A Comparison of Muscle Soreness and Damage Following Contact and Non-Contact Team Games

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“Success is sweet: It gets even sweeter if its long awaited for and attained through manifold struggles and defeats.”

~A. Branson Alcott
Executive Summary

Many team-sport athletes are required to compete weekly, leaving limited time for full recovery before the next training session or competitive event. One potential performance-limiting factor after a competitive match is muscle soreness and damage, with the resultant stiffness, swelling, reduced range of movement, fatigue and loss of strength, all contributing to performance decrements. Although the precise cause of post-exercise muscle soreness is unclear, it is typically attributed to internal mechanical strain or injury imposed on muscle fibres during intense or repeated muscular contractions. However, it is also possible that muscle soreness and damage may be the result of direct physical impact resulting from tackling, rucking, shepherding or other collisions between players in team sports involving body contact. Despite the suggestion that body contact may contribute to post-exercise muscle soreness, no previous research has directly compared the degree of muscle soreness and damage resulting from contact and non-contact team sports.

In order to investigate the effect of ‘body contact’ on muscle soreness and damage under more controlled conditions than a real game situation, a testing protocol is required that simulates the activity patterns of team sports. However, a potential limitation of many currently used protocols is their lack of ‘body contact’. Accordingly, the first study of this thesis (Chapter 2) aimed to assess the reliability of a simulated team game circuit with and without ‘contact’ to determine whether it may be suitable for monitoring key performance indicators in response to training or other interventions. Eleven male, team-sport athletes completed four separate testing trials; two ‘non-contact’ trials (NCON) and two ‘contact’ (CON) trials of a simulated
A game protocol was used to determine the reliability of a range of team sport performance indicators, including repeated 15-m sprint time, vertical jump height, heart rate responses and ratings of perceived exertion (RPE). This protocol involved four sets of 15-min of intermittent running around a circuit replicating the movement patterns observed in team sports, either with or without simulated contact in the form of a tackle bag being taken to ground every 3 circuits, together with the use of bump pads to provide 3 contacts to each side of the legs at the end of each set. Both CON and NCON produced reliable results for repeated 15-m sprint time, vertical jump height, heart rate response and RPE. Repeated sprint and jump performance declined significantly over time throughout the simulated game (p < 0.05), while heart rate and RPE increased significantly. There was no difference in these performance measures between CON and NCON protocols.

Using this simulated team game protocol, the second study of this thesis (Chapter 3) compared the effect of CON and NCON on perceived muscle soreness and blood markers of muscle damage, as well as performance when the same team sport circuit was repeated 48 h later. In this study, eleven male team-sport athletes completed the NCON and CON version of the simulated team sport activity circuit in a crossover design with at least 1 week between trials. The effect of CON and NCON on repeated 15-m sprint and vertical jump performance was assessed by completing the same version of the circuit 48 h after the initial trial. The effect on perceived muscle soreness and blood markers of muscle damage and inflammation in the 48 h between trials was also determined. Subsequent performance was affected to a greater extent by CON, with both best and mean sprint times significantly slower 48 h following CON (p < 0.05), while performance was maintained after NCON. Best and mean
vertical jump performance was significantly impaired following CON \((p < 0.05)\), while only best vertical jump was affected by NCON \((p < 0.05)\). Perceived soreness and pressure sensitivity were elevated following both NCON and CON \((p < 0.001)\); however, the increase in soreness was greater with CON \((p = 0.012)\). Both CON and NCON resulted in elevated serum creatine kinase, myoglobin and lactate dehydrogenase, while C - reactive protein increased following CON but not NCON. In summary, the addition of ‘contact’ to a simulated team sport activity circuit resulted in greater levels of perceived soreness, together with a greater impairment in subsequent repeated sprint and vertical jump performance 48 h later. These observations are likely to be the result of extra muscle trauma resulting from the addition of ‘contact’ itself. The greater reduction in performance following CON may have implications for training and recovery, since minimising subsequent performance decrements may be vital in determining the outcome of the next competitive match.
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<th>Description</th>
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<tr>
<td>AF</td>
<td>Australian Football</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>BMI</td>
<td>Body Mass Index</td>
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<tr>
<td>bpm</td>
<td>Beats Per Minute</td>
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<tr>
<td>BURST</td>
<td>Bath University Rugby Shuttle Test</td>
</tr>
<tr>
<td>CK</td>
<td>Creatine Kinase</td>
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<tr>
<td>CK-BB</td>
<td>Creatine Kinase (Brain Type)</td>
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<tr>
<td>CK-MB</td>
<td>Creatine Kinase (Muscle and Brain Type)</td>
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<tr>
<td>CK-MM</td>
<td>Creatine Kinase (Muscle Type)</td>
</tr>
<tr>
<td>CL</td>
<td>Confidence Intervals</td>
</tr>
<tr>
<td>cm</td>
<td>Centimeter</td>
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<tr>
<td>cm²</td>
<td>Centimeters Squared</td>
</tr>
<tr>
<td>COD</td>
<td>Change of Direction Speed</td>
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<tr>
<td>CON</td>
<td>Contact</td>
</tr>
<tr>
<td>CRP</td>
<td>C - Reactive Protein</td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of Variation</td>
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<tr>
<td>DOMS</td>
<td>Delayed Onset Muscle Soreness</td>
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<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>HR</td>
<td>Heart Rate</td>
</tr>
<tr>
<td>HR&lt;sub&gt;max&lt;/sub&gt;</td>
<td>Maximum Heart Rate</td>
</tr>
<tr>
<td>h</td>
<td>Hours</td>
</tr>
<tr>
<td>ICC</td>
<td>Intra-Class Correlation</td>
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<tr>
<td>ISE</td>
<td>Intermittent Sprint Exercise</td>
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<tr>
<td>Abbreviation</td>
<td>Unit Description</td>
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<tr>
<td>IU/L</td>
<td>International Units per Litre</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>kg.cm$^2$.s$^{-1}$</td>
<td>Kilograms per Square Centimeter per Second</td>
</tr>
<tr>
<td>km</td>
<td>Kilometer</td>
</tr>
<tr>
<td>km.h$^{-1}$</td>
<td>Kilometer Per Hour</td>
</tr>
<tr>
<td>LDH</td>
<td>Lactate Dehydrogenase</td>
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<tr>
<td>LS</td>
<td>Linear Speed</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
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<tr>
<td>MB</td>
<td>Myoglobin</td>
</tr>
<tr>
<td>mg/L</td>
<td>Milligrams Per Litre</td>
</tr>
<tr>
<td>min</td>
<td>Minutes</td>
</tr>
<tr>
<td>mL</td>
<td>Milliliter</td>
</tr>
<tr>
<td>N.s$^{-1}$</td>
<td>Newtons per Second</td>
</tr>
<tr>
<td>NCON</td>
<td>Non-Contact</td>
</tr>
<tr>
<td>ºC</td>
<td>Degrees Celsius</td>
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<tr>
<td>PPT</td>
<td>Pressure Pain Threshold</td>
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<tr>
<td>RAS</td>
<td>Reactive Agility Speed</td>
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<tr>
<td>RPE</td>
<td>Ratings of Perceived Exertion</td>
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<tr>
<td>rpm</td>
<td>Revolutions per Minute</td>
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<tr>
<td>s</td>
<td>Seconds</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SSEP</td>
<td>Soccer Specific Exercise Protocol</td>
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<tr>
<td>VAS</td>
<td>Visual Analogue Scale</td>
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<tr>
<td>VO$_2$ max</td>
<td>Maximal Oxygen Consumption</td>
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</tbody>
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I would never have been able to complete my dissertation without the guidance and support of the kind people around me, to only some of whom it is possible to give particular mention here.

