Recovering from repeat sprint activity and elite Australian football training and competition: Do compression garments help?

by

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ABSTRACT

Introduction: Elite athletes constantly search for the edge over their opponent (Applegate and Grivetti 1997). Indeed, athlete training and competition schedules have resulted in a need to fully recover rapidly from such sessions (Dawson, Gow et al. 2005; Cormack, Newton et al. 2008a; Cormack, Newton et al. 2008b; Elias, Varley et al. 2012; Elias, Wyckelsma et al. 2012; Mooney, Cormack et al. 2012). To overcome the stressors from training and competition, sports compression garments which offer low levels of compression, are commonly used to enhance recovery due to their ease of use, accessibility and affordability. Although a substantial body of research exists investigating compression garment use after a variety of exercise stimuli (Kraemer, Bush et al. 1998a; Kraemer, Bush et al. 1998b; Kraemer, Volek et al. 2000; Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Chatard, Atlaoui et al. 2004; Kraemer, French et al. 2004; Duffield and Portus 2007; Duffield, Edge et al. 2008; French, Thompson et al. 2008; Montgomery, Pyne et al. 2008a; Montgomery, Pyne et al. 2008b; Davies, Thompson et al. 2009; Duffield, Cannon et al. 2010; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a; Kraemer, Flanagan et al. 2010; De Glanville and Hamlin 2012), their influence on perceptual, biochemical and performance recovery after actual team sport training and competition, where physical contact is a key component, is lacking. Further, the positive physiological actions of compression garments have mostly been established using a medical style garment, which typically exert a greater volume of compression, in clinical settings. Recent research has sought to determine performance, perceptual and physiological differences when wearing compression garments *during* exercise that offer varying levels of compression, where the level of compression (low, medium, or high) made no difference to performance or physiological measures (Ali, Creasy et al. 2011; Dascombe, Hoare et al. 2011). It remains unknown if differences in recovery, where the garment is worn exclusively *post* exercise, would occur between a sports (low level of compression) and medical (high level of compression) style garment in team sport scenarios. Thus this thesis investigated the influence of wearing compression garments on perceptual, biochemical and performance variables following repeat sprint exercise on consecutive days in recreationally trained individuals (Chapter 4); following elite Australian football (AF)

training (Chapter 5) and competition (Chapter 6). It also included a comparison between a sports (Spo) and medical (Med) style compression garment. A magnitude based effects approach, using effect sizes and the smallest worthwhile change was used to analyse treatment effects.

Main findings and practical recommendations:

- Compression garments exert positive recovery effects on perceived muscle soreness, fatigue and performance of the countermovement jump.
- There is a high recovery demand after AF training and competition.
- Perceptual measures of muscle soreness and fatigue should not be used as standalone indicators of readiness to train/compete.
- Medical compression garments do not offer any additional benefits to recovery compared to sports compression, despite the greater level of pressure exerted on the body.
- Positive recovery effects are inconsistent within and between exercise modalities.

STUDENT DECLARATION

"I, Emma Louise Gallaher, declare that the PhD thesis entitled 'Recovering from repeat sprint activity and elite Australian football training and competition: Do compression garments help' is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work. The studies contained in Chapter 4 and 5 were part of larger studies. Specifically, in Chapter 4, an additional treatment group was included to investigate anti-oxidant supplementation. In Chapter 5, accelerometer and player load data was collected for the small sided games component of the training sessions."

Signature Date

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PUBLICATIONS

The following publications are presented in support of this thesis:

Gallaher E., Boyd L., Stepto N., Snow R., and Aughey R.J. (2010). Compression garments enhance recovery following Australian Football training. <u>Journal of Science and Medicine in Sport</u> (Australian Conference of Science and Medicine in Sport, Queensland). Vol. 13 Supp 1:e39-e40.

Boyd L.J., **Gallaher E.**, Ball K., Stepto N.K., and Aughey R.J. (2010). "Practical application of accelerometers in Australian football". <u>Journal of Science and Medicine in Sport</u> (Australian Conference of Science and Medicine in Sport, Queensland). Vol. 13 Supp 1:e14-e15.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AF	Australian football
ATP	Adenosine triphosphate
Ca^{2+}	Calcium
CANP	calcium activated neutral protease
CI	Confidence interval
CK	Creatine kinase
CMJ	Countermovement jump
CNS	Central nervous system
CV%	Coefficient of variation percentage
DOMS	Delayed onset muscle soreness
EIMD	exercise induced muscle damage
ES	Effect size
FT	Flight time
FT:CT	Flight time:contraction time
GPS	Global positioning systems
hr	Hour
K^+	Potassium
$[K^+]ext$	Extracellular potassium
$[K^+]_i$	Intracellular potassium
LDH	Lactate dehydrogenase
M1	Motor cortex
Mb	Myoglobin
Mg^{2+}	Magnesium
min	Minute
$mmol.L^{-1}$	Millimoles per litre
Na^+	Sodium
$ng.ml^{-1}$	Nanograms per millilitre
$[Na^+]_i$	Intracellular sodium
Na^+, K^+-ATPase	Sodium - potassium ATPase
P_i	Inorganic phosphate
SSG	Small sided game
SWC%	Smallest worthwhile change (%)
TMS	Transcranial magnetic stimulation
VAS	Visual analogue scale
$\dot{V}O_{2max}$	Maximal oxygen uptake

CHAPTER 1. INTRODUCTION

Recovery is an essential component of the elite athlete training regime (Calder 1990; Calder 1991). Primarily, the aim of recovery is to return physiological (Gill, Beaven et al. 2006; Montgomery, Pyne et al. 2008a), psychological (Duffield, Edge et al. 2008; Montgomery, Pyne et al. 2008b; Vaile, Halson et al. 2008b) and performance variables (Duffield, Edge et al. 2008; Montgomery, Pyne et al. 2008b; Vaile, Halson et al. 2008a; Duffield, Cannon et al. 2010) to normal 'pre-exercise' levels. If successful, recovery interventions should allow the athlete to train optimally, with the ultimate goal to enhance sporting performance. Further, recovery should facilitate training adaptations experienced by the athlete (Kentta and Hassmen 1998), via minimising fatigue, muscle damage and muscle soreness.

Training and playing often result in both acute and prolonged fatigue, muscle damage, muscle soreness, and performance decrements (Mohr, Krustrup et al. 2003; Dawson, Gow et al. 2005; Rampinini, Coutts et al. 2007; Ascensao, Rebelo et al. 2008; Cormack, Newton et al. 2008a; Bradley, Sheldon et al. 2009; Duffield, Coutts et al. 2009; Rampinini, Impellizzeri et al. 2009; Aughey 2010; Coutts, Quinn et al. 2010). It is not surprising that recovery interventions have gained such popularity. Although a growing body of research has been conducted on a variety of recovery modalities, each method is not fully understood. Therefore, investigating different recovery methods and their effect on fatigue, muscle damage/soreness, and performance is warranted.

Compression garments are a popular recovery modality worn by recreational exercises and elite athletes alike. Physiologically, compression garments exert positive actions through alterations to the vascular and lymphatic systems (Swedborg 1984; Mayberry, Moneta et al. 1991; Yasuhara, Shigematsu et al. 1996; Johansson, Lie et al. 1998; Jonker, de Boer et al. 2001; Beidler, Douillet et al. 2009). Wearing compression garments also blunts the pro-inflammatory cytokine response in patients suffering from DVI and leg ulcerations (Beidler, Douillet et al. 2009). More recently, it has been established in recreationally active participants, that tissue oxygenation during exercise is increased with the use of compression garments (Ali, Creasy et al. 2011; Coza, Dunn et al. 2012), reflecting increases in muscle blood flow. Compression garments may also offer positive effects through a reduction in muscle oscillation (Kraemer, Bush et al. 1998a; Doan, Kwon et al. 2003), improved proprioception (Kraemer, Bush et al. 1998a; Pearce, Kidgell et al. 2009) and the comfort of the garment (Kraemer, Bush et al. 1996). Some authors also suggest that wearing compression garments permit the limbs to remain in anatomical positions when not used and that this restriction in movement enhances the regeneration and repair process (Kraemer, Bush et al. 1998a; Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b).

Despite the wealth of information detailing the influence of compression garments on vascular and lymphatic distribution in clinical populations, and recovery responses after laboratory and non sporting scenarios (Kraemer, Bush et al. 1998a; Kraemer, Bush et al. 1998b; Kraemer, Volek et al. 2000; Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Chatard, Atlaoui et al. 2004; Kraemer, French et al. 2004; Duffield and Portus 2007; Duffield, Edge et al. 2008; French, Thompson et al. 2008; Davies, Thompson et al. 2009; Duffield, Cannon et al. 2010; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a; Kraemer, Flanagan et al. 2010; De Glanville and Hamlin 2012), less evidence is available concerning high level athletic performance. Due to the discrepancies in the exercise interventions and the recovery effects of wearing the garments in the few studies focussing on compression garments and actual sporting scenarios (Gill, Beaven et al. 2006; Montgomery, Pyne et al. 2008a; Montgomery, Pyne et al. 2008b), it is very difficult to decipher clear outcomes of compression garment research within the athlete population.

This thesis will explore the influence of such garments on fatigue, muscle soreness/damage and performance through a comprehensive review of the literature (Chapter 4); the presentation of three novel studies (Chapter 4, 5 and 6); and a final discussion with concluding remarks (Chapter 7) and future directions to address the limitations of this thesis (Chapter 8).

CHAPTER 2. REVIEW OF LITERATURE

2.1 Introduction

Australian football (AF) is a team sport comprising a substantial level of physical contact overlaid on a large volume of player running. This review begins with a discussion of the activity profiles of AF athletes (Section 2.2), thus highlighting the necessity to optimise recovery in this sport. The fatigue an athlete experiences during competition and training is considered transient, where recovery occurs within seconds to minutes of exercise cessation. Factors involved in such recovery are discussed in Section 2.3. Athletes may also experience prolonged fatigue, persisting for several hours to days (Section 2.5), which may impact subsequent performance. It is also likely that there is some overlap between these two broad categories of fatigue, where some of the fatigue experienced during exercise will recover quickly after exercise has ceased, with other elements taking hours to days to recover. The review then addresses the occurrence of muscle damage in team sport athletes (Section 2.6), and examines mechanisms underlying such damage (Section 2.6.2 and 2.6.4) as well as its impact on subsequent performance (Section 2.6.6). The reader is then lead to a discussion on the muscle soreness associated with muscle damage, its role in reduced performance (Section 2.6.8) as well as the possible link between muscle soreness and central fatigue during subsequent exercise sessions (Section 2.6.9). The review then moves to a discussion pertaining to recovery concepts (Section 2.7), including the importance of recovery in AF (Section 2.7.1). Practical tools by which the efficacy of recovery modalities can be investigated will also be briefly considered (Section 2.9).

The use of compression garments to augment between session recovery is extremely fashionable in elite sport, particularly AF. The efficacy of compression garments for recovery is discussed in the context of accelerating the recovery of performance, as well as perceptual and biochemical parameters (Section 2.8). Studies investigating the influence of these garments, where they have been worn exclusively during exercise will not be discussed in this review. Such studies do not shed light on the actions of compression garments to augment recovery. Studies will however be discussed when the garments have been worn during exercise *and* the subsequent recovery period, and solely in the recovery period. These studies better highlight the recovery properties of this intervention. Finally, this review culminates with a summary of the key ideas explored (Section 2.11), and the central aims of the thesis (Section 2.14).

Literature was located over a five year period (up to October 2012) using a combination of database searches (PubMed, MEDLINE, Google Scholar; with key words including 'compression', 'compressive', 'garment', 'stocking', 'exercise', 'sport', 'recovery', 'performance', 'muscle soreness', 'fatigue', 'muscle damage', 'team sport', 'elite', 'athlete', and 'movement demands') and extensive follow up through reference sections of identified papers. To establish inclusion criteria, a compression garment, in the context of sport and exercise, was defined as a garment that is worn to apply pressure to a particular area of the body with the intention of mitigating exercise induced discomfort, or aiding aspects of current or subsequent exercise performance; and of a construction that permits prolonged wear if required.

2.2 The activity profile of Australian Football

2.2.1 Activity patterns in Australian football games

Australian football athletes compete on a weekly basis across a seven month period (Ebert 2000). Games have a duration of ~120 min, consisting of four 20 min quarters in addition to 'time on' equivalent periods when the ball is out of play (Ebert 2000; Dawson, Hopkinson et al. 2004b). Players cover approximately 108 to 150 $m \cdot min^{-1}$ (Coutts, Quinn et al. 2010; Aughey 2011). Further, athletes undertake a maximal acceleration on average once each minute (Aughey 2010). In addition, more than 50% of all sprints undertaken involve a change of direction (Dawson, Hopkinson et al. 2004b). During finals games, the number of maximal accelerations approximately doubles, and there is also an increase in the amount of high intensity running (9%) and total distance covered (11%) (Aughey 2011). Table 2.1 is presented as traditional and contemporary GPS analysis.

There is a high level of physical contact in AF games when the ball is in dispute, and players repeatedly collide with both opposition players and the ground (Dawson, Hopkinson et al. 2004b). Excluding foot contact with the ground, midfielders and ruckmen (centre players, who help set up scoring shots, recover the ball from the backline and trap the ball further forward) make contact with the ground 21-23 times per game (Dawson, Hopkinson et al. 2004b). Players are also involved in numerous tackles with opposition players (Dawson, Hopkinson et al. 2004b). The combination of repetitive physical contact and locomotive activities in AF suggests that a considerable level of muscle damage and soreness will be induced (Zuliani, Bonetti et al. 1985; Thompson, Nicholas et al. 1999; Takarada 2003). It is likely that levels will exceed that of team sports such as soccer, where players cover roughly 37% less distance (Mohr, Krustrup et al. 2003) and lack similar levels of physical contact as AF. What's more, the greater distance covered at various speeds and accelerations and decelerations is associated with a greater volume of muscle damage as measured by plasma creatine kinase concentrations in elite junior AF athletes during competition matches (Young, Hepner et al. 2012). Additionally, 24 and 48 hr after elite AF competition, elite AF athletes still experienced elevated muscle soreness (257%, 161%), perceived fatigue (190%, 95%), and reduced CMJ flight time:contraction time ratio performance (-15%, -11%) (Elias, Wyckelsma et al. 2012). This game related muscle soreness tends to dissipate after three days, regardless of game load. Using a rating scale adopted from the Borg CR-10 method, general muscle soreness was 4.6 ± 1.1 units 24 hr post game, falling to 1.9 ± 1.0 by day six (Montgomery and Hopkins 2012). Further, there is only a small increase in general muscle soreness (0.22 ± 0.07 to 0.50 ± 0.13 units; mean±SD) in the three days following high load games relative to low load games.

Table 2.1: Locomotive activities of AF games using global positioning system (GPS) technology.

Game details	Total distance	Low to moderate speed	High speed	High intensity speed
Traditional GPS analysis (total distance covered within a set velocity band)				
2 games (Duffield, Coutts et al. 2009)	9,380±1,470 m (mean total)	71 % (<7.0 km·hr^{-1} to 14.4 km·hr^{-1})	18 % (2,720±850 m) (>14.5 km·hr^{-1})	11 % (1,070±350 m) (>20.0 km·hr^{-1})
16 games (Coutts, Quinn et al. 2010)	12,939±1145 m (mean total)		(3,880±633 m) (>14.4 km·hr^{-1})	
4 seasons (Wisbey, Montgomery et al. 2009)	Forwards: 11,700±2,000 m; nomadic players: 12,300±1,900 m; defenders: 11,900±1,700 m			
Contemporary GPS analysis (the distance covered within a set velocity band per minute of actual game play)				
29 games; Distances covered in games were reported per unit of game time (m·min^{-1}) (Aughey 2010)	127±17 m·min^{-1} 12,734±1,596 m; (total distance)	89±11 m·min^{-1} 9,011±1,137 m (0.01 and 4.17 m.sec^{-1} or 0.036 to 15.0 km·hr^{-1})		34±9 m·min^{-1}; 3,334±756 m (4.17 to 10.00 m.sec^{-1} or 15.0 to 36.0 km·hr^{-1})
3 in-season games, 3 finals game; Distances covered in games were reported per unit of game time (m·min^{-1}) (Aughey 2011)	119.0 ± 16.0 to 137.9 ± 17.7 m·min^{-1} during in-season games; 130.6 ± 33.7 to 152.7 ± 17.8 m.min^{-1} during finals games.			

Distances covered at low-moderate (<7.0 km·hr^{-1} to 14.4 km·hr^{-1} (Duffield, Coutts et al. 2009); (0.036 to 15.0 km·hr^{-1}) (Aughey 2010)), high (14.5 to 20 km·hr^{-1} (Duffield, Coutts et al. 2009); >14.4 km·hr^{-1} (Coutts, Quinn et al. 2010)), and high intensity speeds (> 20 km·hr^{-1} (Duffield, Coutts et al. 2009); 14.9 to 36.0 km·hr^{-1} (Aughey 2010)) are expressed in absolute terms (m) using traditional analysis, and relative to game time played (m·min^{-1}) as per the contemporary analysis approach. The ranges for each 'speed zone' vary according to the investigation.

2.2.2 The activity profile of Australian football training

The activity profile of AF training is reflective of game activities (Dawson, Hopkinson et al. 2004a; Loader, Montgomery et al. 2012), and is likely to contribute to fatigue, muscle damage, soreness and reductions in performance (Elias, Varley et al. 2012). Specifically, fast-running and sprinting efforts during training reflect those of game activities (Dawson, Hopkinson et al. 2004a). Moreover, the frequency of change of direction when sprinting during games is replicated during training (Dawson, Hopkinson et al. 2004a). Players conduct a similar number of high intensity movements during training and game play (Dawson, Hopkinson et al. 2004a). The movement demands and intensity levels of drills classified as game-specific conditioning simulate those of competitive game play, while skill refining drills of both moderate and low physiological intensity do not replicate these characteristics (Loader, Montgomery et al. 2012). These training sessions are repeated up to three times per week, in addition to two or more resistance training sessions as well as individual skill sessions (Cormack, Newton et al. 2008a). The strenuous nature of these training sessions is likely to be compounded by the repetition of these tasks across the week. Indeed, cumulative fatigue is evident during team sport training and tournament scenarios. A three day international handball tournament reduced CMJ performance by 6.7% and 20 m sprint ability by 3.7% (Ronglan, Raastad et al. 2006b). A five day handball training camp elicited reductions in knee extension strength (-8.4%) and jump height (-6.9%) (Ronglan, Raastad et al. 2006b). Similarly, substantial cumulative fatigue from three consecutive days of basketball play was evident in several performance measures and elevations in the subjective rating of general fatigue. There were small impairments in line-drill ability, which decreased by 0.5+1.8 s (mean±90% confidence limits); a moderate decrement in 20-m acceleration of

0.04+1.3 sec; and a large to very large decrement in agility of 0.1+1.2 sec. Sit and reach test performance decreased by 5.4+4.0 cm and general fatigue had a very large increase of 2.2+1.5 arbitrary units (scale 1–10) (Montgomery, Pyne et al. 2008b).

Australian football training sessions result in changes in perceptual and performance parameters, with athletes still recovering 24-48 hr later (Elias, Varley et al. 2012). Immediately following training, acute decreases in sprint performance (0.71-1.10%) were evident along with increased perceived muscle soreness (1.4 to 2.7 %) and fatigue (2.8 to 4.8 %). Muscle soreness and perceived fatigue were evident 24 and 48 hr after training, with some athletes still displaying impaired repeat sprint performance (4%).

2.3 Fatigue occurs during Australian football

Fatigue can be defined as a reduction in muscle force and/or power with continuous or repeated muscle contractions which can be restored after a period of recovery (McKenna, Bangsbo et al. 2008). Fatigue can result from disturbances in the nervous system (central fatigue) and/or within skeletal muscle (peripheral fatigue). The activity profile of team sport athletes during the latter stages of competitive game play suggest that players experience in-game fatigue (Mohr, Krustrup et al. 2003; Rampinini, Coutts et al. 2007; Bradley, Sheldon et al. 2009; Duffield, Coutts et al. 2009; Rampinini, Impellizzeri et al. 2009; Aughey 2010; Coutts, Quinn et al. 2010) which is likely attributable to both central and peripheral factors. This in-session fatigue likely differs from the fatigue that persists for hours to days following competition and training (see Section 2.4). There is, however, some overlap between these two broad categories of fatigue. Indeed, factors which contribute to in-session fatigue may not reach full recovery immediately after exercise, for example fatigue associated with glycogen depletion (Jacobs, Westlin et al. 1982; Zehnder, Rico-Sanz et al. 2001). As such, these factors can also be involved in prolonged fatigue, where performance may be impaired for hours to days.

In-session fatigue is characterised by performance declines during the actual game or training session. Elite AF athletes experience reductions in total distance and higher speed running distance later in games (Duffield, Coutts et al. 2009; Aughey 2010; Coutts, Quinn et al. 2010). Similarly, reductions in high intensity running distance and maximal accelerations also occur later in AF games (Aughey 2010). However, in-session fatigue is not limited purely to the latter stages of competition or training, a player may partake in a strenuous period of play during any stage of the session, during which their performance may decline during the latter stage of this period. Elite soccer players also display reductions in high intensity running during the latter portion of games (Mohr, Krustrup et al. 2003; Rampinini, Coutts et al. 2007; Bradley, Sheldon et al. 2009; Rampinini, Impellizzeri et al. 2009). Although this does not provide actual proof of fatigue per se, just reduction in distances covered, reductions in measures of performance are also observed after game play that are more indicative of fatigue. Indeed, as discussed in Section 2.5.1, lower body maximal voluntary contractions, squat jump, drop jump, countermovement jump, lower limb strength, and sprint test performance are all depressed after team sport activity (Hoffman, Nusse et al. 2003; Ascensao, Rebelo et al. 2008; Cormack, Newton et al. 2008a; Oliver, Armstrong et al. 2008; Duffield, Cannon et al. 2010; McLean, Coutts et al. 2010). It is possible that if an athlete has not fully recovered from the sessions preceding game play, e.g. training or competition, that an earlier onset of in-game performance declines may occur.

2.4 Potential causes/mechanisms of fatigue

2.4.1 Reduced neural drive contributes to fatigue associated with in-session performance declines.

Central fatigue represents the loss of force through inadequate activation of motor neurons (Baker, Kostov et al. 1993; Taylor, Allen et al. 2000). Central fatigue may be a consequence of local reflex effects on the motor neuron or higher centres, reduced cortical drive, or reduced descending drive via descending spinal pathways (Kernell 1969; Garland 1991; Macefield, Hagbarth et al. 1991; Garland and Kaufman 1995; Taylor, Allen et al. 2000; Gandevia 2001). Ultimately, the CNS is not ‘driving’ the muscles as intensely as required to maintain muscle force or power.

The manifestation of central fatigue may be the consequence of either conscious or unconscious mechanisms (Taylor, Allen et al. 2000). In the first instance, the individual may feel that the sensations are not tolerable and intentionally lower the level of activity or intensity of exercise (Taylor, Allen et al. 2000). Alternatively, afferent feedback from working muscles, joints or tendons may inhibit motor activity at spinal and supraspinal levels, through unconscious mechanisms (Taylor, Allen et al. 2000). This may lead to an obligatory decrement in performance that no amount of voluntary effort can overcome (Taylor, Allen et al. 2000). Central fatigue is likely to recover within 30 – 60 min following exercise cessation (Brasil-Neto, Pascual-Leone et al. 1993; Samii, Wassermann et al. 1996; Lentz and Nielsen 2002; Verin, Ross et al. 2004). However, through an interaction with muscle soreness, a reduced neural drive may play a role in a more prolonged fatigue, which may influence performance for a period of hours to days (See Section 2.5.9).

2.4.2 Ionic imbalances contribute to fatigue

The exact physiological mechanisms that contribute to fatigue during intermittent high intensity exercise remain largely unknown. However it is possible that ionic imbalances may in part contribute to in-session fatigue. Disruptions to the intra- and extra-cellular balance of the cations Na^+ and K^+ may contribute to transient declines in skeletal muscle contractile function (Clausen 2003). The exercise induced alterations to muscle intracellular Na^+ concentration ($[Na^+]_i$) (Gonzalez-Serratos, Somlyo et al. 1978; Sjogaard, Adams et al. 1985; Fong, Atwood et al. 1986; Juel 1986; Nagaoka, Yamashita et al. 1994) and extracellular K^+ concentration ($[K^+]_{ext}$) (Sjogaard, Adams et al. 1985; Green, Bulow et al. 1999; Green, Langberg et al. 2000; Juel, Pilegaard et al. 2000; Nielsen, Mohr et al. 2004) evoke reductions (~10-15 mV) in the resting membrane potential, rendering the membrane depolarised (Westerblad and Lannergren 1986; Balog, Thompson et al. 1994; Light, Comtois et al. 1994; Comtois, Light et al. 1995; Balog and Fitts 1996; Karelis, Peronnet et al. 2005; Street, Nielsen et al. 2005), manifesting in a loss of excitability of muscle (Hodgkin and Horowicz 1959; Renaud and Mainwood 1985; Lannergren and Westerblad 1986; Juel 1988; Renaud 1989; Clausen, Andersen et al. 1993; Renaud and Comtois 1994; Cairns, Flatman et al. 1995; Cairns, Hing et al. 1997). This primarily results from depolarisation and the inactivation of voltage dependent Na^+ channels (Hodgkin and Huxley 1952; Hodgkin and Horowicz 1959; Ildefonse and Roy 1972; Ruff, Simoncini et al. 1988), lowering action potential amplitude (Renaud and Light 1992; Ruff 1999) and the force generating capacity of the muscle. The reduced maximal activity of the Na^+, K^+-ATPase with fatiguing exercise (Yonemura 1967; Fowles, Green et al. 2002; Fraser, Li et al. 2002; Yensen, Matar et al. 2002; Leppik, Aughey et al. 2004; Aughey, Gore et al. 2005; Petersen, Murphy et al. 2005; Aughey, Clark et al. 2006; Aughey, Murphy et al. 2007) jeopardises the maintenance of the transport capacity of

Na^+ and K^+, and ultimately muscle excitability (Clausen 2003), culminating in a reduction in muscle force generating capacity (McKenna, Bangsbo et al. 2008). These changes are involved primarily in transient fatigue as observed by the return of plasma K^+ levels to near pre exercise levels 10 min following exercise, and Na^+, K^+-ATPase recovery within 3 hr of recovery (Petersen, Murphy et al. 2005). In the presence of muscle damage, independent of transient fatigue, cellular structures may become damaged. As a consequence, ionic disturbances may occur, and possibly persist for hours to days whilst the damage is apparent. See sections 2.6.3.

2.4.3 Exercise induced accumulations of inorganic phosphate and its effect on calcium homeostasis contributes to fatigue development.

The accumulation of P_i during repetitive muscular contraction (Dawson, Gadian et al. 1978) contributes to transient muscular fatigue through an impaired cross-bridge attachment and reduction of maximum Ca^{2+} activated force (Pate and Cooke 1989; Millar and Homsher 1990; Martyn and Gordon 1992; Phillips, Wiseman et al. 1993; Gordon, Homsher et al. 2000; Dahlstedt, Katz et al. 2001); a dampened sarcoplasmic reticulum Ca^{2+} release (Fryer, Owen et al. 1995; Westerblad and Allen 1996; Posterino and Fryer 1998 ; Kabbara and Allen 1999; Duke and Steele 2000; Dahlstedt, Katz et al. 2001; Duke and Steele 2001); and a reduced myofilament Ca^{2+} sensitivity (Godt and Nosek 1989; Millar and Homsher 1990; Martyn and Gordon 1992; Fryer, Owen et al. 1995; Dahlstedt, Katz et al. 2001). As little is known as to the exact mechanisms of fatigue during high intensity intermittent activity such as team sport exercise, it can only be speculated that the accumulation of P_i plays a role. However, as P_i recovery occurs within 1-3 minutes of exercise cessation (Harris, Edwards et al. 1976; Yoshida 2002), it is unlikely that P_i accumulation and its effects on Ca^{2+} regulation will contribute substantially to between session fatigue, and is involved to a greater extent in transient fatigue.

2.4.4 Magnesium and adenosine triphosphate in peripheral fatigue.

A large part of the intracellular pool of magnesium (Mg^{2+}) is present as MgATP. As the affinity of ATP for Mg2+ is approximately tenfold greater than that of ADP, ATP hydrolysis leads to a rise in intracellular magnesium ($[Mg^{2+}]_i$)(Leyssens, Nowicky et al. 1996; Blazev and Lamb 1999b). The accumulation of intracellular magnesium ($[Mg^{2+}]_i$) and associated reduction in adenosine triphosphate (ATP) leads to sub-optimal Ca^{2+} release from the sarcoplasmic reticulum, culminating in a reduction in force generating capacity. These factors are normally recovered within minutes (Edwards, Hill et al. 1977) and thus unlikely to alter the between session recovery of athletes. Nonetheless, during exercise, contraction induced increases in cytoplasmic Mg^{2+} strongly inhibit the Ca^{2+} release channel (Meissner, Darling et al. 1986; Lamb and Stephenson 1991; Lamb and Stephenson 1994; Laver, O'Neill et al. 2004) with sarcoplasmic reticulum Ca^{2+} release decreasing by ~40% (Meissner, Darling et al. 1986; Westerblad and Allen 1992; Dutka and Lamb 2004). Additionally, reductions in $[ATP]_i$ reduce sarcoplasmic reticulum Ca^{2+} release by ~20% (Owen, Lamb et al. 1996; Blazev and Lamb 1999a; Blazev and Lamb 1999b; Dutka and Lamb 2004). Elevated $[Mg^{2+}]_i$ also inhibits the sarcoplasmic reticulum Ca^{2+} pump function (Krause 1991), and competes with Ca^{2+} for binding sites on parvalbumin (a calcium binding albumin protein located in fast twitch skeletal muscle cells) (Robertson, Johnson et al. 1981). However as these mechanisms of fatigue have been largely established from single muscle fibre experiments using animal models (mouse, rat, rabbit and toad), it is unknown if these fatigue mechanisms will transfer to intermittent high intensity activity such as team sport games and training in human skeletal muscle.

2.5 Athletes experience fatigue for hours to days following exercise.

2.5.1 Performance decrements are evident hours to days following team sport exercise.

In contrast to the nature of in-session fatigue, the fatigue following exercise cessation can persist for hours to days following team sport activity (Hoffman, Nusse et al. 2003; Ascensao, Rebelo et al. 2008; Oliver, Armstrong et al. 2008; McLean, Coutts et al. 2010), with the recovery of performance falling somewhere along a recovery continuum (Figure 2.1).

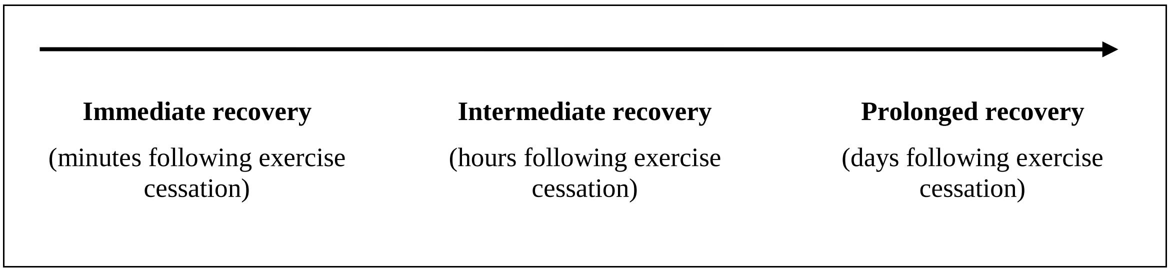

Figure 2.1: Recovery continuum.

Some of the in-session fatigue, may be recovered with a short rest period, whereas other components of fatigue may require hours to days to recover due to significant glycogen depletion and possibly sub optimal ionic regulation, probably due to muscle damage (Section 2.6). Further, as discussed in Section 2.6.9, muscle soreness may contribute to a reduced neural drive during this recovery period.

Reductions in performance tests conducted during the post competition/training period highlight the degree of fatigue present. Soccer specific, non-motorised treadmill exercise (42 min), elicits immediate decrements in squat jump (-3%), drop jump (-4%) and countermovement jump (CMJ) (-5%) test performance (Oliver, Armstrong et al. 2008). A greater degree of performance decrement occurs immediately after actual soccer competition, where lower limb strength (~ -10-15%) and sprint test performance (-7%) are reduced

(Ascensao, Rebelo et al. 2008). Female soccer players also experience post game declines in squat jump and CMJ test performance 24 hr following competition (Hoffman, Nusse et al. 2003). Elite AF athletes experience similar reductions in test performance as soccer players immediately after competition. Specifically, CMJ flight time (-4%), mean power (-9%), relative mean power (-8%), relative mean force (-2%) and flight time:contraction time (FT:CT) (-17%) are substantially depressed immediately post game (Cormack, Newton et al. 2008a). What's more, test performance decrements in these elite AF athletes are still evident 24 hr later with all CMJ variables still depressed (-3% to -17%). These athletes had still not recovered three days after competition, where CMJ mean (-6%) and relative (-6%) power were still lower than baseline (Cormack, Newton et al. 2008a). Similarly, in the 48 hr following elite rugby league competition, players experienced reductions in CMJ FT, with CMJ test performance recovery occurring within four days following competition (McLean, Coutts et al. 2010).

Tournament scenarios where multiple competition games are conducted in a short period of time elicit similar levels of fatigue to single game/training sessions. In the scenarios described below, the level of fatigue measured through performance tests does not appear to accumulate to a greater extent compared to after a single exercise bout. For example a three day international handball tournament caused reductions in CMJ performance (-7%) and 20 m sprint performance (-4%) (Ronglan, Raastad et al. 2006a). Similarly, athletes experienced reductions in knee extension strength (-8%) and jump height (7%) after a five day handball training camp (Ronglan, Raastad et al. 2006a). Line drill ability (-0.4%), 20 m sprint (-1%), agility (-2%), and sit and reach (5%) performance also decreased in state level basketball players following three games separated by 24 hr (Montgomery, Pyne et al. 2008b).

An accumulation of fatigue is not always present during hockey tournaments (Spencer, Bishop et al. 2005; Jennings, Cormack et al. 2011). Such discrepancies may be due to differences in recovery time permitted or movement analysis approach. Time motion analysis through video footage suggests fatigue accumulation is evident during an elite, three game, international hockey tournament, played over four days (Spencer, Rechichi et al. 2005). The locomotive profile of these elite athletes changed across the tournament, reflecting this fatigue. In particular, athletes spent more time standing and striding, with the number of repeated sprints and time spent jogging decreased across the tournament (Spencer, Rechichi et al. 2005). Yet when elite hockey players participated in a world class hockey tournament, with six games played over nine days, exercise intensity, measured using 5 Hz GPS, was maintained (Jennings, Cormack et al. 2011). The inclusion of recovery days separating games two and three, three and four, and four and five may account for this difference compared to the former study, with only one rest day separating games one and two. It is also possible that different tactical strategies or analysis methods could explain the differences between these studies (Rampinini, Coutts et al. 2007). High level junior soccer players also display accumulated fatigue during a four day tournament. Indeed, repeated match-play in a tournament led to decrements in several match-performance variables (total distance and high-intensity running distance) and subjective ratings of fatigue and recovery (Rowsell, Coutts et al. 2011).

In contrast to the more transient fatigue observed during exercise (Section 2.3), force deficits due to changes in muscle function may persist for hours to days, and are observed following team sport exercise (Section 2.5.1). This prolonged fatigue is not exclusively related to a reduced availability of high energy phosphates, associated metabolites or Ca^{2+} regulation, as these variables return close to homeostatic values within 10-60 min (Harris, Edwards et al.

1976; Edwards, Hill et al. 1977; Hill, Thompson et al. 2001; Petersen, Murphy et al. 2005). Additionally, prolonged fatigue is unlikely entirely the result of changes in neuromuscular transmission or excitation of the sarcolemma, as voluntary activation (VA) remains unchanged in most exercise scenarios (Edwards, Hill et al. 1977; Baker, Kostov et al. 1993). Instead the slow recovery of depleted glycogen stores associated with exercise induced muscle damage (EIMD) (Section 2.6.3) and disruption to the musculature also through EIMD (Section 2.6.1) are likely causes of prolonged dampened force generation. It is important to note that damage to the musculature may influence the ability to regulate ionic balance, which may indirectly contribute to a prolonged reduction in force generating capacity during subsequent exercise bouts. It is customary to make a distinction between exercise induced muscle fatigue and muscle damage, although unquestionably the two phenomena overlap (Allen, Lamb et al. 2008). This review acknowledges the link between the two, particularly as recovery from both muscle damage and fatigue may take hours to days, however for the purpose of this review, each area is addressed separately. A reduced neural drive may also contribute to a more prolonged depression in force generating capacity through the influence of post exercise muscle soreness (Section 2.6.9). The prolonged duration to recover between sessions becomes problematic when multiple high intensity and damaging exercise sessions are conducted in close proximity, such as the schedule of AF athletes (Cormack, Newton et al. 2008a), particularly if depleted glycogen stores are not recovered. Indeed recovery of muscle structures from exercise induced muscle damage (EIMD) may take 1-3 days (Friden, Sjostrom et al. 1983; Newham, McPhail et al. 1983) as indicated by streaming, broadening and total disruption to the sarcomere Z-lines following eccentric exercise (Friden, Sjostrom et al. 1983). Such muscle injury is likely to elicit prolonged force depression through damage to cellular structure and contents (Friden, Sjostrom et al. 1983; Newham, McPhail et al. 1983;

Jones, Newham et al. 1986; Clarkson and Tremblay 1988; Stauber, Clarkson et al. 1990; Friden and Lieber 1992; Gibala, MacDougall et al. 1995; Hortobagyi, Houmard et al. 1998; Lieber and Friden 1999; Friden and Lieber 2001).

