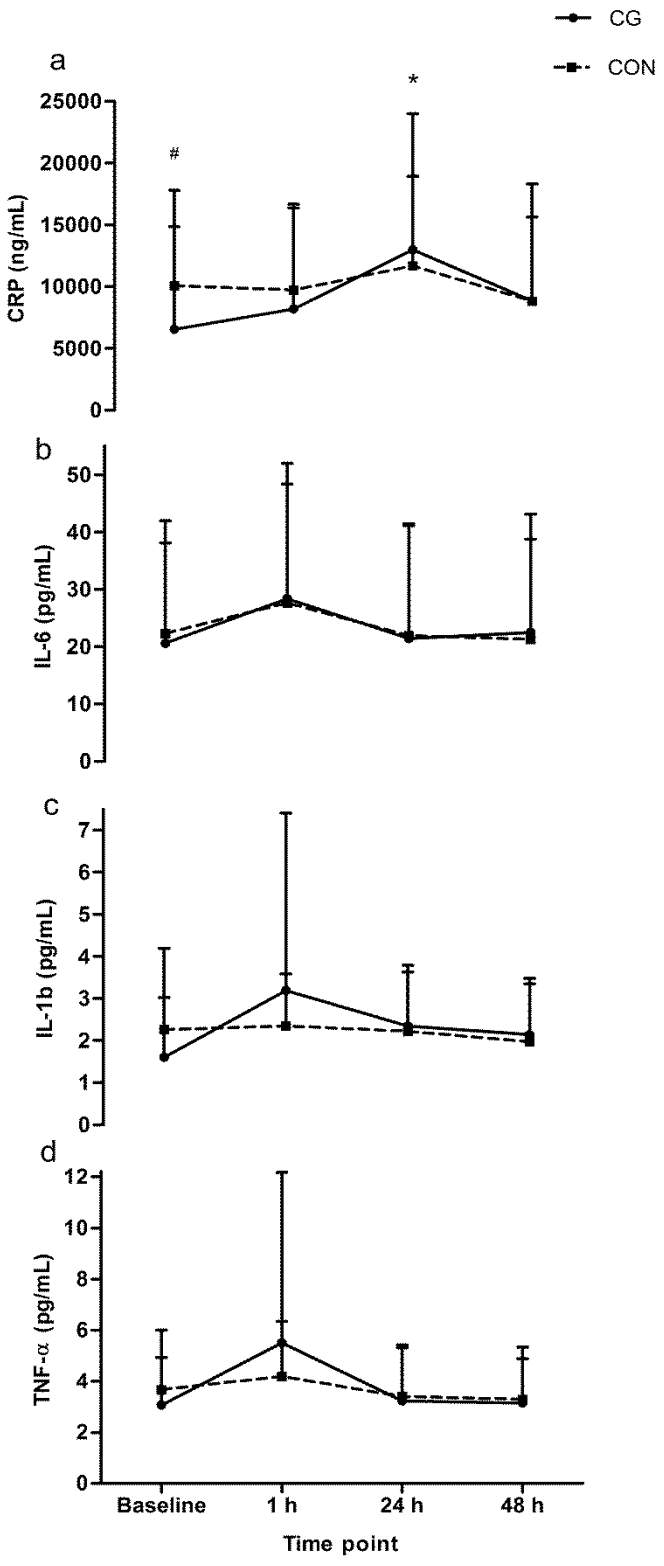

Figure 4.2. C-reactive protein and cytokine responses following intermittent exercise: CRP (A), IL-6 (B), IL-1β (C), TNF-α (D). *P < 0.05 from baseline, 1h and 24h for CG, and, different from 48h for CON. #P < 0.05 CG different from CON. Values are presented as means ± SD.

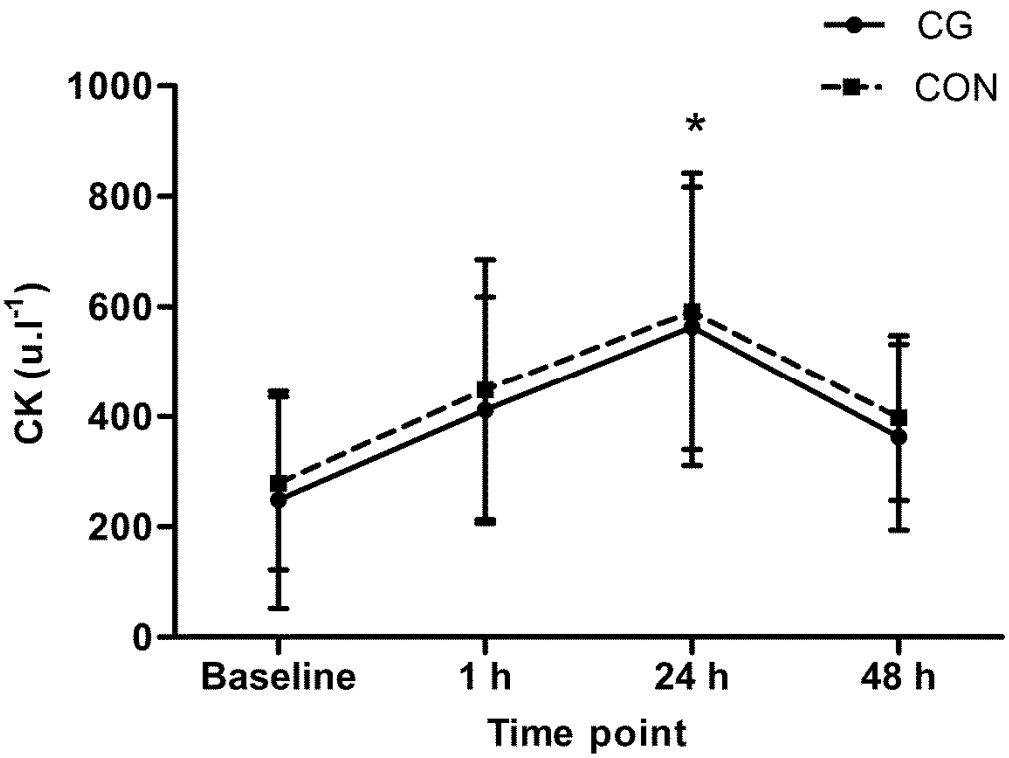

Figure 4.3. CK concentration. *P<0.01 from all other time points for CG and CON. Values are presented as means ± SD.

Table 4.3. Tests of muscle function (5CMJ and Squat jump) at baseline and 1h, 24h and 48h after the LIST exercise protocol.

	CG				CON			
	Baseline	**1 h**	**24 h**	**48 h**	**Baseline**	**1 h**	**24 h**	**48 h**
5CMJ Mean Power (w)	3711 (790)	3576 (680)#	3610 (706)	3666 (668)$^{\alpha}$	3648 (776)	3541 (768)#	3675 (790)	3824 (799)*$^{\alpha}$
5CMJ Mean Force (N)	2000 (421)	1923 (361)^	1941 (356)	2016 (431)	2032 (420)	1950 (404)^	2033 (471)	2061 (484)
SJ Peak Force (N)	1876 (341)	1838 (340)	1834 (325)	1834 (331)	1848 (320)	1829 (362)	1839 (302)	1873 (309)

Values are presented as means (SD).

* P<0.05 from CG

# P<0.05 from baseline

$^{\alpha}$ P<0.01 from 1h and 24h

^ P<0.05 from baseline, 24h and 48h

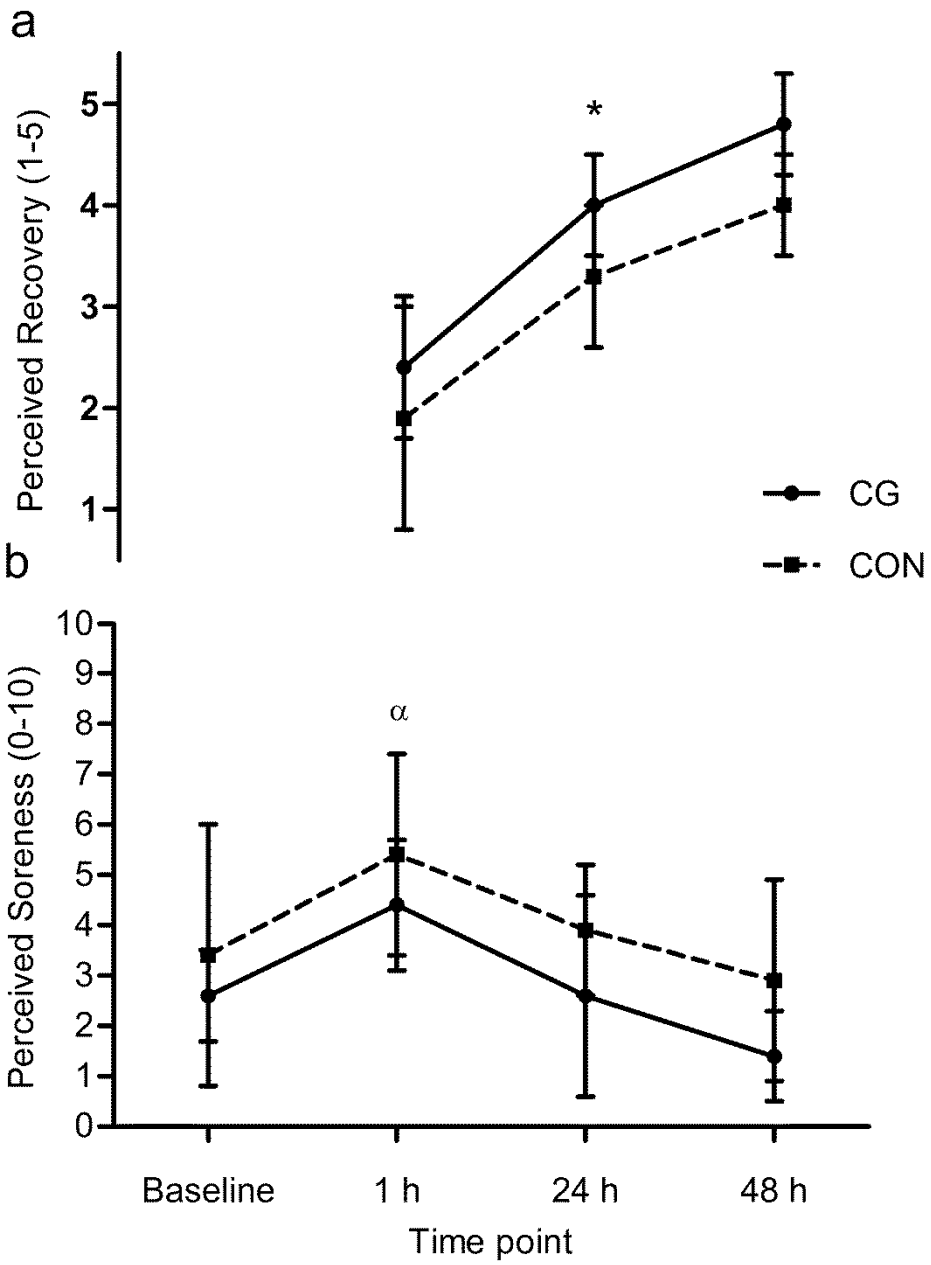

Figure 4.4. Perceived recovery and readiness for exercise (A) from strongly disagree (1) to strongly agree (5) at 1 h, 24 h and 48 h post-exercise, and Rating of Perceived Soreness (B) from no soreness (0) to extreme soreness (10) at baseline, 1 h , 24 h and 48 h post-exercise. *P<0.01 from 1h and 48h for CG and CON. αP<0.05from all other time points for CG and CON. Main effect for treatment observed for both Perceived recovery (P<0.01) and RPS (P<0.05). Values are presented as means ± SD.

CHAPTER 5

DISCUSSION

The focus of the present study was on the efficacy of wearing full length lower body compression garments for 24 h post-exercise as a recovery aid for highly-trained athletes. Additionally, it provided a unique comparison of blood variables, perceptual responses and muscle function in the 48 h following intermittent activity. The majority of subjects in the present study felt better recovered and reported earlier exercise readiness after 24 h of wearing compression garments following the LIST. Despite this, blood markers and tests of muscle function monitored in this study revealed that compression garments provided no assistance to the recovery process.

Compression garments have been shown to increase femoral vein flow velocity by reducing the pooling of blood in the lower extremities and stimulating venous return of blood to the heart. Sigel et al. (1975) found that garments which applied a compressive force of 18 mm Hg around the ankle, reducing to 8 mm Hg around the thigh, generated the fastest average flow velocity of 38.4% above baseline, in inactive recumbent subjects. A garment which applies graduated compression in this way has been shown to increase blood flow to a greater degree than compression distributed evenly over the lower extremity in patients with normal venous systems (Sigel, et al., 1975). The commercial garments used in the present study provided interface pressures of 19.1 mm Hg at the ankle, 7.2 mm Hg at the calf and 4.9 mm Hg at the thigh. Given the pressure applied at the extremities and the graduated nature of the garments used in this study, the expected influence on blood flow would be similar to what has previously been described (Sigel, et al., 1975).