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Thank you everyone for helping me learn a lot about life, and the continuous challenges that it comes with. I really appreciate it!
I dedicate this thesis to

my family, my husband, Jiwa, and my beloved children

Kryshant, Kriish & Yashica

for their constant support and unconditional love.

I love you all dearly.
Statement of Candidate Contribution

The work involved in designing and conducting the research studies described in this thesis has been completed primarily by Tarveen Kaur Ragbir Singh (the candidate). The candidate, under the guidance and assistance of Associate Professor Kym Guelfi, Assistant Professor Grant Landers, Winthrop Professor Brian Dawson (the candidate's supervisors) and Professor David Bishop has been responsible for the development and planning of the thesis outline and experimental design of the studies. All participant recruitment and management was carried out by the candidate, along with the organisation, implementation and performance of all experimental trials and exercise protocols described. In addition, all data analysis and original drafting of the thesis and manuscripts were the responsibility of the candidate. Associate Professor Kym Guelfi, Assistant Professor Grant Landers, Winthrop Professor Brian Dawson and Professor David Bishop have provided feedback for subsequent drafts and reviews of the thesis and manuscripts. Permission has been given by Associate Professor Kym Guelfi, Assistant Professor Grant Landers, Winthrop Professor Brian Dawson and Professor David Bishop for the published work listed on page IV to be included in this thesis.

Signed:

--------------------------------------------------------  -------------------------------
Tarveen Kaur Ragbir Singh              Dr Kym Guelfi
(Candidate)                             (Co-ordinating Supervisor)

XV
CHAPTER 1

Literature Review
1.1 Introduction

Many team-sport athletes are required to compete weekly, leaving limited time for full recovery before the next training session or competitive event (Dawson, Gow, Modra, Bishop, & Stewart, 2005). These demanding training and competition schedules often require repeated, high-intensity exercise sessions performed on consecutive days, multiple times per week (King & Duffield, 2009). Such volumes of intense training and competition, particularly with minimal recovery time, can place great physiological demands on the musculoskeletal, nervous, immune, and metabolic systems, potentially causing a negative effect on subsequent exercise performance (Reilly & Ekblom, 2005).