2.6 Exercise induced muscle damage

2.6.1 Muscle damage impairs force generating capacity.

Exercise induced muscle damage (EIMD) involves the breakdown of muscle fibres (Lippi, Schena et al. 2008) where cellular contents are released into the extracellular space and circulation. Muscle damage is likely to contribute to a reduced force generating capacity in the hours and days following exercise through disruption to the intracellular muscle structure, sarcolemma and the extracellular matrix (Friden, Sjostrom et al. 1983; Newham, McPhail et al. 1983; Jones, Newham et al. 1986; Clarkson and Tremblay 1988; Stauber, Clarkson et al. 1990; Friden and Lieber 1992; Gibala, MacDougall et al. 1995; Hortobagyi, Houmard et al. 1998; Lieber and Friden 1999; Friden and Lieber 2001). Prolonged reductions in neural drive following exercise may be attributed to the muscle soreness associated with EIMD (Section 2.5.9). Further, glycogen restoration is hindered in the presence of EIMD (Section 2.5.3). Prolonged impairment of muscle function (Friden, Sjostrom et al. 1983; Gibala, MacDougall et al. 1995; Hortobagyi, Houmard et al. 1998); and delayed onset muscle soreness (DOMS), stiffness and swelling (Newham, Mills et al. 1983; Jones, Newham et al. 1987; Clarkson, Nosaka et al. 1992; Cleak and Eston 1992; Rodenburg, Bar et al. 1993) are typical outcomes of EIMD. Accordingly, recovery research has concentrated on investigating the efficacy of strategies to abate these outcomes (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Byrne, Twist et al. 2004; Duffield, Edge et al. 2008; French, Thompson et al. 2008; Montgomery, Pyne et al. 2008a; Montgomery, Pyne et al. 2008b; Davies, Thompson et al. 2009; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). Evidence from histological examination suggests that muscle damage is present up to three days following damaging eccentric exercise (Friden, Sjostrom et al. 1983; Newham, McPhail et al. 1983), with elevations in biomarkers of muscle damage such as plasma [Mb] elevated 24 hr following a variety of exercise modalities (Refer to Table 2.2). This reiterates the need for recovery interventions aimed at accelerating the repair of the musculature, particularly when multiple sessions are conducted within a short period, as is the case for most team sport athletes.

2.6.2 Mechanical and metabolic factors contribute to the manifestation of exercise induced muscle damage

Mechanical and metabolic factors act synergistically in the manifestation of EIMD (Armstrong, Warren et al. 1991; Kuipers 1994; Sorichter, Puschendorf et al. 1999). Mechanical stress, the strain placed on the muscle during contraction, or the application of external forces such as a tackle (Pointon and Duffield 2012) or making contact with the ground or opponent, contribute to EIMD. The mechanical manifestation of EIMD is depicted through the greater prevalence of EIMD following eccentric contractions (Davies and White 1981; Armstrong, Oglivive et al. 1983; Friden, Sjostrom et al. 1983; Newham, Mills et al. 1983; Schwane, Johnson et al. 1983; McCully and Faulkner 1985; Stauber 1989). Specifically, during muscular contraction, a lower number of fibres are recruited during eccentric, versus concentric contractions. These individual fibres endure a greater level of mechanical stress, increasing their susceptibility to micro-trauma, and eventuating in focal damage (Davies and White 1981; Enoka 1996).

Metabolic deficiencies in the working muscle, typically associated with fatigue (eg ATP, see Section 2.4.4) are hypothesised to increase the susceptibility of the muscle fibre to mechanical stress and contribute to EIMD. This model helps explain EIMD incidence during concentric contraction based activities. Specifically, an increased permeability of the cell membrane, due to mechanical forces, facilitates an influx of Ca^{2+} into the cell, raising $[Ca^{2+}]_i$ (Armstrong 1984). An elevated $[Ca^{2+}]_i$ facilitates surges in intracellular calcium activated neutral protease's (CANP's) (Sayers and Hubal 2008). Desmin and α-actinin, cytoskeletal proteins involved in maintaining the integrity of the myofiber, are substrates for the action of calpain, a CANP (Fridén and Lieber 1996; Lieber, Thornell et al. 1996). This leads to the degradation of cytoskeletal proteins, increasing the susceptibility of the z-lines to contraction induced damage (Sayers and Hubal 2008). Additionally, a reduction in $[ATP]_i$ may induce damage within the muscle fibres, more so in the presence of severe glycogen depletion (Tee, Bosch et al. 2007). The focal and restricted damage to fibres with almost complete glycogen depletion in marathon runners (Warhol, Siegel et al. 1985) illustrates this point.

2.6.3 Muscle damage impairs the recovery of muscle glycogen

Glycogen depletion, and more specifically an impaired recovery of glycogen levels post exercise, may result in performance decrements during subsequent sessions. This is particularly true when the preceding exercise contains a substantial eccentric component. Glycogen levels, and their role in future performance, are an example of the overlap between muscle damage and fatigue, where muscle damage compromises the structural integrity of the cell, impacting on future force generating capacity (fatigue).

Muscle glycogen stores become depleted during team sport competition such as soccer (Jacobs, Westlin et al. 1982; Leatt and Jacobs 1989; Zehnder, Rico-Sanz et al. 2001; Krustrup, Mohr et al. 2006). Post exercise glycogen accumulation is impaired in eccentrically exercised muscle (Widrick, Costill et al. 1992). Eccentric exercise superimposed on previously glycogen depleted muscles results in sub-optimal recovery of glycogen stores in endurance trained men, compared to a glycogen depleted control leg (Widrick, Costill et al. 1992). These non-strength trained men completed eccentric knee extensions to fatigue 12 hr following a cycle ergometer test to fatigue. Eighteen hours after exercise, the eccentrically exercised leg contained 15% less glycogen than the control leg. After 72 h of recovery, this difference had increased to 24% (Widrick, Costill et al. 1992). Similarly, eccentrically exercised muscles contained 27% less glycogen than non-eccentrically exercised control muscle after 72 hr of recovery (Costill, Pascoe et al. 1990). In untrained healthy individuals, this may last for 10 or more days following intense 45 min eccentric cycling exercise (O'Reilly, Warhol et al. 1987). The infiltration of phagocytic cells in the initial hours following the exercise stimuli has been suggested as a possible mechanism modulating carbohydrate metabolism (Costill, Pascoe et al. 1990). If multiple damage inducing exercise sessions are conducted with minimal recovery time, for example during the hectic training and competition schedule of athletes, they may enter subsequent exercise bouts with less than optimal glycogen stores. The amount of high intensity activity conducted during intermittent multiple sprint exercise is in fact compromised with low pre-exercise glycogen stores (Balsom, Wood et al. 1999), presenting as in-session fatigue. Low glycogen levels may impact on force generating capacity during subsequent exercise sessions. Glycogen depletion is likely to influence Ca^{2+}, Na^{+}, and K^{+} transport through alterations to the sarcoplasmic reticulum and Na^{+}, K^{+}-ATPase (Entman, Keslensky et al. 1980; Friden, Seger et al. 1989; Okamoto, Wang et al. 2001; Dutka and Lamb 2007; Ortenblad, Nielsen et al. 2011). Glycogen depletion may also reduce Ca^{2+} sensitivity of the myofilament (Helander, Westerblad et al. 2002), and result in a reduction in tricarboxylic acid cycle intermediates, also contributing to fatigue (Sahlin, Katz et al. 1990; Helander, Westerblad et al. 2002). Interestingly, when young elite soccer players followed their normal diet ($4.8 \pm 1.8 g.kg^{-1}$ body mass of CHO), muscle glycogen concentration had returned to pre exercise levels 24 hr following a soccer running task designed to simulate game running profiles and cause muscle glycogen depletion (Zehnder, Rico-Sanz et al. 2001). Although glycogen levels had statistically returned to baseline levels, these athletes were experiencing an approximate 10% deficit in muscle glycogen content at this time point. The authors note that cumulative deficits in glycogen replenishment of 10%, as observed in this group of athletes, might provoke decrements in future performance (Zehnder, Rico-Sanz et al. 2001).

2.6.4 Team sport activities contribute to exercise induced muscle damage.

Activities integral to successful team sport performance have the potential to elicit EIMD. High intensity running, intermittent running, distance running, plyometrics and resistance training each induce EIMD through the eccentric component of the stretch shortening cycle (Armstrong, Oglivive et al. 1983; Hikida, Staron et al. 1983; Sherman, Armstrong et al. 1984; Warhol, Siegel et al. 1985; Williams 1985; Saxton, Donnelly et al. 1994; Nicol, Komi et al. 1996; Chambers, Noakes et al. 1998; Kyrolainen, Takala et al. 1998; Avela, Kyrolainen et al. 1999; Thompson, Nicholas et al. 1999). Physical contact activities also elicit muscle damage, indeed traditional boxing generates more pronounced increases in biochemical markers of muscle damage ([CK] and [Mb]) versus shadow boxing (Zuliani, Bonetti et al. 1985). It is not apparent if the movement patterns of the boxers differed between the conditions, possibly contributing to such differences. What’s more, rugby competition tackle frequency is strongly correlated ($r=0.92$, $P<0.01$) with biochemical indices of muscle damage [CK] (Takarada 2003).

2.6.5 Team sport athletes experience muscle damage.

Team sports that comprise a substantial level of physical contact overlaid on high volumes of player running, elicit EIMD (Hoffman, Maresh et al. 2002; Takarada 2003; Hoffman, Kang et al. 2005; Ascensao, Rebelo et al. 2008; Ispirlidis, Fatouros et al. 2008). This is despite the high level of pre-conditioning that elite athletes possess due to the frequent repetition of eccentric actions in their weekly training and competition cycles. Indeed, the protective effect of prior eccentric contractions has been well established (Nosaka and Newton 2002; Bowers, Morgan et al. 2004; Nosaka, Newton et al. 2005; Chen, Chen et al. 2009). Typical increases in muscle soreness, biochemical markers of muscle damage and optimal angle of the muscle are lessened during a second bout of eccentric exercise repeated as early as 48 hr later in untrained participants (Nosaka and Newton 2002), with effects lasting up to six months (Nosaka, Clarkson et al. 1991). What's more, this 'protection' is evident in well trained college athletes. In fact muscle damage was not exacerbated when an eccentric arm exercise was repeated three days after the initial stimulus (Chen and Nosaka 2006). Clearly, any intervention aiming to minimise muscle soreness and muscle damage elicited by training or game play must provide small, but meaningful effects within the elite athlete setting, as increases in muscle damage and soreness may be smaller in magnitude compared to untrained individuals.

The physical contact in team sport activity contributes substantially to overall EIMD. Peak plasma [Mb] and [CK] in one player with a bruised thigh, resulting from a tackle by an opposing player during rugby competition, were 1.7- and 2.4-fold higher than the remaining 14 players tested (Takarada 2003). American football players experience game induced elevations in serum [Mb] (Hoffman, Maresh et al. 2002), with concomitant increases in serum [CK] after a ten day training camp (Hoffman, Kang et al. 2005). Soccer games, with lower levels of physical contact than American football, AF or rugby, highlight the involvement of game activities other than physical contact to total muscle damage. Plasma [Mb], [CK] and [lactate dehydrogenase] ([LDH]) are all elevated following soccer competition, persisting up to 72 hr (Ascensao, Rebelo et al. 2008; Ispirlidis, Fatouros et al. 2008).

2.6.6 Force production and running economy are compromised by muscle damage

Muscle function and force generating capacity are impaired following EIMD (Newham, Jones et al. 1987; Clarkson, Nosaka et al. 1992), with reductions of more than 50 % persisting for up to ten days after eccentric arm curl activity in untrained participants (Newham, Jones et al. 1987; Clarkson, Nosaka et al. 1992; Byrne, Twist et al. 2004). Jump test performance, reflective of force production, is also reduced after weighted barbell squats (70% body mass load), which, in active, non-resistance trained individuals, can persist for up to three days (Byrne and Eston 2002), further highlighting the role of EIMD in prolonged fatigue.

Elite AF athletes spend approximately 71 % of game time running at low to moderate velocities (<7.0 to 14.4 $km \cdot hr^{-1}$ or 1.9 to 4.0 $m \cdot sec^{-1}$) (Duffield, Coutts et al. 2009). Given the duration spent at these velocities, running economy becomes important for overall game performance. When running economy is high, an athlete is able to conserve more energy for game activities that require large energy expenditure, such as jumping, tackling, accelerating and high velocity running. Running economy in athletes may be compromised through the modification of the normal gait pattern secondary to EIMD. Specifically, this manifests through an altered pattern of motor unit activation, compromised range of motion about the knee, ankle, and/or the hip, and general discomfort associated with the symptoms of DOMS (Braun and Dutto 2003). Running economy appears less sensitive to the detrimental effects of EIMD in untrained individuals, possibly due to less refined gait patterns (Paschalis, Koutedakis et al. 2005).

2.6.7 Delayed onset of muscular soreness: a symptom of exercise induced muscle damage

Damage and inflammation of non-contractile connective tissue, myobifrillar membranes and intracellular structures such as the sarcomere, following muscular overuse, or high levels of impact through physical contact, result in DOMS (Jones, Newham et al. 1987; Jones, Newham et al. 1989).

It is likely that the oedema after EIMD (Sayers and Hubal 2008) is responsible for the sensation of DOMS (Dierking and Bemben 1998). When exercise intensity reaches a certain threshold, myofibrilar cell membrane permeability alters, allowing the release of enzymes and proteins into the interstitial space (Brancaccio, Limongelli et al. 2006; Brancaccio, Maffulli et al. 2007). Consequently, capillary osmotic pressure gradients allow fluids to shift from the vascular to the interstitial space (Wilcock, Cronin et al. 2006). Simultaneously, increases in capillary permeability and blood flow to the sites of EIMD (Wilcock, Cronin et al. 2006) generate abnormal increases in interstitial fluid in localised areas after tissue damage (Armstrong 1986; Smith and Miles 2000). This oedema surrounding muscle fibers stimulates free nerve endings (pain receptors), eliciting painful sensations in the muscle (Dierking and Bemben 1998). It is possible that interventions that can minimise oedema will potentially reduce the painful sensation of DOMS.

In the presence of DOMS, palpation, stretching or activation of the damaged muscle elicits painful sensations (Byrne, Twist et al. 2004), developing within 12-24 hr following a variety of exercises (Table 2.2), with heightened sensations 24-72 hr after exercise (Asmussen 1956; Newham, Mills et al. 1983; Armstrong 1984; Jones, Newham et al. 1987; Newham 1988; Jones, Newham et al. 1989; Clarkson, Nosaka et al. 1992; Cleak and Eston 1992). When untrained participants are exposed to unaccustomed activity, DOMS prevails for 24-48 hours (Asmussen 1956; Newham, McPhail et al. 1983); however it is not uncommon for painful sensations to persist for three days (Thompson, Nicholas et al. 1999). Yet when untrained participants complete protocols designed to induce very high levels of EIMD, such as passive arm curl exercise, the duration of DOMS is at its greatest, with symptoms persisting for five days (Kraemer, Bush et al. 2001b; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). The duration of DOMS in untrained participants is largely dictated by the type of activity. In contrast to untrained individuals, athletes typically experience DOMS across a shorter duration, particularly when exposed to high intensity activity such as competition. This may be due in part to the protective effect of prior eccentric contractions (Nosaka and Newton 2002; Bowers, Morgan et al. 2004), which in the elite training and competition environment are repeated regularly. Indeed, when team sport athletes partake in actual or simulated game play, athletes tend to experience DOMS for 24 – 48 hr (Dawson, Gow et al. 2005; Ingram, Dawson et al. 2009; McLean, Coutts et al. 2010; Ascensao, Leite et al. 2011).

Table 2.2: The occurrence of muscle soreness following laboratory and field based exercise stimuli.

Exercise type	Participant details	Duration of muscle soreness
Laboratory based studies		
Triceps extension and step ups until fatigue (Asmussen 1956)	Female students	48 hr
15 or 20 min step test (46 cm) (Newham, Mills et al. 1983)	4 healthy normal participants	Pain first evident 8-10 hr post exercise, peaked 24-48 hr post.
90 min of intermittent shuttle running and walking (Loughborough Intermittent Shuttle Test: LIST) (Thompson, Nicholas et al. 1999)	16 male students	Peak at 24-48 hr, and persisted for 72 hr.
Passive arm curl exercise (Kraemer, Bush et al. 2001b)	20 non strength trained females	5 days
51.0±1.5 min downhill treadmill run (-16.5%; 8.7±0.3 $km \cdot hr^{-1}$) (Kingsley, Kilduff et al. 2006)	8 recreationally active males	Immediately, 24 hr and 48 hr post exercise.
90 minute intermittent shuttle run (Bailey, Erith et al. 2007)	20 healthy males	0, 1, 24 and 48 hr post exercise.
80 min of simulated team sports exercise followed by a 20-m shuttle run test to exhaustion (Ingram, Dawson et al. 2009)	11 male team sport athletes	0, 24 and 48 hr post exercise.
Plyometric activity (Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a)	Untrained females	72 hr
Field based studies		
Marathon (Sherman, Armstrong et al. 1984)	10 trained male runners	3 days
Australian football game (sub elite) (Dawson, Hopkinson et al. 2004b)	17 well trained sub elite AF athletes	48 hr post game.
Ironman Triathlon (Suzuki, Peake et al. 2006)	9 well trained triathletes	Immediately post and 24 hr post race.
3 day basketball tournament (Montgomery, Pyne et al. 2008b)	29 male state level basketball players	End of the tournament.
Soccer game (Ispirlidis, Fatouros et al. 2008)	24 professional soccer players	0, 24 and 48 hr post game.
Rugby game (McLean, Coutts et al. 2010)	12 professional rugby players	48 hr post game.
Soccer game (friendly) (Ascensao, Leite et al. 2011)	20 male junior soccer players	30 min post, 24 and 48 hr post game.
Australian football training (Elias, Varley et al. 2012)	14 professional Australian football athletes	0, 1, 24 and 48 hr post training.
Australian football game (Elias, Wyckelsma et al. 2012)	24 professional Australian football athletes	1, 24 and 48 hr post game.
Rugby league game (Webb, Harris et al. 2012)	21 professional rugby league athletes	1, 18 and 42 hr post game.

2.6.8 Delayed onset muscle soreness is detrimental to performance indicators.

The deleterious effect of DOMS on performance is well established (Armstrong 1986; Clarkson, Nosaka et al. 1992; MacIntyre, Reid et al. 1995; Dierking and Bemben 1998; Clarkson and Sayers 1999; Rawson, Gunn et al. 2001; Braun and Dutto 2003). Although muscle soreness is a symptom of muscle damage, these parameters are investigated independently using different tools. The occurrence of DOMS is ascertained through questionnaires of the individuals' level of soreness, whereas muscle damage is determined through obtaining concentrations of biochemical markers of muscle damage found in the blood (Brancaccio, Limongelli et al. 2006), through the muscle biopsy technique (Friden and Lieber 1992), ultrasound (Warren, Lowe et al. 1999), diffusion tensor imaging and magnetic resonance imaging (McMillan, Shi et al. 2011).

Muscle soreness is accompanied by an attenuation of maximal force in the affected muscles, both for voluntary and involuntary contractions (Armstrong 1986; Clarkson, Nosaka et al. 1992; MacIntyre, Reid et al. 1995; Clarkson and Sayers 1999; Braun and Dutto 2003). When DOMS affects muscles around a particular joint, there is typically a reduction in range of motion of that joint (Dierking and Bemben 1998; Rawson, Gunn et al. 2001; Lee, Goldfarb et al. 2002). Of practical significance, functional impairments associated with DOMS (Armstrong 1986; Clarkson, Nosaka et al. 1992; MacIntyre, Reid et al. 1995; Dierking and Bemben 1998; Rawson, Gunn et al. 2001; Braun and Dutto 2003) may impact an athlete's weekly preparation for competition. Reciprocal inhibition around a joint also acts as a protective mechanism in response to the pain associated with movement when experiencing DOMS (Willer 1977; Sandrini, Serrao et al. 2005). This may interfere with the athletes normal biomechanics when completing conditioning and skill based tasks.

Despite a poor relationship with histological evidence of muscle damage (Newham, Mills et al. 1983; Jones, Newham et al. 1986) and measures of muscle function (Newham, Mills et al. 1983; Rodenburg, Bar et al. 1993; Nosaka, Newton et al. 2002), DOMS is commonly used as a gauge of EIMD. This assumption can lead to practical problems when the absence of DOMS is used as a signal to resume normal training, particularly as the muscle is likely to remain in a compromised state (Byrne, Twist et al. 2004). Specifically, function may be impaired before soreness actually arises (Jones, Newham et al. 1986; Rodenburg, Bar et al. 1993; Nosaka, Newton et al. 2002).

2.6.9 Central fatigue, muscle damage and muscle soreness: a possible interaction.

Central fatigue may play a role in prolonged fatigue through its overlap with muscle damage, specifically the soreness ensuing from such exercise. It has been hypothesised that muscle soreness, secondary to damage inducing exercise, may reduce neural drive to the muscles (Racinais, Bringard et al. 2008). For example, motor system excitability can be modified by experimental tonic pain induced either in muscles or in subcutis (layer of connective tissue below the dermis) (Le Pera, Graven-Nielsen et al. 2001). This inhibition of motor evoked potentials was observed during the peak-pain and persisted also after the disappearance of the pain sensation (Le Pera, Graven-Nielsen et al. 2001). It has also been suggested that increased group III and IV muscle afferent inputs may induce H-reflex depression when muscle soreness progresses as muscle pain is believed to reflect activity in group III and IV muscle afferents (O'Connor and Cook 1999). As such, muscle soreness may reduce the neural drive to the muscles, and reduce force generating capacity and performance. There is also a conscious element to central fatigue during exercise, where the individual may feel that the sensations (of soreness) are not tolerable and intentionally lower the level of activity or intensity of exercise (Taylor, Allen et al. 2000). This becomes problematic in the elite sporting world.

Athletes are commonly required to compete in weekly competition, as well as multiple training sessions before competing again, often with only short recovery periods provided.

Central fatigue secondary to EIMD may also be detrimental to game performance in tournament scenarios, where multiple competitive games are conducted with minimal recovery time. In some cases, more than one game is played per day, for example during rugby sevens tournaments, further compounding this fatigue.

2.7 Recovery is an important component of the athletes training schedule

Complete recovery from exercise is defined as the post exercise return of variables to a pre-exercise homeostatic range (Calder 1990; Calder 1991). Rest alone, given time, will normally achieve this (Kentta and Hassmen 1998). When either 1) the athlete has failed to recover within this time; or 2) 72 hr are not available to dedicate to rest for recovery (Kentta and Hassmen 1998), actions may need to be taken to accelerate natural recovery processes. Accordingly, recovery interventions are incorporated into the training program. Such interventions are adopted with the intent to return test performance parameters to pre-exercise levels (Duffield, Edge et al. 2008; Montgomery, Pyne et al. 2008b; Vaile, Halson et al. 2008a; Duffield, Cannon et al. 2010) and to abate perceptions of muscle soreness and fatigue (Duffield, Edge et al. 2008; Montgomery, Pyne et al. 2008b; Vaile, Halson et al. 2008b). On a mechanistic level, such interventions also endeavour to reduce circulating concentrations of biochemical indicators of muscle damage and inflammation (Gill, Beaven et al. 2006; Montgomery, Pyne et al. 2008a). Specifically, inflammation exacerbates existing disruptions to skeletal muscle tissue, as this immune response is coupled with secondary damage via transient hypoxia as well as the non-specific cytotoxic actions of leukocytes (MacIntyre, Reid et al. 1996; Kyriakides, Austen et al. 1999; Owen, Wong del et al. 2011). The importance however of reducing biochemical indicators of muscle damage to functional impairments remains to be elucidated. See section 2.9.2 for more detail.

Recovery interventions also aim to allow the athlete to tolerate higher training loads, and to optimise the quality at which they perform each session. A plethora of recovery interventions have been suggested to successfully augment recovery and are frequently incorporated into the athlete's schedule, despite sufficient evidence to confirm their effectiveness and validity in athletic scenarios.

The consequences of inadequate recovery are likely tied to the training principle supercompensation. Ultimately, physical preparation is underpinned by supercompensation, whereby the breakdown (training) process is succeeded by the recovery process, resulting in an 'overshoot' or rebound in adaptation and performance improvement (Viru 1984). Training and recovery constitute the two underpinning factors related to supercompensation. When multiple training-recovery cycles are completed with inadequate recovery, residual fatigue, muscle damage, inflammation and soreness from previous sessions build up (Duffield, Edge et al. 2008; Montgomery, Pyne et al. 2008a). Such a mismatch has the potential to lead to the accumulation of fatigue and training stressors which take time to recover from, ultimately impairing the athlete's performance.

2.7.1 Recovery and Australian Football

There is a growing body of research investigating recovery interventions following AF competition and training (Dawson, Gow et al. 2005; Elias, Varley et al. 2012; Elias, Wyckelsma et al. 2012; Bahnert, Norton et al. 2013). Stretching, pool walking and hot showers alternated with cold water immersion immediately post game, in addition to a standard 'next day' pool recovery session (25-30 min) compared to a control were investigated in sub elite AF athletes (Dawson, Gow et al. 2005). The rapidity of recovery of muscle soreness 15 hr following competition was not different between conditions. Yet players who partook in a recovery condition were better able to maintain vertical jump, and 6 second cycling performance 15 hr after the game compared to the control condition, where decrements were actually observed in these parameters. Performance ratios indicated that pool walking produced a greater recovery of vertical jump performance 15 hr post game compared to the control group (Dawson, Gow et al. 2005). In those same athletes, the recovery of cycling power during a six second maximal test was enhanced with the use of stretching for recovery compared to the control group (Dawson, Gow et al. 2005). Effects for both recovery conditions were reported as moderate to large (ES>0.3) (Dawson, Gow et al. 2005). However, this superior recovery compared to the control was diminished 48 hr post game, with no differences between conditions. The authors concluded that the recovery of muscle soreness, flexibility and power at 48 hr post game was not enhanced by performing an immediate post game recovery beyond that achieved by performing only next day recovery training (Dawson, Gow et al. 2005).

Elias and colleagues investigated the use of cold and contrast water immersion after elite AF training (Elias, Varley et al. 2012) and competition. After elite AF training, for restoring physical performance and psychometric measures, cold water immersion was more effective than contrast water immersion, with passive recovery being the least effective. Twenty four hours after training, repeat-sprint time had deteriorated by 4.1% for athletes in the passive treatment, and 1.0% for contrast water immersion, but was fully restored with the use of cold water immersion (0.0%). What's more, 24 and 48 hr after training, both immersion treatments attenuated changes in mean muscle soreness, with cold water immersion (0.6±0.6 and 0.0±0.4) more effective than contrast water immersion (1.9±0.7 and 1.0±0.7) and passive recovery exerting a minimal effect

(5.5±0.6 and 4.0±0.5). Similarly, after 24 and 48 hr, both immersion treatments effectively reduced changes in perceived fatigue, with cold water immersion (0.6±0.6 and 0.0±0.6) being more successful than contrast water immersion (0.8±0.6 and 0.7±0.6) and the passive treatment having the smallest effect (2.2±0.8 and 2.4±0.6) (Elias, Varley et al. 2012).

Similar results were observed after elite AF competition (Elias, Wyckelsma et al. 2012). Repeat-sprinting performance remained slower 24 and 48 hr after the game for athletes receiving the passive (3.9% and 2.0%) and contrast water immersion treatments (1.6% and 0.9%), but was restored with cold water immersion (0.2% and 0.0%) use. Soreness after 48 hr was most effectively attenuated by cold water immersion (ES 0.59±0.10) but remained elevated for athletes who used contrast water immersion (ES 2.39±0.29) or no immersion at all (ES 4.01±0.97). Similarly, cold water immersion more successfully reduced fatigue after 48 hr (ES 1.02±0.72) compared to contrast water immersion (ES 1.22±0.38) and passive recovery (ES 1.91±0.67). Declines in static and countermovement jump were also ameliorated best by cold water immersion (Elias, Wyckelsma et al. 2012).

A more recent study tracked elite AF athletes across a 23 game season monitoring a full squad of 44 footballers on a weekly basis (Bahnert, Norton et al. 2013). Players were required to choose from a number of recovery modalities available immediately post-game. These included floor stretching, pool stretching, bike active recovery, pool active recovery, cold-water immersion, contrast therapy and use of a compression garment. Perceptual measures of recovery were recorded throughout the week and a test of physical performance was conducted two days post-game. Game performance ratings were also recorded. Perceptual recovery among players was enhanced through the selection of specific combinations of recovery protocols post game. However, no links were found between recovery protocols and physical or game performance measures. Players who chose cold water immersion, floor stretching, use of a compression garment and no active recovery (either bike or pool) in varying combinations post game, had an increased probability of also reporting greater perceptual recovery in the following week. The inclusion of the cold water immersion modality was part of all five protocols that significantly enhanced perceived recovery. There was an average of about twice the probability of feeling ‘recovered’ versus ‘un recovered’ when cold water immersion was included as part of the recovery protocol post game. The authors noted that players varied in their preferred combinations of post-game recovery modalities. They suggested that such variety reflects personal preference and perceived benefit and the fact that relatively little specific guidance can be confidently provided by conditioning staff concerning optimal recovery (Bahnert, Norton et al. 2013).

The pool of research presently available suggests that cold water immersion plays an important role as a post training and game recovery modality. However little is known regarding the efficacy of compression garments in this scenario.

2.8 Compression garments: a practical tool used to assist post exercise recovery

2.8.1 Garment considerations

Compression as a treatment for human disease dates back to Hippocrates 450 BC, utilised primarily in the treatment of venous disorders and leg ulcers (Gladfelter 2007). This progressed to body wrapping in the treatment of soft tissue injury to minimise swelling and edema and to minimise scar tissue formation following burns (Gladfelter 2007). The introduction of synthetic fabrics in 1983, including nylon, in addition to the progressive development of women’s undergarments, saw the increase in the number of surgeons using commercially available undergarments in postoperative care of patients (Gladfelter 2007). Today, compression garments are designed to cover a small section such as the part of a limb or to cover whole body segments such as items of clothing, e.g. pants and tops.

Compression garments are constructed from an elastic material, with a graduated compression design most commonly adopted (Linnitt and Davies 2007a). Compression is measured in millimetres of mercury (mmHg), which refers to the pressure exerted at the ankle by the garment at rest (100% of the compression is at the ankle, this then reduces to 40% at the thigh (Figure 2.3).

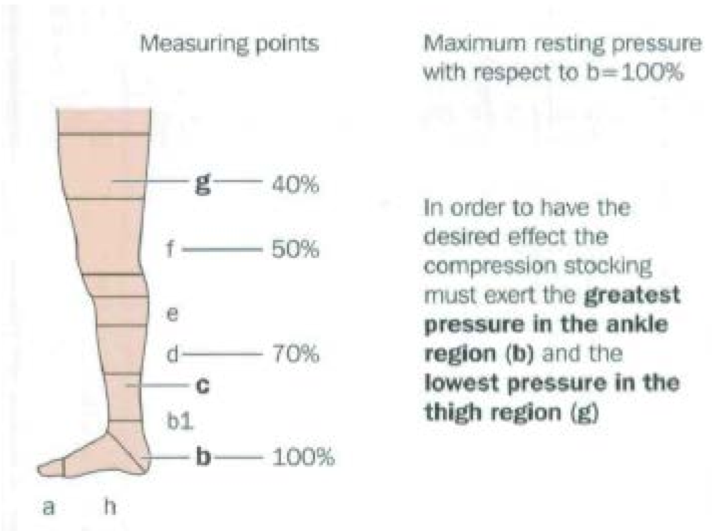

Figure 2.2 Graduated Compression Garments

Source: (Linnitt and Davies 2007b)

There are differing classifications of compression available, including the German RAL GZ387 (for Hohenstein Institute tested hosiery), French Standard ASQUAL and British Standard BS 6612 (Figure 2.4) (Bianchi and Todd 2000; Clark and Krimmel 2006; Linnitt and Davies 2007a). Sports compression garments typically fall into the lower of the three classes, class I, due to the lower level of compression exerted, with medical garments typically being allocated class II and III.

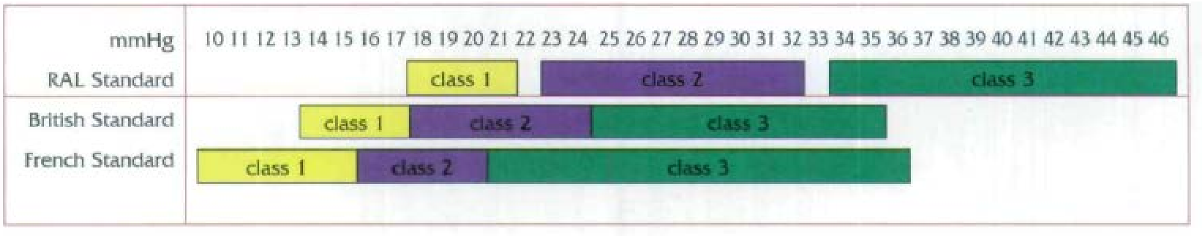

Figure 2.3 Classification of compression

Source: Linnitt and Davies 2007

As a broad principle, the level of compression is directly proportional to the tension with which the compression device is applied, and inversely related to the size of the limb according to Laplace's Law (Clark and Krimmel 2006). The tension exerted by a compression garment is related to both the type of yarn used in its construction, and the knitting technique used to produce the fabric. The fabric selected to make compression garments is produced by knitting two types of yarn together. Inlay yarn provides the compression and body yarn delivers the thickness and stiffness of the knitted fabric (Figure 2.5) (Clark and Krimmel 2006).

A B

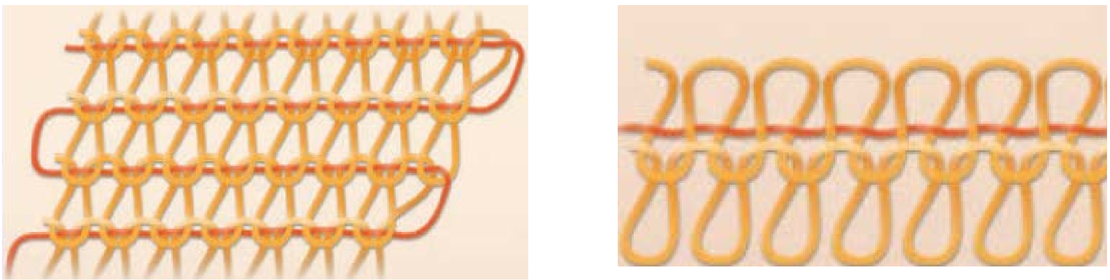

Figure 2.4: The arrangement of inlay and body yarn in flat knit (A) and circular knit fabric (B).

Source: Clark and Krimmel 2006.

Both types of yarn are produced by wrapping polyamide or cotton around a stretchable core such as latex or elastane (Lycra) (Figure 2.6). The wrapping can be adjusted to vary the stretchability and power of the yarn. The stretchability is a measure of how far the yarn can be elongated, and the power is a measure of how easily it stretches. High power yarn is less easy to stretch and is stiffer than its low power counterpart, and thus applies greater compression (Figure 2.6). The thickness, texture and appearance of the knitted fabric can also be changed by adapting the wrapping of the yarn. Higher levels of compression are achieved by increasing the thickness of the elastic core of the inlay yarn, although adjustments may also be made to the body yarn (Clark and Krimmel 2006).

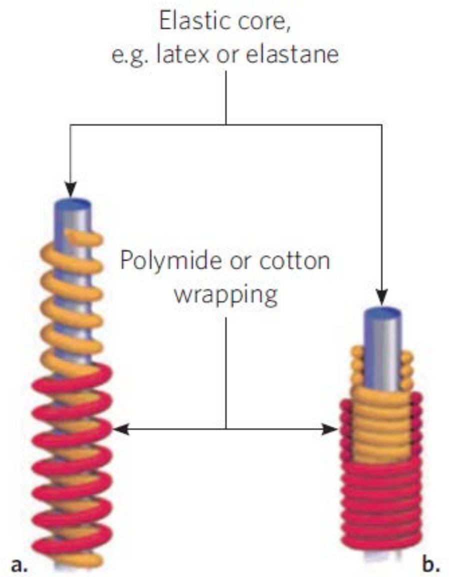

Figure 2.5: The fibres that make up body and inlay yarn. The wrapping of the outer fibre around the stretchable core can be adjusted to vary the stretchability and power of the yarn. Looase wrapping (a) means the yarn has more stretch and less power than a yarn in which the fibres are tightly wrapped (b). ***Source: Clark and Krimmel 2006.***

Proper fit is essential in the optimisation of compression garment use (Kraemer, Bush et al. 1996). With high compression or with compression used to treat extreme soft tissue injury, compression may augment feelings of discomfort during the period the garment is used despite the positive results because of mechanical blocking of edema (Kraemer, Bush et al. 1996; Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Silver, Fortenbaugh et al. 2009). Proper fit (e.g. seams not problematic or constrictive) and feel (e.g. garment material) are important mediators of garment efficacy, particularly when worn for long periods of time. Adequate compression and proper construction create the potential for optimal skin contact, which is vital for proprioception (Kraemer, Flanagan et al. 2010). It is also an important consideration that garment movement is minimal and stays in contact with the skin to prevent air bubbles breaking the linkage with the skin, and thus the stimulation of skin receptors (Kraemer, Flanagan et al. 2010).