In the present study, a range of blood variables was monitored in the post-exercise period to determine whether any influence of the garments on the recovery process could be observed. The effect of altered circulation on the removal of blood lactate may have provided some insight into the effect of compression garments worn in the post-exercise period. However, the blood lactate response of our subjects in the present study (average 2.7 mmol.L^{-1} across the five bouts) was much lower than previously reported for this protocol (Nicholas, et al., 2000) and as such, it is difficult to elucidate the specific impact on blood lactate removal post-exercise.

The LIST protocol has previously been reported as being a valuable measurement tool in the evaluation of physiological and metabolic responses to intermittent, *high-intensity* exercise (Nicholas, et al., 2000). The validation of this exercise protocol with "trained" subjects revealed average heart rates across 5 exercise bouts of 170bpm which was reported as being similar to those recorded in Swedish National League and Belgian university players. The average blood lactate response of the same subjects was reported as 6.0 mmol.L^{-1} (Nicholas, et al., 2000). However, in the present study, the metabolic response of our highly-trained subjects was lower for both average heart rate (166bpm) and average blood lactate (2.7mmol.L^{-1}) across the 5 bouts in both trials.

The speed required by each subject for the majority of the LIST protocol is tightly regulated by audio cues which signify the start, middle and end points of each shuttle. The only part of the protocol during which the running speed is determined by the subject are the 20 m sprints performed at maximal running speed. These sprint are performed approximately every 90 sec throughout each 15 min exercise bout (approximately ten sprints per 15 min). Given that the exact timing of each 20 m sprint was not directly measured, it is possible that the subjects did

not provide a maximal effort on each occasion and this may account for some variability in the physiological response. However, it should also be considered that, although the LIST was chosen and has previously been defined as a "*high-intensity*" exercise protocol, our subjects were well adapted to this type of exercise and they likely tolerated the exercise well as a result. We may have seen more changes in the HR, RPE and blood lactate response to this protocol in less well-trained subjects, and this may have had a greater impact on the recovery process overall.

Following EIMD, the inflammatory response is generally accepted as part of the post-exercise recovery process and it has been previously documented that eccentric exercise with an endurance component produces a robust cytokine response (Sayers & Hubal, 2008, p43). However, whether the post-exercise cytokine response is actually associated with a fully-developed inflammatory response has been questioned. Malm et al. (2004) found that, although there is an increase in cytokines following eccentric exercise, this does not indicate skeletal muscle inflammation. Instead the relationship between cytokines, growth factors and hormones post-exercise may be more closely related to the regeneration and adaptation of human skeletal muscle rather than the inflammatory process (Malm, et al., 2004). Ostrowski et al. (1999) suggested that the magnitude and duration of the inflammatory response following endurance exercise is restricted; cytokines are produced locally and are rapidly cleared from circulation following exercise. Previous studies demonstrate that IL-6, IL-1β and TNF-α reach their peak and are then rapidly removed from the circulation possibly within the first hour following exercise, much quicker than would be expected of a traditional inflammatory response (Ispirlidis, et al., 2008; Montgomery, Pyne, Cox, et al., 2008; Ostrowski, et al., 1999; Ostrowski, et al., 1998; Peake et al., 2008). IL-1β and TNF-α have been shown to increase only modestly post-marathon but decrease by 2 h (Ostrowski, et al.,

1999; Ostrowski, et al., 1998). This was not the case in the present study, as there was no main effect for time observed for either IL-1β or TNF-α following intermittent exercise.

Endurance exercise has been shown to bring about an increase in IL-6 levels immediately after a marathon (128-fold increase) (Ostrowski, et al., 1999), after 60 min of treadmill running (10-fold increase) (Cox, Pyne, Saunders, Callister, & Gleeson, 2007) and following 120 min of cycling (12-fold increase) (Peake, et al., 2008), with values declining dramatically by 1-2 h post-exercise (Cox, et al., 2007; Ostrowski, et al., 1999; Ostrowski, et al., 1998; Peake, et al., 2008). Intermittent exercise has also been shown to increase IL-6 with 3-4-fold elevations reported immediately after basketball (Montgomery, Pyne, Cox, et al., 2008) and 4-fold elevations immediately following soccer (Ispirlidis, et al., 2008).

Whilst it is expected that exercise of longer duration such as marathon running or long-distance cycling, would elicit a greater muscle damage response that team-sport activity, it is interesting that the IL-6 response in the present study was lower than that previously observed following basketball and soccer match-play. In the present study, IL-6 levels were only 1.5-fold above baseline values at 1 h post-LIST. It is possible that the lower IL-6 response compared with previous findings may have been the result of the LIST exercise protocol not having been challenging enough to create a large physiological response in this subject group compared with that which has previously been described (Nicholas, et al., 2000). In contrast, depending on the trigger for production, it is also possible that the post-exercise peak of IL-6 in the present study occurred either earlier than 1 h post-exercise, or closer to 8 h post-exercise which has previously been reported (Miles, Andring, et al., 2007; Miles, Pearson, et al., 2007). The two independent pathways of IL-6 production in response to exercise, as specified by Miles et al. (2007) suggest that IL-6, which is produced as a

normal response to exercise, peaks during or immediately after exercise and declines very quickly following exercise. In comparison, the IL-6 peak in response to muscle damage may be smaller, occurring hours after the completion of exercise (Miles, Pearson, et al., 2007). Although the IL-6 peak observed in the present study was small and not significant, a significant elevation of CRP at 24 h post-exercise in both trials was observed. Given that IL-6 is a trigger for CRP production (Pedersen, et al., 1998), it is possible that, although not detected in the present study, a significant increase in IL-6 may have occurred at some stage throughout the recovery period. However, given the timing of sampling in the present study, the magnitude of the IL-6 response and any impact that the potential circulatory benefits of CG had on this, remains unclear.

Furthermore, the baseline IL-6 levels in the present study, were higher than reported elsewhere (Cox, et al., 2007; Ispirlidis, et al., 2008; Montgomery, Pyne, Cox, et al., 2008; Ostrowski, et al., 1998). Whilst it is difficult to explain the elevated IL-6 values reported in this study at baseline, it should be noted that there may be a range of factors with which it is associated, including different assay systems used across different studies, the impact of a previous training response, or, the pre-exercise carbohydrate snack ingested in the current study. The snack delivered 1.2g.kg BM^{-1} carbohydrate 2.5 h prior to exercise. Whilst this was intended to ensure that pre-exercise glycogen stores were similar between the two trials, glycogen ingestion has previously been shown to cause an increase in some baseline pro-inflammatory factors (Aljada, Friedman, & Ghanim, 2006). However, in spite of the elevation compared with previous findings, in the present study there was no difference in IL-6 values at baseline between the two trials. There was however, a difference in CRP values at baseline.

Previous research has shown that a low fat, high carbohydrate diet may influence basal levels of CRP, with the glycaemic load of the diet directly related to resting CRP concentrations (Kasim-Karakas, et al., 2006). The previous study implemented dietary controls over its subjects lasting for months at a time then assessed the impact of such a sustained dietary change with samples collected months apart. Whilst all care was taken in the present study to control the diet of subjects in the 24 h prior to exercise, it should be noted that, the longer term dietary habits of the subjects, particularly if they were variable in nature, may have influenced baseline CRP values.

The LIST exercise protocol appears to have provided a sufficient physical load to bring about some change at the cellular and muscular levels in the post-exercise period. CK increased significantly and peaked 24 h after the conclusion of exercise suggesting cell membrane permeability had been disturbed, but this was evident in both conditions and there was no impact of the garment worn. In addition, there is evidence that muscle function was reduced at 1 h after exercise when the 5CMJ was performed in the present study. However, similar to the impact on CK, the lower body CG worn for 24 h post-exercise in the present study did not enhance the recovery of muscle function in the lower limbs. Several previous studies investigating the use of lower body garments on recovery, have found similar results with regards to CK activity (Davies, et al., 2009; Duffield, et al., 2010) and recovery of muscle function (Davies, et al., 2009; Duffield, et al., 2010; French, et al., 2008; Montgomery, Pyne, Hopkins, et al., 2008). Kraemer et al. (2010), however, found that a whole body compression garment reduced CK values by half at 24 h post-exercise in men and women after an upper and lower body resistance workout, and Kraemer et al. (2001) reported reduced CK values after subjects wore a compression sleeve over the arm for 5 days following eccentric exercise. Both studies reported that recovery of upper body muscle function was significantly

improved after wearing compression garments compared with control conditions, however there was no impact on the lower body measures of muscle function when whole body compression was worn (Kraemer, et al., 2010). This may be because eccentric exercise of the arm has been shown to induce much larger increases in CK activity and have a greater impact on muscle function compared with lower body exercise of the same relative intensity (Jamurtus, et al., 2005). As such, the effect on CK activity and muscle function reported by Kraemer et al. (2001) when an arm sleeve was worn, and Kraemer et al. (2010) when a whole body garment was worn, may be primarily due to the specific characteristics of the upper body response and may be why the same outcome was not evident in the present or previous studies investigating lower body garments.

In contrast to blood and muscle function results, the perceived response of subjects in the present study suggests that there may be a psychological benefit of wearing the compression garments in the post exercise period. Perceived muscle soreness was rated higher in CON throughout the entire trial period and peaked at 1 h post-exercise in both conditions. This is much earlier than the observed peak in CK activity at 24 h post exercise in the present study. The poor relationship between plasma CK activity and muscle soreness has previously been reported with suggestion that the muscle soreness commonly associated with EIMD may not directly reflect the magnitude of damage to the muscle itself (Malm, et al., 2004; Nosaka, 2008, p66). Malm et al. (2004) provided evidence that damage to the connective tissue rather than the muscle itself may be more likely associated with delayed onset muscle soreness following EIMD, and furthermore, the increase in CK activity is not related to muscle inflammation post-exercise. This may explain the evident dissociation between muscle soreness, plasma CK activity and changes in muscle function observed in the current and previous research (Nosaka, et al., 2002). Although muscle soreness may not specifically

reflect the magnitude of exercise-induced muscle damage, it does provide further information regarding the state of the muscle environment (Nosaka, et al., 2002) and likely contributes to the athlete's perceived readiness for exercise.

This was certainly the case in this study whereby perceived recovery and readiness for exercise was significantly greater at 24 and 48 h after exercise in both conditions. Perceived recovery responses were only collected in the post-exercise period, with a statement which subject were asked to subjectively rate: "I feel well recovered and physically ready to perform at my best in a match right now". Although it is unclear as to which treatment was superior, subjects always felt better recovered and more ready for exercise when CG were worn. One possible explanation for this may be that the garments felt comfortable to wear and the subjective response of the subjects reflected this notion. In addition, compression garments have previously been found to reduce muscle oscillation during jumping (Doan, et al., 2003) and as such, it is possible that a reduction in the displacement of functioning muscles may attenuate the sensation of pain and stiffness following EIMD. As such, by providing mechanical stability to exhausted limbs, compression garments enhance the functionality of the connective tissue following EIMD thereby reducing the perception of soreness, however we have no specific data to support this notion.

The negative relationship that was established between the perceptual markers in the post-exercise period indicates that the perception of reduced soreness was linked, in part, to the subjects' recovery and readiness to perform exercise. However, the magnitude of the correlation between the two variables suggests that the perception of reduced muscle soreness may not be the only factor influencing exercise readiness. Readiness to perform indicators have previously been used to assess subjects' response to the ingestion of caffeine-containing

beverages prior to resistance exercise to fatigue (Duncan, Smith, Cook, & James, 2012). Readiness to invest physical effort was higher prior to exercise and overall performance was enhanced when caffeine was ingested compared to the ingestion of a placebo (Duncan, et al., 2012). Furthermore, when subject's thought they had ingested sodium bicarbonate prior to exercise but had been given a placebo, performance was better than when they had actually been given the drug, but told that they hadn't received it (McClung & Collins, 2007). As such, both the physiological and psychological impact of a particular ergogenic aid has been shown to enhance readiness to perform and actual performance in both the presence and absence of biochemical alterations (Duncan, et al., 2012; McClung & Collins, 2007). There is a range of psychophysiological factors which contribute to an individual's readiness to exercise or perform which is outside the scope of this research. However, from the results of the present study we can deduce that the subjects' perceived readiness improved as recovery time increased and as muscle soreness decreased, and perceived readiness was consistently higher through the recovery period when CG were worn. Given the heavy promotion of compression garments to athletes and the absence of a completely blinded control trial, the potential for an overestimation of the treatment effectiveness should be considered. However, given that the "expectancy effect" alone has been shown to improve performance (McClung & Collins, 2007), then if an athlete's belief in a product is strong, the ultimate performance impact may be positive.