Today, commercially available sports compression garments are worn by individuals ranging from recreational exercisers to elite athletes in a bid to accelerate post exercise recovery and to gain an edge over their opponent. Thirty one studies have investigated the effect of wearing compression garments on indicators of performance and recovery from exercise, with sixteen focused specifically on recovery from exercise (Born, Sperlich et al. 2013). Yet only three studies have explored compression garment use exclusively during the recovery period, with elite athletes in actual sporting scenarios (Gill, Beaven et al. 2006; Montgomery, Pyne et al. 2008a; Montgomery, Pyne et al. 2008b). Compression garments are widely used by team sport athletes in training and competition scenarios to aid their recovery. It is clear that despite the current body of research on compression garments, little is known regarding their efficacy for these elite athletes in actual training and competition scenarios.

2.8.2 Compression garment mechanisms

Section 2.4 discussed potential causes and mechanisms of fatigue that may contribute to in-session and between session fatigue. It is unlikely however that compression garments will influence these physiological factors. Instead, clinically, compression garments exert positive actions through alterations to the vascular and lymphatic systems (Swedborg 1984; Mayberry, Moneta et al. 1991; Yasuhara, Shigematsu et al. 1996; Johansson, Lie et al. 1998; Jonker, de Boer et al. 2001; Beidler, Douillet et al. 2009). Specifically, these garments compress superficial limb tissues, which in turn compress underlying superficial veins, reduce their diameter, increase blood flow velocity and reduce pooling (Morris and Woodcock 2004). A reduction in pooling in the deep veins may lessen the risk of stasis during surgery, prevent travel deep vein thrombosis and minimise deep venous insufficiency (DVI) (Morris and Woodcock 2004). In deep veins such as the popliteal vein, peak flow velocity and vein diameter increase when wearing compression garments in both healthy patients and those suffering DVI (Mayberry, Moneta et al. 1991). The authors state that this increase may reflect an increase in deep venous blood flow as a result of compression of the superficial venous system by the compression garment (Mayberry, Moneta et al. 1991). Over the course of daily activity, or simulated daily activity, oedema and swelling in the legs of healthy individuals is reduced with compression stocking application (14–18 mmHg at the ankle) (Jonker, de Boer et al. 2001) and compression hosiery (7.6–15.4 mmHg at the ankle) (Kraemer, Volek et al. 2000). These effects presumably result from a reduced hydrostatic pressure gradient across the vessel walls. Reductions in lymphodema also occur with the use of compression garments in a variety of patients such as mastectomy patients (Swedborg 1984), leg lymphodema patients (Yasuhara, Shigematsu et al. 1996), post-operative leg lymphodema patients (Johansson, Lie et al. 1998), and healthy volunteers with no symptoms of chronic venous insufficiency (Jonker, de Boer et al. 2001). Ultimately, these physiological changes act to aid the natural action of the 'muscle pump'. Wearing compression garments also blunts the pro-inflammatory cytokine response in patients suffering from DVI and leg ulcerations (Beidler, Douillet et al. 2009). Elderly patients with myocardial infarct also benefit from wearing compression garments. Specifically, patients experienced increases in calf blood volume, facilitating reductions in deep vein thrombosis (Mayberry, Moneta et al. 1991). These physiological mechanisms, attributed to the positive actions of compression garments, have been predominantly investigated in clinical settings, yet the manufacturers of sports compression garments hypothesise that such clinical effects are transferable to a healthy, elite athlete population. However, as it is presumed that the vascular and lymphatic systems of these individuals are well functioning, it is unknown if such a leap from clinical to athletic populations can be made. Indeed, these mechanisms may not actually be operational due to the absence of pathologies in this population group.

Tissue oxygenation is increased when wearing compression garments during exercise tasks (Dascombe, Hoare et al. 2011; Coza, Dunn et al. 2012). At slower running velocities (8–10 $km \cdot h^{-1}$), wearing either an undersized (21.7±4.3 mmHg at ankle) or regular size (19.2±3.2 mmHg at the ankle) full lower body compression garment significantly increased muscle blood flow and oxygen utilization, as well as oxygen pulse compared with the control condition in well trained middle-distance runners and triathletes (Dascombe, Hoare et al. 2011). During the faster running velocities (>12 $km \cdot h^{-1}$), both garments significantly increased deoxygemoglobin concentration of the vastus lateralis, which coincided with a decrease in heart rate and tissue oxygenation index, suggestive of an improvement in venous flow and cardiac return (Dascombe, Hoare et al. 2011). Similar observations have been made in recreationally active participants. Tissue oxygenation during isolated calf exercise increased with the use of compression garments compared to a control (Coza, Dunn et al. 2012). The garment type used was not revealed. It is unknown if increases in tissue oxygenation are seen when such garments are worn purely in the post exercise period.

The mechanism by which wearing compression garments may facilitate an enhanced recovery following damaging exercise scenarios is likely to be different to that in a clinical setting. Some authors suggest that wearing compression garments permit the limbs to remain in anatomical positions when not used and that this restriction in movement enhances the regeneration and repair process (Kraemer, Bush et al. 1998a; Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b). However, it is not entirely clear how this may actually enhance such processes, nor do the authors provide any evidence or explanation for possible mechanisms.

It is theorised that compression garments may help reduce possible secondary muscle damage, initiated by metabolic/chemical pathways which may create further damage due to factors such as Ca^{2+} influx, decreased membrane resistance, and free-radical production (Montgomery, Pyne et al. 2008a). The authors provide no evidence that this may in fact be the case or even plausible. It is unclear as to exactly how abating secondary muscle damage would actually occur consequent to the use of compression garments. It is also suggested that wearing compression garments may accelerate the restoration of membrane permeability, as highlighted by lower levels of biomarkers of damage (Montgomery, Pyne et al. 2008a) measured during recovery. Yet once again, no evidence is presented to support this theory. Indeed, simply observing a lower concentration of such biomarkers of damage does not indicate restoration of membrane permeability. It is postulated that alterations to the vascular (Mayberry, Moneta et al. 1991) and lymphatic (Jonker, de Boer et al. 2001) systems when wearing compression garments are able to hasten the removal of biochemical markers of muscle damage. It is theorised that following initial injury a cascade of events occur during the inflammatory and repair process whereby neutrophils are released (Hurme, Kalimo et al. 1991; Tidball 1995) initiating the phenomena of secondary damage (Smith, Kruger et al.

2008). Neutrophils generate free radicals during phagocytosis (Evans and Cannon 1991), with neutrophil depletion prior to ischaemia-reperfusion injury reducing muscle damage by almost 40% in mouse skeletal muscle (Kyriakides, Austen et al. 1999). Blood flow increases due to compression garment use (Mayberry, Moneta et al. 1991) are hypothesised to increase the clearance of biochemical indices from the site of damage, and thus the concentration in the blood. This *may* provide an indirect indication of an increased clearance of neutrophils from the site of damage, and possibly attenuate secondary muscle damage. It remains purely speculative if [Mb] provides an indication of neutrophil clearance from the site of injury, and if secondary muscle damage contributes significantly to overall muscle damage and thus the general recovery process.

It is more plausible that mechanical blocking of oedema, elicited by wearing compression garments (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b) may minimise the sensations of muscle soreness, lessening the stimulation of free nerve endings by exercise induced oedema (Dierking and Bemben 1998). Specifically, the compression garments may increase the hydrostatic pressure applied to the muscle tissue, facilitating lymphatic drainage and reducing fluid extraction from the capillaries (Kraemer, Bush et al. 2001a). Such reductions in muscle soreness are suggested to improve the functional muscle capacity (Jakeman, Byrne et al. 2010a). It is well established that muscle soreness is detrimental to subsequent performance (Armstrong 1986; Clarkson, Nosaka et al. 1992; MacIntyre, Reid et al. 1995; Dierking and Bemben 1998; Clarkson and Sayers 1999; Rawson, Gunn et al. 2001; Braun and Dutto 2003). By reducing oedema with the use of compression garments following damaging exercise, the degree of muscle soreness, and possibly the associated performance impairment, may be lessened. As discussed in Section 2.5.9, this may help minimise the impact of a reduced neural drive associated with muscle soreness on subsequent performance.

Research however is yet to confirm such a relationship, with possible associations only speculated.

Vertical muscle oscillation is reduced when wearing compression garments. Longitudinal and anterior-posterior muscle oscillation of the thigh are decreased during vertical jump landing when compression shorts were worn versus loose fitting shorts (Doan, Kwon et al. 2003). Similar results were seen during a vertical jump landing study where compression shorts were compared to a control (Kraemer, Bush et al. 1998a). This was accompanied by a greater ability to maintain power output during repeated vertical jumps when wearing the compressive garment (Kraemer, Bush et al. 1998a). Reductions in oscillatory disruption of the musculature being compressed by the garment may reduce the amount of fatigue due to enhanced neurotransmission and more optimal mechanics at the molecular level of the muscle (McComas 1996). The reduction in muscle movement may be important in augmenting repetitive jump performance by producing a short ground contact (Kraemer, Bush et al. 1998a). Reduction in muscle movement and other oscillation related fatigue mechanisms require further study. It is plausible that a reduction in such oscillation related fatigue may improve recovery of performance measures such as a jumping task even when the garment has been removed.

Proprioception is positively influenced by compression garment use (Kraemer, Bush et al. 1998a; Pearce, Kidgell et al. 2009). When active males and females replicated hip positions while supine, when wearing compression garments compared to control, error scores were lower at 45° and 60°, while no differences were detected at 30° and 90° (Kraemer, Bush et al. 1998a). The authors postulated surface compression could act on receptors in the skin to enhance proprioception (Barrack, Skinner et al. 1989; Perlau, Frank et al. 1995), particularly when the limb is distanced from an endpoint of the range of motion.

The question of the level of compression required in recovery scenarios to elicit positive physiological, performance and perceptual responses in elite athletes remains unknown. Indeed, much of the research underpinning physiological actions of compression garments has been established using medical, high level, compression garments, particularly within clinical settings as discussed above. Despite this, sports, but not medical compression garments, have been used to investigate the potential enhancement of post exercise recovery. It was suggested in the 1980's, in a clinical environment, that the pressure exerted by compression garments should be at least 18 mmHg at the ankle, and 8 mmHg at the level of mid-thigh in lower limb garments (Lawrence and Kakkar 1980). A similar 'pressure requirement' of compression garments to obtain optimal physiological and recovery responses in elite-athletes has not been investigated, and thus current recommendations for compression levels have not been made.

Research has recently explored differences between compression garments offering high and low levels of compression in their efficacy to enhance performance and elicit physiological alterations (Ali, Creasy et al. 2011; Dascombe, Hoare et al. 2011). These investigations have been limited to during exercise only, with no exploration as to differences in recovery efficacy. Ali and colleagues had male and female competitive runners complete a 10 km time trial on an outdoor 400 m track wearing either control (0 mmHg), low (12–15 mm Hg), medium (18–21 mmHg), or high (23–32 mmHg) knee high graduated compression garments in a randomized counterbalanced order (Ali, Creasy et al. 2011). Time trial performance was not different between groups, however low and medium compression garments resulted in greater maintenance of leg power (CMJ height) after the time trial versus control and high compression garments. The authors found no difference in physiological measures (lactate and heart rate), with similar rating of perceived exertion (RPE) values with each garment type. There were however treatment effects for perceptions of compression garment comfort, where the low level garment was more comfortable than medium and high. The high level garment was also perceived as tighter than all other groups, with the medium garment tighter than low and control (Ali, Creasy et al. 2011).

Similarly, Dascombe et al (2011) failed to detect performance differences between a regular fit and an undersized lower body compression garment. Well trained triathletes and middle distance runners completed separately, a progressive maximal test and a time to exhaustion test at 90% $\dot{V}O_{2max}$ on a motorised treadmill wearing either a manufacturer recommended 'normal' fitting (19.2 ± 3.2 mmHg calf region and 13.7 ± 2.3 mmHg thigh region), or undersized (21.7 ± 4.3 mmHg calf region and 15.9 ± 2.6 mmHg thigh region) full lower body compression garment. Under the control condition participants wore loose fitting shorts exerting minimal compression. At slower running velocities (~8–10 $km \cdot hr^{-1}$), both compression garment conditions significantly increased muscle blood flow, oxygen utilization and oxygen pulse compared with control. During the faster running velocities (>12 $km \cdot hr^{-1}$), both garment conditions significantly increased the deoxyhemoglobin concentration within the vastus lateralis, which coincided with a decrease in heart rate and tissue oxygenation index. This is suggestive of an improvement in venous flow and cardiac return. However, no performance improvements were observed between the garment conditions. The authors note that overall, the limited physiological changes and absence of performance benefits while wearing the undersized compared with the regular sized garment and control conditions suggest that increasing the compression gradient of lower body compression garments did not benefit endurance running performance (Dascombe, Hoare et al. 2011).

During the progressive maximal test, a significant decrease in heart rate was observed in both garment conditions during moderate intensity running (12–16 $km \cdot hr^{-1}$). The authors postulate that this may be the result of an increase in venous return and subsequent stroke volume, via the Frank- Starling mechanism (Moss and Fitzsimons 2002). Indeed, this finding supports previous research that has reported a non significant trend for heart rate to be lower during a 10 km run when wearing lower body compression garments (Ali, Caine et al. 2007). In support of the hypothesis of improved venous function and return, the deoxyhemoglobin concentration within the vastus lateralis was significantly increased in the regular sized garment condition across several speeds (approx. 10–16 $km \cdot hr^{-1}$). Wearing both garment types increased oxygen consumption and oxygen pulse at 8 $km \cdot hr^{-1}$ (Dascombe, Hoare et al. 2011). Yet these results contrast those presented by Bringard and colleagues (2006) who reported that wearing lower body compression garments significantly lowered the oxygen required and improved the metabolic efficiency during submaximal running (ie 12 $km \cdot hr^{-1}$). However Dascombe et al suggest their results indicate an increased oxygen requirement at lower running velocities to overcome the increased resistance to movement that wearing lower body compression may cause.

Although the work of Ali et al (2011) and Dascombe et al (2011) highlighted no advantage to wearing garments offering higher levels of compression, it is unknown if compression differences would elicit different recovery responses when worn purely as a recovery tool. Indeed, a direct comparison of medical (high level compression) and sports compression (low level compression) garments in an athletic population in the post exercise period is warranted.

2.8.3 Compression garments as a recovery tool in un-trained populations

Wearing compression garments exerts the strongest positive effects on post exercise recovery in untrained individuals, notably following severely damaging protocols (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b). In untrained individuals, wearing a compressive arm sleeve enhances recovery beyond a control treatment one to five days following passive isokinetic dynamometry arm curl exercise (Kraemer, Bush et al. 2001a; Kraemer, Bush et al.

2001b; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). Higher torque and power values in addition to superior elbow angle maintenance resulted when participants wore the compressive arm sleeve (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b). Further, these participants experienced lower levels of soreness with active range of motion, and palpation two to five days after exercise compared to their control counterparts (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b). During the recovery period, global assessments of soreness were lower (days four and five) when wearing compression garments compared to no compression (Kraemer, Bush et al. 2001b). Wearing the compressive arm sleeve also blunted the normal elevation in serum [CK], however serum [LDH] and serum [cortisol] were not influenced by compression garment use (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b). No changes in serum [LDH] were observed during the recovery period compared to pre-exercise values, explaining why compression did not alter serum [LDH]. It is important to note that plasma concentrations of such markers reflect not only the rate of release of these proteins and enzymes, but also the rate of removal of such markers from the plasma. Thus it is difficult to determine if concentrations reflect changes to clearance rates alone when using interventions such as compression garments. Participants wearing the compression garments also experienced less swelling compared to the control condition, as indicated through changes in bicep circumference measured with a spring loaded tape measure (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b). It is likely that the compression garments produced a mechanical blocking of oedema (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b), which could have lessened the perception of muscle soreness, through reducing the stimulation of free nerve endings by exercise induced oedema (Dierking and Bemben 1998).

Untrained females experienced an improved recovery when wearing compression garments for 12 hours following plyometric activity, compared to their control counterparts (Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). These participants experienced an accelerated recovery of test performance, specifically squat jump, CMJ and isokinetic muscle strength, 24 to 96 hr following the preceding plyometric activity (Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). Further, one hour post exercise, those wearing compression garments experienced lower perceptions of muscle soreness, with effects lasting up to 76 hr. The authors attribute this to the garment abating oedema (Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). Interestingly, the improved test performance and perception of muscle soreness after, wearing a compression garment did not facilitate lower levels of plasma CK beyond the control participants, despite substantial elevations in both groups (Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a).

2.8.4 Compression garments as a recovery tool in trained populations

When worn for recovery, the most consistently reported positive action of compression garments on trained individuals is the blunting of muscle soreness (Duffield, Edge et al. 2008; French, Thompson et al. 2008; Montgomery, Pyne et al. 2008b; Davies, Thompson et al. 2009; Duffield, Cannon et al. 2010). Accelerated recovery of performance and biochemical variables, however appears less likely. Based on the research presented below, it is difficult to decipher clear guidelines regarding compression garment use in trained individuals for the purpose of enhancing recovery.

It is unclear as to whether compression garment use following resistance exercise is beneficial for recovery in resistance trained individuals. Countermovement jump height was maintained when wearing compression garments overnight (12 hr) following resistance exercise compared to a control (French, Thompson et al. 2008). Of concern, 30 m sprint performance was actually 2 % slower in the treatment group, but not in the control group. However, lower soreness was evident in the compression garment group compared to the control (French, Thompson et al. 2008). It appears, in this population group, that there is dissociation between the recovery performance and perceptual measures. The recovery of elbow flexion and extension angle, and not force production, correlates with measures of soreness (Rodenburg, Bar et al. 1993), possibly explaining this uncoupling. In that same study, wearing compression garments did not influence post exercise serum [Mb]. In both the control and treatment group the [Mb] had fully recovered in the 24 hr period post exercise (French, Thompson et al. 2008). It remains unclear if compression garments enhance recovery at some stage in the first 24 hrs, but it is clear that at 24 hrs the recovery state is identical. Despite reductions in muscle soreness, compression garment use did not influence serum [CK], even though unlike serum [Mb], serum [CK] was still elevated 24 hr after the exercise. Compression garments were also ineffective at abating swelling, as measured by mid-calf and thigh girth, in these participants. However mid-thigh girth was only elevated immediately post exercise, and only in the control group, making comparisons difficult (French, Thompson et al. 2008). Wearing compression garments contributed to higher feelings of vitality in recovery following resistance exercise, in resistance trained individuals (Kraemer, Flanagan et al. 2010). It is possible that this sensation is associated with placebo effects.

Five minute maximum cycling power of trained elderly cyclists was maintained to a greater extent when compression garments were worn for 80 minutes following an initial five minute cycling bout (Chatard, Atlaoui et al. 2004). The 80 min recovery period is less likely to reflect the competition demands of elite athletes, unless they are competing in a tournament scenario with multiple games/heats completed per day. The training schedule of the elite athlete includes multiple sessions per day, when the recovery period is only short in duration like this current study, compression garments *may* be useful at maintaining the athlete's performance, however the completion of only 5 min of cycling exercise limits possible extrapolations to field sports. The role of the placebo effect in this positive response is discussed in Section 2.10.

When a longer duration cycling protocol is adopted, positive effects on subsequent performance are also evident (De Glanville and Hamlin 2012). Team sport trained participants who wore a lower body compression garment for 24 hr separating two 40 km cycling time trials were better able to maintain their follow up performance time (ES ±90% CI; -1.2 ± 0.4%). This improvement resulted in a substantially higher average power output after wearing the compression garment compared with that after the placebo garment (ES ±90% ; 3.3 ± 1.1%) (De Glanville and Hamlin 2012). Interestingly, the author's hypothesized that performance improvements may be due in part to an improved glucose metabolism via compression garment mediated blood flow increases, yet the garments were only worn during recovery and not the actual exercise bout. The authors did not however measure muscle glycogen levels, blood flow, blood glucose levels or to control dietary intake. To support this hypothesis, the authors reference the moderately higher (9.3%) but unclear blood lactate concentration at 40-km in the compression relative to the placebo group following the second time trial. The authors do however cite the observed trend towards a lower oxygen cost during the second cycling bout with compression use compared to placebo, suggesting that lower oxygen consumption may be due to a move toward greater carbohydrate and less fat use in oxidative phosphorylation. They also postulate that an increase in carbohydrate metabolism in the compression group was not because of any change in diet but may have resulted from increased muscle glycogen storage secondary to enhanced glucose availability via the blood. The theory presented by the researchers is theoretically possible. It remains unclear however, if such increases in blood flow due to wearing compression garments actually aid in an increased delivery of glucose to glycogen storage sites, and if the effect of this increased delivery outweighs that of consuming additional carbohydrates in the diet.

It currently remains unclear if similarly positive recovery responses to compression garment use occur in team sport athletes. Academy level female netball and male basketball players wore compression (48 hr) following drop jump exercise, and experienced mixed recovery outcomes. Agility and CMJ test performance were superior with compression garment use compared to the control. Yet despite a decline in sprint test times (5, 10, 20 m), wearing compression garments did not alter sprint recovery beyond that of the control group. Wearing compression also failed to impact serum [CK], [LDH] or mid-thigh circumference. Indices of muscle damage however, were not elevated in the post exercise period (Davies, Thompson et al. 2009), most likely accounting for the inability to detect differences between groups. Importantly, lower levels of muscle soreness in the netball participants compared to the control occurred with compression garment use (Davies, Thompson et al. 2009).

More promising effects of compression garments were seen when cricket players wore full length lower body, and long sleeve garments during, and for 24 hr, following throwing activities and a 30 min intermittent repeat sprint protocol (Duffield and Portus 2007). Consistent with the pool of compression garment research, wearing this type of garment facilitated lower muscle soreness in both the upper and lower body. Creatine kinase concentration was lower 24 hr later in players wearing compression garments versus the control (Duffield and Portus 2007). As the participants also wore the compression garments during the exercise in addition to 24 hr of recovery, it is difficult to clearly differentiate the ‘during exercise’ effect of the garments from possible recovery effects.

Much of the investigation into the influence of post exercise compression garment use has focused on rugby players following actual and simulated games as well as sprint and plyometric exercise. Recovery was not enhanced when moderately trained rugby players wore compression garments during, and for 24 hr of recovery, following a 10 min sprint and plyometric jumping protocol. Peak extension force for quadriceps, peak flexion force for hamstrings, or knee extensor peak twitch force two or 24 hr post exercise remained unaltered compared to the control (Duffield, Cannon et al. 2010). However, knee extensor peak twitch force was the only variable depressed at two hours post. Wearing compression garments did however result in lower levels of muscle soreness at 24 hr compared to the control condition. Aspartate amino transferase, an enzyme found in skeletal muscle and used primarily as a marker of liver function (Kirsch, Eichele et al. 1984), was also lower 24 hr later with the use of compression garments. However, despite significant increases in C-reactive protein and [CK] at 24 hr, these indices remained unaltered consequent to compression garment usage (Duffield, Cannon et al. 2010). Likewise, compression garments worn during a 15 hr recovery period (and the exercise bout), separating two simulated team games, did not enhance in-game repeat 20 m sprint performance, or dynamometer peak power in elite junior rugby players (Duffield, Edge et al. 2008). It appears that there was no substantial performance decrement in either the treatment or control group when the simulated game was repeated, most likely explaining the inability to detect a treatment effect for performance. On the other hand, wearing compression was effective at dampening muscle soreness 24 hr following the first game, and also 48 hr following the second game compared to the control condition (Duffield, Edge et al. 2008). Capillary [CK] remained unaltered (Duffield, Edge et al. 2008), however following elite rugby competition, transdermal [CK] was lower in athletes wearing compression (12 hr overnight) compared to a control at 36 and 84 hr of recovery (Gill, Beaven et al. 2006). Transdermal samples show a high correlation with plasma constituents at rest and during exercise and recovery (r^2>0.67) (Cook 2002).

Agility and line drill ability improved beyond control when compression garments were worn during recovery between three consecutive basketball games, separated by 24 hr (Montgomery, Pyne et al. 2008b). Of concern, there were greater decrements in vertical jump and 20 m acceleration in compression versus control (Montgomery, Pyne et al. 2008b). Soreness as well as fatigue were lower (50%) when wearing compression garments for 18 hr during recovery (Montgomery, Pyne et al. 2008b). Serum [Mb] however remained unaltered in athletes wearing compression garments (Montgomery, Pyne et al. 2008a).

2.9 Practical tools to assess recovery

The true test that an athlete has achieved full recovery is the repetition of the actual performance. For example, the ability to replicate the number of maximal accelerations in a game. Unfortunately, it is not practical to replay a game, or possible to replicate the game and context of the acceleration exactly. The appropriate selection of tools to investigate post exercise recovery is crucial. Importantly, practicality and reliability must be considered. This is pertinent when investigating recovery in elite athletes, where athlete access is often limited, and thus measures must be obtained quickly. Further, when investigations occur during important phases of training and competition, invasive measures may not always be feasible, despite their ability to often deliver a greater amount of information, compared to less invasive techniques. The subsequent sections will briefly discuss practical tools to assess recovery.

2.9.1 Statistical analysis of treatment effects: the use of magnitude based effects

When assessing the influence of an intervention on particular parameters, it is important to consider the magnitude of the smallest worthwhile enhancement in the given parameter, and the uncertainty or noise in the test result (Hopkins 2004). Traditionally, inferential statistics are used to test the null-hypothesis, where a *'P'* value is produced for an outcome statistic. The *P* value is the probability of obtaining any value larger than the observed effect, regardless of sign, (i.e. positive or negative) if the null hypothesis were true. When $P<0.05$, the null hypothesis is rejected and the outcome is said to be statistically significant (Fisher 1970). However, the *P* value does not provide information regarding the direction or size of the effect or, given sampling variability, the range of likely values (Batterham and Hopkins 2006). In fact, depending on sample size and variability, among other things, an outcome statistic with $P<0.05$ could represent an effect that is mechanistically, practically, or clinically irrelevant. On the other hand, a non-significant result of $P>0.05$ does not always imply the absence of a worthwhile effect. A combination of large measurement variability, and a small sample size may actually overshadow important effects (Batterham and Hopkins 2006).

When assessing elite athletes, the smallest worthwhile enhancement in a given parameter, such as performance, is often small (Hopkins 2004) and may be missed by traditional inferential statistics. Hopkins (2004) notes that for elite athletes competing in individual sports, the smallest worthwhile enhancement in performance would give the athlete an extra medal per 10 competitions. With this in mind, the required change in performance is 0.3 of the typical variation in an athlete's performance from competition to competition, equating to ~0.3-1% when expressed as a change in power output, depending on the sport (Hopkins 2004). For team sport athletes, where a direct relationship between team and test performance is not present, an appropriate default for the smallest change in test performance is one-fifth of the between-athlete standard deviation (a standardized or Cohen effect size of 0.20) (Hopkins 2004). An alternative approach to *P* values is the use of confidence intervals and magnitude based inferences.

Confidence intervals represent the likely range of the true, real, or population value of the statistic (Batterham and Hopkins 2006). They can be used to interpret the magnitude of the size of the true value, and also the direction of the statistic (positive or negative) (Batterham and Hopkins 2006). Such values also highlight non-significant outcomes, where the confidence intervals cross the boundaries of negative and positive effects (Figure 2.2) (Batterham and Hopkins 2006). To further characterise the magnitude or size of the effect, the use of effect size statistics can be applied. Hopkins suggests categorising effect size statistics according to the following: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, 2.0-4.0 very large, >4.0 extremely large (Hopkins 2004).

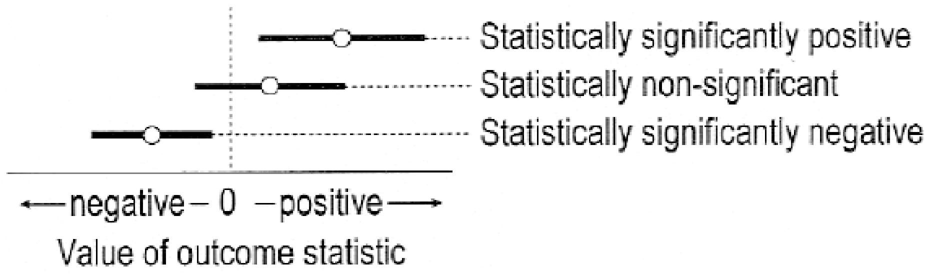

Figure 2.6: Negative, positive and non-significant magnitudes. Only 3 inferences can be drawn when the possible magnitudes represented by the likely range in the true value of an outcome statistic (the confidence interval, shown by horizontal bars) are determined by referring to a 2-level (positive and negative) scale of magnitudes. Source Batterham et al 2006, pg 52.

2.9.2 The countermovement jump

The CMJ is a practical tool routinely (Cormack, Newton et al. 2008a; Cormack, Newton et al. 2008b) used to quantify neuromuscular fatigue and the extent of recovery in athletes (Carlock, Smith et al. 2004; Cormack, Newton et al. 2008c). The CMJ is far less time consuming and demanding of the athlete compared to other performance measures such as sprint testing (single and repeated) and dynamometry. It is essential to quantify the impact of training/competition on the neuromuscular system to allow effective planning of training (Cormack, Newton et al. 2008a), to monitor recovery progress, and the effectiveness of recovery. The elastic behaviour of leg extensor muscles are similar in a vertical jump and running (Bosco, Montanari et al. 1987). Hence, when running is a principal component of a sport, a vertical jump assessment, such as the CMJ, is useful for assessing neuromuscular fatigue (Bosco, Montanari et al. 1987), and displays a high level of reliability (Table 2.3). The CMJ has been used extensively and validated as an indicator of neuromuscular fatigue amongst AF athletes (Cormack, Newton et al. 2008a; Cormack, Newton et al. 2008c). Although this does not reflect the athlete's ability to replicate in-game physical performance, it can be used as a monitoring tool. When the athlete's typical 'free from fatigue' jump performance is determined, as well as their natural variation in said performance, substantial deviations in performance may indicate fatigue. The CMJ is also used to evaluate changes in lower limb force and power capabilities following intensive training programs (Sheppard, Cormack et al. 2008), a predictor of strength and weightlifting performance (Carlock, Smith et al. 2004; Nuzzo, McBride et al. 2008; Vizcaya, Viana et al. 2009), and a training adaptation monitoring tool (Cormie, McBride et al. 2009).

Table 2.3: Reliability of measures obtained using a countermovement jump.

Population	Measurement tool	Measurement variable	CV % (TE)	ICC
Elite AF athletes (Cormack, Newton et al. 2008c)	Force platform	Mean force (N)	1.1 % (13)	-
		Relative mean force (N/kg)	1.2 % (13)	-
		Flight time (sec)	2.9 % (0.017)	-
Students and colleagues (Slinde, Suber et al. 2008)	Contact mat	Calculated jump height	-	0.93
National level weight lifters (Carlock, Smith et al. 2004)	Contact mat	Calculated jump height	-	0.98
Physically active men (Moir, Button et al. 2004)	Contact mat	Calculated jump height	2.4 % (95 % CI 1.5-3.9)	0.93, 95 % CI 0.85-0.98
Physical education students (Markovic, Dizdar et al. 2004)	Contact mat	Calculated jump height	2.8 %	0.98
Experienced jumpers (Brandenburg, Pitney et al. 2007)	Contact mat	Calculated jump height	-	0.97
Physically active men (Hori, Newton et al. 2009)	Force platform	Peak power, peak force, and peak velocity	1.3-4.1 %	0.92-0.98

Reliability reported as Coefficient of variation % (CV%); technical error (TE). The test-retest reliability is also shown with the intra class correlation coefficient (ICC).

2.9.3 The measurement of muscle damage to assess post exercise recovery

The most commonly employed technique to indirectly quantify the level of muscle damage is the analysis of blood biochemical markers of muscle damage. Figure 2.7 displays the time course of release and decay of this biochemical marker. The ability to assess muscle damage through blood samples is far less invasive, and provides a more practical alternative to muscle biopsies. When the structural integrity of the muscle fibre is compromised, intracellular enzymes and proteins, such as CK (isoenzyme CK-MM, found in the myofiber (Crinnion, Homer-Vanniasinkam et al. 1994)) and Mb, are released and the blood concentration of these rise (Brancaccio, Limongelli et al. 2006; Brancaccio, Maffulli et al. 2007). Plasma [Mb] is elevated following half marathon running, American football, soccer, rugby and boxing (Zuliani, Bonetti et al. 1985; Hoffman, Maresh et al. 2002; Takarada 2003; Lippi, Schena et al. 2008; Kraemer, Spiering et al. 2009), providing an estimation of the extent of muscle damage caused by these activities (Table 2.4).

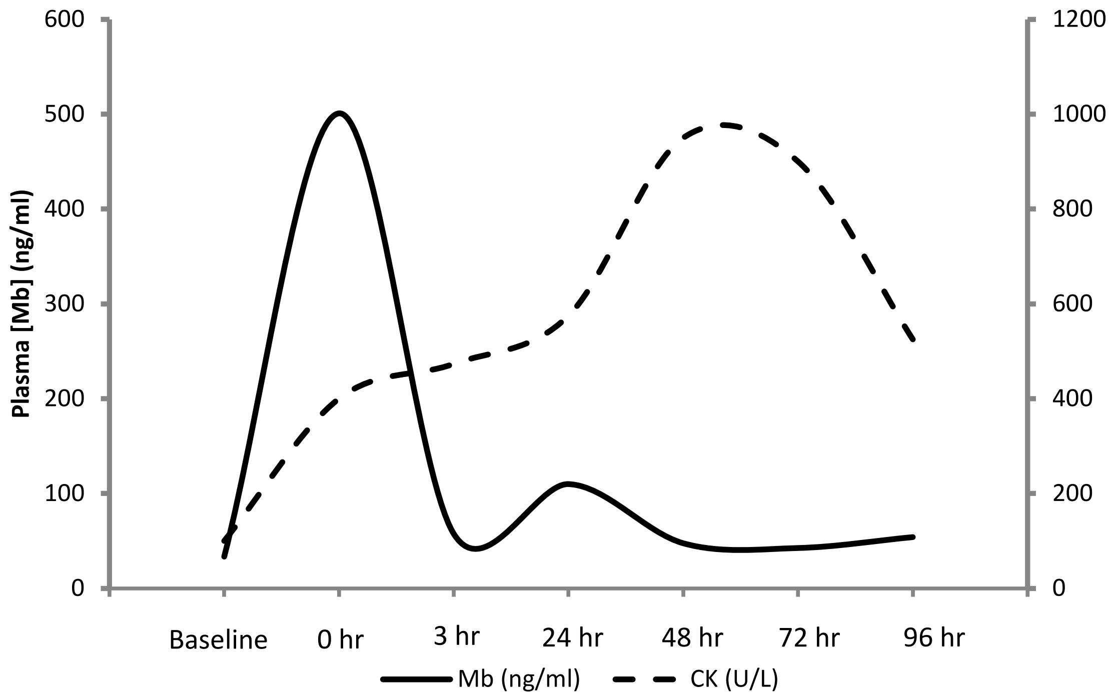

Figure 2.7: The release and breakdown of muscle damage markers after exercise. The solid line represents plasma myoglobin concentration ([Mb]) and the broken line represents plasma Creatine kinase concentration ([CK]). Adapted from: (Zuliani, Bonetti et al. 1985; Sorichter, Mair et al. 2001; Takarada 2003; Peake, Nosaka et al. 2005; Peake, Nosaka et al. 2006; Ascensao, Rebelo et al. 2008; Ispirlidis, Fatouros et al. 2008; Lippi, Schena et al. 2008; Neubauer, Konig et al. 2008; Kraemer, Spiering et al. 2009).

Table 2.4: Changes in Myoglobin concentration following various exercise modalities.

Exercise mode	Pre exercise [Mb] concentration ($ng.ml^{-1}$)	Post exercise [Mb] concentration ($ng.ml^{-1}$)	24 h Post exercise [Mb] concentration ($ng.ml^{-1}$)
Laboratory based research			
Downhill running well trained (10 % decline, 45 min) (Peake, Suzuki et al. 2005)	~25	~450	~ 70
20 min downhill running (16 % decline) (Sorichter, Mair et al. 2001)	57; 43-63 (median; IQR)	500 (median)	60 (median)
Field based research			
Rugby game (Takarada 2003)	- Positive correlation (r=0.85) between [Mb] and number of tackles. - Peak [Mb] (45min post) was 980±166 $ng^{\cdot}ml^{-1}$. - One participant exhibited a post game [Mb] of 1641 $ng^{\cdot}ml^{-1}$ consequent to a tackle.		
Soccer game (Ascensao, Rebelo et al. 2008)	~25	~350	~50
21km Half Marathon (Lippi, Schena et al. 2008)	36.3	102 (note: 73 % of samples were above reference values)	47 (note: 27 % of samples above reference value)
Ironman triathlon (Neubauer, Konig et al. 2008)	-	~ 2000	~ 500
American Football (Kraemer, Spiering et al. 2009)	~ 45	-	95 ($ng^{\cdot}ml^{-1}$) (18-20 hr post)
Boxing (3 x 3min rounds with 1 min rest) (Zuliani, Bonetti et al. 1985)	15 ($ng^{\cdot}ml^{-1}$)	52±27 ($ng^{\cdot}ml^{-1}$)	75±36 (5 hr post); 27±21 (16 hr post)

Values are expressed in nanograms per milliliter ($ng.ml^{-1}$), and mean ± standard deviation.