In summary, typical indicators of EIMD including muscle soreness, loss of muscle function, elevated CK and cytokine levels were evident in the present study, even though the level of muscle damage appears to have been low and the inflammatory response was subtle. This may in part, be due to the specific timing of blood sampling in the present study. Additional information in the initial hour and between 1 and 24 h post-exercise, may provide further

insight into the complete cytokine response to the intermittent exercise and the impact, if any, of the garments worn. Furthermore, had the increase in HR, lactate and RPE in response to the LIST protocol been greater in the present study, we may have seen more changes during the post-exercise recovery period. Even so, muscle soreness was reported, mild loss of muscle function was evident and there was some indication of an acute-phase inflammatory response. When CG were worn, subjects always felt better recovered and reported lower levels of muscle soreness, however, this was not associated with a significant effect on the restoration of muscle function post-exercise or the levels of the specific biomarkers investigated. As such, the biochemical and physical responses observed in this study provide no evidence of a benefit on the recovery process of highly-trained athletes wearing lower body CG for 24 h following exercise, however, perceptual indicators suggest a psychological benefit may exist.

FUTURE STUDIES

The results of the present study, along with much of the previous research in this area, have shown that the evidence in support of the benefits gained from wearing sports compression garments post-exercise is not strong. However, no research to-date has investigated the use of medical grade compression garments in the sporting setting, or, a comparison of medical grade compression with the more popular sports garments. Whilst the haemodynamic effect of medical garments have been reported, it is still unknown whether the commonly used sports garments are able to deliver a similar outcome for the athletic population. As such, for future research, further consideration should be given to an in-depth assessment of the haemodynamic effects of the garment being investigated in order to fully understand what pressure gradients are required to bring about improvements in venous flow velocity and venous return in this population. Further control may be considered with regards to the posture and activity levels carried out by athletes during the post-exercise period as these will influence the haemodynamic effect. Finally, with regards to the monitoring of inflammatory markers, if similar exercise is employed, greater consideration may be given to monitoring these variables immediately after and in the first few hours after exercise (particularly for IL-6) when the greatest changes may be prevalent.

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APPENDIX A

CONSENT FORM

CONSENT FORM

Physiological and performance benefits of compression garments

Name of participant:

Name of investigators: Prof. Mark Hargreaves, PhD; Cathryn Pruscino, BSc(Hons); A.Prof. Gordon Lynch, PhD

1. I consent to participate in the project named above, the particulars of which - including details of strenuous, intermittent exercise, tests of muscle strength and power, and blood sampling and analysis - have been explained to me.

2. I authorise the researchers to **perform** the testing and experimental procedures referred to under (1) above.

3. I acknowledge that:

   (a) the possible effects of the testing and experimental procedures have been explained to me to my satisfaction.

   (b) I have been informed, and I understand that I am free to withdraw from the project at any time without explanation or prejudice and to withdraw any unprocessed data previously supplied.

   (c) the project is for the purpose of research and not for treatment.

   (d) I have been informed that the confidentiality of the information I provide will be safeguarded subject to any legal requirements.

   (e) blood samples obtained during this study will be used for a number of biochemical and molecular analyses and may also be used in additional future studies.

   (f) this consent form will be retained by the researchers

Signature: Date:

(Participant)

APPENDIX B

INFORMATION FOR PARTICIPANTS

THE UNIVERSITY OF MELBOURNE

Plain Language Statement

Physiological and performance benefits of compression garments

Thank you for your interest in the study. This study will be conducted within the Department of Physiology, The University of Melbourne, and the Victorian Institute of Sport (VIS) by Prof. Mark Hargreaves, B.Sc, M.A., PhD; Ms. Cathryn Pruscino, BSc(Hons); and Assoc Prof. Gordon Lynch, BSc(Hons), PhD. This project has been approved by the Human Research Ethics Committee (HREC 0719389).

Overview and Aims of Project

The major aim of this study is to test the efficacy of commercially available compression garments in relation to recovery from strenuous exercise. Athletes look for the smallest of potential advantages, but often claims made in relation to potential ergogenic aids are not well supported by experimental data. Compression garments have been used clinically to minimise lower limb venous pooling and to facilitate venous return. In recent years, they have been heavily promoted to athletes with claims that they enhance muscle blood flow, facilitate lactate removal, reduce muscle soreness and enhance muscular function. Very few studies support such claims. The aim of this study is to systematically examine the physiological and biochemical responses to recovery from intermittent exercise, with and without compression garments.

You will be required to visit the VIS gymnasium on two occasions, separated by at least 7 days, for the 90 min exercise tests – follow up visits will occur after 24 and 48 hr of recovery. Each visit involving the LIST (x2) will take approximately 3 hours, while the other visits (x4) will take approximately 30 min each. Therefore, the total time commitment involved is approximately 8 hours during 6 visits to the VIS over 2-3 weeks.

Your involvement

An initial briefing session will provide an overview of the project and, if you agree to take part, require completion of a medical questionnaire and consent form. The medical questionnaire contains sensitive information and will only be seen by the Principal Researcher, Prof. Mark Hargreaves. Under no circumstances will it be released to VIS management unless you provide written permission or the Principal Researcher is legally compelled to surrender the information.

You will complete two 90 min intermittent exercise sessions utilising the Loughborough Intermittent Shuttle Test (LIST), separated by at least 1 week. This test involves variable speed running, jogging and walking and was developed to simulate the "stop and go" nature of field sports such as soccer and hockey. This exercise test is no more stressful than one of your routine training sessions. The exercise test will be undertaken in the gymnasium at the VIS, Olympic Park, Melbourne. Immediately before the exercise session, you will rest quietly for 15 min before a resting venous blood sample is obtained by venepuncture ie. the insertion of a needle into a forearm vein for the purpose of collecting blood into a plastic syringe. A small compression bandage will be applied to prevent any bleeding from the venepuncture site. You will then complete two tests of dynamic muscle strength and power – the squat jump and the counter movement jump using standard protocols employed by the VIS and familiar to you. During the 90 min LIST, capillary blood samples will be obtained every 15 min during the LIST and after 4, 8, 12, 20 and 30 min of recovery from a fingertip using a small lancet. This is a standard monitoring protocol within the VIS. Upon completion of the LIST and after obtaining the last capillary blood sample, you will wear either your

loose tracksuit pants or the full length, lower limb compression garment for the next 24 hr. During this 24 hr period, you are able to remove the garment for a 30 min period to enable bathing if you wish. The size of compression garment will be selected according to manufacturer's specifications. Additional venous blood samples, measures of muscle strength and power, leg blood flow using a non-invasive Doppler flow probe over the femoral artery and subjective measures of muscle soreness will be obtained after 1, 24 and 48 hr of recovery. During this time, you will not train, but complete your activities of daily living and wear the compression garment or loose track pants, except when bathing. The blood samples will be analysed for inflammatory markers (eg. C-reactive protein and other cytokines) and commonly used indicators of muscle damage (CK activity and myoglobin).

Explanation of Risks
There are slight risks associated with invasive, blood sampling procedures in volunteers that include bruising and infection. To minimise the risk of any bleeding from the venepuncture site during the LIST, a small compression banadge will be applied to the site and worn during the LIST. These are minimised by having all procedures performed by a qualified personnel and by using accepted antiseptic technique. The exercise associated with the LIST is no more strenuous than some of your regular training sessions.

Summary
You will be required to visit the VIS gymnasium on two occasions, separated by at least 7 days, for the 90 min exercise tests – follow up visits will occur after 24 and 48 hr of recovery. Each visit involving the LIST (x2) will take approximately 3 hours, while the other visits (x4) will take approximately 30 min each. Therefore, the total time commitment involved is approximately 8 hours during 6 visits to the VIS over 2-3 weeks.

Confidentiality
No findings that could identify any individual participant will be published. The anonymity of your participation is assured by our procedure, in which your name will not be revealed in any results. Access to data is restricted to only the 3 researchers directly involved in the study. Coded data are stored for five years, as prescribed by University regulations. The information and samples generated from this study will not be used for any other studies than those outlined in this document.

Voluntary Participation
Participation in this research is entirely voluntary, and if you agree to participate, you may withdraw your consent at any time without being penalised or disadvantaged in any way. You may also decline to participate in any section of the procedure, by expressing your desire that you do not wish to undertake the task to the investigators. This includes removal of the compression garment at any time should you wish. Yoru participation in this project is in no way tied to your ongoing role within the VIS or in any way to team selection.

Feedback
You will be provided with information on your individual results and group data will be summarised for publication in a scientific journal.

Should you require any further information, or have any concerns, please do not hesitate to contact either Prof Mark Hargreaves (8344 8007) or. Should you have any concerns about the conduct of the project, you are welcome to contact the Executive Officer, Human Research Ethics, The University of Melbourne, on ph: 8344 2073, or fax: 9347 6739.

Thank you for taking the time to read this document and we look forward to your participation.
Mark Hargreaves, Cathryn Pruscino & Gordon Lynch

APPENDIX C

MEDICAL QUESTIONNAIRE

MEDICAL QUESTIONNAIRE

NAME: …… AGE: ……. (yrs) SEX: …….

BODY MASS: …… (kg) HEIGHT: …….. (cm)

Are you currently undertaking any form of regular exercise? YES NO
If yes, briefly describe the type and amount (i.e frequency, duration) of exercise you perform.

Are you a smoker? YES NO

Has anyone ever told you that you:
- are overweight? YES NO UNKNOWN

- have high blood pressure? YES NO UNKNOWN

- have a heart condition or heart murmur? YES NO UNKNOWN

- have asthma or a respiratory condition? YES NO UNKNOWN

- have diabetes? YES NO UNKNOWN

- have a bleeding disorder (e.g. haemophilia)? YES NO UNKNOWN

Have you ever had:
- chest pain, chest discomfort, chest tightness or chest heaviness?
YES NO UNKNOWN

- shortness of breath out of proportion to exercise undertaken?
YES NO UNKNOWN

- heart palpitations (sensation of abnormally fast and/or irregular heart beat)?
YES NO UNKNOWN

- episodes of fainting, collapse or loss of consciousness?
YES NO UNKNOWN

- abnormal bleeding or bruising? YES NO UNKNOWN

- gastrointestinal problems? YES NO UNKNOWN

Do you have a family history of cardiovascular disease? (eg. heart attack, chest pain/angina, stroke, rheumatic heart disease) YES NO UNKNOWN
If YES, please elaborate:

Do you have a family history of diabetes? **YES** **NO** **UNKNOWN**
If YES, please elaborate:

Have you ever suffered any musculoskeletal injury? **YES** **NO** **UNKNOWN**
If YES, please elaborate:

Have you ever experienced difficulty swallowing or any other gastrointestinal problem? **YES** **NO** **UNKNOWN**
If YES, please elaborate:

Do you have any allergies? (including to medications) **YES** **NO** **UNKNOWN**
If YES, please elaborate:

Are you currently on any medication? **YES** **NO**
If YES, please describe:

Are you currently taking anabolic steroids or any other performance-enhancing agents? **YES** **NO**

Neither the investigators nor The University of Melbourne condone the use of anabolic steroids or other banned substances known to enhance athletic performance; however, in certain circumstances, information on their use is required for research purposes.

Is there any other reason which you know of that would prevent you from undertaking the proposed exercise and other tests? **YES** **NO**
If YES, please elaborate:

I believe the information I have provided to be true and correct.

SIGNED: …….. **DATE: ……..**

COMMENTS ON MEDICAL EXAMINATION (where appropriate):

APPENDIX D

PROCEDURES AND GUIDELINES

Procedures and Guidelines for Participants

Thank you for volunteering your time to be involved in this study.

Below is a list of guidelines which we would like you to follow during the 3-day testing period to ensure that the conditions for testing are as controlled as possible. If you have any questions please don't hesitate to contact Cath on_____.

1) To ensure that you arrive at testing in the same state at the start of both trials (Dec & Jan) please follow these guidelines with regards to pre-test food and fluid intake:

    - You have been given a food pack containing a pre-exercise meal (Cereal & Banana) which should be eaten with 300ml of milk (just over 1 cup). This volume has been specifically prepared for you based on your body mass to deliver a specific amount of carbohydrate prior to exercise. This meal should be taken 2.5hr prior to commencing exercise (approx 1.5 hour before arriving at the VIS).
    - If you feel you need to eat more food earlier in the morning, please do so and record it in the Food diary attached.
    - In the 24 hr period prior to testing on Saturday, please record all the food you eat using the 24hr Food diary attached.
    - You will be asked to replicate this food intake for the 24hr period prior to the next test period in January, so try to choose foods that are readily available to you.
    - On the night before testing, please drink 2 bottles of Powerade (included in your food pack) between the hours of 6:00-7:30pm (or finishing at least 3 hrs before going to bed) to ensure you are well hydrated for testing.

2) In the 24 hr period prior to testing on Saturday, please limit the intensity of any training session you perform to low intensity. During the 3-day testing period, any low intensity training sessions performed should be recorded and replicated during the next trial in January.

3) Following testing on Saturday, please remember to keep your compression garment on for the full 24 hr period. Garments can be removed for showering, however, time out of the garment should be limited to 30 mins during the 24 hr period.

4) Please refrain from taking anti-inflammatory medication (aspirin, ibuprofen) in the days prior to the study and throughout the study period as inflammatory blood markers will be investigated throughout the testing period.

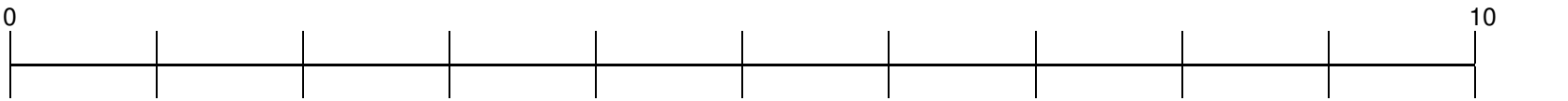
5) Please limit the water temperature and duration of your showers during the 48 hr test period.

6) During the 3-day study period, please refrain from using the following therapeutic modalities:
    - ice, ice baths, contrast water therapy, cold water immersion
    - heat massage
    - massage therapy
    - stretching (other than required squad based regular stretching)

APPENDIX E

RATING OF PERCEIVED SORENESS SCALE

Rating of Perceived Soreness



No Soreness

Extreme Soreness

APPENDIX F

RECOVERY AND READINESS FOR EXERCISE

QUESTIONNAIRE

RECOVERY & READINESS FOR EXERCISE QUESTIONNAIRE

Subject code:_____

From your involvement in the above study, please answer the following questions regarding the treatments administered:

Please indicate how much you agree with the following statement by ticking the appropriate box

At 1 hr post-exercise:

1. At 1 hour post-exercise, I feel well recovered and physically ready to perform at my best in a match right now:

- ☐ Strongly Disagree
- ☐ Disagree
- ☐ Neither agree nor disagree
- ☐ Agree
- ☐ Strongly Agree

At 24hr post-exercise:

2. At 24 hours post-exercise, I feel well recovered and physically ready to perform at my best in a match right now:

- ☐ Strongly Disagree
- ☐ Disagree
- ☐ Neither agree nor disagree
- ☐ Agree
- ☐ Strongly Agree

At 48hr post-exercise:

3. At 48 hour post-exercise, I feel well recovered and physically ready to perform at my best in a match right now:

- ☐ Strongly Disagree
- ☐ Disagree
- ☐ Neither agree nor disagree
- ☐ Agree
- ☐ Strongly Agree

APPENDIX G

RAW DATA

Table 3.1: Multistage fitness test results

Subject	Multistage fitness test score (Level)
1	13.03
2	10.01
3	13.01
4	12.05
5	12.01
6	13.07
7	13.09
8	13.05

Figure 4.1: Pressure Interface between the compression garment and the skin

Subject	Ankle (mmHg)	Calf (mmHg)	Thigh (mmHg)
1	21.5	5.7	4.8
2	19.2	3.0	4.5
3	16.6	9.6	5.0
4	18.5	6.7	3.6
5	17.4	8.0	7.5
6	13.9	8.0	4.5
7	19.5	11.8	6.6
8	26.2	4.8	2.5

Table 4.1: HR, Blood lactate concentration and RPE after each 15 min LIST exercise bout

HR

CG						CON					
Subject	**Bout 1**	**Bout 2**	**Bout 3**	**Bout 4**	**Bout 5**	**Subject**	**Bout 1**	**Bout 2**	**Bout 3**	**Bout 4**	**Bout 5**
1	156	161	159	159	165	1	151	155	157	160	162
2	167	175	177	171		2	169	173	174	167	
3	151	152	149	154	155	3	144	145	154	152	154
4	176	156	157	162	158	4	160	159	161	163	165
5	164	172	173	174	176	5	156	158	159	160	160
6	178	181	179	179	181	6	177	192	180	172	179
7	149	158	160	160	161	7	154	160	162	165	167
8	165	172	170	171	176	8	173	180	180	180	180

Lactate

CG						CON					
Subject	**Bout 1**	**Bout 2**	**Bout 3**	**Bout 4**	**Bout 5**	**Subject**	**Bout 1**	**Bout 2**	**Bout 3**	**Bout 4**	**Bout 5**
1	2.4	2.7	2.4	2.2	2.2	1	2.2	2.4	2.6	2.6	2.2
2	4.4	6.2	6.7	4.9		2	4.9	4.1	3.9	2.9	
3	2.0	1.6	1.4	1.8	1.6	3	2	1.9	2	2.1	1.8
4	2.1	1.9	2.0	1.8	2.0	4	2.2	2.4	2.1	2.6	3.3
5	2.7	2.9	2.9	3.3	3.3	5	2.8	2.3	2	2.1	2.3
6	2.8	2.9	2.9	3.4	4.1	6	3.3	3.2	3.1	2.9	3
7	1.3	1.7	1.3	1.1	1.2	7	1.8	2	2.1	1.7	2
8	3.3	3.0	3.0	3.1	4.2	8	3.7	3.8	3.4	3.7	3.9

RPE

CG						CON					
Subject	**Bout 1**	**Bout 2**	**Bout 3**	**Bout 4**	**Bout 5**	**Subject**	**Bout 1**	**Bout 2**	**Bout 3**	**Bout 4**	**Bout 5**
1	10.0	13.5	14.5	15.0	15.0	1	10.0	11.0	11.5	12.0	13.0
2	12.0	14.0	18.5	19.0		2	11.0	13.0	15.0	10.0	
3	12.0	12.0	13.0	13.0	14.0	3	11.0	12.0	13.0	13.5	14.0
4	13.0	13.0	13.0	15.0	14.0	4	15.0	12.0	13.0	15.0	14.0
5	12.0	12.0	14.0	15.0	15.0	5	14.0	14.0	15.0	15.0	15.0
6	13.0	14.0	14.0	15.0	16.0	6	12.0	14.0	14.0	15.0	16.0
7	11.0	12.5	14.0	14.0	15.0	7	13.0	13.0	14.0	14.5	15.0
8	7.0	9.0	11.0	13.0	14.0	8	11.0	12.0	13.0	13.0	14.0

Table 4.2: Blood lactate concentration in the 30min following exercise.

CG

Subject	0 min	4 min	8 min	12 min	20 min	30 min
1	2.2	2.2	1.2	0.9	0.9	0.9
2	4.9	3.3	3.0	1.9	1.7	1.0
3	1.6	1.9	1.9	1.7	1.0	1.0
4	2.0	1.7	1.2	0.9	0.8	0.8
5	3.3	2.6	2.1	1.7	1.3	1.0
6	4.1	3.4	3.1	2.6	2.3	1.6
7	1.2	0.9	1.2	1.0	0.9	0.9
8	4.2	3.3	2.2	1.7	1.2	1.1

CON

Subject	0 min	4 min	8 min	12 min	20 min	30 min
1	2.2	1.6	0.9	0.8	0.8	0.8
2	2.9	1.9	1.7	1.3	1.2	1.0
3	1.8	1.4	1.1	1.2	0.8	0.8
4	3.3	2.2	1.4	1.8	1.0	1.0
5	2.3	1.2	0.9	0.9	0.9	0.8
6	3.0	2.0	1.9	1.7	1.2	0.8
7	2.0	1.4	1.3	1.0	0.9	0.9
8	3.9	2.9	2.4	1.8	1.3	1.2

Figure 4.3: CK concentration

CG

Subject	Baseline	1 h	24 h	48 h
1	113	403	942	569
2	109	268	661	477
3	508	600	650	431
4	117	271	494	253
5	256	406	455	314
6	600	831	817	554
7	181	256	198	162
8	106	262	295	144

CON

Subject	Baseline	1 h	24 h	48 h
1	325	440	560	348
2	275	433	631	406
3	553	799	759	556
4	133	306	731	400
5	303	412	596	514
6	407	796	968	569
7	172	254	216	256
8	67	155	263	138

Figure 4.2: Cytokine and Protein response after exercise

CRP

CG

Subject	Baseline	1 h	24 h	48 h
1	1771.37	2830.61	14758.84	7564.06
2	21439.64	16734.60	26993.27	16976.42
3	2321.33	2412.79	3555.80	1568.77
4	1976.04	1754.41	4262.22	2412.79
5	5328.27	16956.21	17179.12	13077.31
6	18063.24	20208.38	30000.00	26971.68
7	775.33	1057.09	2733.26	619.13
8	677.43	3551.26	4491.26	1522.65

CON

Subject	Baseline	1 h	24 h	48 h
1	5799.32	7020.94	10827.90	4510.04
2	21800.13	21632.77	25353.98	19174.54
3	13886.64	12185.13	13553.36	10392.58
4	9021.48	8042.82	11671.46	6868.85
5	5560.49	7036.19	10057.14	6667.16
6	20000.16	17192.68	15464.05	18674.73
7	4118.21	4308.83	6074.48	2804.03
8	477.92	304.47	334.43	1412.07

IL6

CG

Subject	Baseline	1 h	24 h	48 h
1	57.81	67.68	65.69	69.05
2	2.28	5.45	3.53	3.86
3	24.18	20.88	21.03	22.22
4	17.22	23.79	14.46	16.09
5	7.36	10.56	5.78	8.15
6	22.78	61.12	27.89	25.96
7	26.44	28.44	24.80	26.32
8	6.73	8.69	8.37	8.33

CON

Subject	Baseline	1 h	24 h	48 h
1	62.19	63.42	63.05	56.00
2	4.08	5.42	4.96	4.31
3	25.59	24.18	24.03	17.39
4	15.21	24.86	13.68	15.94
5	3.84	9.34	6.06	7.22
6	33.17	52.31	31.52	34.08
7	27.47	30.25	23.73	28.02
8	6.69	11.18	8.19	7.31

IL1b

CG					CON				
Subject	**Baseline**	**1 h**	**24 h**	**48 h**	**Subject**	**Baseline**	**1 h**	**24 h**	**48 h**
1	0.22	0.99	0.79	0.96	1	0.75	1.11	0.53	0.16
2	0.49	2.05	2.35	3.42	2	2.54	2.68	2.88	1.67
3	3.83	2.80	4.00	3.65	3	5.16	4.07	4.15	1.94
4	0.23	0.06		0.10	4	0.06	0.77	0.32	0.91
5	2.82	2.53	1.84	2.11	5	1.05	1.96	2.18	3.22
6	2.35	12.49	3.70	3.12	6	4.50	3.73	4.09	4.25
7	1.29	1.40	1.40	1.62	7	1.76	2.11	1.37	1.66
8					8				

TNFa

CG					CON				
Subject	**Baseline**	**1 h**	**24 h**	**48 h**	**Subject**	**Baseline**	**1 h**	**24 h**	**48 h**
1	2.82	4.05	2.53	2.57	1	2.95	4.21	3.01	2.76
2	1.81	2.78	2.29	3.14	2	3.08	3.60	2.98	2.74
3	5.57	4.80	4.48	5.07	3	4.47	3.55	4.24	2.84
4	2.13	3.24	2.23	2.20	4	1.89	3.90	2.11	2.25
5	4.70	5.57	4.10	3.76	5	4.68	5.07	4.09	5.15
6	5.26	21.50	7.71	6.03	6	8.65	8.90	7.43	7.45
7	1.60	1.40	1.76	1.58	7	2.34	2.65	1.84	2.12
8	0.65	0.71	0.73	0.86	8	1.18	1.59	1.49	1.01

Table 4.3: Tests of Muscle Function

5CMJ Mean Power Output	CG Subject	Baseline	1 h	24 h	48 h	CON Subject	Baseline	1 h	24 h	48 h
	1	2978.52	3081.54	2966.24	3117.48	1	3148.62	3003.22	3221.74	3464.98
	2	5061.76	4951.50	4848.72	4930.58	2	5022.52	4959.02	5173.72	5181.68
	3	3041.98	3026.78	2969.48	3182.20	3	3309.24	3174.22	3339.90	3442.74
	4	4440.48	4057.72	4315.84	4225.68	4	4038.06	3944.06	4358.36	4591.52
	5	4335.40	3775.72	3972.56	4048.26	5	4467.28	4282.52	4096.90	4424.62
	6	3165.56	3099.20	3186.24	3154.30	6	2877.86	2861.06	3111.84	3124.24
	7	3174.40	3027.96	3043.06	3176.36	7	2973.94	2909.36	2885.76	2971.18
	8	3489.86	3590.58	3583.08	3496.94	8	3342.56	3190.58	3210.14	3394.94