Plasma/serum concentration of creatine kinase ([CK]) is the other widely investigated biochemical indicator of muscle damage. Figure 2.7 displays the time course of release and decay of this biochemical marker. The use of CK to investigate muscle damage and the effectiveness of an intervention is questionable. Specifically, [CK] varies markedly (Nosaka, Clarkson et al. 1991; Aughey 2011), with high and low responders (Nosaka and Clarkson 1996). Participants exposed to the same exercise can experience a large variation in post exercise peak [CK] activity, which in one study ranged from 236 to 25,244 $IU \cdot L^{-1}$(Nosaka and Clarkson 1996). The authors note that this variability could be partly explained by an adaptation or training effect (Nosaka and Clarkson 1996). However short-term immobilisation after eccentric exercise does blunt the CK, but not Mb response, where the lymphatic transport of CK is likely responsible (Sayers and Clarkson 2003). As such, when the level of activity post exercise cannot be controlled, CK may be an inappropriate marker.

Circumference measurements of limbs are taken as an indicator of acute changes in limb volume (Chleboun, Howell et al. 1995; Eston and Peters 1999) which are likely to occur from osmotic fluid shifts or inflammation associated with muscle-damage (Fielding, Violan et al. 2000). Investigations typically do not take into consideration the possible contribution of increased muscle blood flow to post exercise changes in limb circumferences. In addition to the practical and non-invasive nature of this measure, it also displays a good level of reliability (technical error of measurement = 1.48% to 4.59%).

2.9.4 Measurement of perceptions of soreness and fatigue to assess recovery

Perceptions of soreness and fatigue are anecdotally used by coaches and practitioners as an indication of the state of recovery, and readiness to train. This provides a practical and non-invasive means to investigate the level of recovery experienced, with such assessment completed through the use of questionnaires. A commonly used form is the visual analogue scale (VAS). The VAS has been used extensively in clinical settings displaying good reliability (Spearmans r = 0.60 to 0.77) (Boonstra, Schiphorst Preuper et al. 2008). This scale is also commonly used in sporting settings and sport science research (Cleather and Guthrie 2007; Montgomery, Pyne et al. 2008b). Indeed, the 7-point Likert scale and VAS display similar sensitivity to muscle soreness caused by eccentric contractions during the first 96 hours after plyometric exercises (Impellizzeri and Maffiuletti 2007). However, correlations between levels of muscle soreness and functional performance are not always strong (Rodenburg, Bar et al. 1993). Following eccentric arm curl exercise, force production did not correlate with measures of soreness. The authors suggest that when possible, more objective measures, such as that of plasma [CK] or [Mb] be measured, as these are more tightly correlated with functional performance during 24, 48, 72 and 96 hr of recovery (Spearmans r = -0.47 to -0.90) (Rodenburg, Bar et al. 1993). However within actual sporting scenarios, it is not always possible for practitioners to collect blood samples, particularly in the elite environment. Thus subjective measures of soreness and fatigue may be warranted, as long as the weak correlations to performance are understood by the practitioner. When using a VAS, participants are asked to rank their perception of soreness and fatigue on an unmarked horizontal line (100 mm in length) with ‘No soreness/fatigue’ and ‘Very severe soreness/fatigue’ at each end. The participant’s score is then calculated based on the number of millimetres their ‘ranking’ (in the form of a marked line on the scale provided) is placed from the ‘No soreness/fatigue’ end of the scale (Wewers and Lowe 1990). Consequently this provides a quick, easy, and practical tool to assess athlete perceived soreness and fatigue.

2.10 The placebo effect in sports performance: possible action of compression garments

The placebo effect occurs when a positive outcome results from the belief that a beneficial treatment has been received (Clark, Hopkins et al. 2000). Ultimately, the placebo effect catalyses or reinforces the individuals expectation of the intervention via a ‘belief intervention’ (Beedie and Foad 2009). Increased expectations of an intervention lead to increased activity in the medial orbitofrontal frontal cortex (Plassmann, O'Doherty et al. 2008), an area of the brain that encodes for expected pleasantness (McClure, Li et al. 2004; Rolls, Grabenhorst et al. 2008). What’s more, increased activity in the medial orbitofrontal frontal cortex is seen even when participants are prompted to think about a particular stimuli, without actual exposure (Rolls, Grabenhorst et al. 2008). Psychological variables including motivation, expectancy and conditioning, and the interaction of these variables with physiological variables, may be significant factors in eliciting both positive and negative outcomes (Beedie and Foad 2009). The individual’s belief in the intervention may increase motivation and perhaps a greater than usual attention to training and recovery. Such responses, although behavioural, satisfy the definition of a placebo effect.

Wearing compression garments for recovery between cycling bouts assisted in the maintenance of cycling power compared to a control condition (Chatard, Atlaoui et al. 2004). Of interest, fifty percent of participants reported that the garments could have modified their second performance either a bit, or a lot, with the authors noting that a placebo effect could not be ruled out (Chatard, Atlaoui et al. 2004). However, the contribution of the placebo effect in this case is not completely certain, as a placebo group was not included for comparison.

Determining the contribution of the placebo effect, particularly when participants have previously worn compressions garments, and possess pre-existing beliefs regarding their actions is difficult. For example, netball circuit (Higgins, Naughton et al. 2009) and cycling time trial performance (De Glanville and Hamlin 2012) are both superior when wearing compression garments compared to a placebo group. It may be argued that this reflects a ‘true’ effect for compression garments. However, participants in both investigations were well trained, and it is likely that they previously had worn compression garments, and were able to differentiate between wearing a ‘real’ versus placebo compression garment. This may have led them to perform better when wearing the ‘real’ garment. Additionally, this population type is likely to possess pre-existing beliefs regarding the efficacy of such garments as a recovery tool, further contributing to the improved performance. However, in both experiments, participants were randomised in a counterbalanced order into the placebo or compression garment group, and were blinded to their condition (Higgins, Naughton et al. 2009; De Glanville and Hamlin 2012). It is expected that this designed swamped the placebo effect, particularly if the participants truly believed they were wearing compression garments in the placebo conditions. Without information regarding which condition participants believed they were in, and if they believed compression garments were a useful recovery tool, these theories remain speculative. Ultimately, it is impossible to rule out the likelihood that the placebo effect may account for some of the effectiveness of compression garments on post exercise recovery.

2.11 Summary of the literature

Australian football training and competition are characterised by a considerable level of physical contact (Dawson, Hopkinson et al. 2004b; Dawson, Hopkinson et al. 2004a) overlaid on large volumes of high intensity, intermittent running based activity (Duffield, Coutts et al. 2009; Aughey 2010; Coutts, Quinn et al. 2010; Aughey 2011). Reductions in in-game performance suggest that elite AF players experience fatigue during games (Duffield, Coutts et al. 2009; Aughey 2010; Coutts, Quinn et al. 2010). This more temporary fatigue is likely attributed to disturbances to ionic (Pate and Cooke 1989; Clausen 2003) and metabolic (Dawson, Gadian et al. 1978; Meissner, Darling et al. 1986; Dutka and Lamb 2004) regulation in addition to an altered central drive (Kernell 1969; Garland 1991; Macefield, Hagbarth et al. 1991; Garland and Kaufman 1995; Taylor, Allen et al. 2000; Gandevia 2001). These athletes also experience reductions in performance attributed to fatigue that may last hours to days following training/competition (Hoffman, Nusse et al. 2003; Ascensao, Rebelo et al. 2008; Cormack, Newton et al. 2008a; Oliver, Armstrong et al. 2008; McLean, Coutts et al. 2010), with the recovery of performance falling somewhere along a continuum. Some of the in-session fatigue may be recovered with a short rest period, whereas other components of fatigue may require hours to days to recover. Further, as discussed in Section 2.6.9, muscle soreness may also contribute to a reduced neural drive during this recovery period. It is likely that prolonged performance reductions are attributed in part to EIMD, with indicators of EIMD present following team sport exercise (Hoffman, Maresh et al. 2002; Takarada 2003; Hoffman, Kang et al. 2005; Ascensao, Rebelo et al. 2008; Ispirlidis, Fatouros et al. 2008) (Section 2.6.5). Ultimately, recovery interventions, with the aim to return performance, perceptual and biochemical parameters to within homeostatic ranges, focus on abating fatigue, muscle damage and soreness.

Compression garments, a fashionable recovery intervention amongst the athlete population, are proposed to accelerate between session recovery, based on alterations to the lymphatic and vascular systems as outlined through clinical research (Swedborg 1984; Mayberry, Moneta et al. 1991; Yasuhara, Shigematsu et al. 1996; Johansson, Lie et al. 1998; Jonker, de Boer et al. 2001). Indeed, these garments are proposed to reduce oedema, and subsequently muscle soreness through the mechanical blocking of the oedema (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Beidler, Douillet et al. 2009). This in turn may accelerate the post exercise recovery of performance. It is also suggested that wearing compression garments permits the limbs to remain in anatomical positions when not used, affording straight-line tissue repair geometrics (Kraemer, Bush et al. 1998a; Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b). Wearing compression garments exerts the strongest positive effects on post exercise recovery in untrained individuals, notably following severely damaging protocols (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a), with lower levels of muscle soreness and a greater recovery of performance (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b). The impact on biochemical parameters does vary depending on the indices assessed (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a), and in some cases remains completely unaltered (Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). When worn for recovery, the most consistently reported positive action of compression garments on trained individuals is the blunting of muscle soreness (Duffield, Edge et al. 2008; French, Thompson et al. 2008; Montgomery, Pyne et al. 2008b; Davies, Thompson et al. 2009; Duffield, Cannon et al. 2010). When assessing the recovery of performance, well trained participants experienced an improved recovery in some but not all variables (French, Thompson et al. 2008; Montgomery, Pyne et al. 2008b; De Glanville and Hamlin 2012), with the recovery of some performance parameters actually worsened with compression garment use compared to a control (French, Thompson et al. 2008; Montgomery, Pyne et al. 2008b). The biochemical responses to wearing compression garments, with specific reference to muscle damage, are currently unknown amongst trained individuals (French, Thompson et al. 2008; Montgomery, Pyne et al. 2008a). Research is yet to investigate possible recovery differences between medical and sports style compression within athletic scenarios. Further, the efficacy of such garments when worn during recovery following AF activities remains unknown.

2.12 Significance/influence on athletic performance

The use of recovery interventions, in particular compression garments, is a topical issue. There is a large body of evidence to suggest that their use is ineffective at enhancing recovery. Consequently, athletes and exercise practitioners have been unable to make informed decisions about whether compression garments might be the most appropriate recovery modality for their athletes. Further research is required to enable coaches and athletes alike to base their choice of recovery intervention on scientific evidence.

2.13 Statement of the problem

The present thesis investigated the efficacy of post exercise compression garment use to enhance recovery. Specifically, performance, perceptual and physiological parameters were investigated. Compression garment use is prevalent amongst team sport athletes, particularly AF. This particular code of football is characterised by high locomotive and physical activities, deeming it an appropriate model to investigate the influence of compression garment use on recovery. Current research on the influence of compression garments on performance, perceptual and biochemical parameters is sparse and in-conclusive. Further, research has failed to investigate the influence of compression garment use on recovery in elite athlete post training and in-season competition settings. As such, high quality research pertaining to changes in said variables secondary to compression garment usage is warranted.

2.14 Specific aims of the studies

This thesis aimed to investigate the influence of post-exercise compression garment usage on the augmentation of recovery.

2.14.1 Chapter 4: The effects of compression garments on high intensity intermittent exercise performance and recovery on consecutive days.

This study aimed to elucidate the influence of between session sports compression garment use on recovery when worn between three once daily repeat sprint exercise sessions in recreationally active individuals.

2.14.2 Chapter 5: Recovery following elite Australian football training.

The purpose of this investigation was to explore the influence of wearing compression (sport and medical) garments to facilitate recovery from two elite AF training sessions. Further, this investigation aimed to illustrate possible recovery differences present between medical and sports compression garments. This investigation also sought to determine if positive recovery effects associated with wearing compression garments would be consistent and reproducible when two elite AF training sessions were conducted.

2.14.3 Chapter 6: Recovery effects of medical and sports compression garments after elite Australian football competition.

First, this study aimed to investigate whether wearing compression (medical and sports) garments could accelerate post competition recovery in elite AF athletes. A secondary aim of this investigation was to decipher possible differences in the recovery capacity between medical and sports compression garments. This investigation also aimed to elucidate performance, perceptual and biochemical responses to elite AF competition.

CHAPTER 3. GENERAL METHODS

General methods used in Chapter 4, 5 and 6 are described below. Chapter specific methods are detailed within the methods section of each relevant chapter.

3.1 Biochemical sampling and analysis

Prior to blood sampling, participants lay quietly for 5 min to minimise posture induced fluid shifts (Fawcett and Wynn 1960). A 22 gauge needle was inserted into an antecubital vein, and blood was drawn into a 5 mL (Chapter 4 and Chapter 6) or 10 mL (Chapter 5) syringe. Whole blood (0.5 mL) was analysed for haematocrit and haemoglobin in duplicate using electrical resistance detection (Sysmex K-800, TOA Medical Electronics CO, LTD, Kobe, Japan). From these measurements plasma volume changes were calculated (Dill and Costill 1974). Remaining whole blood was transferred into a sterile vacutainer containing EDTA (Greiner Bio One, Frickenhausen, Germany) and was centrifuged (Allegra™ 25R Centrifuge, Palo Alto, CA, USA) at 2500 RPM for 10 min at 4°C to separate plasma and stored at -80°C prior to subsequent analysis of plasma Myoglobin concentration ([Mb]).

Plasma [Mb] was determined by a commercially available enzyme immunoassay kit (Myoglobin Enzyme ImmunoAssay Test Kit, Oxis International Inc, Foster City California, USA). In all chapters, plasma [Mb] samples were tested in duplicate at all sample points. These duplicate measures were used in a custom spreadsheet (Hopkins 2000) to determine the reliability of the assay. The reliability (coefficient of variation, as a percentage (CV%) for this measure was 11.7% (Chapter 4), 9.1% (Chapter 5), and 7.3% (Chapter 6) (Hopkins 2000). The smallest worthwhile change (SWC) (Section 3.4.2) in plasma [Mb] was 14.8% and 11.6% in Chapters 4 and 6. Chapter 5 consisted of two individual components, the SWC% for plasma [Mb] was 12.3% for training session 1 and 9.2% for training session 2 (Batterham and Hopkins 2006).

3.2 Perceptual measures

Perceived muscle soreness and fatigue were ascertained via two independent visual analogue scales (Chapter 4, 5 and 6). See appendices in Section 9.6.1 and 9.6.2 for the VAS scales used. Perceptions of soreness and fatigue were ranked on an unmarked horizontal line (100 mm in length) with 'No soreness/fatigue' and 'Very severe soreness/fatigue' at each end. Scores were calculated based on the number of millimetres the 'ranking' (in the form of a marked line on the scale provided) was placed from the 'No soreness/fatigue' end of the scale (Gould D, Kelly D et al. 2001). A rating of perceived exertion (RPE) (Chapter 4, 5, and 6)was recorded immediately after the completion of exercise using a 10 point scale (Borg 1982) . The SWC for perceived muscle soreness was 23.0% in Chapter 4. The SWC for perceived muscle soreness was 17.4% and 8.1% for training session 1 and 2 in Chapter 5, and 11.9% in and 6. The SWC% for perceived fatigue was 16.5% in Chapter 4. The SWC for perceived fatigue was 13.7% and 6.7% for training session 1 and 2 in Chapter 5, and 11.1% in Chapter 6.

3.3 Performance measurement: Countermovement jump

Prior to all testing, the force platform was calibrated following the associated softwares standard procedures. With hands on hips, players performed a single CMJ (Cormack, Newton et al. 2008a) on a commercially available force plate (400 Series Performance Plate – Fitness Technology, Adelaide, Australia) connected to a computer running software (Ballistic Measurement System – Fitness Technology, Adelaide, Australia) (Chapter 5 and 6). A sample rate of 200 Hz was set (Hori, Newton et al. 2009). The depth of the CMJ was self-selected (Domire and Challis 2007).

A warm up was conducted prior to baseline measures at ‘Pre’ and follow up testing of the CMJ. In Chapter 5, players completed a standardised six minute warm up, including three practice CMJ prior to testing at Pre and 24 hr post (+24). In Chapter 6, players completed a 10 min AF specific warm up at a self-selected intensity prior to Pre game testing, and moderate intensity cycling (3 min) on a stationary bicycle was completed prior to the +40 CMJ taken 40 hr following the game. Post game (Chapter 6) CMJ measures were not preceded by a warm up as this sample time point was immediately after the game. The CMJ warm up technique differed between Pre and +40 in Chapter 6 due to the availability of equipment and a different testing location.

The most useful CMJ variables for monitoring neuromuscular fatigue in an elite AF population are flight time (FT, seconds), and flight time:contraction time ratio (FT:CT) (Cormack, Newton et al. 2008a; Cormack, Newton et al. 2008c). Consequently, FT (Chapter 5 and Chapter 6) and FT:CT (Chapter 6) were acquired at each sample point.

In Chapter 5, athletes performed a CMJ prior to each of the training sessions conducted, which were separated by seven days. Athletes had experienced a three day break from training activities prior to each of the training sessions. These CMJ scores for FT were analysed using a custom spreadsheet to determine the level of reliability of CMJ FT, producing a coefficient of variation (CV%) of 36.9%. In Chapter 6, athletes performed a CMJ prior to the main training session leading up to the game (approximately -72 hr) as well as part of the pre game program. The CMJ test scores were compared using a custom spreadsheet to determine the level of reliability of CMJ FT and FT:CT. Expressed as a CV%, they were 2.8% (FT) and 18.7% (FT:CT) respectively. The difference in the time between CMJ sampling for reliability purposes in Chapter 5 (7 days) and Chapter 6 (3 days) may have contributed to this discrepancy in CV% for FT. This effect was possibly compounded by the effect of previous training sessions (Chapter 5) which may have influenced jump performance, despite a three day break prior to each of the training sessions. Data collection in the pre-season phase could have exacerbated this effect due to the typically high training loads. Indeed, although not required to attend formal training with the club during this three day break, athletes were not prohibited from partaking in activities that may have influenced neuromuscular fatigue levels. What's more, athletes were not required by the club to complete the same activities in the three days preceding each of the training sessions. In both Chapter 5 and 6 access to athletes was limited, and thus familiarisation and more thorough reliability testing was not possible.

The reliability of CMJ FT displayed in the athletes in Chapter 5 and 6 is vastly different to that displayed by other elite AF athletes (CV% =3.1%) (Cormack, Newton et al. 2008c). Similarly, the reliability of CMJ FT:CT displayed in athletes in Chapter 6 was also different to that displayed by other elite AF athletes (CV% =8.2%) (Cormack, Newton et al. 2008c). Limited access to the athletes prevented familiarisation of the countermovement jump, likely contributing to this measurements variability. The athletes were expected to be familiar with correct CMJ technique, as they partook in weekly CMJ testing as part of their weekly monitoring conducted by sport science staff. The SWC% (Batterham and Hopkins 2006) for CMJ FT was identified as 6.8% and 1.0% for training session 1 and 2 in Chapter 5; and 1.6% in Chapter 6. In Chapter 6, the SWC% (Batterham and Hopkins 2006) identified for FT:CT was 6.9%.

3.4 Statistical analysis

3.4.1 Data preparation

Change scores for all raw data were plotted against pre-test values to identify any heteroscedasticity (non-uniformity of error) in the data. Data was subsequently log transformed to increase the uniformity in the effect of the treatment. These analyses were conducted using processes embedded in custom designed spreadsheets (Hopkins 2006b) used for each chapter to identify treatment effects for both cross over trials (Chapter 4) and parallel group trials (Chapter 5 and 6). In Chapter 5, CMJ FT data was normalised against Pre values prior to analysis using the methods described below. Within the spreadsheets, the smallest effect was set to Cohen's effect size 0.2, representing a small effect. This is an acceptable threshold when there is no clear indication in the participant groups used as to the smallest important value to include (Hopkins 2006b). This threshold was used by the spreadsheet to estimate the chances any treatment effect was a true effect, termed a substantial effect. Ninety percent confidence intervals were set in each batch of analysis to determine the likely range of the true value. Data were excluded as outliers if their value was greater than, or less than, two times the standard deviation of the mean.

3.4.2 Analysis of treatment effects

All data were analysed using effect size statistics to determine the magnitude of treatment effects on performance, perceptual and biochemical variables. The final outcome statistic represented the difference in a change, which is the difference between groups in their mean change due to the experimental and control treatments using a pair-wise comparison. This was expressed as a percentage (%) with the associated effect size and 90% confidence intervals (%, ES±90%CI). Magnitudes of change were classified as a substantial increase or decrease when there was a ≥ 75% likelihood of the effect being equal to or greater than the SWC estimated as 0.2 x between subject standard deviation (small ES). If the chance of higher or lower differences was >5 %, the true difference was assessed as 'unclear'. Effect size statistics were classified according to the following: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, 2.0-4.0 very large, >4.0 extremely large (Hopkins 2004). Effects with less certainty were classified as trivial and where the ± 90% CI of the ES crossed the boundaries of ES -0.2 and 0.2, the effect was reported as unclear (Batterham and Hopkins 2006). Where a treatment effect is observed, the chances (% and qualitative) that the true value of the statistic is mechanistically or practically probable is reported. The qualitative probabilities are defined by the following scale: <0.5%, almost certainly not, <5%, very unlikely, <25%, unlikely, probably not, 25-75%, possibly, possibly not, >75%, likely, probably, >95%, very likely, >99.5%, almost certainly (Hopkins 2006b).

To determine potential differences in the duration that compression garments were worn (Medical lower body compression garment: Med; and a commercially available sports style compression garment: Spo) (Chapter 5 and 6), a custom spreadsheet designed for the analysis of post-only crossover trial with adjustment for a predictor (Hopkins 2006b) was used. This same spreadsheet was used to determine differences in internal loads (Chapter 5 and 6), minutes of game time played (Chapter 6), and session RPE (Chapter 5 and 6).

To assess between group differences in the magnitudes of change in variables in Chapter 4, a custom spreadsheet designed for the analysis of a pre-post crossover trial with adjustment for a predictor (i.e. covariate) was used (Hopkins 2006b). Each variable was assessed in an individual spreadsheet, with pair-wise comparisons made between each time point. Work (kJ) conducted during repeat sprint exercise bout one was used as a covariate in the analysis of perceptual and biochemical variables (Chapter 4). As order effects were not accounted for in the spreadsheet, participants were randomised to the control and treatment group in a counterbalanced manner. Chapter 5 and 6 used a custom designed spreadsheet to assess a parallel groups trial (Chapter 5 only) (Hopkins 2006b). A separate spreadsheet was used for each treatment comparison.

To assess between group differences in variables at a specific sample time point in Chapter 4, 5 and 6, a custom spreadsheet for the analysis of a post-only crossover trial, with adjustment for a predictor where required (Chapter 4), was used (Hopkins 2006b). These differences were expressed as a percentage difference and ES±90% CI.

In Chapter 4, Pearsons correlation (*r*) for the change in perceived muscle soreness and fatigue was calculated using a custom spreadsheet (Hopkins 2000). The variance explained (R^2) was calculated for this relationship as r^2 x 100, and expressed as a percentage.

The SWC% for perceptual, biochemical and performance parameters was calculated as 2 x the between subject standard deviation expressed as a coefficient of variation (Batterham and Hopkins 2006) which was calculated through processes embedded within a custom spreadsheet (Hopkins 2006b).

3.4.3 Reliability

Analysis of reliability with a custom spreadsheet (Hopkins 2000) was used to determine the reliability of countermovement jump performance (Chapter 5 and 6) and plasma [Mb] (Chapter 4, 5 and 6). Reliability was expressed as the coefficient of variation (CV%). Due to the subjective nature of perceptual measures of perceived fatigue and muscle soreness, the CV% was not calculated.

CHAPTER 4. THE EFFECTS OF COMPRESSION GARMENTS ON HIGH INTENSITY INTERMITTENT EXERCISE PERFORMANCE AND RECOVERY ON CONSECUTIVE DAYS

4.1 Introduction

The positive effects of compression garment use for recovery of performance tests, perceptual and biochemical parameters are typically reported following severely damaging exercise protocols executed by untrained participants (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). These studies typically have the advantage of tighter control, but may therefore lack external validity if trying to extrapolate results to athletic scenarios and populations. It is thus a lot less clear if trained individuals can gain positive recovery effects from these garments (Duffield, Edge et al. 2008; Montgomery, Pyne et al. 2008a; Montgomery, Pyne et al. 2008b).

When more typical athletic exercise has been used in compression studies, there has been a failure to elicit performance decrements, and thus proper investigation of compression for the recovery of performance. For example, sprint performance and tackling power were unchanged following a rugby circuit, deeming recovery effects of compression garments inconclusive (Duffield, Edge et al. 2008). Positive recovery effects on test performance were also unclear 24 hr following a sprint and plyometric protocol, where lower body strength was not diminished (Duffield, Cannon et al. 2010).

In a study that did induce performance decrements, 30 m sprint times were actually worse when wearing compression garments for recovery following resistance exercise (French, Thompson et al. 2008). Likewise, athletes wearing compression between three basketball games actually performed worse at a vertical jump and 20 m acceleration test compared to control participants (Montgomery, Pyne et al. 2008b). However, those who wore the garments did perform better for agility and line drill ability compared to control (Montgomery, Pyne et al. 2008b). It is unclear as to why such discrepancies in the recovery of performance occurred within the one study.

Whether wearing compression garments influences post exercise markers of muscle damage remains to be elucidated. Following drop jump (Davies, Thompson et al. 2009) and resistance exercise (French, Thompson et al. 2008) performed by trained individuals, serum [CK] and [Mb] were not elevated, making comparisons with control groups difficult. Therefore protocols using trained participants must be sufficiently damaging to overcome the pre-conditioning 'protective' effects of prior exercise (Nosaka and Newton 2002; Bowers, Morgan et al. 2004; Nosaka, Newton et al. 2005; Chen, Chen et al. 2009). Yet despite an elevated serum [CK] following resistance exercise performed by trained individuals, wearing compression garments did not facilitate lower serum [CK] compared to control (French, Thompson et al. 2008). It may be that the variable nature of plasma and serum CK responses following exercise (Nosaka, Clarkson et al. 1991; Aughey 2011) precluded observation of an effect of compression garments. When the protocol is sufficiently demanding, and an appropriate marker is used, such as the plasma Mb response following three days of basketball game play, compression garments did not lower serum [Mb] compared to control (Montgomery, Pyne et al. 2008a). However the influence of game activities such as jumping and sprint number, which contribute to muscle damage, were not accounted for. Thus a study with a controlled number of high intensity activities, known to be fatiguing is required to help answer this question. It is also quite possible that compression garments do not actually influence the concentration of circulating biochemical markers of muscle damage. Without information on the rate of entry, and clearance of such markers into the blood, it is difficult to determine.

Positive effects of compression on perceived muscle soreness are observed following not only severely damaging protocols performed by untrained individuals, such as eccentric arm curl exercise (Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a) and plyometric activity (Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a), but also following exercise protocols that attempt to mimic training and game activities (Duffield, Edge et al. 2008; French, Thompson et al. 2008; Montgomery, Pyne et al. 2008b; Davies, Thompson et al. 2009; Duffield, Cannon et al. 2010). Similarly, lower perceived fatigue and higher ratings of vitality are observed following basketball game play (Montgomery, Pyne et al. 2008b) and resistance exercise (Kraemer, Flanagan et al. 2010) with compression. Perceptual parameters appear more easily influenced not only by the exercise protocol adopted, but also through the use of compression garments for recovery. It is anticipated that the most common effects of compression garments are improved perceptual measures, and that they may be in part attributed to the placebo effect (Chatard, Atlaoui et al. 2004; Higgins, Naughton et al. 2009; De Glanville and Hamlin 2012).

This study therefore sought to investigate performance, physiological and perceptual recovery effects of compression garments following an exercise task both known to elicit fatigue and with external validity to team sport (Duffield, Coutts et al. 2009; Aughey 2010; Coutts, Quinn et al. 2010; Aughey 2011). A further aim of this investigation was to test if compression garments were able to augment recovery in an acute 24 hr period as well as following repeated daily exercise, which more accurately reflects the training schedule and tournament scenarios of elite athletes.

4.2 Methods

Data collected for this study was part of a larger investigation. A third group was included in this larger investigation where participants ingested a pre-exercise antioxidant supplement (N-Acetyl Cysteine). A one week wash out period was provided between each condition. When participating in the control and sports compression condition, participants did not consume this antioxidant supplement. This chapter will deal exclusively with the results obtained from the control and sports compression groups only. The results pertaining to antioxidant supplementation are beyond the scope of this thesis.

4.2.1 Participants

Nine healthy, recreationally active individuals (7 males and 2 females; 25.1 ± 3.7 yrs; height 174.1 ± 8.7 cm; body mass 70 ± 12.6) (Mean ± Standard Deviation)) gave written informed consent to participate. All participants completed each component of the study. The experimental protocol was approved by the Victoria University Human Research Ethics Committee. Sample size estimation on the fly (Hopkins 2006a) was used whereby the magnitudes of change observed in all parameters was assessed against the SWC.

4.2.2 Familiarisation Sessions

Prior to familiarisation, participants performed a Yo-Yo Intermittent Recovery Test 1 (Yo-Yo IR1) (Bangsbo, Iaia et al. 2008). The motorised treadmill speed during the warm up prior to the repeat sprint exercise (RSE) was set at 60% of the participant's peak speed, correlating to their predicted $\dot{V}O_{2peak,}$ as determined from their Yo-Yo IR1 result (Serpiello, McKenna et al. 2011). Participants completed two familiarisation sessions on the non motorised treadmill to gain awareness and confidence with the equipment. Each familiarisation session required the participant to undertake a condensed version of the RSE protocol. Participants performed two sets of five 4-second sprints on the non-motorised treadmill. Each sprint was interspersed by 20 seconds passive recovery, with four and a half minutes passive recovery between each set (Serpiello, McKenna et al. 2011).

4.2.3 Experimental overview

Participants were instructed to refrain from physical activity and caffeine consumption in the 24 hours preceding all testing sessions. Seven days following the final familiarisation, participants commenced the testing phase of the study (See Figure 4.1). The RSE was conducted once daily, for three consecutive days. This was repeated twice, with a one week wash-out period between conditions. Two hours prior to RSE, participants consumed sport drink (Gatorade^{TM} 750 mL) across a one hour period. Plasma [Mb] (See Section 3.1), and perceived muscle soreness and fatigue data (See Section 3.2) were collected pre (Pre) and after (Post) each of the three RSE sessions (RSE1, RSE2 and RSE3), and 24 hr (+24) following RSE3. Participants removed compression garments before completing the measures 24 hr post each of the RSE sessions. A further perceptual measure, rating of perceived exertion (RPE) (See Section 3.2) was collected Post each RSE. Chilled water (250 mL) was consumed during each RSE session. Dietary intake, particularly carbohydrate, was not controlled as it was unlikely that glycogen depletion would influence performance (Hargreaves, McKenna et al. 1998).

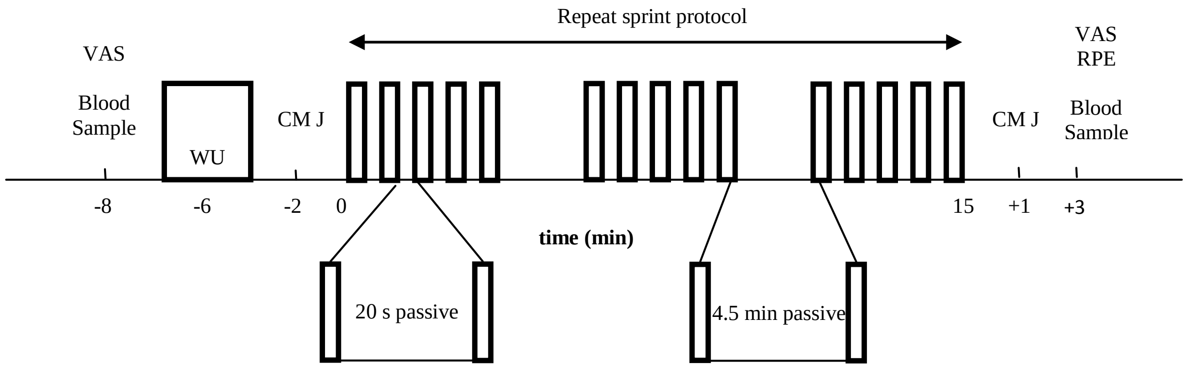

Figure 4.1: Overview of the repeat sprint exercise (RSE) protocol. The open bars denote each 4 second sprint. WU = warm up; CMJ = countermovement jump; VAS = Visual analogue scale (measurement of perceived muscle soreness and fatigue); RPE = rating of perceived exertion.

4.2.4 Repeat sprint exercise protocol

Each RSE session, conducted on a non-motorised treadmill (Woodway Force 3, Waukesha, WI, USA), consisted of three sets of 5 x 4 sec sprints, with each sprint separated by 20 sec, and each set separated by 4.5 min. Motivation was kept constant throughout each RSE session. The start point for sprint calculation was defined as a velocity attainment of 1 $m \cdot sec^{-1}$; from then, a 4 sec period was calculated (Serpiello, McKenna et al. 2011). All sprint data was calculated using custom software. Peak and mean values for velocity ($m \cdot sec^{-1}$) and power (watts) in addition to total work (J) were calculated and averaged per RSE session, as well as per set. The fatiguing nature of this protocol has previously been established (Serpiello, McKenna et al. 2011). Specifically, decrements in mean power (-4.8%, ES±90%; CI -0.21 ± 0.07), peak power (-9.2%, -0.28 ± 0.11) and mean velocity (-2.2%, -0.18 ± 0.33) occur from set one to three of an individual RSE session. The fatiguing nature of this protocol remains after ten sessions of RSE training where mean power in set 3 remained 4.1% lower than set 1 (-0.19 ± 0.06), and mean velocity remained lower by 2.1% (-0.17 ± 0.06) (Serpiello, McKenna et al. 2011).

4.2.5 Recovery intervention

In a counterbalanced cross-over design, participants were randomly assigned to control (Con) or lower body sports compression garment groups (Spo; recovery range, RY400, Skins Australia). The Spo garments were from fabric containing 76% Nylon and 24% Spandex and were graduated in nature, designed to exert the highest level of pressure, decreasing when moving more proximally. Participants were only made aware of their treatment allocation once they had completed the RSE protocol on the first day. Only loose clothing was permitted in Con. The Spo participants were only permitted to wear the compressive garments supplied; all other clothing was to be loose fitting. Compression garments were worn during recovery between each RSE session and removed overnight. Participants recorded when they put on/took off their compression garments. Participants were instructed that no other recovery modalities were permitted at this time.

4.2.6 Assessment of acute and cumulative responses to RSE

To control for differences across groups, perceptual and biochemical results were adjusted for Work (J) completed during RSE1 as a covariate. To determine the acute response (immediate and 24 hr) to the RSE and acute recovery, comparisons between Pre RSE1 to both Post RSE1 and Pre RSE2 (i.e. 24 hr Post RSE1) were made. Cumulative responses to RSE and the recovery intervention were determined via comparisons between Pre RSE1 and Pre RSE3 (i.e. 24 hr Post RSE2) and 24 hr Post RSE3.

4.3 Results

The magnitude of treatment effects for perceptual parameters exceeded the SWC (Table 4.1). The 90% CI indicates the likely range in which the true value may lie. The observed range of 90% confidence intervals (90% CI) for changes in plasma [Mb] were large and thus effects were uncertain. To minimise this uncertainly to an acceptable level (ES of 0.2), it is estimated that approximately 20 x more participants would be required ((0.91/0.2)^2)) (Hopkins 2012, Personal Communication), with likely unclear findings. Thus there was no additional benefit in testing more participants.

Compression garments were worn for 19.3±4.3 hr between each RSE session. Mean power (watts), work (joules), and peak velocity ($m \cdot sec^{-1}$) values obtained during the RSE were lower in Spo than Con for RSE1 when averaged across all three sets conducted in each RSE (Figure 4.2).