5CMJ Peak Force	CG Subject	Baseline	1 h	24 h	48 h	CON Subject	Baseline	1 h	24 h	48 h
	1	1726.14	1723.86	1695.90	1762.34	1	1790.92	1720.42	1810.58	1869.54
	2	2869.38	2617.16	2592.12	2764.32	2	2765.52	2564.16	2741.66	2692.58
	3	2008.66	1967.22	1967.98	2054.20	3	1979.52	1933.08	1955.12	1938.90
	4	2307.04	2235.26	2313.45	2562.18	4	2508.62	2497.00	2760.94	2863.68
	5	2041.44	1927.34	1961.00	1983.64	5	2178.90	2106.18	2067.50	2195.24
	6	1666.24	1668.48	1649.66	1669.90	6	1616.78	1626.40	1679.76	1621.64
	7	1612.92	1468.62	1535.44	1591.52	7	1692.26	1537.06	1582.26	1613.66
	8	1768.86	1775.52	1816.36	1741.20	8	1721.46	1614.28	1663.98	1690.78

SJ Peak Force	CG Subject	Baseline	1 h	24 h	48 h	CON Subject	Baseline	1 h	24 h	48 h
	1	1581.6	1506.7	1493.9	1535.4	1	1557.3	1457.4	1638.8	1611.9
	2	2460.4	2419.0	2340.8	2420.9	2	2412.4	2441.0	2323.6	2339.6
	3	1937.8	1985.4	1914.9	1996.1	3	1900.5	1901.4	1806.3	1870.1
	4	2223.9	2170.0	2217.7	2066.1	4	2142.5	2180.4	2251.4	2310.2
	5	1978.0	1897.3	1947.8	1958.9	5	1999.8	2005.0	1905.4	1951.6
	6	1762.5	1681.2	1663.6	1694.5	6	1581.0	1607.6	1654.0	1717.8
	7	1557.1	1535.3	1581.2	1504.9	7	1564.7	1541.9	1595.9	1624.7
	8	1507.4	1505.7	1508.6	1497.3	8	1629.1	1493.3	1534.0	1557.3

Figure 4.4 Perceived Recovery and Rating of Perceived Soreness

Perceived Recovery

CG				CON			
Subject	**1 h**	**24 h**	**48 h**	**Subject**	**1 h**	**24 h**	**48 h**
1	2	3	5	1	2	3	4
2	2	4	4	2	1	2	3
3	2	4	5	3	1	3	4
4	2	4	4	4	1	4	4
5	2	5	5	5	3	4	5
6	2	4	5	6	1	3	4
7	3	4	5	7	2	3	4
8	4	4	5	8	4	4	4

Rating of Perceived Soreness

CG					CON				
Subject	**Baseline**	**1 h**	**24 h**	**48 h**	**Subject**	**Baseline**	**1 h**	**24 h**	**48 h**
1	2.5	3.0	2.0	1.0	1	1.0	3.0	3.5	2.0
2	3.0	4.5	6.0	2.0	2	1.5	6.5	6.0	1.5
3	2.0	7.0	2.0	2.0	3	7.0	9.0	5.0	3.0
4	1.0	4.0	1.5	1.0	4	1.0	6.0	4.0	6.5
5	3.0	4.0	3.0	1.0	5	6.5	6.0	5.0	4.0
6	3.0	4.5	0.0	0.0	6	6.0	6.0	2.0	0.0
7	4.0	5.0	5.0	3.0	7	2.0	3.0	3.0	4.0
8	2.0	3.0	1.0	1.0	8	2.0	4.0	3.0	2.0

APPENDIX H

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ORIGINAL ARTICLE

Effects of compression garments on recovery following intermittent exercise

Cathryn L. Pruscino · Shona Halson · Mark Hargreaves

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Abstract The objective of the study was to examine the effects of wearing compression garments for 24 h post-exercise on the biochemical, physical and perceived recovery of highly trained athletes. Eight field hockey players completed a match simulation exercise protocol on two occasions separated by 4 weeks after which lower-limb compression garments (CG) or loose pants (CON) were worn for 24 h. Blood was collected pre-exercise and 1, 24 and 48 h post-exercise for IL-6, IL-1β, TNF-α, CRP and CK. Blood lactate was monitored throughout exercise and for 30 min after. A 5 counter-movement jump (5CMJ) and squat jump were performed and perceived soreness rated at pre-exercise and 1, 24 and 48 h post-exercise. Perceived recovery was assessed post-exercise using a questionnaire related to exercise readiness. Repeated measures ANOVA was used to assess changes in blood, perceptual and physical responses to recovery. CK and CRP were significantly elevated 24 h post-exercise in both conditions ($p < 0.05$). No significant differences were observed for TNF-α, IL1-β, IL-6 between treatments ($p > 0.05$). Power and force production in the 5CMJ was reduced and perceived soreness was highest at 1 h post-exercise ($p < 0.05$). Perceived recovery was lowest at 1 h post-exercise in both conditions ($p < 0.01$), whilst overall, perceived recovery was greater when CG were worn ($p < 0.005$). None of the blood or physical markers of recovery indicates any benefit of wearing compression garments post-exercise. However, muscle soreness and perceived recovery indicators suggest a psychological benefit may exist.

Keywords Cytokines · Inflammation · Creatine kinase · Muscle function · Team sports

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C. L. Pruscino · M. Hargreaves
Department of Physiology, University of Melbourne, Melbourne, Australia

C. L. Pruscino (✉)
Department of Sport Science, Victorian Institute of Sport, A'Beckett Street, PO Box 12608, Melbourne, VIC 8006, Australia
e-mail: cathryn.pruscino@vis.org.au

S. Halson
Department of Physiology, Australian Institute of Sport, Canberra, Australia

Introduction

The underlying feature of lower body, graduated compression garments is their ability to alter the flow of blood and, in particular, enhance the return of blood from the peripheries to central regions of the body (Sigel et al. 1973, 1975). The compressive force applied by the garments to the lower limbs reduces the size of the venous bed at the extremities, thereby increasing femoral vein blood flow velocity (Sigel et al. 1973, 1975). The associated reduction in stasis and increased venous return at rest has proved beneficial in the treatment of patients with chronic venous insufficiency (Horner et al. 1980; Zajkowski et al. 2002) and has reduced the incidence of deep vein thrombosis following major surgery (Holford 1976). Inactive, hospitalised patients and those with venous conditions have traditionally been the beneficiaries of such enhanced haemodynamics; however, the benefit of wearing lower-body compression garments on blood flow has also been reported in patients with normal venous systems (Sigel et al. 1973, 1975).

In recent years, compression garments have been promoted to athletes as a means of optimising circulation during and following exercise. The potential influence of compression therapy on the inflammatory and repair process post-exercise has emerged as a new frontier in the recovery of elite athletes. Physiological recovery and repair of muscle fibres following exercise-induced muscle damage (EIMD) can take up to 4–5 days (Armstrong et al. 1991; Connolly et al. 2003) and can, therefore, be a limiting factor for elite team-sport athletes during consecutive days of training or competition (Barnett 2006; Ispirlidis et al. 2008). An acceleration of the muscle repair process, even for minor episodes of muscle damage, is advantageous in their capacity to return to competition or training at the earliest opportunity. Compression garment use is now being incorporated into athlete recovery strategies in an attempt to attenuate the inflammatory response, reduce the effects of EIMD and restore optimal muscle function sooner (Barnett 2006; MacRae et al. 2011). However, the efficacy of such garments to deliver these outcomes in elite athletes is yet to be clearly demonstrated.

Given the effect of compression garments on blood flow, it is anticipated that enhanced circulation may attenuate the increase in the concentration of cytokines in the post-exercise period and, therefore, influence the inflammatory response. However, the effect of compression garments on the post-exercise inflammatory response has been investigated only once before with the impact on the appearance of specific cytokines (IL-6 and IL-10) reported as unclear (Montgomery et al. 2008a). The appearance of a range of cytokines in the blood suggests that an acute-phase inflammatory response has been initiated and is thought to reflect the magnitude of the muscle damage that has occurred (Pedersen et al. 1998). The sequence of cytokine appearance begins with TNF-α and IL-1β which are pro-inflammatory cytokines and are thought to trigger the release of IL-6, which is restorative rather than pro-inflammatory in nature (McIntyre et al. 1995; Pedersen et al. 1998). IL-6 is also thought to be involved in substrate delivery during exercise through its ability to induce lipolysis and fat oxidation and through its involvement in glucose homeostasis (Petersen and Pedersen 2005). Further along the inflammatory cascade, the presence of IL-6 promotes synthesis of C-reactive protein (Pedersen et al. 1998), a marker of systemic inflammation and tissue damage (Malm et al. 2004) which is involved in the suppression of pro-inflammatory cytokine production (Petersen and Pedersen 2005).

Previous research has provided evidence that different types of exercise can trigger the production of cytokines in the post-exercise period. A 2.3-fold increase in TNF-α, a 2.1-fold increase in IL-1β and a 128-fold increase in IL-6 was reported within 10 min of completion of a marathon race (Ostrowski et al. 1999). Both soccer (Ispirlidis et al. 2008) and basketball (Montgomery et al. 2008a) match-play resulted in a 3- to 4-fold elevation of IL-6 concentrations immediately after exercise, and following the soccer match, the peak in IL-6 preceded the peak in CRP which is in line with the previous findings (Malm et al. 2000). In contrast, maximal eccentric resistance training produced a peak in IL-6 concentrations 8 h after exercise with an almost 2-fold elevation above resting conditions (Miles et al. 2007a). Maximal isometric contractions produced a 1.5-fold elevation of IL-6 levels at 8 h post-exercise, with no significant change in CRP concentrations (Miles et al. 2007b). Distance-related increases in CRP concentrations after five running races of varying durations (15–88 km) have been reported, with CRP peaking 24 h after each race regardless of the distance travelled (Strachan et al. 1984). As such, it is clear that the magnitude and time course of the cytokine response varies with different types of exercise. Whether wearing compression garments in the post-exercise period reduces the time course or magnitude of this biochemical response in the hours and days after exercise will be further investigated in the present study.

The specific effect of wearing compression garments in the post-exercise period on commonly used indicators of EIMD, have previously been investigated with mixed results. Untrained subjects demonstrated an enhanced recovery of force production, reduced creatine kinase (CK) concentrations and decreased perceived soreness in the days following maximal eccentric muscle contractions after wearing a compressive sleeve (Kraemer et al. 2001). Similarly, resistance-trained subjects showed reduced CK response and improved upper body restoration of strength after wearing full body compression garments in the recovery from a whole-body heavy resistance exercise protocol (Kraemer et al. 2010). However, subjects ranging from recreational performers to regional level athletes who wore lower-body compression for 12 h following a resistance exercise protocol (French et al. 2008) displayed reduced range of movement through knee and hip joints 48 h after exercise, showed no restoration of lower leg power above control conditions and suffered a slower recovery of 30 m sprint times compared to control at 48 h after exercise. Furthermore, similar garments worn by trained subjects after a plyometric drop-jump protocol (Davies et al. 2009) and a simulated basketball tournament (Montgomery et al. 2008b) appear to have also impeded recovery of 5–20 m sprint performance with sprint times increasing beyond control values in the post-exercise period.

Although a growing body of research has investigated the efficacy of wearing lower-body compression garments on post-exercise recovery, the benefit to the highly trained

athlete remains unclear. The main reasons for this include the differences in type and pressure characteristics of the compression garments utilised, as well as the variation in the training status of the subjects used to assess this recovery strategy. Furthermore, much of the research examining the effect of compression garments on exercise recovery employs eccentric resistance exercise regimens traditionally used to elicit muscle damage. Whilst this method is highly effective for measuring and monitoring purposes, for elite athletes, this may not reflect the extent of typical damage incurred during training or competition. As such, the recovery from this type of exercise may not be specific to the training recovery required for their sport (Bishop et al. 2008).

The present study aimed to investigate the efficacy of wearing commercially available, full-length, lower-body compression garments following a hockey-simulation exercise protocol to determine whether this strategy influenced the post-exercise biochemical response and recovery of muscle function in highly trained athletes. The pressure exerted by the compression garment was measured and a practical post-exercise protocol utilised. The physiological, biochemical and perceptual responses of highly trained subjects were examined to determine the effect on post-exercise recovery, of wearing versus not wearing lower-body compression garments.