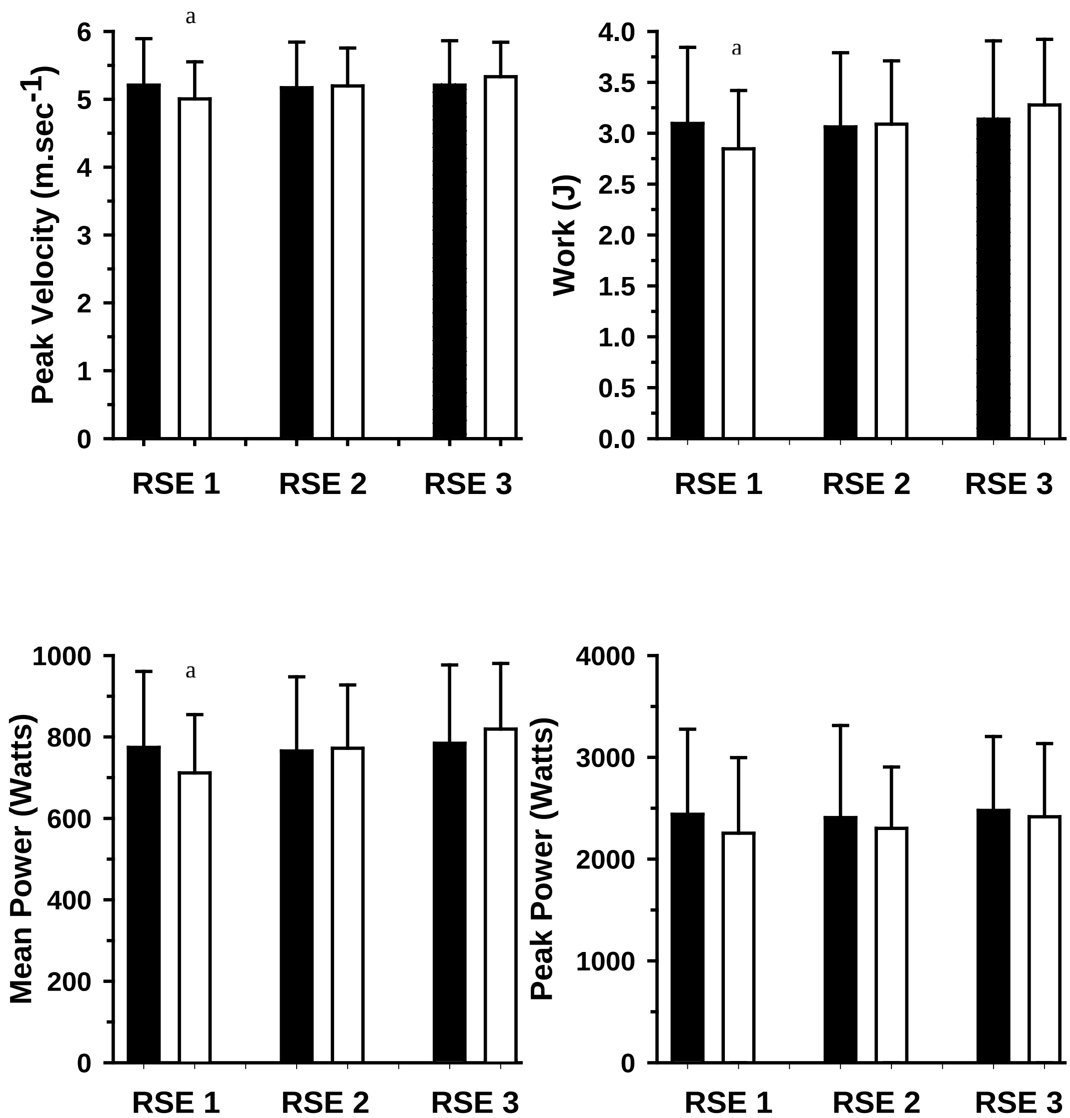

Figure 4.2: Effect of compression garments on sprint performance per repeat sprint exercise session (RSE). Closed bars indicate control group (Con). Open bars indicate compression garment group (Spo). Magnitudes of change were classified as a substantial increase or decrease when there was a ≥ 75% likelihood of the effect being equal to or greater than the SWC estimated as a small effect size. a denotes a substantial difference from control. All data are mean ± SD, n= 9.

During RSE1, work and peak velocity were lower in the Spo group compared to Con during Set 2 and 3 (Figure 4.3). No other differences in sprint performance parameters occurred per set or per RSE.

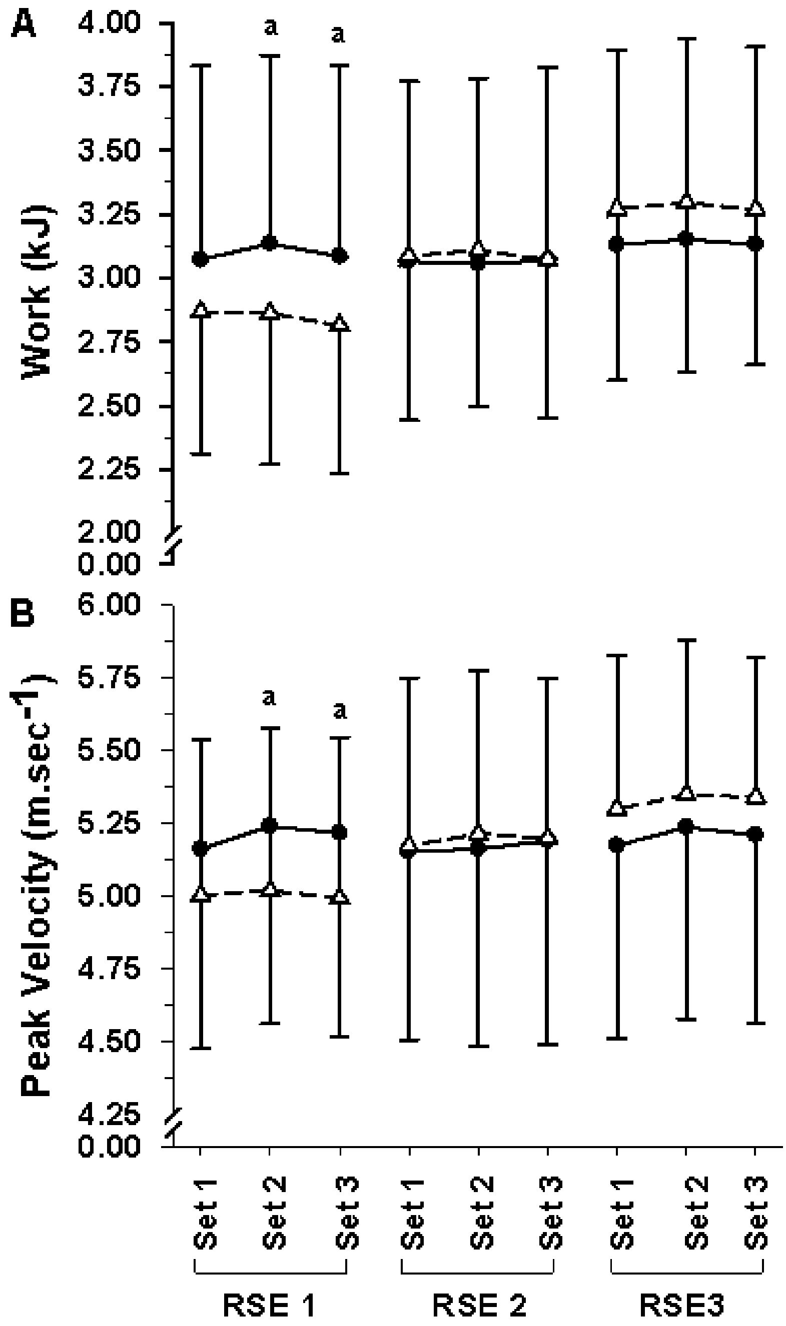

Figure 4.3: Effect of compression garments on sprint performance per set, for work in kilojoules (A) and peak velocity in meters per second (B). Closed circles indicate control group (Con). Open triangles with dashed line indicate the sports compression garment group (Spo). [a] denotes a substantial difference from control. All data are mean ± SD, n=9.

The average RPE per RSE session was 7.2±1.5. The RPE for the control during RSE1, 2 and 3 was 8.0±0.8, 7.6±1.3 7.8±1.1 and 7.1±1.4, 7.1±1.5, 7.3±1.6 for the compression garment group. The RPE did not change with day or group.

4.3.1 Acute responses to repeat sprint exercise and acute recovery responses

Decrements in running performance representative of neuromuscular fatigue were not present when sprint performance was compared between all three sets in each RSE across the three days (Figure 4.2 and Figure 4.3).

The SWC in perceived fatigue and muscle soreness was 16.5% and 23.0%. The immediate increase in perceived fatigue in Con and Spo after a single RSE was 13.5- and 5.7-fold larger than the SWC. In Con, elevated perceived fatigue persisted for 24 hr, and was 1.6-fold larger than the SWC. Control also displayed a substantial increase in muscle soreness immediately after the first RSE, which was 7.4 times greater than the SWC. In Con, this heightened soreness persisted 24 hr later, the magnitude of which was 3.4-fold larger than the SWC (Table 4.1). Participants wearing Spo had a smaller increase in soreness from Pre RSE1 than control to 24 hr following RSE 1 (-50.3%, 0.8±0.9, extremely large) (Table 4.1), with the magnitude of this treatment effect being 3.4-fold greater than the SWC. The probability of this treatment effect was 88% (likely-probably). Individual muscle soreness responses to a single RSE displayed a high level of individual variation and are displayed in Figure 4.4.

A single RSE did not elicit an increase in plasma [Mb] immediately, or 24 hr after RSE. There were no differences between Spo and Con in the change in plasma [Mb]. Outliers in both Con and Spo were removed for plasma [Mb], which bore no influence on the results. Refer to Table 9.1 in Chapter 9 (Appendix) for raw plasma Myoglobin values (mean±standard deviation).

Table 4.1: Acute and cumulative biochemical and perceptual responses to repeat sprint activity.

		Con				Spo			
		Acute Response		Cumulative Response		Acute Response		Cumulative Response	
	SWC %	Pre RSE1 – Post RSE1	Pre – 24 hr Post RSE1	Pre RSE1 – 24 hr Post RSE2	Pre RSE1 - 24 hr Post RSE3	Pre RSE1 – Post RSE1	Pre – 24 hr Post RSE1	Pre RSE1 – 24 hr Post RSE2	Pre RSE1 - 24 hr Post RSE3
[Mb]	14.8%	3.1 % 0.20±0.28 unclear	42.3 % 0.10±0.22 unclear	23.5 % 0.19±0.37 unclear	30.6 % 0.24±0.29 unclear	-2.5 % 0.04±0.43 unclear	11.8 % 0.18±0.70 unclear	12.1 % 0.18±0.80 unclear	75.5 % [a] 0.89±0.93 moderate
Soreness	23.0%	169.6 % [a,b] 0.63±0.78 moderate	78.2 % [a b] 0.36±0.49 small	121.0 % 0.50±1.16 unclear	78.9 % [b] 0.37±0.74 unclear	17.0 % 0.12±0.35 unclear	-29.8 % -0.28±0.59 unclear	-29.1% -0.27±0.59 unclear	-51.0 % [a] -0.56±0.69 small
Fatigue	16.5%	223.9 % [a,b] 1.5±0.93 large	26.8 % [a] 0.30±0.49 small	59.6 % [a b] 0.60±0.54 moderate	40.3 % [a] 0.43±0.29 small	93.7 % [a] 0.59±0.36 small	25.6 % 0.20±0.41 unclear	-17.2 % -0.17±0.55 unclear	-30.6 % -0.32±0.62 unclear

Immediate changes in plasma [Mb], perceived muscle soreness and fatigue were compared acutely from Pre RSE1 to immediately Post RSE1. Acute recovery was assessed by comparing Pre RSE1 and 24 hr Post RSE1. Cumulative changes were measured by comparing Pre RSE1 to 24 hr Post RSE2 and Pre RSE1 to 24hr Post RSE3. Values are % change between the two time points, ES±90% CI and the effect size descriptor for the control group (Con) and sports compression garment group (Spo). The SWC expressed as a percentage represents estimated as 0.2 x between-subject standard deviation expressed as a CV (%) for each parameter. [a] denotes a substantial increase or decrease between the two time points, [b] denotes a substantial difference between the Con and Spo in the change between the two time points.

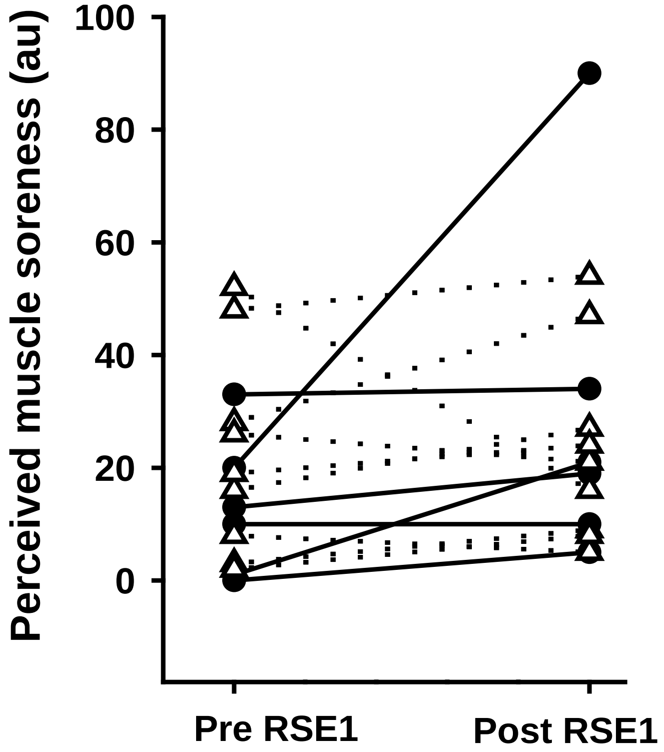

Figure 4.4: Individual acute changes in perceived muscle soreness following a single RSE. Closed circles indicate control group (Con, n=9). Open triangles with dashed line indicate the sports compression garment group (Spo, n=9).

4.3.2 Cumulative responses to repeat sprint exercise and cumulative recovery responses

A cumulative reduction in muscle soreness occurred in participants wearing compression 24 hr following RSE3 compared to Pre RSE1 (Table 4.1). This change in muscle soreness was 2.2-fold greater than the SWC. The Con had a substantially larger (52.5%, -0.7±0.6, moderate) increase in muscle soreness versus Spo from RSE1 to 24 hr after RSE3, 2.3-fold larger than the SWC (Table 4.1). The probability of this treatment effect was 88% (likely-probably).

The substantial elevation in perceived fatigue in Con 24 hr following RSE2 and RSE3 was 3.6 and 2.4-fold larger than the SWC identified for this parameter. A similar effect was not apparent for Spo (Figure 4.5 and Table 4.1). Perceived fatigue was lower (-42.0%, 0.6±0.5, moderate) in Spo than Con 24 hr following two consecutive days of RSE compared to pre study levels (Table 4.1). The level of this treatment effect was 2.6 times larger than the SWC for perceived fatigue, with a 94% likelihood of a true effect (likely probably – very likely).

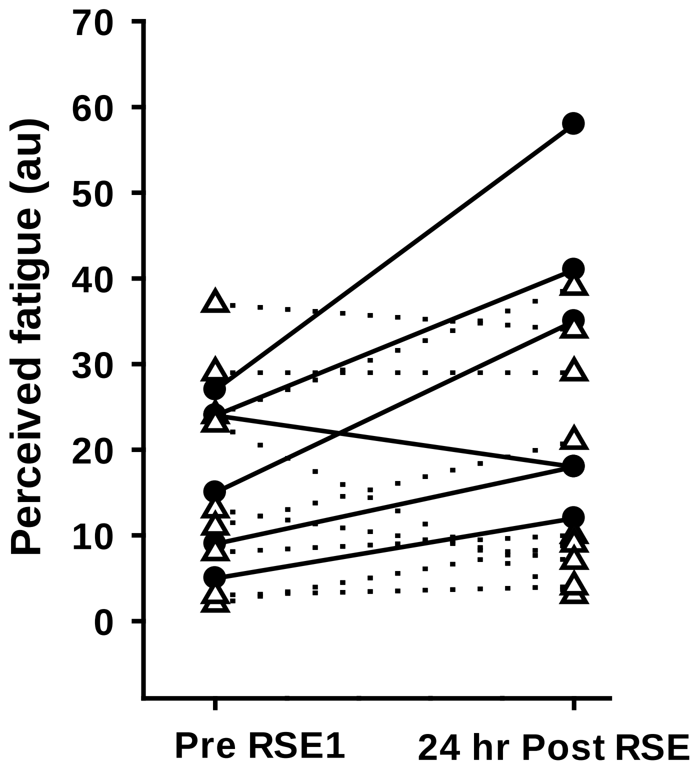

Figure 4.5: Individual changes in perceived fatigue. The change in perceived fatigue was compared from Pre RSE1 to 24 hr following RSE2 (i.e. pre RSE3). Closed circles indicate control group (Con, n=7). Open triangles with dashed line indicate the sports compression garment group (Spo, n=9).

The SWC in plasma [Mb] was 14.8%. Plasma [Mb] was 5.1-fold greater than the SWC 24 hr following the third RSE compared to Pre RSE1 in Spo (Table 4.1). The plasma [Mb] response to RSE was not different between the two groups when assessing cumulative changes.

4.4 Discussion

Perceptual recovery is enhanced between multiple days of high intensity exercise when wearing sports compression. Indeed, participants experienced less soreness 24 hr after completing not only one, but three such sessions with compression use. Further, perceptions of fatigue were lower 24 hr after two of these sessions when using the sports garments for recovery, compared to control participants. Neither acute nor cumulative recovery of treadmill running performance or biochemical parameters were enhanced with compression use, most likely resulting from an insufficiently taxing protocol. This study also suggests that there is an uncoupling between performance and perceptual measures.

Participants wearing Spo experienced less muscle soreness both acutely and after completing three RSE sessions compared to Con. The magnitude of the treatment effect for acute and cumulative recovery was double that of the SWC for muscle soreness. The literature consistently points toward a blunting of muscle soreness as a key outcome of compression garment use for recovery (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Duffield, Edge et al. 2008; French, Thompson et al. 2008; Montgomery, Pyne et al. 2008b; Davies, Thompson et al. 2009; Duffield, Cannon et al. 2010; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). It is important to note that the initial increase in muscle soreness was substantially greater in Con versus Spo. The completion of more work during RSE1 by Con is the likely culprit facilitating this difference, despite its inclusion as a covariate in the analysis. As symptoms of muscle damage (i.e. muscle soreness) are unlikely to present until 24-48 hr following exercise (Thompson, Nicholas et al. 1999), this initial increase in soreness is more likely a representation of the discomfort associated with fatigue initially after the high intensity RSE, than DOMS *per se*.

Physiologically, compression garments are suggested to offer positive effects on muscle soreness through a mechanical blocking of oedema (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b) which is associated with muscle damage (Jones, Newham et al. 1987; Jones, Newham et al. 1989). It is believed this occurs through a reduced hydrostatic pressure gradient across the vessel walls (Jonker, de Boer et al. 2001). In fact oedema and swelling in the legs of healthy individuals are reduced with compression stocking application (Jonker, de Boer et al. 2001) and even compression hosiery (Kraemer, Volek et al. 2000). This mechanism can only be speculated as the current study did not measure oedema, or any physiological parameters that may indicate vessel wall hydrostatic pressure. Lower plasma [Mb] might however indicate a reduction in oedema as plasma [Mb] (Brancaccio, Limongelli et al. 2006; Brancaccio, Maffulli et al. 2007) and oedema (Jones, Newham et al. 1987; Jones, Newham et al. 1989) are both associated with muscle damage. The reduction in muscle soreness in this study in Spo was not accompanied by lower plasma [Mb] levels; in fact plasma [Mb] remained elevated above pre study levels throughout the measurement period, whilst muscle soreness was actually lower than pre study levels. Ultimately, the plasma [Mb] data do not support the notion of a reduction in oedema driving the lower perceived muscle soreness.

Sports compression abated perceived fatigue 24 hr after high intensity running conducted on two consecutive days. The magnitude of this treatment effect was ~2.5-fold greater than the SWC. Similarly, following three days of basketball game play, Spo use between games facilitated 50% less perceived fatigue compared to control participants (Montgomery, Pyne et al. 2008b). In the present study, similar to muscle soreness, Con did however experience a greater increase in perceived fatigue immediately following the first RSE compared to the treatment group. This difference in perceived fatigue is surprising given the greater amount of work conducted during RSE1 by Con versus Spo was accounted for as a covariate in the analysis. It is important to note that this initial difference in perceived fatigue cannot be attributed to actual treatment effects, as treatments (Con/Spo) were not allocated until after RSE1 was completed.

An enhanced perceptual recovery with Spo may also be driven by placebo effects. Participants wearing Spo rated their muscle soreness as even lower than *prior* to starting the study when assessed 24 hr after the third RSE. Sports compression participants also reported lower perceived fatigue than prior to commencing the study, this time 24 hr after completing two RSE sessions. At the same time, Con displayed substantial elevations in perceived fatigue, and a trend towards elevated muscle soreness. As physiological mechanisms underpinning these effects are yet to be confirmed, it would be negligent to dismiss the role of a placebo effect.

The placebo effect has been explored in compression garment research, however it has been limited to its influence on performance parameters (Chatard, Atlaoui et al. 2004) with no reference yet to perceptions of muscle soreness or fatigue. For example, wearing compression garments for recovery between cycling bouts assisted in the maintenance of cycling power compared to a control condition (Chatard, Atlaoui et al. 2004). Of interest, fifty percent of participants reported that the garments could have modified their second performance either a bit, or a lot (Chatard, Atlaoui et al. 2004), highlighting the placebo effect. However, when the garments were worn *during* a 40 min treadmill run (80% $\dot{V}O_{2max}$) by competitive runners, there were no differences between a placebo (12–15 mmHg at ankle) and standard sports style lower body compression garment (23–32 mmHg at ankle) for plasma Creatine Kinase,

[Mb], jump height or muscle soreness (Ali, Creasy et al. 2010). It is possible that the two levels of compression were too similar to allow for the detection of possible placebo effects.

Participants maintained sprint performance, irrespective of compression garment use as the RSE did not elicit within, or between session decrements in sprint performance. Previous use of this protocol in a similar participant population demonstrated reductions in mean power in set 3 versus set 1 (-4.8%, ES±90%CI = -0.21 ± 0.07), peak power (-9.2%, -0.28 ± 0.11), and mean velocity (-2.2%, -0.18 ± 0.33) (Serpiello, McKenna et al. 2011). Even after ten sessions of repeated sprint training, decrements in performance were observed. For example, mean power in set 3 was 4.1% lower than set 1 (-0.19 ± 0.06, P=0.006), and mean velocity was reduced by 2.1% (-0.17 ± 0.06, P=0.014) (Serpiello, McKenna et al. 2011). Prior knowledge of the RSE protocol through familiarisation may have contributed to the development of a conservative pacing strategy in these participants (Billaut, Bishop et al. 2011), prohibiting performance decrements. This may have been exacerbated with the knowledge of the repetition of the RSE across three consecutive days, in contrast to its use by Serpiello et al (2011), with only a single RSE bout performed after familiarisation. Indeed pacing occurs during short repeated-sprint efforts in anticipation of the number of sprints that are included in the trial (Billaut, Bishop et al. 2011). It is also plausible that 24 hr of recovery was sufficient between RSE to permit performance maintenance. In the current study, the Con actually performed more work, and attained higher peak velocities compared to Spo during RSE1, specifically set 2 and 3. It is unclear why this occurred, despite the random allocation of participants.

Regardless of intervention, the RSE was expected to elicit elevations in plasma [Mb] (Williams 1985; Friden, Seger et al. 1988; Thompson, Nicholas et al. 1999; Howatson and Milak 2009). Despite Con completing more work during the initial RSE session, those who wore compression garments for recovery had elevated plasma [Mb] 24 hr following the final RSE compared to pre study levels, with a similar elevation not present in Con. There was however no clear difference between the two conditions in this change. Although asked to refrain from activity between RSE sessions, it is possible that those wearing Spo partook in activities that elicited muscle damage, possibly accounting for this elevation. It is otherwise uncertain why Spo and not Con displayed elevated plasma [Mb]. Serum [Mb] also remained unchanged with Spo use by elite basketball athletes between three games played across three consecutive days (Montgomery, Pyne et al. 2008a).

An uncoupling between perceptual measures and performance occurred in these recreationally active participants. Indeed Con maintained their performance despite acute and cumulative muscle soreness and fatigue. Conversely, the lower than pre study levels of muscle soreness and fatigue 24 hr after RSE1, 2 and 3 were not coupled with an enhanced running performance in Spo. Rugby players experienced this uncoupling after a simulated rugby circuit, where they were able to maintain performance 24 hr after the circuit despite elevated perceived soreness (Duffield, Edge et al. 2008). Further, measurements of muscle soreness only show a moderate (Hopkins 2011) correlation (r= -0.38) with the recovery of force production following damaging eccentric arm curl exercise (Rodenburg, Bar et al. 1993). Ratings of fatigue and soreness are used in conjunction with an array of measures in predicting an athlete's readiness to train/compete. Thus it is important that these measures are used in conjunction with a battery of tools to ascertain a more global overview of the athlete's condition and readiness to train/compete. Indeed, it may be possible for an athlete who is experiencing muscle soreness and perceived fatigue to still perform to the required level. However, the longer term consequences of residual soreness and fatigue may have greater implications on performance (Lehmann, Foster et al. 1993; Kentta and Hassmen 1998).

4.5 Conclusions

Sports compression garment use was beneficial at improving the recovery of perceived muscle soreness after repeat sprint activity performed on not only one occasion, but after the completion of three sessions. Similarly, cumulative perceived fatigue was abated with sports compression use, proving the garments to be useful in the recovery of perceptual parameters of both soreness and fatigue. The mechanisms facilitating this effect remain unknown. Despite evidence to the contrary in previous research, the insufficiently taxing nature of the RSE protocol prevented conclusions regarding the influence of sports compression on the maintenance of running performance, or plasma [Mb]. Perceived soreness and fatigue were uncoupled from performance, and each should be treated with caution if being used as a standalone indicator of recovery and readiness to train/compete.

CHAPTER 5. RECOVERY FOLLOWING ELITE AUSTRALIAN FOOTBALL TRAINING

5.1 Introduction

The optimisation of recovery is crucial for Australian football (AF) athletes undertaking multiple training sessions per week. Training sessions result in fatigue, muscle damage, muscle soreness and performance reductions (Boyd, Gallaher et al. 2010; Elias, Varley et al. 2012) due to the similarity in activity profiles to actual games (Dawson, Hopkinson et al. 2004a) and the larger load incurred. These sessions are repeated up to three times per week, in addition to resistance exercise and individual skill sessions during the competitive phase of the year (Cormack, Newton et al. 2008a). Compression garments are routinely worn after training sessions to improve between session recovery, despite a dearth of consistent evidence to support their use.

Clinically, medical compression garments (Med) exert positive actions through reduced lymphodema (Jonker, de Boer et al. 2001) and increased blood flow (Mayberry, Moneta et al. 1991; Coza, Dunn et al. 2012). Reduced exercise-induced oedema may facilitate decreased muscle soreness (Dierking and Bemben 1998) in the ensuing recovery period, and possibly even the functional impairments associated with such soreness (Armstrong 1986; Clarkson, Nosaka et al. 1992; MacIntyre, Reid et al. 1995; Ruff 1999; Green, Langberg et al. 2000; Rawson, Gunn et al. 2001). Assuming these systems are well functioning in elite athletes, it is unknown if clinically meaningful physiological responses, which translate into an improved recovery in the hours following exercise, will occur. Further, in studies that have obtained these positive results, medical grade compression, that exerts a higher compressive action rather than sports grade garments, were used. Dascombe and colleagues (2011) attempted to decipher if an undersized compression garment (21.7 ± 4.3 mmHg calf region and 15.9 ± 2.6 mmHg thigh region) offered greater effects on performance and tissue oxygenation than a regular sized compression garment (21.7 ± 4.3 mmHg calf region and 15.9 ± 2.6 mmHg thigh region) worn during a progressive maximal test and time to exhaustion test. The authors noted no difference between garment types in performance or physiological parameters (Dascombe, Hoare et al. 2011). It is possible that the difference in the level of compression offered between the two garment types was not sufficient to detect differences. Currently, it is not know if a Med garment offers additional benefits to a Spo garments when worn during the recovery period exclusively.

It is difficult to decipher the effectiveness of compression garments for team sport athlete recovery, as studies often report vastly inconsistent findings, within *and* between studies, or do not use typical training sessions. For example, positive recovery effects on performance measures were not identified after sprint and plyometric activity (Duffield, Cannon et al. 2010), or a rugby circuit (Duffield, Edge et al. 2008), as performance had recovered to pre exercise levels at the time of assessment. Conversely academy netball and basketball athletes who wore Spo (48 hr) following drop jump exercise experienced mixed recovery outcomes. Agility and CMJ performance were superior with garment use compared to the control. However wearing Spo did not allow athletes to maintain sprint performance to a greater extent versus the control (Davies, Thompson et al. 2009). Similarly, agility and line drill ability were maintained to a greater extent with Spo use than the control 24 hr after a three day basketball tournament consisting of three games (Montgomery, Pyne et al. 2008b). Of concern however, there were greater decrements in vertical jump and 20 m acceleration with Spo versus control (Montgomery, Pyne et al. 2008b). With such large inconsistencies across the literature, it is uncertain if recovery effects are in fact consistent and reproducible if investigated after more than one exercise session in isolation. This is an important consideration, as team sport athletes complete multiple training sessions across the week.

Unlike the recovery of performance measures, more consistent positive recovery effects are reported across the literature for perceptual measures. Perceived muscle soreness is reduced with the use of Spo for recovery. Academy netball and basketball athletes reported lower perceived muscle soreness than the control with Spo use 48hr after drop jump exercise (Davies, Thompson et al. 2009). Muscle soreness was also lower in rugby athletes after sprint and plyometric activity (Duffield, Cannon et al. 2010) and simulated rugby circuits (Duffield, Edge et al. 2008). Further, muscle soreness and perceived fatigue were lower with Spo between three basketball games (Montgomery, Pyne et al. 2008b). This being the only study using athletes to assess perceived fatigue. As such, it is anticipated, that these positive recovery effects on perceptual parameters would be reproducible within the same group of athletes after more than one training session.

Clear effects of compression garments on biochemical markers of muscle damage during recovery are not apparent in the literature. Plasma C-reactive protein (Duffield, Cannon et al. 2010) and plasma [CK] (Duffield, Edge et al. 2008; Duffield, Cannon et al. 2010) remained unaltered with Spo use by rugby players after sprint and plyometric activity (Duffield, Cannon et al. 2010) or simulated rugby circuits (Duffield, Edge et al. 2008). Serum [Mb] also remained unchanged with Spo use during a three day basketball tournament (Montgomery, Pyne et al. 2008a). Conversely, after elite rugby union competition, transdermal [CK] was lower in athletes wearing Spo (12 hr overnight) compared to the control at both 36 and 84 hr of recovery (Gill, Beaven et al. 2006). Thus it appears unlikely that compression garments will influence post exercise circulating biochemical markers of muscle damage.

Accordingly, this study aimed to examine: (1) the extent to which wearing compression garments modulate the recovery of performance, perceptual and biochemical parameters in elite athletes, consequent to two independent Australian Football training sessions; (2) differences in the above parameters between sports and medical style compression garments; and (3) if positive recovery effects for compression garments are consistent and reproducible when two independent ‘typical’ Australian Football sessions are conducted by the same group of athletes.

5.2 Methods

5.2.1 Participants

Twenty four elite AF athletes from the same club (Age 24.2±3.5 yrs; height 189±5.6 cm; body mass 88.6±7.6 kg (Mean ± Standard Deviation)) provided written informed consent to participate. The experimental protocol was approved by the Victoria University Human Research Ethics Committee. The sample size was confined to the number of participants permitted to participate by the club.

5.2.2 Experimental overview

In a quasi-experimental design, the same participants performed a typical AF training session (TR1), followed seven days later by a similar session (TR2). Both TR1 and TR2 were conducted on the same day of the week, at the same time. Five participants were not cleared to participate in TR2 by the club. Training session one and two consisted of two individual warm ups (warm up 1 and 2), a 12 min non-contact (TR1) or contact (TR2) small sided game, 20 minute running drills, 75 minutes of football specific skills and 70 minutes of lower body resistance training. Compression garments were worn during the 24 hr recovery period after TR1 and TR2, and were removed whilst sleeping, showering and if any discomfort occurred

(Figure 5.1). It was not possible to precisely control the work conducted by participants during the running, skills and resistance training components due to the critical stage of the pre-season, however a session RPE was obtained after the completion of each of the components of training. Due to limited access to participants, it was only possible to assess participants prior to training (Pre), and 24 hr after training (+24). The warm ups, training stimulus and recovery strategies, which are part of the team's weekly routine, were matched to minimise differences between testing weeks.

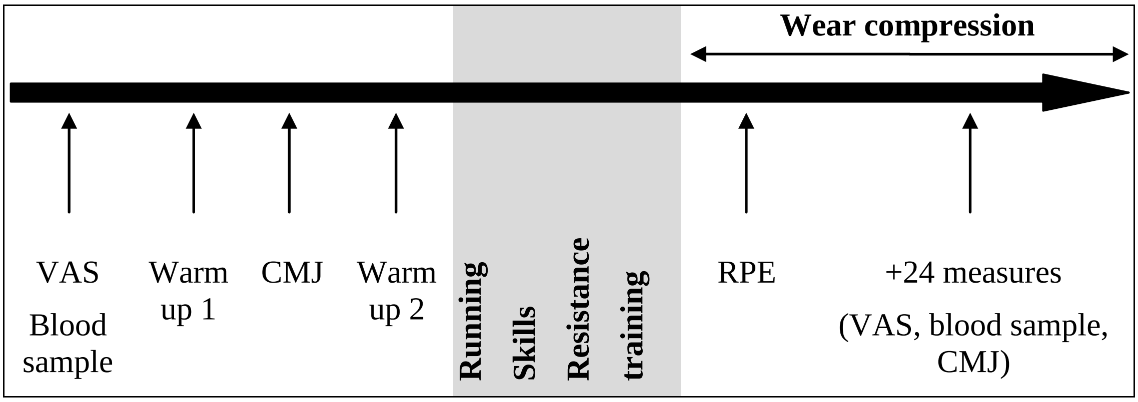

Figure 5.1: Experimental overview. VAS = visual analogue scale for perceived muscle soreness and fatigue; CMJ = countermovement jump; RPE = rating of perceived exertion.

5.2.3 Measurements

Measures included blood sampling to assess plasma [Mb] (Section 3.1), VAS for perceived muscle soreness and fatigue (Section 3.2) and CMJ flight time (FT) (Section 3.3). Measures were taken 2 hr before TR1 and TR2 at baseline (Pre). Recovery was assessed 24 hours after training at +24. All measurements were taken when participants were not wearing compression garments. Additionally, an RPE rating (Section 3.2) was collected after the SSG, running, skills and resistance training component of TR1 and 2. These athletes were accustomed to using the VAS, CMJ and RPE scale as part of the routine monitoring conducted by the club.

5.2.4 Warm ups

Prior to the Pre CMJ measure, all participants completed a standardised six minute warm up (warm up 1) which consisted of dynamic lower body (legs and back) activities and stretches. This warm up was used weekly by the participants as part of their routine CMJ monitoring. Prior to the commencement of TR1 and TR2, all participants completed a standardised warm up incorporating general running drills, flexibility, and football activities conducted by strength and conditioning staff (warm up 2).

5.2.5 Session RPE and calculation of internal load

The session RPE method (RPE x duration [minutes]) (Foster, Florhaug et al. 2001) was used to quantify each player's internal load for each of the components of the training session (excluding the warm ups) in TR1 and 2. An RPE value was obtained after each of these components. The 'total' internal load represents the combination of the internal load derived from the SSG, running, skills and resistance training components to characterise the total load of the training session.

5.2.6 Recovery intervention

After the cessation of TR1 and TR2, participants were randomised and matched according to playing position into one of three groups: wearing a sports grade lower body compression garment (Skins, Australia) (Spo; TR1 n=9; TR2 n=7; Figure 5.2); a medical grade thigh high compression garment (JOBST forMen Medical Legware, USA, 30-40 mmHg at the ankle) (Med; TR1 n=8; TR2 n =6; Figure 5.3); or normal clothing, with little compression (Con; TR1 n=7; TR2 n=6), which were worn until +24. Due to a lack of a validated method available, the level of pressure exerted by the garments was not measured. Participants were allocated to the same treatment group after TR1 and TR2. Compression garments (Med and Spo) were worn for the remainder of the day and temporarily removed overnight. The garments were worn again upon waking the next day until the +24 measure. Garments were removed temporarily if discomfort was experienced and whilst showering. Participants were instructed that no other recovery interventions were permitted during the recovery period. Food and fluid intake during the recovery period was not controlled. Participants were expected to follow post training food and fluid guidelines as prescribed by the club's dietitian. Participants removed the garments immediately prior to completing +24 measures. All participants were provided with instruction on when to wear the garments as well as a diary to record when the garments were removed (Appendix 9.1). A custom spreadsheet designed for the analysis of post-only crossover trial with adjustment for a predictor (Hopkins 2006b) was used to determine any differences in the duration that compression garments were worn following TR1 and TR2.

Figure 5.2: Sports compression garment.

Figure 5.3: Medical compression garment.

5.3 Results

Training session one and two were conducted independently. The results for each training session are presented individually below. The mean total internal load was 1162.2±175.6 for TR1 and 1195.6±76.1 for TR2. There were no differences in the total internal load between TR1 and TR2.

5.3.1 Training session 1 (TR1)

There were no differences between groups in the total internal load for TR1 (Table 5.1). When summing the RPE from each of the four components of training (score out of 40) the RPE for TRI was 23.8±1.6 au.

Table 5.1: Internal load units (au) for training session one (TR1).

	Con	**Med**	**Spo**
Total internal load	1132.7 ± 189.9	1212.9 ± 71.1	1181.9 ± 174.1

The internal load units (au) derived from the session RPE method (RPE x duration of activity, [min]). The total internal load was determined by combining the internal load for each component of the training session for the control (Con, n=7), medical (Med, n=8) and sports (Spo, n=9) compression garment groups. Values are mean±standard deviation.

Compression garments (Med and Spo) were worn for 8.5±0.6 and 10.1±3.0 hr following TR1. The duration of compression usage was not different between Med and Spo.

The SWC for CMJ FT was 6.8% in this group of participants. Compared to Pre values, 24 hr after TR1, FT scores were not substantially depressed in any group. There were no differences between groups in the change in flight time from Pre to +24 (Figure 5.2).