Methods

Subjects

Eight highly trained male hockey players (mean age 21.9 ± 2.3 years, height 180.1 ± 8 cm, body mass 77.9 ± 13.9 kg, sum of 7 skinfolds 70.6 ± 21.1 mm) who compete at either National or International level, volunteered to participate in this investigation. Prior to commencing the study, all participants were informed of the requirements, risks and benefits of the investigation, and written informed consent was obtained from each. Approval for the procedures of the study was granted by the University of Melbourne Human Research Ethics Committee.

Pre-test protocol

Data were collected during two 3-day trial periods separated by 4 weeks. The 3-day trial procedure is outlined in Fig. 1. In the days prior to each trial and throughout the study period, subjects were asked to refrain from taking anti-inflammatory medication (aspirin, ibuprofen). During each trial period, subjects were asked to limit the water temperature and duration of showers and refrain from using the following therapeutic modalities: ice, ice baths, contrast water therapy, cold water immersion, heat massage, massage therapy, stretching. A pack containing sports drinks, a urine container, an instruction sheet, a food pack and a food diary was delivered to each subject prior to the commencement of each trial. The food pack contained hydration fluids for the night before each trial and a normalised breakfast pack for the morning of the trial aimed to deliver 1.2 g CHO kg BM^{-1}. Food diaries were kept by each athlete in the 24 h prior to the start of the first trial and throughout the 3-day trial period and this food intake regimen was then replicated prior to the subsequent trial. Subjects were restricted from performing high-intensity exercise in the 24 h prior to each trial.

The Loughborough Intermittent Shuttle Test (LIST) exercise protocol, used in the present study, includes exercising at varying percentages of each individual's maximal oxygen consumption. As such, initial indication of the aerobic capacity of each subject was required prior to testing in order to determine the appropriate protocol to be used. At least 7 days prior to the commencement of the study and in accordance with procedures previously recommended (Nicholas et al. 2000), the predicted VO_{2max} of each subject was ascertained using a progressive multistage shuttle running test (Ramsbottom et al. 1988). Following completion of the multistage shuttle running test, subjects were grouped according to their predicted VO_{2max} scores. Subjects with a predicted VO_{2max} in the range 53–57 ml kg^{-1} min^{-1} were assigned the 55 ml kg^{-1} min^{-1} LIST exercise protocol and those in the range 57–62 ml kg^{-1} min^{-1} were assigned the 60 ml kg^{-1} min^{-1} LIST exercise protocol to perform during the study period. As such, the running speeds required of subjects during testing, were suitable to the aerobic fitness level of each individual.

Each subject also participated in a familiarisation session for the tests of muscle function to be used during the study. Body mass (BM) and waist girth measurements assisted the process of fitting compression garments which was overseen by a representative of the manufacturer to ensure sizing was appropriate. Subjects were fitted into a comfortable size, smaller than that outlined on the packaging, which is in line with current manufacturer's recommendations. Two garments were then labelled and put aside for each subject.

Pressure interface monitoring

Separate to testing, the interface pressure between the compression garment and the skin was monitored for each subject using a portable interface pressure evaluator (Talley Medical, Miami, USA). Measurements were recorded at three sites on the lower limb (minimal ankle, maximal calf and maximal thigh) according to international recommendations (Partsch et al. 2006). Subjects were

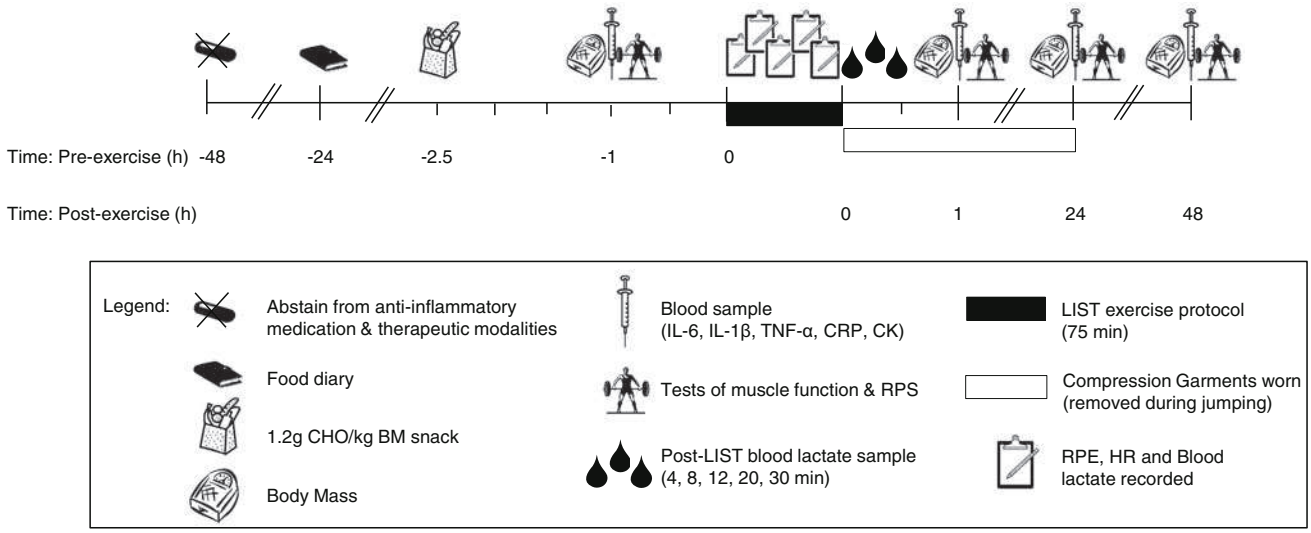

Fig. 1 Experimental design and study timeline

measured, in the standing position, using a 2.8 cm pressure sensor positioned at each of the three designated sites. The pressure sensor was attached to the hand held pressure evaluator via a jack plug and air connector. The sensor was slowly inflated and then deflated, whilst the pressure (mmHg) between two surfaces was displayed on the digital screen. The interface point was indicated by visual and auditory signals.

Experimental protocol

On the first morning of each trial, subjects were required to collect a urine sample on waking. Urine-specific gravity was measured to assess hydration status of the subject prior to exercise. Subjects arrived at the testing venue at the same time on both trials. Upon arrival, subjects had body mass (BM) measured and were then required to rest seated for 15 min before a baseline venous blood sample was obtained for later analysis of IL1-β, IL-6, TNF-α and CRP, and, a baseline capillary sample was obtained for CK analysis. This blood collection procedure was repeated at 1, 24 and 48 h post-exercise (Fig. 1). Following baseline blood measurements, subjects moved to the indoor gymnasium where they completed a standard warm-up consisting of low intensity stationary bike, running drills, 30 m run throughs increasing in intensity and box jumps. A maximum of 5-min rest was allowed before commencing baseline tests of muscle function.

Tests of muscle function

A 5-repetition counter movement jump (5CMJ) and a squat jump (SJ) were performed by each subject at baseline, 1, 24 and 48 h post-exercise to monitor the effect of fatigue and recovery on lower-body force and power production.

A repeated counter movement jump was used instead of a single counter movement jump due to the potential for unique high or low scores in a single effort jump test and the likelihood that the measurement of repeated efforts may be more reliable (Hopkins et al. 2001). It has previously been suggested that the 5CMJ is suitable for assessing the training and performance of elite athletes (Cormack et al. 2008) with good overall reliability for peak power and peak force (CV 4.4 and 3.3 %, respectively).

For the 5CMJ, subjects were instructed to exert maximal effort for five consecutive jumps, without a pause between them. An average of the five peak force and peak power values was calculated for each set of jumps and the highest average value is reported as the 5CMJ mean force and 5CMJ mean power, respectively.

According to previous recommendations for the SJ (Sheppard and Doyle 2008), subjects were required to begin from a 90° squat position which was briefly held prior to jumping vertically as high as possible. The brief isometric hold prior to the jump prevents counter movement activity removing the contribution of the stretch–shortening cycle. The peak force for each SJ was recorded and reported as SJ peak force.

Participants performed each jump test at least three times or until maximal force and power values no longer increased. This was to ensure that the maximal values at each time point were recorded. Warm-up procedures and tests of muscle function were repeated at 1, 24 and 48 h post-exercise.

Vertical displacement of each jump was measured with a cable-extension potentiometer (distance transducer) attached to a lightweight pole resting on the subject's

shoulders. Peak force data was calculated by Ballistic Measurement System (Fitness Technology, Adelaide, Australia) computer software.

Wearing compression garments during jumping has previously been reported to improve mean force and power production over a ten counter-movement jump test (Kraemer et al. 1996) and a single maximal vertical jump (Doan et al. 2003) and as such, compression garments were removed prior to jumping in the present study.

Rating of perceived soreness

An adapted visual analogue scale (VAS) (Mattacola et al. 1997) was used to measure the rating of perceived muscle soreness (RPS) that subjects experienced during muscle function testing. Immediately following the 5CMJ and SJ, subjects rated their perceived muscle soreness (RPS) on the 11-point VAS which had anchors at either end indicating no soreness (0) and extreme soreness (10). Subjects were asked to point to the marker on the line which best indicated their soreness during jumping.

LIST protocol

The LIST exercise protocol was used to induce fatigue and was performed on day 1 of each trial. The LIST protocol was performed on an indoor running track in moderate conditions (24.8 ± 1.1 °C; 51.4 ± 6.1 % RH) on both occasions.

The LIST is made up of variable speed running, jogging and walking and was developed to simulate the intermittent nature of sports such as soccer and field hockey (Nicholas et al. 2000). It was selected due to its ability to elicit muscle damage and exercise-induced muscle soreness (Thompson et al. 1999).

The exercise bouts are 15 min in duration, interspersed by 3-min rest periods, and include walking, jogging at 55 %$\dot{V}O_{2max}$, cruising at 95 % $\dot{V}O_{2max}$ and sprinting at maximal running speeds up and back on a 20 m course with markers at 0, 10, 15 and 20 m. Five exercise bouts (75 min of exercise in total) were performed in the current study to closely simulate the duration of a field hockey match. Audio cues from a CD indicated when each activity would occur and the activity order was of a repetitive nature. The LIST protocol has been previously outlined in detail (Thompson et al. 1999).

At the conclusion of each 15-min exercise block, average heart rate (HR) and rating of perceived exertion (RPE) were recorded (Borg 1970) and subjects ingested 2 mL kg^{-1} BM plain water from clearly labelled, individually prepared drink bottles. At the start of each rest period and after 4, 8, 12, 20 and 30 min of recovery from the LIST, capillary blood samples were obtained from the earlobe of each subject for blood lactate analysis (Lactate Pro, Arkray, Japan).

Post-exercise procedure

Upon completion of the LIST and after obtaining the 4-min post-exercise capillary blood sample, subjects changed into either a full length, lower-limb compression garment (CG; 2XU Compression, Australia) or loose tracksuit pants (CON). The subjects were randomly assigned to the two treatments over two trials in a balanced crossover research design and were blinded to their order of treatment up until the first LIST protocol was completed. During the CG trial, compression tights were worn for the full 24 h post-exercise period and were only allowed to be removed for bathing and during jumping for muscle function testing, ensuring that the total time out of the compression garment did not exceed 30 min.

In the hour following completion of the LIST, subjects rested in a seated position. At the 1 h time point, subjects had blood samples collected and then repeated the standard warm-up, tests of muscle function and RPS protocols. Subjects returned to the lab at 24 and 48 h post-exercise to repeat the blood collection, warm-up, tests of muscle function and RPS procedures.

Perceived recovery

Whilst resting quietly prior to blood collection at 1, 24 and 48 h post-exercise, participants were asked to respond to the following statement to assess their perceived recovery: "I feel well recovered and physically ready to perform at my best in a match right now". The participants responded using a scale ranging from strong disagreement (1) to strong agreement (5).

Blood collection and analysis

Venous blood was analysed for inflammatory mediators IL1-β, IL-6, TNF-α and CRP. 5–6 ml of whole blood was collected into a plastic syringe and then separated into blood collection tubes. Following centrifugation for 10 min at 2,000 rpm, the plasma was collected into four clearly labelled storage tubes and frozen (−80 °C) until analysis. Plasma concentrations of IL1-β, IL-6 and TNF-α were determined using a standard analysis kit (Human High Sensitivity Multiplex panel, Millipore, USA) whilst CRP was analysed using a separate analysis kit (Human Cardiovascular Disease Panel 2, Millipore, USA). Both assays were carried out according to manufacturer's instructions using Luminex 100 instrumentation (Bio-Rad Laboratories, Hercules, CA, USA). The reliability (%CV) of measuring

each analyte using these kits was 3.11 % for IL1-β, 3.51 % for IL-6, 3.49 % for TNF-α and 8.0 % for CRP.