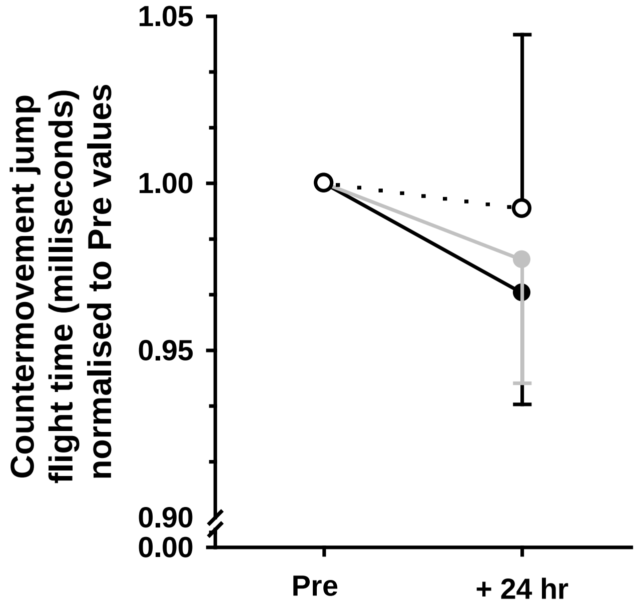

Figure 5.4: Countermovement jump flight time. Countermovement jump flight time (milliseconds) normalised to pre values 24 hr after training session one (TR1). Data are mean±standard deviation. Solid line and closed circles represents the control (Con, n=7), dotted line and open circles represent the medical compression garment group (Med, n=8), and solid grey circles with the solid grey lines represent the sports compression garment group (Spo, n=9).

Muscle soreness was elevated 24 hr after TR1 in all groups compared to Pre. The magnitude of this elevation for Con, Med and Spo was 23.0, 10.8, and 21.8 times the SWC, respectively. The probability of a true effect for Con, Med and Spo was 98% (very likely), 97% (very likely) and 100% (almost certainly), respectively. There were no differences between groups in the change in muscle soreness from Pre to +24. Muscle soreness responses varied markedly between participants (Figure 5.3).

Table 5.2: The percentage change in perceived fatigue, muscle soreness and plasma Myoglobin concentration ([Mb]) following training session 1 (TR1).

	SWC	Group	Data sets	Pre - +24	% chances for values to be higher/trivial/lower at +24 than Pre	Qualitative rating of the change	% chances for Spo or Med values to be lower/trivial/higher than Con	Rating of the treatment effect (vs Con)	% chances for Spo values to be lower/trivial/higher than Med	Rating of the treatment effect (Spo v Med)
Perceived Fatigue (au)	13.7%	**Con**	6	205.5 [a]	98/1/1	very likely	-	-	-	-
		Med	7	181.5 [a]	94/4/2	likely-probably	45/20/35	unclear	-	-
		Spo	9	230.5 [a]	100/0/0	almost certainly	33/20/47	unclear	51/19/30	unclear
Muscle Soreness (au)	17.4%	**Con**	6	400.7 [a]	98/1/1	very likely	-	-	-	-
		Med	6	187.3 [a]	97/2/1	very likely	71/16/13	unclear	-	-
		Spo	9	379.4 [a]	100/0/0	almost certainly	42/22/36	unclear	75/12/13	unclear
Plasma [Mb] (ng.ml-1)	12.3%	**Con**	3	96.5	88/4/8	unclear	-	-	-	-
		Med	8	61.3 [a]	98/2/0	very likely	53/9/38	unclear	-	-
		Spo	9	153.4 [a]	98/2/0	very likely	31/12/57	unclear	60/30/10	unclear

The SWC was calculated as 0.2 x the between subject standard deviation as a CV% (Batterham and Hopkins 2006). The number of data sets represents the number of full data comparisons available for analysis. Percentage changes (%) are compared from Pre to 24 h post TR1 (+24) for the control (Con, n=7), medical compression group (Med, n=8), and sports compression garment group (Spo, n=9). The chances (%) for each parameter to be higher, trivial, or lower at +24 than Pre for each group are presented along with a qualitative rating of the within group change. The chances (%) for a treatment effect for Med and Spo versus the Con, and Spo versus Med are also presented, along with a qualitative rating of the respective effect. [a] denotes a substantial change for each specific group.

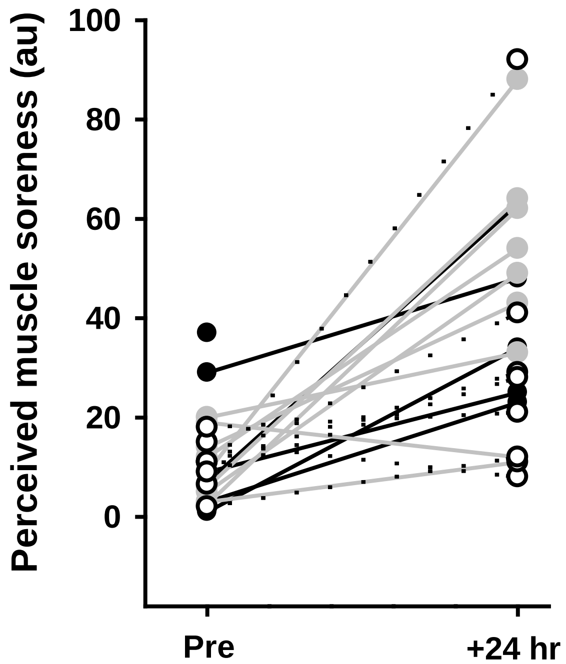

Figure 5.5: Individual muscle soreness responses to training session 1 (TR1). Solid line and closed circles represents the control (Con, n=7), the dotted line and open circles represent the medical compression garment group (Med, n=8), and the solid grey circles with the solid grey line represents the sports compression garment group (Spo, n=9). Values are expressed in arbitrary units (au).

The SWC for perceived fatigue was 13.7%. This perceived fatigue persisted for 24 hr after TR1 to the order of 15.0, 13.2, and 16.8 times the SWC for Con, Med and Spo, respectively (Table 5.2). The likelihood of this perceived fatigue for Con, Med and Spo was 98% (very likely), 94% (likely probably) and 100% (almost certainly) respectively. There were no differences between groups in the recovery of perceived fatigue 24 hr after TR1.

Plasma [Mb] remained elevated 24 hr after TR1 compared to Pre in the Med and Spo groups only, and not the Con (Table 5.2). The magnitude of this increased for Med and Spo were 5 and 12.5 times the SWC, with 98% (very likely) and 98% (very likely) probability of a true effect. There were no differences between groups in the change in plasma [Mb]. See Table 9.2 in Chapter 9 (appendix) for raw values for plasma [Mb] (mean±SD).

5.3.2 Training Session 2 (TR2)

There were no differences between groups in the total internal load for TR2 (Table 5.3). When summing the RPE from each of the four components of training (score out of 40) the RPE for TRI was 29.9±1.9 au.

Table 5.3: Internal load units (au) training session two (TR2).

	Con	**Med**	**Spo**
Total internal load	1210.4 ± 32.4	1180.8 ± 105.7	1230 ± 89.2

The internal load units (au) derived from the session RPE method (RPE x duration of activity, [min]). The total internal load was determined by combining the internal load for each component of the training session for the control (Con, n=6), medical (Med, n =6) and sports (Spo, n=7) compression garment groups. Values are mean±standard deviation.

Compression garments (Med and Spo) were worn for 8.4±1.3 and 7.3±2.0 hr respectively following TR2. The duration that each garment type was worn after TR2 was not different.

The SWC for FT was 1.0% in this group of participants. Neuromuscular fatigue was evident 24 hr after TR2, with substantially reduced CMJ FT in the Spo (% change, ES±90%CI; -1.2%, 0.25±0.16, small) compared to Pre values (Figure 5.4). The magnitude of this neuromuscular fatigue was 1.2-fold the SWC, with a 94% probability of a true effect (likely-probably). The Med were better than the Con at returning CMJ FT to pre training levels 24 hr after TR2 when normalised to Pre values (5.6%, 0.96±0.83, moderate) (Figure 5.4). This difference represented 1.4 times the SWC, with a 95% (very likely) probability of a true effect.

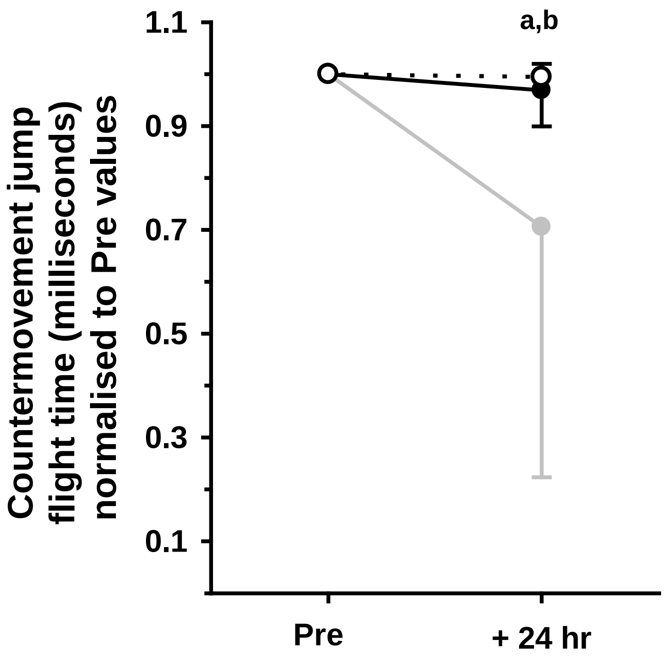

Figure 5.6: Countermovement jump flight time. Countermovement jump flight time (milliseconds) normalised to pre values 24 hr after training session 2 (TR2). Data are mean±standard deviation. Solid line and closed circles represents the control (Con, n=6), the dotted line and open circles represent the medical compression garment group (Med, n=6), and the solid grey circles with the solid grey line represents the sports compression garment group (Spo, n=7). [a] Denotes a substantial change from Pre to +24 in Spo only. [b] Denotes a substantial difference between Med and Con in the change in CMJ FT from Pre to +24.

Perceived muscle soreness had recovered to Pre levels 24 hr after TR2 (Table 5.4). Muscle soreness responses varied markedly between participants in Spo (Figure 5.5). No treatment effects were observed for the recovery of muscle soreness values.

Table 5.4: The percentage change in perceived fatigue, muscle soreness and plasma Myoglobin concentration ([Mb]) following training session two (TR2).

	SWC	Group	Data sets	Pre - +24	% chances for values to be higher/trivial/lower at +24 than Pre	Rating of the change	% chances for Spo or Med values to be lower/trivial/higher than Con	Rating of the treatment effect (vs Con)	% chances for Spo values to be lower/trivial/higher than Med	Rating of the treatment effect (Spo v Med)
Perceived Fatigue (au)	6.7%	**Con**	6	114.2 [a]	100/0/0	almost certainly	-	-	-	-
		Med	6	23.3 [a,b]	88/8/4	likely - probably	98/2/1	very likely	-	-
		Spo	7	15.9 [b]	64/18/18	unclear	96/2/2	very likely	51/16/33	unclear
Muscle Soreness (au)	8.1%	**Con**	6	25.8	62/22/16	unclear	-	-	-	-
		Med	6	26.8	83/10/7	likely -probably	42/18/40	unclear	-	-
		Spo	7	-1.8	25/43/32	unclear	66/16/19	unclear	79/12/9	unclear
Plasma [Mb] ($ng.ml^{-1}$)	9.2%	**Con**	5	24.7	73/21/6	unclear	-	-	-	-
		Med	6	18.1	73/24/3	unclear	24/32/44	unclear	-	-
		Spo	7	65.0 [a,c]	100/0/0	almost certainly	56/22/22	unclear	91/8/2	likely - probably

The SWC was calculated as 0.2 x the between subject standard deviation as a CV% (Batterham and Hopkins 2006). The number of data sets represents the number of full data sets available for analysis. Percentage change (%) are compared from Pre to 24 h post TR2 (+24) for the control (Con, n=6), medical compression group (Med, n=6) and sports compression garment group (Spo, n=7). The chances (%) for each parameter to be higher, trivial, or lower at +24 than Pre for each group are presented along with a qualitative rating of the within group change. The chances (%) for a treatment effect for Med and Spo versus the Con, and Spo versus Med are also presented, along with a qualitative rating of the respective effect. [a] denotes a substantial change for each specific group. [b] indicates a substantial difference compared to the Con in the change between Pre and +24. [c] indicates a substantial difference between Spo and Med in the change between Pre and +24.

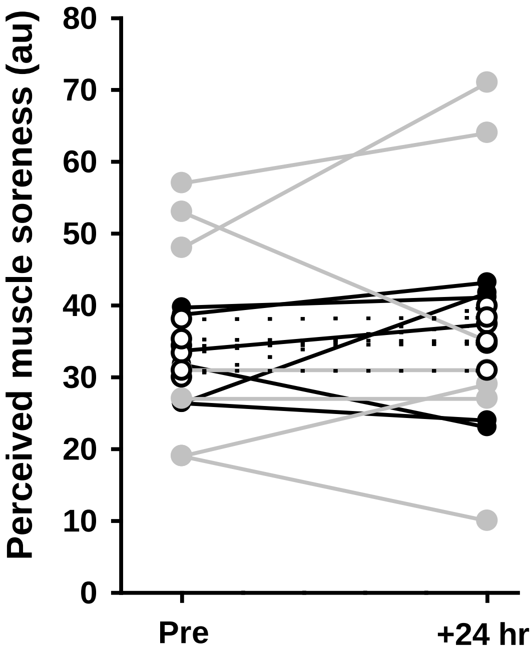

Figure 5.7: Individual muscle soreness responses to training session two (TR2). Solid line and closed circles represents the control (Con, n=6), the dotted line and open circles represent the medical compression garment group (Med, n=6), and the solid grey circles with the solid grey line represents the sports compression garment group (Spo, n=7). Values are expressed in arbitrary units (au).

Perceived fatigue remained elevated 24 hr after TR2 compared to Pre in the Med and Con. This elevation represented 17 and 3.5 times the SWC for Con and Med, with 100% (very likely) and 88% (likely, probably) likelihood of a true effect. The elevation at +24 compared to Pre was substantially greater in the Con compared to Spo and Med (45.9%, 1.63±1.31, large; and 42.5%, 1.50±1.02, large, respectively) (Table 5.4). The magnitude of this treatment effect was 6.9- and 6.3-fold the SWC, with 96% (very likely) and 98% (very likely) probability of a true effect, respectively.

Plasma [Mb] remained elevated 24 hr after TR2 in the Spo compared to Pre, with even greater levels in Spo versus Med (26.4%, 0.65±0.59, moderate). The magnitude of this difference was 2.9 times the SWC, with 91% probability of a true effect (likely-probably) (Table 5.4). See Table 9.3 in Chapter 9 (appendix) for raw values for plasma [Mb] (mean±SD).

5.3.1 Training Session 1 versus Training Session 2

When all groups were combined for TR1 and TR2, plasma [Mb], muscle soreness and perceived fatigue were all higher after TR1 versus TR2. There were no differences between TR1 and TR2 for total internal player load and session RPE.

Table 5.5: Training session one versus training session two.

	Myoglobin	**Soreness**	**Fatigue**	**CMJ FT**
Difference (%)	32.93 %	72.08 %	53.31 %	0.61 %
ES±90%CI	0.80±0.51	2.14±0.76	3.02±1.70	0.02±0.08
Rating of the difference	very likely	most likely	most likely	most likely trivial

The percentage difference in plasma Myoglobin concentration, muscle soreness, perceived fatigue and countermovement jump flight time (CMJ FT) after training session one versus training session two.

5.4 Discussion

This study demonstrates for the first time that Med compression garments can enhance the recovery of CMJ performance following elite team sport training (TR2), although this response is inconsistent. The rise in perceived fatigue was blunted when participants wore both styles of compression (Med and Spo) after TR2 but not TR1. Yet muscle soreness remained unchanged with compression garment use after both training sessions. This study also reports an uncoupling between perceptual measures and performance after both training sessions. For the first time the effectiveness of a Med and Spo garment for recovery were compared in a team sport scenario, with higher [Mb] present in those wearing Spo versus Med 24 hr after TR2. Positive recovery effects for compression garment use were not consistent and reproducible across both training sessions. Each of these training sessions were conducted in an independent manner, thus key findings will be discussed exclusively, culminating with a discussion regarding the inconsistencies between TR1 and 2.

5.4.1 Training session one

Participants did not display neuromuscular fatigue 24 hr after TR1, with CMJ FT recovering to pre training levels at this time in all groups. As a consequence it is not possible to ascertain the effect of wearing compression garments on CMJ FT after this training session. It is not clear why full recovery occurred in all groups, but it is likely to be associated with conducting post testing too long after the session and/or the training session was not intense enough to observe performance fatigue after 24 hrs.

Even after twenty four hours of recovery, and the use of compression garments, these elite participants still had elevated perceived muscle soreness after TR1. Indeed, the garments were no more effective than the Con at reducing perceived muscle soreness. This finding conflicts with other compression garment research which consistently points to positive recovery effects on this perceptual parameter (Kraemer, Bush et al. 2001a; Duffield, Edge et al. 2008; French, Thompson et al. 2008; Montgomery, Pyne et al. 2008b; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). It is unclear why similar effects were not detected in this group of participants.

All groups of participants also reported heightened perceived fatigue 24 hr after training. Yet the use of neither style of compression was able to abate this rise in perceived fatigue. Conversely, the recreationally active participants in Chapter 4, and elite basketball athletes (Montgomery, Pyne et al. 2008b), experienced less perceived fatigue when they wore Spo for recovery after repeat sprint exercise and basketball game play. It is unclear why compression garments did not influence this perceptual parameter.

Perceptual responses can vary markedly between participants, and it is possible that this may have clouded the ability to detect recovery effects for Spo and Med following TR1 for perceived fatigue and muscle soreness. Such variation possibly stems from differences in the interpretation of the word anchors at either end of the VAS, combined with the ability to accurately mark the VAS, particularly as the athlete's previous markings on the VAS were not displayed. It is also possible that players responded differently to the visual analogue scale as they viewed it as being part of a research project, rather than part of their daily wellness monitoring. What's more, there is a highly variable level of fatigue in an elite athlete population, indeed Mooney et al 2012 noted that 46% of AF athletes commenced competition in a fatigue state, with depressed CMJ FT:CT. Thus it is highly likely that this variability in fatigue represented through depressed performance would also be expressed in a varied level of perceived fatigue.

Elite AF training elicited substantial increases in plasma [Mb], a biochemical indicator of muscle damage, in those wearing compression garments (Med and Spo). A similarly 'statistically substantial' increase in plasma [Mb] was not observed in Con, despite the magnitude of the increase in Con being 8 times the SWC. Only three full data sets were available for statistical analysis in the Con, which probably hindered the detection of a substantial increase, particularly as there was an 88% likelihood of a true effect. The lack of more 'complete' data sets was the consequence of difficulty obtaining blood samples from some participants at either Pre or +24. It is probable that this also limited the detection of treatment effects for Med and Spo compared to Con. Similarly, serum [Mb] in elite basketball athletes was not different to the control after wearing Spo between games in a three day tournament (Montgomery, Pyne et al. 2008a), or after resistance exercise (French, Thompson et al. 2008).

Chapter 4 discusses an uncoupling between perceptual measures and performance in recreationally active participants in the Con. It also highlights a similar occurrence after a simulated rugby circuit (Duffield, Edge et al. 2008). In this group of participants, an uncoupling was observed for all groups 24 hr after TR1. Participants were able to maintain their CMJ performance, despite reporting elevated scores for perceived fatigue and muscle soreness.

5.4.2 Training session two

This study establishes for the first time that a Med compression garment can assist in the recovery of neuromuscular fatigue measured through a CMJ after team sport training (TR2). Twenty four hours after TR2, CMJ FT had recovered to pre training levels in Med and Con participants, with Med proving more effective than the Con. In fact, the magnitude of this effect was 1.2-fold the SWC. A corresponding effect was not observed for Spo, with these participants displaying neuromuscular fatigue 24 hr after TR2. It was expected that all participants would experience similar levels of neuromuscular fatigue ensuing from TR2 consequent to similar internal loads and the randomisation of treatment groups. As it was not possible to obtain data immediately after TR2, it is difficult to determine if the depressed CMJ FT in Spo at +24 represents a greater volume of neuromuscular fatigue resulting from TR2, or an inferior recovery. As the change in CMJ FT was not substantially different between Spo and Con, an inferior recovery appears less likely. This lack of perturbation does however highlight the small amount of neuromuscular fatigue after a typical pre season training session, with 24 hr of recovery being adequate to return CMJ to pre training levels. This could be in part explained by the time of season that data was collected, and equally possible that later during the season, more prominent neuromuscular fatigue would be observed due to training. For example, CMJ1Flight time:Contraction time was substantially reduced on 60% of measurement occasions throughout the competitive versus to pre season. These magnitudes of change compared to pre season ranged from 1.0 ± 7.4% (ES 0.04 ± 0.29) to -17.1 ± 21.8% (ES -0.77 ±0.81)(Cormack, Newton et al. 2008b). The literature points to an enhanced recovery of jump performance after resistance exercise in resistance trained individuals, and plyometric activity in untrained participants (French, Thompson et al. 2008; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a) when using Spo for recovery. No other study has investigated the recovery effects of Med on CMJ performance.

The exact mechanisms facilitating an improved recovery of CMJ performance with the Med compression garment are yet to be elucidated. Although not investigated directly in this study, there is evidence to suggest the contribution of a placebo effect to improved performance outcomes with compression use (Chatard, Atlaoui et al. 2004). Alternatively, it may be argued that a blunting of soreness may facilitate this performance improvement, particularly as DOMS is associated with performance impairments (Armstrong 1986; Clarkson, Nosaka et al. 1992; MacIntyre, Reid et al. 1995; Dierking and Bemben 1998; Clarkson and Sayers 1999; Rawson, Gunn et al. 2001; Braun and Dutto 2003). Yet, neither compression style aided the recovery of muscle soreness following this training session, as this perceptual parameter had recovered at +24, reducing the likelihood of this mechanism.

Twenty four hours after TR2, perceived muscle soreness had returned to pre training levels. Accordingly, it is not possible to establish the effect of wearing compression garments on perceived muscle soreness after this training session. It is not clear why full recovery occurred in all groups, but it is likely to be associated with conducting post testing too long after the session and/or the training session was not intense enough to observe elevated perceived muscle soreness after 24 hrs. It is also feasible that the large level of individual variation precluded the statistical detection of muscle soreness at +24, and thus recovery effects. For example, the increase in muscle soreness in the Con was 3.2-fold the SWC, but displayed only a 62% chance of a true effect, highlighting the degree of uncertainty. The Med also displayed an increase in muscle soreness 3.3 times the SWC, but this time displayed a higher probability of a true effect (83%). However, the effect was categorised as ‘unclear-get more data’, suggesting more participants were required. When individual muscle soreness responses were plotted, Spo actually displayed the largest level of individual variation. It is likely that this resulted in the inability to detect an increase in perceived muscle soreness at +24. Thus it is possible that elevations in muscle soreness at +24, and possibly treatment effects, would have been seen if individual variation was reduced.

Conversely, these elite AF participants had lower perceived fatigue 24 hr after TR2 with both Med and Spo compared to the Con. The magnitude of these treatment effects were 6.3- and 6.9-fold the SWC respectively. The recreationally active participants in Chapter 4, and elite basketball athletes (Montgomery, Pyne et al. 2008b) also experienced less perceived fatigue when they wore Spo for recovery after repeat sprint exercise and basketball game play. Differences in internal load values are unlikely to be responsible for these treatment effects as all groups recorded similar values. The mechanisms underpinning this recovery effect for compression garments are yet to be made clear, and may in part be linked to placebo effects. See Section 4.3 for a discussion of the placebo effect.

Elevated plasma [Mb], a biochemical marker of muscle damage, 24 hr after TR2 suggests the occurrence of a substantial volume of muscle damage in Spo participants. Those wearing Spo had even higher plasma [Mb] than Med. It could be that the higher level of compression afforded to Med allowed a more substantial increase in limb blood flow (Mayberry, Moneta et al. 1991), and possibly clearance of Mb from the plasma than Spo. However it cannot be ruled out that differences in the volume of muscle damage occurring as a result of TR2 may instead have driven this difference. The inability to collect data immediately after TR2 to quantify the immediate increase in plasma [Mb] was a key limitation in interpreting these results.

Perceptual and performance parameters were uncoupled in Con, Med and Spo participants after TR2. A similar occurrence was reported in Chapter 4, and also for rugby players after a simulated rugby circuit (Duffield, Edge et al. 2008). As noted above, perceptual parameters should be included in a battery of tests to assess athlete readiness to train, rather than as standalone measures.

5.4.3 Inconsistent effects between TR1 and TR2

Consistent recovery effects with compression garment use were not seen after TR1 and TR2. Indeed, Med participants had a superior recovery of CMJ FT and perceived fatigue after TR2. What's more, those wearing Spo also had an improved recovery of perceived fatigue after TR2. These positive recovery effects were not observed after TR1. In fact no positive recovery effects were detected after TR1.

It is possible that the lack of consistent recovery effects across TR1 and TR2 are linked to inconsistencies in the performance, perceptual and biochemical responses after these two training sessions. Perceived muscle soreness and fatigue were elevated after TR1 in all groups. Yet 24 hr after TR2 muscle soreness had recovered to pre training levels, with heightened perceived fatigue present only in the Med and Con. What's more, neuromuscular fatigue was evident only in Spo after TR2. The only similarities identified between TR1 and 2 were the elevated plasma [Mb] in Spo, and an uncoupling between perceptual and performance measures.

Although the duration and training activities of TR1 and TR2 were the same, it is possible that participants experienced differences in parameters investigated as a consequence of the training sessions. A key limitation of this study was the inability to quantify perturbations in these parameters immediately after TR1 and 2 due to limited player access. Although desirable, it was not possible to use GPS technology to quantify the activity profile of participants during the SSG, running and skill components of the training sessions. Interestingly, plasma [Mb], muscle soreness and perceived fatigue were all higher after TR1 versus TR2, yet positive recovery effects were detected after TR2 for CMJ FT and perceived fatigue. Thus differences between TR1 and TR2 appear not to have influenced recovery responses here.

Although not compared statistically, it is important to note that the smallest worthwhile change for each parameter differed between TR1 and TR2, with uniformly higher thresholds identified for TR1. These higher thresholds may help explain the lack of treatment effects after TR1. The SWC was calculated taking into consideration the variability in the pre-training measures. This highlights that across an athlete population, there is likely to be a large degree of variation in the 'freshness' of the athlete. It may be that when using this type of analysis to monitor athletes, that individual, rather than group thresholds, should be established for the SWC in the most 'fatigue free state' to detect practically important magnitudes of change when assessing recovery.

5.5 Conclusion

Elite AF participants experience elevated plasma [Mb], perceived fatigue and muscle soreness, coupled with depressed performance 24 hr after training sessions. Participants wearing both Spo and Med experienced less perceived fatigue 24 hr after TR2. Those wearing Med after the second training session also experienced a superior recovery of

CMJ performance compared to the control. The higher values for plasma [Mb] 24 hr after both AF training sessions with Spo use versus Med is likely the result of training activities, rather than a treatment effect. After elite AF training, perceptual measures are uncoupled from measurement of performance. Positive recovery effects for compression garments were not consistent and reproducible when two independent AF training sessions are conducted. Thresholds for the detection of meaningful effects can vary between training sessions. A key limitation of this study was the inability to obtain data immediately after the training session.

CHAPTER 6. RECOVERY EFFECTS OF MEDICAL AND SPORTS COMPRESSION GARMENTS AFTER ELITE AUSTRALIAN FOOTBALL COMPETITION

6.1 Introduction

Australian football athletes are placed under a large physical strain during competition games. During games, athletes will cover roughly 150 m per minute of game play (Aughey 2011), and undertake a maximal acceleration on average each minute (Aughey 2010). This is exacerbated by repeated collisions with opposition players and the ground (Dawson, Hopkinson et al. 2004b). Chapter 5 illustrated the high requirement for recovery in this football code after training sessions. The longer duration and larger playing field used during games are expected to elicit substantially more muscle soreness, perceived fatigue, muscle damage and neuromuscular fatigue than AF training, ultimately dictating an even greater need for recovery. Australian football athletes wear sports compression garments (Spo) in the hours and days after competition for recovery, despite a scarcity of evidence to support their use in this manner.

The higher level of compression in medical style garments (Med) is anticipated to facilitate recovery to a greater extent versus sports style garments, through alterations to vascular (Mayberry, Moneta et al. 1991) and lymphatic properties (Jonker, de Boer et al. 2001). This was not the case following AF training, where obvious differences in recovery properties were not detected (Chapter 5). Both garment styles improved the recovery of perceived fatigue, with medical compression also decrements in CMJ performance, however neither garment proved superior.

There is a scarcity of scientific investigation into the effects of compression garments for recovery from team sport competition. Elite rugby union athletes had lower transdermal [CK] after competition when they wore Spo for recovery (Gill, Beaven et al. 2006). The meaningfulness of these results is diluted by reliability and validity concerns associated with this measure (Section 2.7.3). Conversely, serum [Mb] remained unchanged with Spo at the end of a three day basketball tournament when elite athletes wore the garments between games (Montgomery, Pyne et al. 2008a). However, perceived fatigue and muscle soreness were lower at the end of the tournament with garment use (Montgomery, Pyne et al. 2008b). In those same athletes, agility and line drill performance benefited from wearing the garments, yet there were larger decrements in vertical jump and 20 m acceleration versus control (Montgomery, Pyne et al. 2008b). A host of factors make it difficult to extrapolate these positive recovery responses to the AF post game period. For example, the basketball tournament was conducted during the pre-season, weakening comparisons to in-season competition, especially considering that the stress response (cortisol) and session RPE values are substantially lower following simulated basketball games versus official competition (Moreira, McGuigan et al. 2012). Further, there are vast differences in playing field area and game time with AF competition, compared to basketball games. Finally, basketball game play lacks a high level of physical contact, a key feature of AF competition. Thus a more comprehensive investigation into recovery effects of compression garments after a contact team sport is required.

This study therefore aimed to: (1) quantify the extent of muscle soreness, perceived fatigue, muscle damage and performance test impairments following elite AF competition (2) investigate the capacity of compression garment use to enhance recovery following an elite AF game; and (3) investigate any differences in recovery responses between a sports and medical grade garment following an AF match.

6.2 Methods

6.2.1 Participants

Twenty two elite AF athletes from the same team ((Mean ± Standard Deviation) Age 24.2±3.5 yrs; height 189±5.6 cm; body mass 88.6±7.6 kg) provided written informed consent to participate. The experimental protocol was approved by the Victoria University Human Research Ethics Committee. During AF competition games, only 22 athletes are allowed to participate per team, restricting participant numbers. It was not possible to repeat the experimental protocol during additional games to increase the participant numbers.

6.2.2 Experimental overview

All participants played in the same competition game, where pre game (Pre), post game (Post) and 40 hr post game (+40) measures were taken (Figure 6.1: Experimental overview). Measures included blood sampling to assess plasma [Mb] (Section 3.1), VAS for perceived muscle soreness and fatigue (Section 3.2) and CMJ flight time (FT) and flight time to contraction time ratio (FT:CT) (Section 3.3). Additionally, an RPE rating (Section 3.2) was collected at Post. This investigation was conducted in an elite athlete training environment, as such, participants completed their normal post game routines which included assessment and treatment by the clubs physiotherapists and myotherapists.

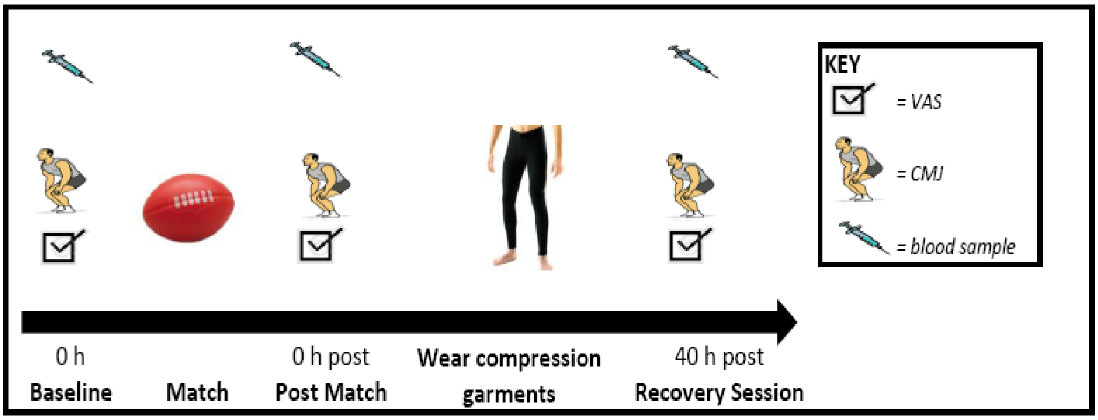

Figure 6.1: Experimental overview. Measurements were collected at baseline, immediately after the game, and 40 hr after the game. Measurements taken were a countermovement jump (CMJ), visual analogue scale (VAS) for perceptions of fatigue and muscle soreness, and a venous blood sample for plasma Myoglobin concentrations. Compression garments were worn between the end of the game until 40 hr later at the follow up recovery session.

6.2.3 Session RPE and internal load on participants

An RPE value was obtained after the game. The session RPE method (RPE x duration [minutes]) (Foster, Florhaug et al. 2001) was used to quantify the internal load placed on each player for the game, and expressed in arbitrary units (au).

6.2.4 Recovery intervention

Within one hour post game, participants were matched for playing position and randomly assigned to one of three recovery conditions: a lower body sports compression garment (Spo, Skins Australia; n=7), thigh high medical compression socks (Med, JOBST forMen Medical Legware, USA, 30-40 mmHg at the ankle; n=8); or the control, normal clothing that exerted minimal compression (Con; n=7). All garments were worn within one hour post game until +40. Normal post game recovery regimes (3-4 min walk, stretch-band assisted flexibility routine and 5-6 min cold water immersion to the arm-pits (12-15°C)) were completed by all participants before compression garments were applied. The post game recovery regime was overseen by the club's strength and conditioning staff. Compression garments were temporarily removed if discomfort was experienced. The removal of the garments by participants was confirmed verbally by the researchers at +40. Participants were advised to abstain from alcohol consumption during the recovery period prior to data collection at +40.

6.3 Results

Mean total playing time, and internal load as determined by the session RPE method, were 99±12.4 min and 1076.8±139.5 au respectively. No differences between groups occurred for playing time or player load (Table 6.1).

Table 6.1: Internal load units (au) obtained from the game and total time spent on the field (min) during the game.

	Con	Med	Spo
Internal Load Units (au)	1122.3±124.0	1075.0±155.0	1033.5±141.9
Game Time (min)	104.03±12.67	99.49±12.93	93.41±10.65

Internal player load units (au) were determined by the session RPE method and total playing time (min) obtained during the game for the control (Con, n=7), medical compression garment (Med, n=8) and sports compression garment group (Spo, n=7). All values are mean±standard deviation.

The SWC for perceived muscle soreness was 11.9%. All groups had an immediate increase in perceived muscle soreness. The magnitude of this increase was 13.9, 7.1 and 4.7 times the SWC for the Con, Med and Spo. Forty hours later perceived muscle soreness had recovered to pre game levels (Table 6.2). There were no differences between groups in muscle soreness responses. A large degree of individual variability was observed in this measure in all groups (Figure 6.2).

Table 6.2: Perceptual responses to Australian football competition.

	SWC		Pre - Post	Pre - +40	Post - +40
Perceived Fatigue	**11.1%**	**Con**	178.3 % [a] (0.99±0.70) moderate	140.0% (0.85±1.84) unclear	-34.3 % [a] (-0.41±0.54) small
		Med	187.8% [a] (1.01±0.81) moderate	104.6% (-0.68±1.87) unclear	-13.3% (-0.14±0.21) unclear
		Spo	8.8% (0.64±1.12) unclear	-39.9% (-3.88±6.56) unclear	-33.0% (-3.05±4.14) unclear
Muscle Soreness	**11.9%**	**Con**	165.3 % [a] (0.85±0.61) moderate	84.1 % (0.54±1.75) unclear	-57.2 % [a] (-0.75±0.76) unclear
		Med	84.4 % [a] (0.65±0.62) moderate	74.3 % (0.59±2.06) unclear	-16.4 % (-0.19±0.74) unclear
		Spo	55.4 % [a] (0.80±0.89) moderate	-65.4 % (-1.92±2.88) unclear	-51.7 % (-1.31±2.07) unclear

The SWC was calculated as 0.2 x the between subject standard deviation as a CV% (Batterham and Hopkins 2006) and represented as a percentage (%). Change in perceived fatigue and muscle soreness from Pre to post game (Post), Pre to 40 h post game (+40), and Post to +40 for the control, (Con; n=7), medical compression (Med; n=8) and sports compression groups (Spo; n=7). All values are % change between the two time points, ES±90%CI and the effect size descriptor. [a] indicates a substantial change between time points. [b] indicates a substantial change between groups.

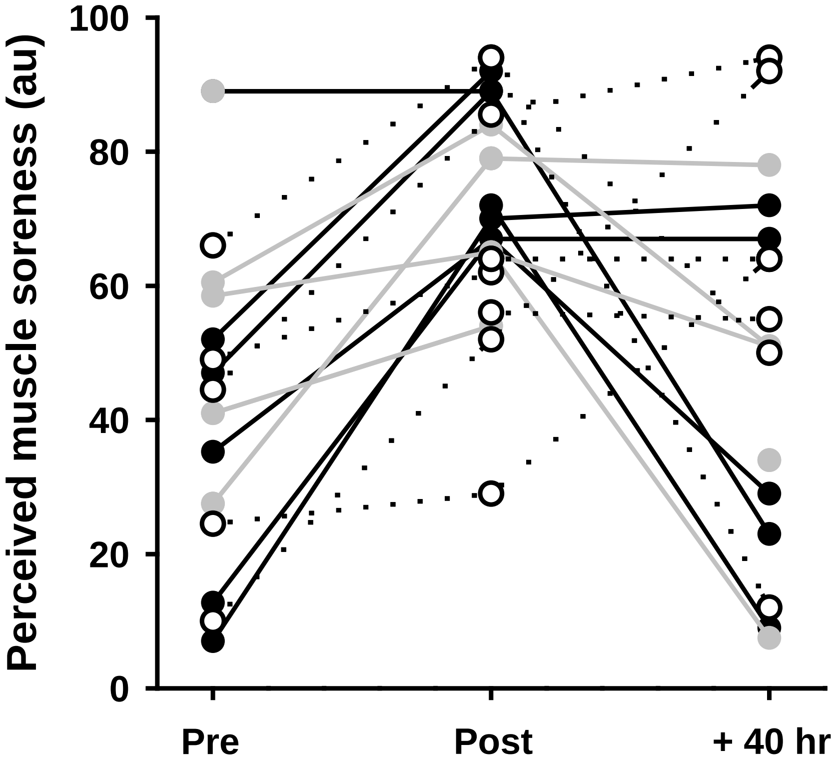

Figure 6.2: Individual muscle soreness responses to an Australian Football game. Solid line and closed circle represents the control (Con, n=7), the dotted line and open circles represent the medical compression garment group (Med, n=8), and the closed grey circles with the solid grey line represents the sports compression garment group (Spo, n=7).

The SWC identified for perceived fatigue was 11.1%. Perceived fatigue increased 16.1-fold the SWC in Con and 16.9-fold the SWC in Med immediately after the game (Post). This immediate elevation had decreased substantially in Con only 40 hr later (Table 6.2). After 40 hr of recovery, perceived fatigue was not elevated above pre game levels in any group. Perceived fatigue displayed a large level of individual variability; individual responses are displayed in Figure 6.3.

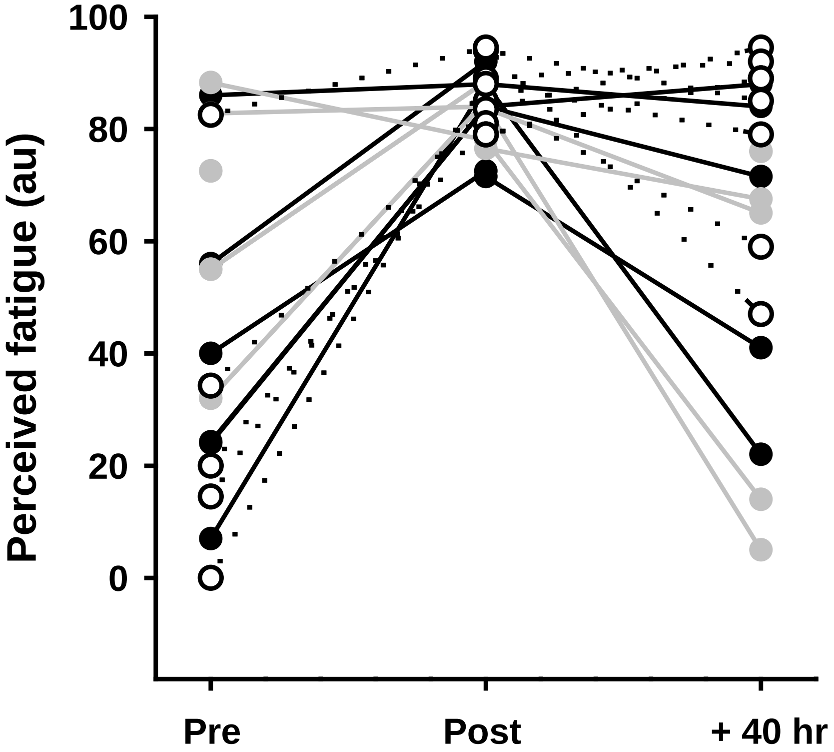

Figure 6.3: Individual perceived fatigue responses to an Australian Football game. Solid line and closed circle represents the control (Con, n=7), the dotted line and open circles represent the medical compression garment group (Med, n=8), and the closed grey circles with the solid grey line represents the sports compression garment group (Spo, n=7).

The SWC for plasma [Mb] was 11.6%. Plasma [Mb] was elevated immediately after the game in each group (Table 6.3). The magnitude of this increase was 127.1, 98.7 and 324.1 times larger than the SWC for the Con, Med and Spo. In the Spo, plasma [Mb] was increased from Pre to Post more than in the Med (250.8%, 3.11±1.74, very large) and Con (186.6%, 1.87±1.57, large) (Table 6.3). The magnitude of this difference was 21.6- and 16.1-fold the SWC for Med and Con respectively. Forty hours after the game, the increase in plasma [Mb] compared to Pre concentrations was substantially greater (61.7%, 2.38±2.04, very large) in athletes wearing Spo versus Med. This difference was 5.3 times the SWC, with 96% probability of a true effect (very likely). Refer to Table

9.4 in Chapter 9 (Appendix) for raw plasma Myoglobin values (mean±standard deviation).

Table 6.3: Change in plasma Myoglobin ([Mb]) concentration ($ng \cdot ml^{-1}$) following elite Australian football competition.

	Pre - Post	Post - +40	Pre - +40
Con	1473.9 % [a] (3.34±0.76) very large	-92.2 % [a] (-3.08±1.00) large	43.3 % (0.44±0.89) unclear
Spo	3759.1 % [a,b,c] (4.94±0.82) extremely large	-96.8 % [a] (-4.65±0.87) extremely large	50.5 % [c] (0.55±1.35) unclear
Med	1145.0 % [a] (4.90±0.88) extremely large	-93.5 % [a] (-5.32±1.22) extremely large	14.7 % (0.27±0.64) unclear

Samples were collected at pre game (Pre), post game (Post) and 40 hr post game (+40) for the control (Con, n=7), sports compression (Spo, n=7) and medical compression garment (Med, n=8) groups. Values are percentage change, ES±90% CI, and the effect size descriptor. [a] denotes a substantial difference between the two time points. [b] denotes a substantial difference compared to the Con in the change between two time points. [c] denotes a substantial difference between Med and Spo in the change between two time points.

The game caused immediate reductions in CMJ FT only in the Spo (Table 6.4). This reduction was 2.6-times the SWC. Compared to pre game scores, CMJ FT was depressed 40 hr after the game in athletes wearing Spo and Med, but not the Con. The magnitude of this neuromuscular fatigue was 2.6-fold the SWC for both Spo and Med. Countermovement jump FT:CT was depressed immediately after the game only in athletes in the Med and Spo (Table 6.4). This reduction in performance was 2.2 and 3.3 times the SWC for Med and Spo. Forty hours after the game, these scores remained substantially depressed compared to Pre in both compression garment groups. This represented 3.0 times the SWC for Med, and 2.8 times the SWC for Spo. A similar effect was not seen in the Con. There were no differences between conditions in the change in flight time, or flight time:contraction time scores.

Table 6.4: Countermovement jump variables following Australian football competition.

	CMJ FT		**CMJ FT:CT**	
SWC	**1.6%**		**6.9%**	
	Pre - Post	**Pre – +40**	**Pre - Post**	**Pre – +40**
Con	0.1% (0.02±0.83) unclear	-1.9% (-0.28±0.47) unclear	7.4% (0.11±0.53) unclear	-12.1% (-0.20±0.45) unclear
Med	-2.0% (-0.41±0.70) unclear	-4.3% [a] (-0.86±0.59) moderate	-15.3% [a] (-0.45±0.56) moderate	-20.8% [a] (-0.61±0.41) moderate
Spo	-4.2% [a] (-0.75±0.80) moderate	-4.2 % [a] (-0.76±0.24) moderate	-22.9% [a] (-0.74±0.61) moderate	-19.0% [a] (-0.60±0.43) moderate

Change in countermovement jump (CMJ) flight time (FT, milliseconds) and flight time:contraction time ratio (FT:CT) from pre (Pre) to post game (Post) and Pre to 40 h post game (+40), in the control (Con, n=7), medical (Med, n=8) and sports (Spo, n=7) compression garment groups. The SWC was calculated as 0.2 x the between subject standard deviation as a CV% (Batterham and Hopkins 2006) and represented as a percentage (%). All values are % change between the two time points, ES±90%CI and the effect size descriptor. a indicates a substantial change between time points. b indicates a substantial change compared to the Con. C indicates a substantial change between Med and Spo.

6.4 Discussion

High levels of muscle soreness, perceived fatigue and muscle damage are elicited after elite AF competition. Even forty hours later, neuromuscular fatigue as measured by a CMJ test is still present in athletes (Spo and Med), despite the use of compression garments. Wearing a Med or Spo garment did not accelerate the recovery of perceptual, physiological or performance test (CMJ) parameters in these elite athletes when used as a recovery tool. Indeed, the level of compression, or type of garment, made no difference to recovery. In line with Chapter 4 and 5, perceived fatigue and muscle soreness appear uncoupled from performance test results.

This study characterised muscle damage through a biochemical marker, perceived muscle soreness and fatigue which manifests from elite AF competition. This work supports the findings of Young et al (2012), where high levels of Creatine Kinase were observed 24 hr after elite junior AF competition (Young, Hepner et al. 2012). The neuromuscular fatigue present after competition, measured through CMJ analysis, mirrors that of previous investigations (Cormack, Newton et al. 2008a). In athletes with neuromuscular fatigue (Med and Spo), even after 40 hr of recovery, the use of compression garments and the club's traditional hydrotherapy protocol did not return CMJ test performance to pre fatigued standards, confirming the high recovery requirement of this code of football.

Unlike Chapter 5, where Med accelerated the recovery of CMJ FT after AF training, wearing either style of compression garment made no difference to the recovery of CMJ performance after this AF game. Upon initial inspection, the presence of neuromuscular fatigue at +40 in both compression groups suggests negative influences of these garments on the recovery of CMJ parameters. However, the absence of depressed CMJ performance immediately post game in Con best explains the subsequent lack of neuromuscular fatigue at +40, rather than an inferior recovery with Med or Spo. Athletes were randomised across conditions, thus it remains ambiguous why discrepancies in post game CMJ performance occurred. Inconsistencies in the effect of Spo on jump test performance are reported in the literature. Indeed, Spo use either enhanced (Rusko 1996; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a), reduced (Rusko 1996), or had no effect (Davies, Thompson et al. 2009) on CMJ performance recovery. What's more, the positive recovery effects of Med on CMJ recovery in Chapter 5 were not consistent across both training sessions conducted, only proving effective after training session number two.

These elite AF athletes experienced muscle soreness and perceived fatigue immediately after the game. The magnitude of this soreness ranged from 4.7 to 13.9 times the SWC. Sensations of soreness were not expected to manifest until 12-48 hr after the game (Dawson, Gow et al. 2005), with this perceptual response more likely reflecting fatigue sensations from the game and soreness from physical contact with opposition participants and the ground. Yet this was not reflected through actual ratings of perceived fatigue across all groups, with athletes wearing Spo lacking this immediate change in perceived fatigue. There were 'high' pre game values for some athletes. Mooney et al reported that elite 46% of AF athletes commenced competition in a fatigue state, with depressed CMJ FT:CT (Mooney, Cormack et al. 2012). Similarly to Chapter 5, participants did not experience less muscle soreness when wearing either style of garment after competition. Yet research consistently reports positive effects of compression garments on perceived muscle soreness (French, Thompson et al. 2008; Montgomery, Pyne et al. 2008b; Davies, Thompson et al. 2009; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). Perceived fatigue also remained unaltered with compression use, despite positive effects occurring after basketball games (Montgomery, Pyne et al. 2008b), repeat sprint activity with Spo use in Chapter 4, and AF training in Chapter 5 with both Med and Spo. It is possible that the long term familiarity that the participants have with match loads contributed to the lack of muscle soreness and fatigue 40 hr after the match. Indeed, in normal research settings participants are typically only exposed to one or two familiarisation sessions prior to the completion of the study. Yet in the present study, these athletes were highly accustomed to the stimulus.

A combination of factors most likely precluded the observation of positive recovery effects for these perceptual measures. For instance, it is likely that the high level of conditioning of these participants (Nosaka and Newton 2002) facilitated the recovery of muscle soreness and perceived fatigue to pre game levels 40 hr after the game. In fact, this game was played during the latter stages of the competitive season, emphasising this ‘pre-conditioning’. To compound this, perceptual responses were highly variable. The increase in muscle soreness from pre game to +40 Con for example highlighted this (12±61 arbitrary units; mean±standard deviation), which was replicated across groups and also for perceived fatigue. What’s more, in the competition phase of the season, access to participants when they are completely free of muscle soreness and fatigue is rare, particularly late in the season as was the case in the current study. Although a valid and reliable tool (Seymour 1982; Du Toit, Pritchard et al. 2002; Boonstra, Schiphorst Preuper et al. 2008), the VAS may be limited in its application in competition scenarios.

Despite a large increase in plasma [Mb], indicating significant muscle damage present after the game, 99 to 324 times the SWC, like Chapter 4 and 5, neither compression garment type influenced the post game plasma [Mb]. Likewise, Spo did not facilitate a faster recovery of serum [Mb] after basketball game play (Montgomery, Pyne et al. 2008a) or resistance exercise (French, Thompson et al. 2008). Although the magnitude of the initial increase in plasma [Mb] after the game was substantial, sampling 40 hr after the game appears to have been too late. Indeed, plasma [Mb] decreased by a similar magnitude across all groups 40 hr later, returning to pre game concentrations. Hence, the detection of recovery effects at +40 was not feasible. Conversely, 24 hr following AF training, plasma [Mb] remained elevated (Chapter 5), and it was anticipated that due to the greater demands of games, that games would cause more pronounced and prolonged elevations. Young et al (2012) observed elevated concentrations of plasma creatine kinase 24 hr after elite junior AF competition also. Other team sport research, such as soccer and American football, have suggested a post exercise plasma [Mb] peak at ~24 hr (Ascensao, Rebelo et al. 2008; Kraemer, Spiering et al. 2009), however due to the large difference in sports it is not known if the peak post AF competition would also occur at +24. Data was collected in an elite athlete environment; as such follow up data collection occurred at the clubs first training session after the game, which was scheduled 40 hr after the game. Like Chapter 5, the plasma [Mb] results suggest that Spo participated in more damage inducing game activities, having larger post game plasma [Mb] increases compared to Med or Con. This is reflected in higher plasma [Mb] at +40 in Spo versus Med compared to Pre levels. It is unlikely that this reflects any physiological action on plasma [Mb] as Spo not only experienced a larger initial increase in plasma [Mb] than Med, but at +40, plasma [Mb] was not substantially elevated above Pre levels in either group.

The notion of an uncoupling between perceptual and performance parameters was discussed in Chapter 4 in recreationally active individuals. Similarly, this uncoupling was observed for the Med after both TR1 and TR2 in Chapter 5, as well as for the Con after TR1. This dissociation was also apparent after AF competition. Indeed, 40 hours after the game, Med and Spo participants were unable to maintain CMJ performance, yet did not display substantial elevations of perceived fatigue or muscle soreness. Rugby participants also experienced this uncoupling after a simulated rugby circuit, where they were able to maintain performance 24 hr after the circuit despite elevated perceived soreness (Duffield, Edge et al. 2008). Rather than acting as standalone indicators of readiness to train/compete, perceptual measures should be incorporated into a global assessment of the athlete, as they do not appear coupled with performance.

It was expected that consistent recovery effects would be detected following competition due to the substantial amount of damage induced by game play. Studies which have observed high levels of muscle damage document the most consistent recovery effects (Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). It is likely that the conditioning status of the participants in this study (Nosaka and Newton 2002) precluded similar observations, with the conditioning level likely to have overcome the taxing nature of the game, at least for perceptual and biochemical measures. However, athlete conditioning level in the current study, and previous research (Cormack, Newton et al. 2008a), was not sufficient to overcome the neuromuscular fatigue evident in the days after competition. Although desirable to use in covariate analysis, a more detailed investigation of player activity profiles, particularly running, through GPS technology was not feasible due to indoor competition. Further, it was not possible to control sleep, medication, alcohol and food intake which may have impacted on recovery during the 40 hr post game period. As the participants were elite athletes, with data collected at a critical stage of the competitive year, professionalism and attention to detail was expected, and thus it is anticipated that such factors may have played a minimal role.

A major and unavoidable limitation of the current study was the use of cold water immersion by all athletes immediately after the match. It is possible that the positive recovery effects of the immersion protocol swamped any positive recovery effects associated with the compression garments. In athletic settings, cold water immersion can assist in attenuating post-exercise power and strength reductions,4,6 alleviate symptoms of exercise-induced muscle soreness (Bailey, Erith et al. 2007; Vaile, Gill et al. 2007; Ingram, Dawson et al. 2009; Elias, Varley et al. 2012), and reduce fatigue between exercise bouts (Vaile, Halson et al. 2008a; Elias, Varley et al. 2012). Reductions in localised swelling, oedema and indices of exercise-induced muscle damage have also been attributed to cold water immersion (Bailey, Erith et al. 2007; Ascensao, Leite et al. 2011). Indeed, after elite AF competition repeat-sprinting performance remained slower 24 and 48 hr after the game for athletes receiving a passive (3.9% and 2.0%) treatment which was restored with cold water immersion (0.2% and 0.0%) use. Soreness after 48 hr was attenuated by cold water immersion (ES 0.59±0.10) but remained elevated for athletes who partook in passive recovery (ES 4.01±0.97). Similarly, cold water immersion more successfully reduced fatigue after 48 hr (ES 1.02±0.72) compared to and passive recovery (ES 1.91±0.67). Declines in static and countermovement jump were also ameliorated by cold water immersion (Elias, Wyckelsma et al. 2012).

6.5 Conclusions

As expected, AF competition produced increases in a marker of muscle damage, muscular soreness and perceived fatigue in the presence of impaired physical performance. Even after 40 hr, AF participants did not achieve full recovery, displaying signs of neuromuscular fatigue. Compression garments did not augment recovery following AF competition beyond that achieved by the routine recovery regime implemented. Further, neither garment type proved superior as a recovery intervention. Finally, this study demonstrated that an uncoupling of perceptions of fatigue and tests of performance are apparent following AF competition.

CHAPTER 7. GENERAL DISCUSSION AND CONCLUSIONS

7.1 Introduction

The effect of wearing compression garments for recovery post-exercise was investigated in this thesis. Specifically, this was evaluated under three distinct scenarios: 1) consecutive days of repeated sprint activity in recreationally active individuals (Chapter 4); 2) elite AF training (Chapter 5); and 3) elite AF competition (Chapter 6). In the elite training and competition setting, a comparison between a medical and sports style garment was also conducted. Perceptual, performance and plasma markers of muscle damage during recovery were assessed in each investigation. The outcomes of each chapter have been discussed in detail; therefore this section will focus on an integrated general discussion of the major results of the thesis.

7.2 Australian football training and competition are strenuous, imposing large recovery demands.

As a consequence of the strenuous nature of AF, the recovery demands after both training and competition are high. Table 7.1 provides the range of the mean percentage change in perceptual, performance and muscle damage responses to AF training and competition.

Table 7.1: Perceptual, performance and muscle damage responses compared to baseline after Australian Football training and competition.

	Training	Competition	
	+ 24 hr	Immediately post	+ 40 hr
Muscle soreness	↑187 – ↑400%	↑ 55 – 165%	↓65 – ↑84*
Fatigue	↑ 23 – 230%	↑ 178 – 187%	↓39 – ↑140%*
Flight time	↓ 1%	↓ 4 %	↓ 4 %
Flight time: Contraction time ratio	NA	↓ 15-22%	↓ 19-21%
Plasma Myoglobin	↑ 61 – 153%	↑1145 – 3759%	↑ 14 – 50%*

The responses following AF training have been combined to include both training session one (TR1) and two (TR2). Changes in parameters were classified as a true effect where there was a ≥ 75% likelihood of the effect being equal to or greater than the SWC, with an effect size ≥0.2, which represents a small effect size. *these values were not substantially different, and only represent a trend in the data. NA= FT:CT was not measured in Chapter 5.

There were mixed recovery demands after elite AF training in Chapter 5. After TR1, participants in all groups had elevated perceived fatigue and muscle soreness, with elevated plasma [Mb] in the Med and Spo. However, CMJ performance had recovered to pre training levels at this stage. Hence recovery interventions after this session should be targeted towards enhancing perceptual recovery. The recovery demands are more varied after TR2. Neuromuscular fatigue was evident, but only in those wearing Spo. Those same participants had elevated plasma [Mb]. Participants in the Med and Con reported heightened perceived fatigue 24 hr after TR2. Although variable between sessions and participants, it is clear that the recovery demands of these participants are high within the weekly training cycle, with no group displaying complete recovery across all parameters at +24. Indeed, skill based training sessions are repeated up to three times per week, in addition to two or more resistance training sessions as well as individual skill sessions (Cormack, Newton et al. 2008a), leaving little time for between session recovery. These inconsistencies within and between TR1 and 2 emphasises the need for an individualised approach to recovery programming due to the heterogeneous recovery status 24 hr after training.

Australian football athletes also have a high recovery demand after competition. Participants were still experiencing neuromuscular fatigue 40 hr after competition, despite the use of compression garments for recovery and the clubs traditional post game hydrotherapy protocol. The prevalence of a similar magnitude of neuromuscular fatigue (CMJ FT) 40 hr after competition compared to only 24 hr after training reflects the greater volume of activity conducted in games, and a greater need for recovery (Table 7.1).

Plasma [Mb] data suggests that elite AF participants experience greater volumes of muscle damage compared to other codes of football. In fact, the post game increase in plasma [Mb] was almost three times more than after soccer (Ascensao, Rebelo et al. 2008) and rugby union competition (Takarada 2003), suggesting a greater recovery demand after AF. Elite soccer and rugby union competition is conducted over a shorter duration (~25 and 33%) (Mohr, Krustrup et al. 2003; Takarada 2003), players cover less distance (37 and 49%), and in the case of rugby union, partake in fewer tackles (Takarada 2003). As muscle damage is the consequence of both intermittent running (Thompson, Nicholas et al. 1999) and physical contact (Zuliani, Bonetti et al. 1985; Takarada 2003), it is likely that the longer duration of games, combined with the larger distances covered and more frequent physical contact, contributes to this higher level of muscle damage, and thus recovery requirement after AF. Despite the large increases in plasma [Mb] immediately after the game, 40 hr of recovery was suffice for this marker to return to pre-game levels.

Despite immediate elevations in perceived muscle soreness and fatigue after elite AF competition, 40 hr of recovery was suffice for these parameters to return to pre game levels. In comparison, 48 hr following sub elite AF competition, muscle soreness ratings remained substantially elevated (Dawson, Gow et al. 2005). The lower conditioning status in the sub elite participants tested (Ingebrigtsen, Bendiksen et al. 2012) may explain the more pronounced muscle soreness response 48 hr after competition compared to the response in Chapter 6. Although data is not available to compare the internal load data between the two studies, it may be suggested that internal load would not be greatly different between the two athlete cohorts as this measure is relative to the individual. It is also possible that differences in training stress may contribute to these differences. In Chapter 6 there was a high level of individual variation in perceptual responses, which may have contributed to the lack of substantial effect. There are multiple factors that could contribute to this individual variation. High pre-game values for both perceptual parameters were observed in some participants. Indeed, a proportion of elite AF athletes commence competition in a fatigued state (Mooney, Cormack et al. 2012). The observed variation may also be attributed to differences in the athlete's interpretation of the word anchors used in the VAS, and the ability to accurately mark the VAS, particularly as their previous 'markings' were not displayed.

7.3 Sports and medical compression garments elicit similar recovery effects

For the first time, differences in recovery effects between sports and medical compression garments were investigated (Chapters 5 and 6). The recovery effects for both garment types are presented below (Table 7.2). Despite the differences in the level of compression, neither garment proved superior in facilitating these recovery effects.

Table 7.2: Overview of recovery effects for sports and medical compression garments after repeat sprint exercise, Australian football training and competition.

	Garment type	
	Sports compression	**Medical compression**
Repeat sprint exercise	✓ Muscle soreness ✓ Perceived fatigue ✖ Muscle damage ([Mb]) ✖ Running performance	NA
Australian football training	**Training session 1** ✖ Muscle soreness ✖ Perceived fatigue ✖ Muscle damage ([Mb]) ✖ Performance (CMJ flight time)	**Training session 1** ✖ Muscle soreness ✖ Perceived fatigue ✖ Muscle damage ([Mb]) ✖ Performance (CMJ flight time)
	Training session 2 ✖ Muscle soreness ✓ Perceived fatigue ✖ Muscle damage ([Mb]) ✖ Performance (CMJ flight time)	**Training session 2** ✖ Muscle soreness ✓ Perceived fatigue ✖ Muscle damage ([Mb]) ✓ Performance (CMJ flight time)
Australian football competition	*No recovery effects were detected*[#]	

Recovery effects were classified as a true effect where there was a ≥ 75% likelihood of the effect being equal to or greater than the SWC, with an effect size ≥0.2, which represents a small effect size. A tick (✓) represents a positive recovery effect, a cross (✖) indicates no recovery effect. [#] Following Australian Football competition recovery effects were not detected due to the late sampling point 40 hr after the game which likely precluded a comprehensive analysis. NA= Medical compression garments were not investigated in the repeat sprint study (Chapter 4).

The larger increases in plasma [Mb] with Spo versus Med observed during recovery in Chapter 5 and 6 are unlikely to represent a true treatment effect. Participants who wore Spo had a substantially larger increase in plasma [Mb] 24 hr after TR2 in Chapter 5 compared to those wearing Med. As discussed throughout this thesis, it is speculated that the higher level of compression afforded to Med style garments *may* facilitate a greater removal of plasma [Mb] from the circulation due to increases in limb blood flow (Mayberry, Moneta et al. 1991). As limb blood flow was not assessed in this thesis, this theory remains purely speculative. Rather than physiological mechanisms, it is possible that differences in the amount of damaging activity conducted during the training session influenced these results. Internal player load was calculated for each session, with no differences identified between garment groups. However it is not yet apparent how sensitive, if at all, this measure is to muscle damage.

Similarly, 40 hr after competition in Chapter 6, Spo had a substantially larger elevation in plasma [Mb] from pre game levels than Med. This time, those participants wearing Spo displayed an initially larger post game increase in plasma [Mb] than Med, explaining this result at +40. Thus it seems unlikely that differences between the garment groups regarding plasma [Mb] are linked to physiological mechanisms, and rather are best explained by the level of damaging activity undertaken.

In Chapter 5 and 6, not all parameters were altered immediately after competition and at +24 in Chapter 5, and +40 in Chapter 6. Thus it is unknown if differences in recovery effects between Spo and Med would have been identified if all parameters tested were altered substantially as a result of training and competition.

7.4 Compression garments do not consistently enhance the recovery of performance.

Similar to previous research, this thesis highlights a lack of positive recovery effects on performance when using compression garments for recovery. The ability to maintain performance when conducting exercise, training sessions and competing on consecutive days, such as tournament scenarios, is crucial, particularly as the training/competition schedule of elite athletes is extremely hectic. Unfortunately the protocol used in Chapter 4 to investigate this was not sufficiently fatiguing, and thus the detection of recovery effects on the maintenance of performance was not possible.

Table 7.2 highlights the mixed recovery effects for CMJ performance after two independent AF training sessions in Chapter 5. It also highlights the lack of positive recovery effects of compression on CMJ recovery after elite AF competition in Chapter 6. The inconsistencies in Chapter 5 may be linked to the inability to quantify, and thus account for, the amount of immediate post training neuromuscular fatigue. It is more likely however, that the compression garments simply did not enhance the recovery of performance.

Inconsistencies in the effect of Spo on jump test performance are reported in the literature, with the majority of studies failing to detect positive treatment effects. Indeed, Spo use either enhanced (Rusko 1996; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a), reduced (Rusko 1996), or had no effect (Davies, Thompson et al. 2009) on CMJ performance recovery. This thesis did not detect negative effects of compression garments on the recovery of CMJ performance or the maintenance of treadmill running, and thus does not discourage their use. As discussed below in Section 7.6, it may be that these inconsistencies may partially be driven by the athlete's belief in the garments.

7.5 Mixed recovery outcomes occur for perceptual parameters with compression garment use.

7.5.1 Positive recovery effects for perceived fatigue and muscle soreness are inconsistent.

To minimise perceived muscle soreness, compression garments are a useful addition to the recovery program, but only for recreational exercisers after consecutive days of repeat sprint activity, and not elite AF athletes following training or competition (Table 7.2). Conversely, the literature consistently points to positive recovery effects of compression garments on perceived muscle soreness (Kraemer, Bush et al. 2001a; Duffield, Edge et al. 2008; French, Thompson et al. 2008; Montgomery, Pyne et al. 2008b; Jakeman, Byrne et al. 2010b; Jakeman, Byrne et al. 2010a). Although not investigated in this thesis, it is theorised that perceived muscle soreness is lessened through alterations to swelling and oedema (Jonker, de Boer et al. 2001; Kraemer, Bush et al. 2001a; Kraemer, Bush et al. 2001b). It is also highly plausible that a placebo effect (Section 7.5.2) contributes to the blunting of muscle soreness. These positive recovery effects for compression garments on perceived muscle soreness were not found after AF competition. Forty hours after the game muscle soreness scores had returned to pre game values.

Like perceived muscle soreness, perceived fatigue was blunted with compression garment use between consecutive days of repeat sprint exercise, and this time elite AF training, but only after one of the two training sessions (Table 7.2). The full recovery of perceived fatigue 40 hr after competition in Chapter 6 precluded similar observations. Following three days of basketball game play, Spo use between games facilitated 50% less perceived fatigue compared to control participants (Montgomery, Pyne et al.

2008b). It is not entirely clear how perceived fatigue is lessened with compression use. Section 7.5.2 discusses the possibility of a placebo effect driving this perceptual recovery.

The inconsistencies in recovery effects are discussed below (Section 7.6).

7.5.2 A placebo effect may influence perceptual recovery with sports compression garment use.

The placebo effect may be contributing to unexpected perceptual responses when wearing Spo for recovery. The individual's belief in, and expectations of Spo may have influenced the response to the VAS. For example, those allocated to Spo in Chapter 4 had perceived muscle soreness that was actually *lower* than pre study levels 24 hr after the first, second and third repeat sprint session. Similarly, perceived fatigue was lower than pre study levels 24 hr after the second and third RSE compared to pre study levels. These participants did not have substantial pre study soreness or fatigue, indeed, their pre study scores did not differ from Con. This observation was not limited to recreational exercisers. After AF competition in Chapter 6, elite AF participants wearing Spo had less perceived soreness and fatigue 40 hr after the game compared to pre game values, despite experiencing neuromuscular fatigue. Yet a similar observation was not apparent in elite AF participants after partaking in training sessions in Chapter 5.

The contribution of the placebo effect in compression garment research has focused primarily on the enhancement of the recovery of tests of performance, or the maintenance of performance (Chatard, Atlaoui et al. 2004; Higgins, Naughton et al. 2009; De Glanville and Hamlin 2012), with little attention paid to perceptual recovery. In one study, 50% of participants reported that the garments could have modified their second performance either a bit, or a lot (Chatard, Atlaoui et al. 2004). However, when compression garments were worn *during* a 40 min treadmill run (80% $\dot{V}O_{2max}$) by competitive runners, there were no differences between a placebo (12–15 mmHg at ankle) and standard sports style lower body compression garment (23–32 mmHg at ankle) for muscle soreness (Ali, Creasy et al. 2010). It is likely that the two levels of compression were too similar to allow for the detection of possible placebo effects. With this in mind, it is not possible to rule out potential placebo effects on perceptual parameters, as it is unlikely that these garments exert such strong recovery effects to allow participants to feel even better than before they commenced the repeat sprint exercise or AF competition.

These placebo effects on perceptual measures may in fact be practically important, and should not be dismissed. A positive mood state is linked to both basketball and volleyball performance (Newby and Simpson 1994; Newby and Simpson 1996). Basketball players exhibiting a positive mood score played more minutes during the season and had more assists than those whose scores reflected a negative mood state (Newby and Simpson 1994). Volleyball players also displayed positive associations between scores of vigor and games played (r=0.6), games played (r=0.6), and percentage of kills to attack attempts (r=0.5) (Newby and Simpson 1996). Placebo effects on perceptual parameters should however be treated with caution, as they may not necessarily always link to improved actual performance. Indeed, it is also possible for perceptual and performance measures to be uncoupled. See Section 7.5.3 for a discussion on this uncoupling. It is important to note that the above mentioned mood states were established using a profile of mood states questionnaire (Newby and Simpson 1994; Newby and Simpson 1996), which *may* be more tightly coupled with actual performance than perceived muscle soreness and fatigue obtained through a VAS.

7.5.3 Perceptual responses may be uncoupled from performance in recreational exercisers and elite athletes.

Perceptual ratings of fatigue and muscle soreness are used in conjunction with an array of measures in predicting an athlete's readiness to train/compete. Yet it appears that these perceptions may not actually be accurate indicators of when to resume training in both recreationally active participants (Chapter 4), and elite participants (Chapter 5 and 6) if used as a standalone measure. Rugby players also experienced this uncoupling after a simulated rugby circuit (Duffield, Edge et al. 2008). Indeed, athletes are often able to complete an exercise test of performance to their 'non-fatigued' level, however when required to repeat such a test hours later, performance is often depressed, despite athletes being accustomed to multiple training bouts per day (Meeusen, Piacentini et al. 2004). This drop in performance can range between 3 and 11%, depending on whether the athlete is in a trained, over-reached or over-trained state (Meeusen, Piacentini et al. 2004). Ultimately, although an athlete may enter training or competition in a state of perceived fatigue or muscle soreness, they are likely to be able to perform at an optimal level. However, the longer term accumulation of muscle soreness and perceived fatigue should be avoided due to implications in the development of the overtraining syndrome (Lehmann, Foster et al. 1993; Kentta and Hassmen 1998).

7.6 Recovery effects are inconsistent across exercise modalities

Table 7.2 highlights the inconsistencies in positive recovery effects with compression garment use after the three exercise modalities investigated in this thesis. This was even more pronounced in Chapter 5 where two independent AF training sessions were conducted. In that study, recovery effects were not reproduced across both training sessions, despite each session lasting the same duration and including the same activities.

A central limitation of this thesis which influenced the detection recovery effects was the inability of the exercise protocol to elicit consistent perturbations in the parameters investigated across all groups. This was exacerbated in Chapters 5 and 6 where it was not feasible to control the amount of work conducted by participants. It would be remiss to ignore the implications that this had on the ability to detect differences between groups when assessing recovery.

When considering the inconsistencies in recovery effects, coupled with the placebo effects (Section 7.5.2), it is possible that individuals may be categorised as responders or non responders to compression garments as a recovery modality. This implies that the efficacy of the garments may be tied in part to the individuals belief in the garments to enhance their recovery. If the treatment groups (Med and Spo) consisted of a combination of responders and non responders, recovery effects may have been missed due to heterogeneous groups. Practitioners should take this into consideration when implementing these garments into the recovery program, as the garments may be more effective for certain participants.

7.7 Final conclusions and practical recommendations

- There is a high recovery demand after AF training and competition.
    - During pre-season training, neuromuscular fatigue, perceived fatigue and muscle soreness, and elevated concentration of markers of muscle damage are still present after 24 hr of recovery. Practitioners should consider this when planning multiple ‘hard’ sessions in each microcycle, as well as the inclusion of additional recovery techniques.
    - Forty hours after competition neuromuscular fatigue was still evident in participants. Practitioners should observe caution when resuming training

within this time frame as residual performance decrements may hinder future performance.

- When recovering from bouts of high intensity exercise conducted across consecutive days, sports compression are useful at minimising perceived muscle soreness and fatigue in recreational exercisers. This enhanced perceptual recovery may be driven by placebo effects and requires investigation.
- Sports compression garments may offer positive recovery effects on CMJ performance and perceived fatigue when recovering from team sport training. The level of efficacy might however be dictated by placebo effects and thus be more effective in those who believe in the recovery properties of these garments.
- Medical compression garments do not offer any additional benefits to recovery compared to sports compression.
- Positive recovery effects are not consistently reported within and between exercise modalities.
    - Although speculative, the individual’s level of belief in compression garments for recovery may dictate positive, or a lack of, recovery effects. Practitioners may need to be aware of the individual’s preconceptions regarding this recovery modality to determine its likely effectiveness.
- Due to an uncoupling with performance parameters, perceptual measures of muscle soreness and fatigue obtained by visual analogue scales should not be used as standalone indicators of readiness to train/compete, and instead should be included in a battery of tests, where the athlete is assessed in a holistic manner.

CHAPTER 8. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The general limitations within this thesis are presented below. These limitations are accompanied by recommendations for future research in this area.