A capillary blood sample was collected from the fingertip of each subject for CK analysis at baseline, 1, 24 and 48 h post-exercise (Fig. 1). 32 µl of blood was collected into a lithium-heparinised capillary tube then transferred to the Reflotron CK test strip and immediately analysed using a Reflotron Plus diagnostic device (Roche Diagnostics, Basel, Switzerland). The co-efficient of variation for the analysis of CK was 3.5 %.

Capillary blood, collected from the earlobe, was used to determine blood lactate concentration immediately following completion of each 15-min exercise bout and throughout the 30-min post-exercise period. A portable lactate analyser (Lactate Pro, Arkray, Japan) was used and has previously been shown to be an accurate and reliable portable analyser for blood lactate concentration (Tanner et al. 2010).

Data analysis

Two-way analysis of variance (ANOVA) with repeated measures (treatment × time) was used to determine differences between the two treatments with regards to blood and muscle function test parameters. Statistical significance is reported when $p < 0.05$. Statistical analysis was carried out using IBM SPSS Statistics (Version 19.0). A Tukey's honestly significant difference post hoc test was used to establish where any significant differences occurred. All data are expressed as mean ± standard deviation (SD).

Results

Pre-exercise hydration variables

There were no significant differences in baseline body mass (78.0 ± 13.6 vs. 77.6 ± 12.7 kg for CG vs. CON, respectively) or urine specific gravity (1.019 ± 0.008 vs. 1.019 ± 0.005 for CG vs. CON, respectively) between trials.

Pressure interface data

The interface pressure between the lower-body compression garment and the skin was measured at three sites of the lower limb. There was a significant difference between the pressure exerted by the compression garment at the ankle and the calf (19.1 ± 3.6 vs. 7.2 ± 2.8 mmHg, $p < 0.01$), ankle and thigh (19.1 ± 3.6 vs. 4.8 ± 1.6 mmHg, $p < 0.01$), but not between the calf and thigh (7.2 ± 2.8 vs. 4.8 ± 1.6 mmHg, $p > 0.05$). Rather than providing uniform pressure along the length of the limb, the garments provide greater pressure at the ankle that at the thigh and, therefore, can be categorized as a graduated compression garment.

HR, blood lactate and RPE during the LIST

The average HR, blood lactate concentration and RPE were recorded following every 15 min bout of the LIST exercise protocol. A main effect for time was found for RPE across the five bouts ($p < 0.01$) with RPE increasing as exercise duration increased. At the completion of the final stage of exercise, regardless of the treatment that was to proceed exercise, there was no difference in average HR (CG 167 ± 10 bpm vs. CON 167 ± 10 bpm, $p > 0.05$), blood lactate concentration (CG 2.7 ± 1.2 mmol L^{-1} vs. CON 2.6 ± 0.8 mmol L^{-1}, $p > 0.05$) or RPE (CG 15 ± 1 vs. CON 14 ± 1, $p > 0.05$). As such, prior to commencing either CG or CON, the amount of work performed by subjects in the LIST, their physiological response to this work, and their physiological state at the conclusion of the LIST exercise protocol was the same.

Post-exercise blood lactate

Table 1 shows the blood lactate concentration of subjects from 0 to 30 min post-exercise under both conditions. No differences were observed between trials for post-exercise blood lactate concentration ($p > 0.05$).

Cytokines and proteins

No significant differences were observed for TNF-α or IL-1β or IL-6 between the two treatments ($p > 0.05$; Fig. 2). The C-reactive protein (CRP) response revealed a significant interaction ($p = 0.030$; Fig. 2) and post hoc analysis identified a difference between the two treatments only at baseline. A main effect for time ($p = 0.001$) also confirmed that CRP was significantly higher at 24 h

Table 1 Blood lactate concentration in the 30 min following exercise ($n = 8$)

Time post-LIST	0 min	4 min	8 min	12 min	20 min	30 min
CG	2.9 (1.4)	2.4 (0.8)	2.0 (0.7)	1.6 (0.6)	1.3 (0.5)	1.0 (0.2)
CON	2.7 (0.7)	1.8 (0.6)	1.5 (0.5)	1.3 (0.4)	1.0 (0.2)	0.9 (0.1)

CG worn from 4 min post-exercise until 24 h post-exercise. Values are presented as mean (SD)

post-exercise than all other time points. For CG, CRP at 24 h was higher than baseline, 1 and 48 h ($p < 0.01$), whilst for CON, CRP at 24 h was higher than at 48 h ($p < 0.05$).

CK

A main effect for time identified that CK concentration was significantly elevated in the post-exercise period in both CG and CON ($p = 0.001$; Fig. 3); however, there were no differences in the concentration of CK when comparing CG with CON ($p > 0.05$). CK values peaked 24 h after the completion of exercise at which time they were higher than all other time points ($p < 0.05$) indicating that the LIST protocol successfully induced some muscle damage, however, the leakage of CK into the blood, appears to have been similar between trials regardless of the recovery technique used.

Tests of muscle function

A significant interaction ($p = 0.039$) and a main effect for time ($p = 0.002$) were observed for mean power production during the 5CMJ (Table 2). Power production had decreased significantly ($p < 0.05$) by 1 h after exercise in both trials and was significantly higher at 48 h compared with 1 and 24 h post-exercise ($p < 0.01$). The post hoc analysis following the significant interaction, revealed a difference between CG and CON only at 48 h post-exercise ($p < 0.05$), however, the magnitude of the difference between treatments at this time point (158 W) and that which was observed across time within each treatment, were generally smaller than the typical error associated with this test (210 W intraday, 278 W interday) (Cormack et al. 2008). For mean force in the 5CMJ, a significant time effect ($p < 0.05$) confirmed that mean force production was significantly lower at 1 h post-exercise than at baseline, 24 and 48 h under both conditions, and the difference was generally greater than the typical error (69N) associated with this parameter (Cormack et al. 2008). There were no significant differences observed between trials for mean force or mean power output in the SJ (Table 2).

Perceived recovery

Although no interaction effect was observed ($p > 0.05$), significant main effects for both treatment ($p = 0.005$) and time ($p = 0.001$) were found. At 1 h after the end of exercise in both CG and CON, subjects disagreed with the notion that they were "well recovered" and "ready to perform at their best". They felt significantly less recovered at 1 h ($p < 0.05$) compared with 24 and 48 h post-exercise. Given the treatment main effect, averaged across all time points it is evident that perceived recovery was reported as superior when CG were worn. Individual data show that after wearing CG for 48 h, six out of eight subjects strongly agreed that they were "ready to perform at their best", compared to one out of eight for CON.

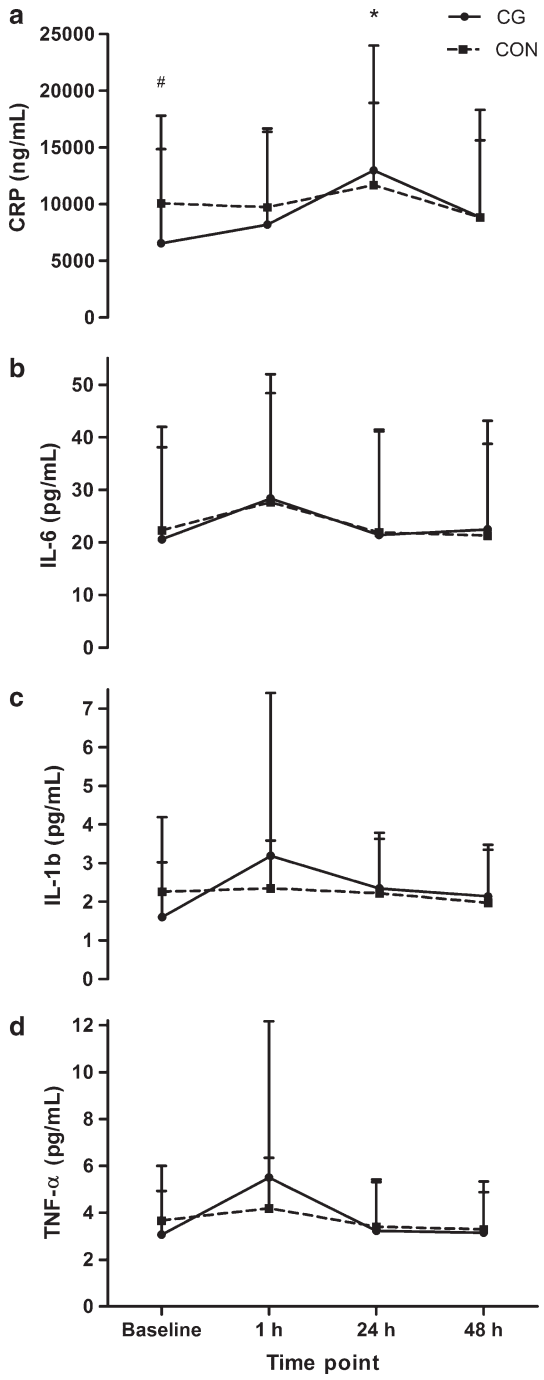

Fig. 2 Cytokine and Protein response following intermittent exercise: CRP (**a**), IL-6 (**b**), IL-1β (**c**), TNF-α (**d**). $^{*}p < 0.05$ from baseline, 1 and 24 h for CG and different from 48 h for CON. $^{\#}p < 0.05$ CG different from CON. Values are presented as mean ± SD

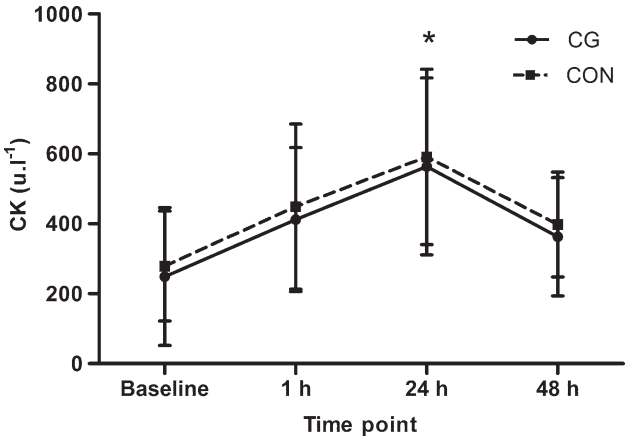

Fig. 3 CK concentration. *$p < 0.01$ from all other time points for CG and CON. Values are presented as mean ± SD

Rating of perceived soreness

Rating of perceived muscle soreness in the post-exercise period is displayed in Fig. 4 (0 = no soreness; 10 = extreme soreness). There was no significant interaction effect, however, the main effect for time was $p = 0.003$ as perceived soreness was higher at 1 h post-exercise in both conditions compared to all other time points ($p < 0.05$). There was a trend for a treatment main effect ($p = 0.053$) with soreness reported to be less in the CG versus control condition averaged over all recovery time points.

Discussion

The focus of the present study was on the efficacy of wearing full length lower-body compression garments for 24 h post-exercise as a recovery aid for highly trained athletes. Additionally, it provided a unique comparison of blood variables, perceptual responses and muscle function in the 48 h following intermittent activity. The majority of subjects in the present study felt better recovered and reported earlier exercise readiness after 24 h of wearing compression garments following a hockey match simulation exercise. Despite this, blood markers and tests of muscle function monitored in this study revealed that compression garments provided minimal assistance to the recovery process.

Compression garments have been shown to increase femoral vein flow velocity by reducing the pooling of blood in the lower extremities and encouraging venous return of blood to the heart. Sigel et al. (1975) found that garments which apply a compressive force of 18 mmHg around the ankle, reducing to 8 mmHg around the thigh, generate the fastest average flow velocity of 38.4 % above baseline, in inactive recumbent subjects. A garment which applies graduated compression in this way has been shown to increase blood flow to a greater degree than compression distributed evenly over the lower extremity in patients with normal venous systems (Sigel et al. 1975). The commercial garments used in the present study provided interface pressure of 19.1 mmHg at the ankle, 7.2 mmHg at the calf and 4.9 mmHg at the thigh. Given the pressure applied at the extremities and the graduated nature of the garments used in this study, the expected influence on blood flow would be similar to what has previously been described (Sigel et al. 1975).