- Despite the previously established fatiguing nature of the exercise protocol used in Chapter 4 (Serpiello, McKenna et al. 2011), the recreationally active participants in this thesis were able to maintain their repeat sprint performance, regardless of the use of a recovery intervention. Thus, it was not possible to investigate the influence of compression garments on the maintenance of performance across multiple days. Previous use of this protocol in a similar participant population demonstrated that mean power decreased by 4.8% in set 3 versus set 1 (ES = -0.21 ± 0.07), peak power was reduced by 9.2% (ES = -0.28 ± 0.11), and mean velocity declined by 2.2% (ES = -0.18 ± 0.33) (Serpiello, McKenna et al. 2011). Even after ten sessions of repeated sprint training decrements in performance were observed. For example, mean power in set 3 was 4.1% lower than set 1 (ES = -0.19 ± 0.06), and mean velocity was reduced by 2.1% (ES = -0.17 ± 0.06). Future investigations should adopt a more demanding protocol to ensure that there is a substantial reduction in performance. It may be that the inclusion of additional sets of sprints, and/or longer sprint duration will achieve this. Ultimately, intensive pilot testing across multiple days is required to ensure the fatigue inducing nature of the protocol and its application to team sport scenarios.
- Sub-elite team sport athletes, or recreational team sport participants should have been identified as the cohort to be recruited for this study to enhance the transference of results to elite team sport athletes. This was a limitation of this study when

determining the practical applications of the findings. Future research should ensure the appropriateness of the cohort selected to improve the validity of the results.

- The repeat sprint protocol in Chapter 4 failed to produce immediate muscle damage as indicated through plasma [Mb]. Plasma [Mb] was only substantially elevated 24 hr after three RSE sessions in Spo only. This made it difficult to draw meaningful conclusions regarding the usefulness of compression garments to influence post exercise plasma [Mb]. It was expected that the deceleration phase of the 15 sprints in each RSE would elicit substantial muscle damage (Williams 1985). Alternatively, a protocol such as the Loughborough Intermittent Shuttle Test may be more appropriate. This test is designed to replicate soccer specific running activity (Nicholas, Nuttall et al. 2000) and elicits muscle damage even 48 hr after its completion in recreational exercisers (Thompson, Nicholas et al. 1999). The reproducibility of this running test has also been established, with no differences in performance and physiological parameters when participants unfamiliar with the protocol were tested 7 days apart (Nicholas, Nuttall et al. 2000). In addition, the activity pattern and the physiological and metabolic responses closely simulate the game demands of soccer (Nicholas, Nuttall et al. 2000), an intermittent running based team sport. The disadvantage of the Loughborough Intermittent Shuttle Test is its longer duration of approximately ~90 min, placing a far greater time requirement on participants.
- Although the magnitude of treatment effects for perceptual measures were greater than the SWC for muscle soreness and fatigue, a noticeable level of individual variation in perceptual responses in this thesis was apparent. It is likely that individual differences in the interpretation of the word anchors at either end of the VAS, for example ‘no fatigue’ and ‘very severe fatigue’ varied between participants

(Wewers and Lowe 1990). Although shown to be a sensitive measure to assess changes in pain scores (Seymour 1982; Du Toit, Pritchard et al. 2002), this limitation was likely compounded by the ability to accurately mark the VAS in the same position. To minimise this variation, participants should be thoroughly familiarised with the VAS. The familiarisation should include a detailed description of muscle soreness and general fatigue at both ends of the VAS to allow participants to more accurately interpret and mark the VAS. Moreover, it may be beneficial to collect multiple baseline scores to ensure a more accurate reflection of a relatively fatigue and soreness free state. The latter may be troublesome within an elite athlete environment, where athletes often experience fatigue and soreness to some extent due to the hectic training and competition cycle.

- Data in Chapter 5 was collected during a critical phase of the AF pre-season, with the actual testing days forming an important component of this phase. With this in mind, combined with limited access to participants, it was not possible to conduct a cross-over study.

  Limited player access also prevented the quantification of neuromuscular fatigue through a CMJ, perceived muscle soreness and fatigue, and plasma [Mb] levels immediately after training. This may have hindered the ability to detect recovery effects, as it remains unknown if all participants experienced the same recovery requirement. What's more, only collecting a recovery sample at +24 may have missed recovery effects associated with compression garments that occurred at an earlier time point.

  It was also not feasible to control the amount of work conducted during each session. Future research should quantify the amount of work conducted during each component of the training session. For example, it would have been desirable to conduct GPS analysis on the small sided game, running and skills component of training to identify possible between group differences; however access to the GPS units was not available at the time.

The use of sub elite participants in future studies may help overcome some of the issues associated with access to participants, control of training activities and the inclusion of a cross over design.

- The time point at which recovery was assessed following AF competition (Chapter 6) may have been inappropriate to detect recovery effects. Multiple variables (perceptual and biochemical) had returned to pre competition levels, making treatment effects difficult to detect. However, the time at which data was collected represented the actual time that the club conducted their first session after the game and is reflective of the clubs regular schedule. Future research should consider multiple sampling points throughout the recovery period to establish a time course of recovery for each parameter. Particularly, data should be acquired 24 hr after competition, as substantial perturbations in performance, perceptual and biochemical parameters were present following AF training at this time point. With the longer duration of games it is anticipated that at +24 after a game that considerable treatment effects may be detected.
- Although desirable, it was not viable to acquire data from multiple games in Chapter 6. This was attributed to data collection occurring during the competition season. Initially, two games were selected for investigation, which were reduced to a single game due to club imposed restrictions. This also precluded the use of a cross over design. As mentioned above, the use of sub elite participants may help overcome the issue of access to participants, which may allow for a cross over design across

multiple games. Combined with sampling at +24 rather than +40 (see above point), this larger sample size should allow for a greater opportunity to detect recovery effects. When selecting multiple games, consideration of the oppositions skill level must be considered to ensure all games are played against opponents of equal standing to prevent any bias in the data.

- An intrinsic limitation of compression garment research is the inability to blind participants, and to include a placebo. The use of elite participants (Chapter 5 and Chapter 6 compounded this, due to regular use of compression garments, and the accompanying familiarity with the sensation of wearing such garments. As such, it was not really a viable option to include elasticised (with very low levels of compression) pants as a placebo group. Similarly, many of the recreationally active participants involved in the repeat sprint study (Chapter 4) were accustomed to wearing compression garments. To overcome this limitation, it may be useful to record the participants' level of belief in the intervention, possibly through a VAS, prior to the study, which may later be used as a covariate during the analysis phase. This may be broken down into specific parameters such as muscle soreness, fatigue, performance, general recovery etc as the level of belief may vary across different parameters. It may also be useful when completing the investigation into the individuals level of belief to map brain activity. The use of functional MRI while completing 'belief' VAS/questionnaires would allow the measurement of the activity in the medial orbitofrontal cortex (Plassmann, O'Doherty et al. 2008), a region know to encode for experienced pleasantness (McClure, Li et al. 2004; Rolls, Grabenhorst et al. 2008). This information would help neurologically quantify the participants' expectations regarding the positive recovery effects of the compression garments.

- Compression garments are anticipated to exert positive actions on post exercise recovery namely through alterations to the vascular and lymphatic systems (Swedborg 1984; Mayberry, Moneta et al. 1991; Yasuhara, Shigematsu et al. 1996; Johansson, Lie et al. 1998; Jonker, de Boer et al. 2001; Beidler, Douillet et al. 2009). Although perceptual and performance recovery was enhanced at times with compression use in this thesis, the physiological mechanisms alluding to this improved recovery were not investigated. The focus of this thesis did not extend to such investigation, particularly in Chapters 5 and 6, as testing was conducted with elite participants in training and competition scenarios were access to participants was highly restricted. There are multiple non-invasive methods to measure limb blood flow including Doppler ultrasound (Chleboun, Howell et al. 1995; Hsieh and Lee 2005), tissue oxygenation measured using near infrared Spectroscopy (Bringard, Denis et al. 2006; Dascombe, Hoare et al. 2011; Coza, Dunn et al. 2012) and venous occlusion plethysmography (Bochmann, Seibel et al. 2005) that could be incorporated into future investigations.

  Compression garment mediated reductions in swelling and odema, through a mechanical blocking of odema, and improvements in vessel wall hydrostatic pressure, are suggested to minimise perceptions of muscle soreness (Kraemer, Volek et al. 2000; Jonker, de Boer et al. 2001). A non-invasive method to indirectly quantify swelling is the measurement of limb circumferences, which has been used in previous studies (Chleboun, Howell et al. 1995; Eston and Peters 1999). It is important that such investigations take into consideration exercise mediated changes in blood flow and limb circumference that may not be directly related to muscle damage or the use of compression garments.

It has been hypothesised that muscle soreness, secondary to damage inducing exercise, may reduce neural drive to the muscles, contributing to perceived fatigue (Racinais, Bringard et al. 2008). Indeed Duffield et al reported depressed evoked twitch properties 2 hr after damaging exercise which were associated with elevated markers of muscle damage 24hr later (Duffield, Cannon et al. 2010).

CHAPTER 9. APPENDICIES

9.1 Compression garment instructions and diary (Chapter 5)

What to do with your compression garments

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When to wear your garments...

- **END OF TRAINING SESSION** after your shower.
- Please wear your compression garment for the **REST OF THE DAY**.
- You may **REMOVE** the compression garment **OVERNIGHT** but please put them back on **THE NEXT MORNING** and wear them to the next training session.

Feeling uncomfortable?

- If you experience any discomfort while wearing your garments, simply **TAKE THEM OFF FOR 30 MINUTES (max)** then put them back on. You can record when you put the garment on and off in the following diary.

Thank you once again for your efforts in this study.

Player name: ____________________________________

Skins/Medical compression (please circle)

Put compression garment on (time and day)		**Took compression garment off (time and day)**	
Time:	Day:	Time:	Day:
Time:	Day:	Time:	Day:
Time:	Day:	Time:	Day:
Time:	Day:	Time:	Day:
Time:	Day:	Time:	Day:
Time:	Day:	Time:	Day:

9.2 Participant recruitment flyer

9.2.1 Chapter 4

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

VOLUNTEERS WANTED

ARE YOU:

ENTHUSIASTIC, HEALTHY, AGED BETWEEN 18 AND 35?

IF SO, YOU ARE INVITED TO PARTICIPATE IN A UNIQUE STUDY INVESTIGATING

The effects of Antioxidant Supplementation and Compression Garment recovery on Repeated sprint training

THE FOLLOWING procedures WILL BE performed:

* Yo-Yo intermittent recovery test * repeated-sprint running * 4 weeks training

BLOOD SAMPLES WILL BE TAKEN DURING NINE of the TRIALS.

As a part of this study, participants will be requested to ingest either a placebo or supplement, or wear compression garments.

FOR FURTHER INFORMATION CONTACT:

Dr. Rob Aughey Ph. 9919 5551 email: robert.aughey@vu.edu.au
Emma Gallaher email: emma.gallaher@live.vu.edu.au
Emma Goff email: emma.goff@live.vu.edu.au

9.3 Information to participants

9.3.1 Chapter 4

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

INFORMATION

TO PARTICIPANTS

INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled "The influence of pre-exercise anti-oxidant supplementation, and compression garment usage during recovery, on repeat sprint training." This project is being conducted by student researchers, Miss Emma Goff, as part of an Honours study at Victoria University and Miss Emma Gallaher, as part of a PhD study at Victoria University under the supervision of Dr. Robert Aughey from the faculty of Arts, Education and Human Development.

Project explanation

This project aims to investigate the effects of using an antioxidant supplement to enhance performance during repeated sprint training. The antioxidant being used, *N*-acetylcysteine, has been shown to have the ability to minimize oxidative stress on cells. Oxidative stress is a commonly associated side effect of intense exercise and it is possible that a decrease in the onset and amount of oxidative stress in the body could increase health and performance. The second part of the project investigates the effects of using compression garments to aid recovery from repeated sprint training. Compression garments are tight fitting pants made from an elastic material designed to exert pressure against your body. Compression pants have been suggested to improve recovery between exercise sessions. Through an enhanced recovery it is proposed that you would be able to train/compete at a greater intensity at the next session.

What will I be asked to do?

We will ask you to fill in several short questionnaires about your family medical history and your exercise habits. You will be asked to do two testing sessions before training, a 4-week period of training and one additional testing session after training. A venous blood sample will be also taken during 9 times throughout the study.

When participating is this study you will be asked to act as a control subject by completing only the repeated sprint training, or to use one of two performance enhancing aids, being an *N*-acetylcysteine supplement or a compression garment for recovery.

*1) Ingestion of N-acetylcysteine (*NAC*)* – This will be completed prior to the sprint training sessions and will involve you drinking a solution in small amounts over a 60 min period as you would any normal drink. *N*-acetylcysteine (NAC) is an anti-oxidant compound that neutralises reactive oxygen compounds. It is used for a number of clinical situations, including treatment of paracetamol overdose. Should you decide to participate in this study, NAC will be dissolved in a sports drink and given to you to ingest in three small doses of 250 ml over the course of an hour.

2) Wearing compression garments for recovery – This will consist of you wearing a medical grade compression garment for 15 hours following each sprint training session. You may remove the garments whenever any discomfort arises and then put them back on within 30 min of their removal. You are also requested to remove the compression garments whilst sleeping. The garments are a full lower body garment.

When taking part in the study you will be asked to dress in appropriate clothing to perform physical activity. If you bring a change of clothes, a changing area is available very close to the Laboratory.

What will I gain from participating?

No payment or reimbursement will be provided for participation in this project. From participating in this study you can expect to gain strong benefits to your aerobic fitness and increase your understanding of fitness and fitness tests. You will also gain the experience of having participated in an exercise science experiment designed to increase knowledge about antioxidant supplementation in repeated sprint training and the effects of using compression garments as a recovery tool. If you are a participant in the group wearing compression garments, upon completion any compression pants that have been provided to you for the project will remain yours to keep.

How will the information I give be used?

The information you provide to the researcher (through personal details and the results of your participation in the project) will be kept strictly confidential. Only group data will be reported and presented. This data may be presented through written publication, posters and conference presentations. Your personal information will not be passed onto any people or organisations other than the principle investigators.

What are the potential risks of participating in this project?

Blood sampling –Risks of blood sampling include unintentional (i) use of out-of-date sterile saline solution (saline is used during the blood sampling procedure), (ii) injection of an unintended compound / solution, (iii) transmission of infection to the participant due to lack of use of aseptic (free of microbiological organisms) techniques, (iv) discomfort, bruising and infection (for example puss, tenderness and/or redness). More serious complications such as bleeding, arterial spasm, distal arterial thromboembolism, thrombosis, and infection are theoretically possible, but rare.

(Arterial spasm: temporary, sudden contraction in one location in the muscles in the wall of an artery; distal arterial thromboembolism: formation of a clot (thrombus) in a blood vessel that breaks loose and is carried by the blood stream to plug another vessel. This form of thromboembolism occurs in the distal section of the artery; thrombosis: a clot within a blood vessel which obstructs blood flow through the circulatory system)

High intensity exercise- The performance of high intensity exercise involves a risk of sudden death due to myocardial infarct (heart attack) or a vasovagal episode (slow pulse, a fall in blood pressure, and sometimes convulsions). Signs and symptoms may include: sudden drop in heart rate during recovery (common) or exercise (rare); drop in blood pressure; pale complexion; fixed facial expression; pupils constricted; participant becomes uncommunicative or slurs words; restless and irritable; sweating; fatigue (if exercising). While vasovagal episodes are not uncommon, they are reversed quickly when employing a vasovagal management plan, and long-term risks are minimal. Exercise that includes running carries the risk of muscle soreness and stiffness.

NAC Ingestion - When NAC is ingested at very high doses to healthy human volunteers, adverse reactions have been reported and include nausea, diarrhoea, vomiting, rash, altered moods, sleepiness, dizziness and coughing. When given in smaller doses to healthy volunteers no side effects have been reported. The dose given to you will be **much lower** than that of previous research which has caused some of the reactions listed above. Thus, we anticipate the risks of adverse reactions to NAC will be extremely low with our ingestion protocol.

How will this project be conducted?

Initially, participants will perform a Yo-Yo Intermittent Recovery Test, which is an aerobic performance test specific for field-based team sports.

After at least 48 hours, the second visit will be a familiarisation trial of the repeated 4-sec sprint exercise. The familiarisation will comprise the participant performing 2 sets of 5 repetitions of sprints lasting 4 seconds each. These sprints will be performed on a non-motorised treadmill.

The main experimental trial consists of 10 sessions comprising 3 sets of 5 repeated 4-sec sprints. Each set of sprints is separated by 4.5 minutes of recovery. These sets of sprints will be performed on three days of the week (Monday, Wednesday and Friday) over a period of 4 weeks.

Blood samples: A small blood sample will be taken from a forearm vein by a qualified professional. This will be taken in order to determine the level of muscle damage occurring as a result of exercise and any intervention. You will be asked to sit quietly for ten minutes prior to the sample being taken. Blood samples will be taken before and after exercise session and at the next day training session. A total of 9 blood samples will be taken across the study period. Each blood sample will consist of 5ml of blood. On any single day a maximum of two blood samples (10 ml each) will be taken. This equates to 10 ml of blood being taken on any one day.

Who is conducting the study?

Organisations Involved in the Project:

Victoria University (Footscray Park Campus:

Principle Researcher:	Student Researcher:	Student Researcher:
Dr Robert Aughey	Ms Emma Gallaher	Miss Emma Goff
Victoria University	Victoria University	Victoria University
Footscray Park Campus	Footscray Park Campus	Footscray Park Campus
Robert.aughey@vu.edu.au	emma.gallaher@live.vu.edu.au	emma.goff@live.vu.edu.au
9919 5551	9919 4207	

Any queries about your participation in this project may be directed to the Principal Researcher listed above.

If you have any queries or complaints about the way you have been treated, you may contact the Ethics and Biosafety Coordinator, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4148.

9.3.2 Chapter 5 & Chapter 6

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled “Compression Garments and Recovery in Elite Australian Rules Football Players: From the laboratory to the field”.

This project is being conducted by a student researcher, Ms Emma Gallaher, as part of a PhD study at Victoria University under the supervision of Dr Robert Aughey from the faculty of Arts, Education and Human Development and Dr Rod Snow from the faculty of Health, Medicine, Nursing and Behavioural Sciences (Deakin University).

Project explanation

This project has been designed to investigate the effectiveness of compression pants as a recovery tool in elite male Australian Football (AF) players in typical AF scenarios. Compression pants are tight fitting pants made from an elastic material designed to exert pressure against your body. Compression pants have been suggested to improve recovery between exercise sessions. Through an enhanced recovery it is proposed that you would be able to train/compete at a greater intensity at the next session. In this project, the effectiveness of compression pants as a recovery tool will be investigated following three different scenarios: 1) following an AF drill (small sided game); 2) during a normal AF training week; and 3) during air-flight travel following an interstate match. The value of the compression pants to enhance recovery will be assessed through simple performance measures as well as physical and psychometric markers (see below).

What will I be asked to do?

As a participant in this research project you will be required to participate in four key phases.

1) <u>Baseline testing of your performance:</u> it is important to measure your baseline performance to see if any changes occur as a result of wearing compression pants. Baseline testing will involve completing two simple performance tests: 1) a countermovement jump test and 2) a repeat sprint ability test, both of which are explained later in this document. Baseline testing of both of these measures will be performed on the same day. Two separate baseline testing sessions will be completed. Each baseline testing session will take approximately 15 minutes. This will be conducted during your normal training schedule.

2) <u>Small sided games:</u> This is the first testing phase of the project. You will be required to participate in two separate AF drills which are referred to as small sided games (to simulate an AF match). Each small sided game consists of four x five minute quarters. One game will be designed to represent a non-contact scenario of AF, while the other will be designed to represent a contact scenario of AF. Following each game, you will be asked to either wear a pair of compression pants or normal (non-compressive) shorts/pants until the next

training session. The total time required per visit (including pre and post game measures) is estimated to be approximately 1 hour. Each small sided game will be separated by one week. Each of the small sided games (including taking measurements) will be completed within your normal training schedule.

3) Normal training week: For this phase of the project you will be requested to participate in a normal seven day week of training. During the time between each training session you will be requested to either wear a pair of compression pants or your normal post training attire (i.e. non-compressive shorts or pants). Various measurements will be taken before and after each training session. As this will be conducted during your normal training regime, no additional time commitments will be required.

4) Air travel: This phase of the project will be completed following an interstate match. Following the match, during air-flight travel and until the next training session you will be requested to wear either non-compressive pants/shorts or compression pants. Various measurements will be taken prior to the match, following the match and at the next training session. As this phase of the project will be conducted within normal post match interstate travel, and at the next day training session, no additional time commitments will be required of you.

All tasks within this project will be completed within the normal training and competition completed as part of being a player at the Western Bulldogs Football Club and/or the Williamstown Football Club and thus should not disrupt your day to day schedule in any considerable manner.

What will I gain from participating?

No payment or reimbursement will be provided for participation in this project. Upon completion, any compression pants that have been provided to you for the project will remain yours to keep.

How will the information I give be used?

The information you provide to the researcher (through personal details and the results of your participation in the project) will be kept strictly confidential. Only group data will be reported and presented. This data may be presented through written publication, posters and conference presentations.

Your personal information will not be passed onto any people or organisations other than the principle investigators.

What are the potential risks of participating in this project?

Repeat sprint ability test and high intensity exercise during AF small-sided games and AF training and competition- The performance of high intensity exercise when participating in the small sided games, AF training and competition involves a risk of sudden death due to myocardial infarct (heart attack) or a vasovagal episode (slow pulse, a fall in blood pressure, and sometimes convulsions). Signs and symptoms may include: sudden drop in heart rate during recovery (common) or exercise (rare); drop in blood pressure; pale complexion; fixed facial expression; pupils constricted; participant becomes uncommunicative or slurring of words; restless and irritability; sweating; fatigue (if exercising). While vasovagal episodes are not uncommon, they are reversed quickly when employing vasovagal management plan, and long-term risks are minimal. Exercise that includes running and physical contact carries the risk of muscle soreness and stiffness.

Blood sampling –Risks of blood sampling include unintentional (i) use of out-of-date sterile saline solution (saline is used during the blood sampling procedure), (ii) injection of an unintended compound / solution, (iii) transmission of infection to the participant due to lack of use of aseptic (free of microbiological organisms) techniques, (iv) discomfort, bruising and infection (for example puss, tenderness and/or redness). More serious complications such as bleeding, arterial spasm, distal arterial thromboembolism, thrombosis, and infection are theoretically possible, but rare.

(Arterial spasm: temporary, sudden contraction in one location in the muscles in the wall of an artery; distal arterial thromboembolism: formation of a clot (thrombus) in a blood vessel that breaks loose and is carried by the blood stream to plug another vessel. This form of thromboembolism occurs in the distal section of the artery; thrombosis: a clot within a blood vessel which obstructs blood flow through the circulatory system)

How will this project be conducted?

During the project, a variety of measurements will be taken to determine any changes in your performance, physical and psychometric markers. These include:

- *Psychometric measures.* Your perceived muscular soreness and your perceived level of fatigue will be assessed using a visual analogue scale (VAS). This is essentially a way of quantifying your level of soreness and fatigue. You will be asked to rank how sore you feel on a scale of “no soreness” to “extremely sore”. You will also be asked to rank how fatigued you feel on a scale of “no fatigue” to “extremely fatigued”. This measurement will be taken immediately before and after exercise sessions you conduct during the project. The VAS is non-invasive and has been used previously at the Australian Institute of Sport to measure changes in perceived muscular soreness and fatigue following exercise.

  In order to quantify how hard you felt each exercise session was, a session rating of perceived exertion (sRPE) will be used. You will be asked to rank your perception of the exertion or intensity of each session based on a scale of 1-10 (with 1 representing the lowest ranking of intensity, and 10 representing the highest ranking of intensity).

- *Blood samples:* A small blood sample will be taken from a forearm vein by a qualified professional. This will be taken in order to determine the level of muscle damage occurring as a result of exercise and any intervention. You will be asked to sit quietly for ten minutes prior to the sample being taken. Blood samples will be taken before and after exercise session and at the next day training session. A total of four blood samples will be taken across the study period. Each blood sample with consist of 10 ml of blood. A total of 40 ml of blood will be taken across the study period. On any single day a maximum of two blood samples (10 ml each) will be taken. This equates to 20 ml of blood being taken on any one day.

- *Hydration Testing:* In order to determine any changes in your hydration status the investigators will be using two measures: changes in your body weight; and changes in the properties of your urine, through a technique known as urine specific gravity (USG), from a small urine sample. No other analysis will be performed on your urine sample. In order to determine changes in your body mass, you will be asked to weigh yourself before and after each exercise session.

- *Performance measures:* You will be required to complete two simple performance tests. This is to assess weather or not an intervention has an effect on your performance. A repeat sprint ability test (RSA) will be used to assess your ability to perform six short repeated sprints. The RSA test is commonly used among team sports. You will also be required to complete a simple jump test, known as the countermovement jump test (CMJ) following exercise. This is a simple jump test performed on a mat that records a multitude of variables during the jump.

Who is conducting the study?

Organisations Involved in the Project:

- Victoria University (Footscray Park Campus)
- Deakin University (Burwood Campus)
- Western Bulldogs Football Club
- Williamstown Football Club

Principle Researcher	Co-Researcher	Student Researcher
Dr Robert Aughey	Dr Rod Snow	Ms Emma Gallaher
Victoria University	Deakin University	Victoria University
Footscray Park Campus	Burwood Campus	Footscray Park Campus
Ballarat Road, Footscray 3011	Burwood Hwy, Burwood 3125	Ballarat Road, Footscray 3C
Robert.aughey@vu.edu.au	Rod.snow@deakin.edu.au	Emma.gallaher@live.vu.edu.a
9919 5551		9919 4207

Any queries about your participation in this project may be directed to the Principal Researcher listed above. If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4781.

9.4 Cardiovascular and other risk factors questionnaire

9.4.1 Chapter 4

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

CARDIOVASCULAR AND OTHER RISK FACTORS QUESTIONNAIRE

In order to be eligible to participate in the experiment investigating: "The influence of pre-exercise anti-oxidant supplementation, and compression garment usage during recovery, on repeat sprint training." you are required to complete the following questionnaire which is designed to assess the risk of you having a cardiovascular event occurring during an exhaustive exercise bout.

Name: ______________________________ Date: ____________________

Age: _______ years Weight: _______ kg Height: _________ cm Gender: M F

Give a brief description of your average activity pattern in the past 2 months:

____

____

____

Circle the appropriate response to the following questions.

1. Are you overweight? Yes No Don't know

2. Do you smoke? Yes No Social

3. Are you an asthmatic? Yes No Don't Know

4. Are you a diabetic? Yes No Don't Know

5. Does your family have a history of diabetes? Yes No Don't Know

6. Do you have a thyroid disorder? Yes No Don't Know

7. Does your family have a history of thyroid disorders?

   Yes No Don't Know

8. Do you have a pituitary disorder? Yes No Don't Know

9. Does your family have a history of pituitary disorders?

	Yes	No	Don't Know
10. Do you have a heart rhythm disturbance?	Yes	No	Don't Know
11. Do you have a high blood cholesterol level?	Yes	No	Don't Know
12. Do you have elevated blood pressure?	Yes	No	Don't Know
13. Are you being treated with diuretics?	Yes	No	
14. Are you on any other medications?	Yes	No	

List all medications? (Including oral contraceptives)

____

____

15. Do you think you have any medical complaint or any other reason which you know of which you think may prevent you from participating in strenuous exercise? Yes No

If Yes, please elaborate

____

16. Have you had any musculoskeletal problems that have required medical treatment (e.g., broken bones, joint reconstruction etc)? Yes No

If Yes, please provide details (including dates)

____

17. Are you currently pregnant or expect to become pregnant during the time in which this experiment is conducted? Yes No

18. Does your family have a history of premature cardiovascular problems (e.g. heart attack, stroke)? Yes No Don't Know

I, ______________________________, believe that the answers to these questions are true and correct.

Signed: ________________________ Date: ______________

9.4.2 Chapter 5 & Chapter 6

COMPRESSION GARMENT RESEARCH MEDICAL QUESTIONNAIRE

Responses to this questionnaire will be kept strictly confidential. The responses from this questionnaire will provide the investigators with appropriate information to establish suitability of your participation in this study. Anyone who is currently carrying a musculo-skeletal injury or has a history of past, serious musculo-skeletal injuries may be excluded from the study for health and safety reasons.

Please complete the following preliminary questionnaire.

Name:________________________________ Age:________________(years)

Weight(kg):________________ Height (cm)_______________Sex:_______________

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 DON'T KNOW
- have high blood pressure? YES NO DON'T KNOW
- have a heart murmur? YES NO DON'T KNOW
- are asthmatic? YES NO DON'T KNOW
- are Haemophiliac? YES NO DON'T KNOW
- have type 2 diabetes? YES NO DON'T KNOW
- heart palpitations (sensation of abnormally fast and/or irregular heart beat)?
  YES NO DON'T KNOW

- episodes of fainting, collapse or loss of consciousness?

  YES NO DON'T KNOW

- abnormal bleeding or bruising? YES NO DON'T KNOW

- gastrointestinal problems? YES NO DON'T KNOW

Have you, or anyone of your family a history of cardiovascular disease? YES NO

(e.g. Heart attack, chest pain, stroke, rheumatic vascular disease)

If YES, please elaborate:____

Have you <u>ever</u> suffered any musculoskeletal injury? YES NO

If YES, please elaborate:____

Have you suffered any musculoskeletal injury in the last 6 months? YES NO

If YES, please elaborate:____

Do you have any allergies (including to medications)

YES NO DON'T KNOW

If YES, please elaborate:____

Have you ever experienced difficulty swallowing or any other gastrointestinal problem?

YES NO DON'T KNOW

If YES, please elaborate:____

Are you currently taking any medications including the following?

- Anti-coagulants YES NO DON'T KNOW

- Anti-inflammatory YES NO DON'T KNOW
- Aspirin YES NO DON'T KNOW
- Steroids (medically prescribed)

  YES NO DON'T KNOW
- Others, please specify: ____

If YES, please elaborate:____

____

Are you currently taking steroids or any performance enhancing substances?

YES NO DON'T KNOW

If YES, please elaborate:

____

Do you have any other reason which you know of which you think may prevent you from undertaking exercise or any of the other proposed 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):

____

____

____

9.5 Consent form

9.5.1 Chapter 4

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study into investigating the influence of a pre-exercise anti-oxidant supplement and compression garment usage during recovery on repeat sprint training. This study aims to investigate the following four points: (1) Does acute NAC enhance acute sprint performance?; (2) Does NAC enhance acute recovery from sprint exercise?; (3) Does NAC enhance sprint training outcomes?; and (4) Does compression worn after sessions enhance acute recovery and therefore chronic training effect?

CERTIFICATION BY SUBJECT

I, ____

of ____

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study: "The influence of pre-exercise anti-oxidant supplementation and compression garment usage during recovery on repeat sprint training" being conducted at Victoria University by Dr. Rob Aughey.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Miss Emma Gallaher and/or Miss Emma Goff

and that I freely consent to participation involving the below mentioned procedures:

- Provision of personal, medical and family history information for the purposes of general medical screening

- Yo-Yo Intermittent Recovery Test
- Repeated Sprint Training Protocol performed on a non-motorised treadmill
- Blood sampling
- Recovery Intervention (use of compression garments)
- Performance intervention (use of antioxidant supplement)

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way. I have been informed that the information I provide will be kept confidential.

Signed: ______________________________

Date: ________________________________

Any queries about your participation in this project may be directed to the researcher Dr. Rob Aughey, ph. 03-9919 5551. If you have any queries or complaints about the way you have been treated, you may contact the Ethics & Biosafety Coordinator, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4148.

9.5.2 Chapter 5 & Chapter 6

Consent Form for Subjects Involved in Research

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study examining the physiological and performance responses to compression garment usage following exercise.

CERTIFICATION BY SUBJECT

I, ____

of ____

certify that I am voluntarily giving my consent to participate in the following study titled:

"COMPRESSION GARMENTS AND RECOVERY IN ELITE AUSTRALIAN RULES FOOTBALL PLAYERS: FROM THE LABORATORY TO THE FIELD."

being conducted at Victoria University by:

Dr Rob Aughey (Principal investigator)

Professor Rod Snow (Co investigator)

Miss Emma Gallaher (Student researchers)

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Dr Rob Aughey (Principal investigator)

Professor Rod Snow (Co investigator)

Miss Emma Gallaher (Student Researchers)

and that I freely consent to participation involving the use on me of these procedures.

Procedures:

- Small-sided games
- Recovery intervention (compression garment therapy).
- Performance test (sprint ability and countermovement jump)
- Blood sampling
- Hydration status testing

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: **...** **Date: ....**

Any queries about your participation in this project may be directed to the researcher (Name: Dr Rob Aughey ph. 03-9919 5551). If you have any queries or complaints about the way you have been treated, you may contact the Secretary, University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, 8001 (telephone no: 03-9919 4710).

9.6 Perceptual measurements

9.6.1 Chapter 4: Visual analogue scale and rating of perceived exertion.

General Fatigue and Muscle Soreness

Name: ____________________ Session:_________ Date: __________ PRE/POST (circle)

PART ONE: **General Fatigue**

INSTRUCTIONS: *How severe is your level of* **GENERAL FATIGUE** *today? Place a vertical mark on the line below to indicate how bad you feel your* **GENERAL FATIGUE** *is today.*

No Fatigue |————————————————| **Very severe fatigue**

PART TWO: **Muscle Soreness**

INSTRUCTIONS: *How severe is your level of* **MUSCLE SORENESS** *today? Place a vertical mark on the line below to indicate how bad you feel your* **MUSCLE SORENESS** *is today.*

No Soreness |————————————————| **Very severe soreness**

PART THREE: **Session RPE**

RPE SCALE	
RATING	*DESCRIPTOR*
0	*Rest*
1	*Very very easy*
2	*Easy*
3	*Moderate*
4	*Somewhat hard*
5	*Hard*
6	
7	*Very Hard*
8	
9	
10	*Maximum*

Session RPE: ☐

9.6.2 Chapter 5 & Chapter 6: Visual analogue scale

General Fatigue and Muscle Soreness

Name: _____________________ Date: _______________

PART ONE: **General Fatigue**

INSTRUCTIONS: *How severe is your level of* **GENERAL FATIGUE** *today? Place a vertical mark on the line below to indicate how bad you feel your* **GENERAL FATIGUE** *is today.*

No Fatigue |————————————————————| **Very severe fatigue**

PART TWO: **Muscle Soreness**

INSTRUCTIONS: *How severe is your level of* **MUSCLE SORENESS** *today? Place a vertical mark on the line below to indicate how bad you feel your* **MUSCLE SORENESS** *is today.*

No Soreness |————————————————————| **Very severe soreness**

9.6.3 Chapter 5 & Chapter 6: Rating of Perceived Exertion Scale

RPE SCALE	
RATING	***DESCRIPTOR***
0	***Rest***
1	***Very very easy***
2	***Easy***
3	***Moderate***
4	***Somewhat hard***
5	***Hard***
6	
7	***Very Hard***
8	
9	
10	***Maximum***

9.7 Raw plasma Myoglobin values

9.7.1 Chapter 4: Raw plasma Myoglobin values

Table 9.1: Raw plasma Myoglobin concentration (ng/ml).

	Pre RSE1	Post RSE1	Pre RSE2	Post RSE2	Pre RSE3	Post RSE3	+24 hr
Spo	25.5±12.3	23.8±14.7	27.5±13.2	24.6±14.7	27.5±13.2	28.1±14.8	31.8±20.1
Con	35.4±40.0	41.3±36.0	29.1±20.9	25.0±14.7	34.4±27.2	29.6±35.8	36.3±29.6

Plasma Myoglobin values expressed in ng/ml for the sports compression garment group (Spo; n=9) and control group (Con; n=9). Values are mean±standard deviation. Data was collected Pre and Post repeat sprint exercise session 1, 2 and 3, and 24 hr after RSE3 (+24 hr).

9.7.2 Chapter 5: Raw plasma Myoglobin values

Table 9.2: Raw plasma Myoglobin concentration (ng/ml).

	Pre	+24 hr
Con	22.7±5.6	44.5±24.2
Med	27.3±10.5	44.0±20.5
Spo	24.4±16.8	49.3±21.2

Samples were collected at Pre and 24 h post training session 1 (TR1) (+24 hr) for the control (Con, n=7), medical compression group (Med, n=8), and sports compression garment group (Spo, n=9). Values are mean±standard deviation

Table 9.3: Raw plasma Myoglobin concentration (ng/ml).

	Pre	+24 hr
Con	29.7±11.9	38.0±17.7
Med	29.6±11.8	36.5±21.4
Spo	22.4±9.9	36.3±12.4

Samples were collected at Pre and 24 h post training session 1 (TR1) (+24 hr) for the control (Con, n=6), medical compression group (Med, n=6), and sports compression garment group (Spo, n=7). Values are mean±standard deviation.

9.7.3 Chapter 6: Raw plasma Myoglobin values

Table 9.4: Raw plasma Myoglobin concentration (ng/ml).

	Pre	Post	+40 hr
Con	31.7±20.6	422.5±239.2	40.4±29.5
Med	38.0±16.7	480.4±48.2	38.0±26.2
Spo	16.4±9.1	580.9±301.8	20.3±18.2

Samples were collected at pre game (Pre), post game (Post) and 40 hr post game (+40) for the control (Con, n=7), sports compression (Spo, n=7) and medical compression garment (Med, n=8) groups. Values are mean±standard deviation. Data was collected Pre, Post and 40 hr after the match (+40 hr).

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