In the present study, a range of blood variables were monitored in the post-exercise period to determine whether any influence of the garments on the recovery process could be observed. The effect of circulation on the removal of blood lactate may have provided some insight into the effect of compression garments worn in the immediate post-exercise period. However, the blood lactate response of our subjects in the present study (average 2.7 mmol L^{-1} across the five bouts) was much lower than previously reported for this protocol (Nicholas et al. 2000) and as such, it is difficult to elucidate the specific impact on blood lactate removal post-exercise. Although the LIST was chosen and has previously been defined as a "high-intensity"

Table 2 Tests of muscle function (5CMJ and SJ) at baseline, 1, 24 and 48 h following exercise

	CG				CON			
	Baseline	1 h	24 h	48 h	Baseline	1 h	24 h	48 h
5CMJ mean power (W)	3,711 (790)	3,576 (680)$^{\#}$	3,610 (706)	3,666 (668)$^{\alpha}$	3,648 (776)	3,541 (768)$^{\#}$	3,675 (790)	3,824 (799)*$^{\alpha}$
5CMJ mean force (N)	2,000 (421)	1,923 (361)$^{\wedge}$	1,941 (356)	2,016 (431)	2,032 (420)	1,950 (404)$^{\wedge}$	2,033 (471)	2,061 (484)
SJ peak force (N)	1,876 (341)	1,838 (340)	1,834 (325)	1,834 (331)	1,848 (320)	1,829 (362)	1,839 (302)	1,873 (309)

Values are presented as mean (SD)

* $p < 0.05$ from CG

$^{\#}$ $p < 0.05$ from baseline

$^{\alpha}$ $p < 0.01$ from 1 and 24 h

$^{\wedge}$ $p < 0.05$ from baseline, 24 and 48 h

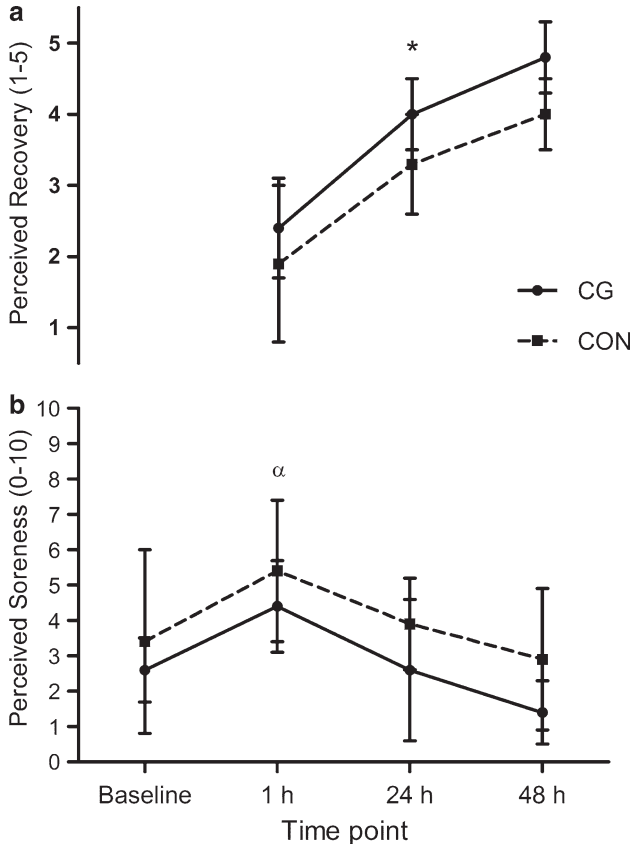

Fig. 4 Perceived recovery (**a**) from strongly disagree (1) to strongly agree (5) at 1, 24 and 48 h post-exercise, and rating of perceived soreness (**b**) from no soreness (0) to extreme soreness (10) at baseline, 1, 24 and 48 h post-exercise. $^{*}p < 0.01$ from 1 and 48 h for CG and CON. $^{\alpha}P < 0.05$ from all other time points for CG and CON. Main effect for treatment observed for both Perceived recovery ($p < 0.01$) and RPS ($p = 0.053$). Values are presented as mean ± SD

exercise protocol (Nicholas et al. 2000), our highly trained subjects were well adapted to this type of exercise and tolerated the exercise well as a result. We may have seen more changes in the HR, RPE and blood lactate response during exercise in less well-trained subjects.

Following EIMD, the inflammatory response is generally accepted as part of the post-exercise recovery process and it has been previously documented that eccentric exercise with an endurance component produces a robust cytokine response (Sayers and Hubal 2008, p. 43). However, whether the post-exercise cytokine response is actually associated with a fully developed inflammatory response has been questioned. Malm et al. (2004) found that, although there is an increase in cytokines following eccentric exercise, this does not indicate skeletal muscle inflammation. Instead the relationship between cytokines, growth factors and hormones post-exercise may be more closely related to the regeneration and adaptation of human skeletal muscle rather than the inflammatory process (Malm et al. 2004). Ostrowski et al. (1999) suggested that the magnitude and duration of the inflammatory response following endurance exercise is restricted; cytokines are produced locally and are rapidly cleared from circulation following exercise. Previous studies demonstrate that IL-6, IL-1β and TNF-α reach their peak and are then rapidly removed from the circulation possibly within the first hour following exercise, much quicker than would be expected of a traditional inflammatory response (Ispirlidis et al. 2008; Montgomery et al. 2008a; Ostrowski et al. 1998, 1999; Peake et al. 2008). IL-1β and TNF-α have been shown to increase only modestly post-marathon but decrease by 2 h (Ostrowski et al. 1998, 1999). This was not the case in the present study, as there was no main effect for time observed for either IL-1β or TNF-α following intermittent exercise.

Endurance exercise has been shown to bring about an increase in IL-6 levels immediately after a marathon (128-fold increase), after 60 min of treadmill running (10-fold increase) and following 120 min of cycling (12-fold increase), with values declining dramatically by 1–2 h post-exercise (Cox et al. 2007; Ostrowski et al. 1998, 1999; Peake et al. 2008). Intermittent exercise has also been shown to increase IL-6 with 3- to 4-fold elevations reported immediately after basketball (Montgomery et al. 2008a) and 4-fold elevations immediately following soccer (Ispirlidis et al. 2008). This is greater than in the present study, where IL-6 levels were only 1.5-fold above baseline values at 1 h post-LIST. The baseline IL-6 levels in the present study, however, were higher than reported elsewhere (Cox et al. 2007; Ispirlidis et al. 2008; Montgomery et al. 2008a; Ostrowski et al. 1998) and may have influenced the magnitude of the post-exercise increase observed. This is likely due to the pre-exercise snack that was ingested prior to the LIST protocol which delivered 1.2 g kg BM^{-1} carbohydrate 2.5 h prior to exercise. Whilst this was intended to ensure that pre-exercise glycogen stores were similar between the two trials, it may actually explain the elevated IL-6 levels at baseline as glycogen ingestion has previously been shown to cause an increased in baseline pro-inflammatory factors (Aljada et al. 2006).

Depending on the trigger for production, it is possible that the post-exercise peak of IL-6 in the present study occurred either earlier than 1 h post-exercise, or closer to 8 h post-exercise which has been reported previously (Miles et al. 2007a, b). The two independent pathways of IL-6 production in response to exercise, as specified by Miles et al. (2007b), suggest that IL-6 which is produced as a normal response to exercise peaks during or immediately after exercise and declines very quickly following exercise. In contrast, the IL-6 peak in response to muscle damage may be smaller, occurring hours after the completion of exercise (Miles et al. 2007b). Although the IL-6 peak

observed in the present study was small and not significant, a significant elevation of CRP at 24 h post-exercise in both trials was observed. Given that IL-6 is a trigger for CRP production (Pedersen et al. 1998) it is possible that, although not detected in the present study, a significant increase in IL-6 may have occurred at some stage throughout the recovery period. However, given the timing of sampling in the present study, the magnitude of the IL-6 response, and any impact that the potential circulatory benefits of CG had on this, remains unclear.

The LIST exercise protocol brought about some changes at the cellular and muscular levels in the post-exercise period. CK increased significantly and peaked 24 h after the conclusion of exercise under both conditions suggesting cell membrane permeability had been disturbed, but there was no impact of the garment worn. In addition there is evidence that muscle function was reduced at 1 h after exercise when the 5CMJ was performed in the present study. However, similar to the impact on CK, the lower-body CG worn for 24 h post-exercise in the present study did not enhance the recovery of muscle function in the lower limbs. Several previous studies investigating the use of lower-body garments on recovery, have found similar results with regards to CK activity (Davies et al. 2009; Duffield et al. 2010) and recovery of muscle function (Davies et al. 2009; Duffield et al. 2010; French et al. 2008; Montgomery et al. 2008b). Kraemer et al. (2010), however, found that a whole-body compression garment reduced CK values by half at 24 h post-exercise in men and women after an upper and lower-body resistance workout, and Kraemer et al. (2001) reported reduced CK values after subjects wore a compression sleeve over the arm for 5 days following eccentric exercise. Both studies reported that recovery of upper body muscle function was significantly improved after wearing compression compared with control conditions; however, there was no impact on the lower-body measures of muscle function when whole-body compression was worn (Kraemer et al. 2010). This may be because eccentric exercise of the arm has been shown to induce much larger increases in CK activity and have a greater impact on muscle function compared to lower-body exercise of the same relative intensity (Jamurtus et al. 2005). As such, the effect on CK activity and muscle function reported by Kraemer et al. (2001) when an arm sleeve was worn, and Kraemer et al. (2010) when a whole-body garment was worn, may be primarily due to the specific characteristics of the upper body response and may be why the same outcome was not evident in the present or previous studies investigating lower-body garments.

In contrast to blood and muscle function results, the perceived response of subjects in the present study suggests that there may be a psychological benefit of wearing the garment in the post-exercise period. Muscle soreness was rated higher in CON throughout the entire trial period and peaked at 1 h post-exercise in both conditions. This is much earlier than the observed peak in CK activity at 24 h post-exercise in the present study. The poor relationship between plasma CK activity and muscle soreness has previously been reported with suggestion that the muscle soreness commonly associated with EIMD may not directly reflect the magnitude of damage to the muscle itself (Malm et al. 2004; Nosaka 2008, p. 66). Malm et al. (2004) provided evidence that damage to the connective tissue rather than the muscle itself may be more likely associated with delayed onset muscle soreness following EIMD, and furthermore, the increase in CK activity is not related to muscle inflammation post-exercise. This may explain the evident dissociation between muscle soreness, plasma CK activity and changes in muscle function observed in the current and previous research (Nosaka et al. 2002). Although muscle soreness may not specifically reflect the magnitude of exercise-induced muscle damage, it does provide further information regarding the state of the muscle environment (Nosaka et al. 2002) and likely contributes to the athlete's perceived readiness for exercise.

This was certainly the case in this study whereby perceived recovery was significantly greater at 24 and 48 h after exercise in both conditions. Perceived recovery responses were only collected in the post-exercise period and subjects always felt better recovered when CG were worn. One possible explanation for this may be that the garments felt comfortable to wear and the subjective response of the subjects reflected this notion. In addition, compression garments have previously been found to reduce muscle oscillation during jumping (Doan et al. 2003) and as such, it is possible that a reduction in the displacement of the functioning muscles may attenuate the sensation of pain and stiffness following EIMD. This may suggest that by providing mechanical stability to exhausted limbs, compression garments enhance the functionality of the connective tissue following EIMD; however, we have no specific data to support this notion.

Conclusions

Typical indicators of EIMD including muscle soreness, loss of muscle function, elevated CK and cytokine activity were evident in the present study, even though the level of muscle damage appears to have been low and the inflammatory response was subtle. This may in part be due to the training status of our subjects and their high level of adaptation to the exercise stimulus performed, and the timing of the blood sampling which may have precluded complete capture of the cytokine changes and any potential impact of altered circulation. Even so,

muscle soreness was reported, mild loss of muscle function was evident and there was some indication of an acute-phase inflammatory response. Based on the perceptual data, subjects always felt better recovered when CG were worn, however, the restoration of muscle function post-exercise and the biomarkers investigated showed no evidence of enhanced physiological recovery. Additional information in the initial hour and between 1 and 24 h post-exercise may provide further insight into the true cytokine response to the intermittent exercise and the impact, if any, of the garments worn. Given the heavy promotion of compression garments to athletes and the general belief that they are of benefit, any positive psychological aspect of wearing the garments should be viewed with caution. As such, in the absence of a completely blinded control trial, the potential for an overestimation of the treatment effectiveness should also be considered. Apart from the perceived response of subjects, the biochemical and physical responses observed in this study provide no evidence of a benefit on the recovery process of highly trained team-sport athletes wearing lower-body CG for 24 h following exercise.

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Conflict of interest The authors acknowledge that sponsorship agreements exist with the Victorian and Australian Institutes of Sport and 2XU Compression, however, in no way did this influence the results of this study.

Ethical Standards The experiments carried out in this study comply with the current laws of Australia.

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Author/s:
PRUSCINO, CATHRYN

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