One potential limiting factor after a competitive match is muscle soreness and damage, with the resultant skeletal muscle stiffness, swelling, reduced range of movement, muscle fatigue and loss of strength, all contributing to performance decrements (Cheung, Huma, & Maxwell, 2003). Although the precise cause of post-exercise muscle soreness is unclear, it is typically attributed to internal mechanical strain imposed on muscle fibres during intense or repeated muscular contractions. However, external factors may also be an important cause of post-exercise muscle soreness. For example, in team sports such as Australian Rules Football (AF), soreness and damage may be the result of direct physical impact resulting from tackling, rucking, shepherding or collisions between players. Despite this potential contribution of body contact to post-exercise muscle soreness and damage, no previous research has directly compared the degree of muscle soreness and damage resulting from contact and non-contact team sports. It is possible that non-contact
Sports mainly invoke symptoms of acute muscle soreness, while contact sports result in additional muscle damage due to direct body contact when tackling and contesting the ball. This review of the literature will focus on the physiological demands of team-sport exercise (particularly AF), with particular reference to body contact and the potential implications for muscle soreness and damage, which in turn may limit subsequent exercise performance.

1.2 Physiological Demands of Team Sport Performance

The physiological demands of team sport games have been determined from studies of the movement patterns of athletes during match-play in a variety of team sports, including field hockey (Paun, Van Der Ploeg, & Stern, 2008; Spencer, et al., 2004), rugby league (Coutts, Reaburn, & Abt, 2003; Kay & Gill, 2003), rugby union (Deutsch, Kearney, & Rehrer, 2007; Duthie, Pyne, & Hooper, 2003a; Duthie, Pyne, & Hooper, 2005), Touch (O'Connor, 1999), AF (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004a) and soccer (Rienzi, Drust, & Reilly, 2000; Krustrup, Mohr, Amstrup, & Rysgaard, 2003; Di Salvo, Baron, & Tschan, 2007). These studies have demonstrated that many team sports involve periods of high-intensity running interspersed with periods of lower intensity activities such as jogging, walking and standing still. These periods of intermittent high-intensity exercise are regularly repeated over a prolonged period of time. For example, these activity patterns may last for up to 120 min in AF (Gray & Jenkins, 2010), 90 min in soccer (Svensson & Drust, 2005) and 80 min in rugby league (Gabbett, 2005).
Accordingly, a typical team sport player must possess high aerobic and anaerobic power, good agility, joint flexibility and muscular development, and be capable of generating high torques during fast movements (Reilly, 2000). However, the specific characteristics of a team-game athlete are highly influenced by the specific sport, the dimensions of the playing area, the standard of competition, and the playing position or tactical role in a game (Reilly, 2007).

With specific reference to AF, the physiological demands on players are high. In a typical match, two teams will contest play over four 20 to 30 min periods with the objective of scoring more points than the opposing team to win (Gray & Jenkins, 2010). A team is composed of 22 players, with 18 players allowed on the field at any one time, while the remaining 4 players are rotated into the game as often as the coach sees necessary. The physiological demands vary considerably between the field positions of these players (Gray & Jenkins, 2010). As an example, midfield players need to have good cardiorespiratory endurance as they run long distances in each match, often in the range of 12-20 km, consisting of much low intensity jogging and walking interspersed with repeated high intensity sprints of less than 60 m in distance (Gray & Jenkins, 2010). In contrast, full backs and full forwards cover less total distance each game, but typically perform a higher number of short sprints, with full forward players averaging 150 high intensity movements in a game (4-6% of total movement time), with virtually all of these efforts lasting less than 6 s, and more than 50% involving at least one change of direction (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004a).
Importantly, the mean duration of high-intensity efforts during many other field based team sports is similar across studies. The average duration of a high intensity effort (sprinting or a combination of striding and sprinting) has been reported to range from 2–3 s in field hockey, with players covering a distance of 10–20 m (Lythe, 2006; Spencer, Bishop, Dawson, & Goodman, 2005), while in rugby union researchers have reported that athletes may take 4-6 s to cover 10 - 20 m in distance (Cunniffe, Proctor, Baker, & Davies, 2009). Furthermore, soccer players have been reported to cover a distance of 18-20 m within 2 to 5 s during high-intensity efforts (Di Salvo, Baron, & Tschan, 2007).

In contrast, there is much variation in the average duration of recovery between these high-intensity bouts reported between sports and studies. In soccer, Bangsbo and colleagues (1991) reported that sprints occur on average every 4 to 5 min, while Reilly and Thomas (1976) reported an average recovery of 90 seconds between sprints. In other sports, such as rugby, AF and hockey, sprints have been reported to occur every 120 s (Docherty, Wenger, & Neary, 1988), every 50 s (Hahn, Taylor, & Hunt, 1979) and every 56 s (Lothian & Farrally, 1994), respectively.

In addition, the recovery duration between bouts of high-intensity intermittent exercise in field sports can vary considerably within a game itself (Withers, Maricic, Wasilewski, & Kelly, 1982). Some game situations demand repeated bouts of high-intensity activity with limited recovery between bouts (~ 30 s), whereas there are other instances when more than 7 min of recovery may occur between sprints (Withers, Maricic, Wasilewski, & Kelly, 1982). Regardless, cardiorespiratory fitness remains an important determinant of the ability of a player to compete effectively in
team sports, not only given the large accumulated distances covered during a game, but also because of the need for players to recover rapidly between bouts of repeated high intensity exercise. Players who can maintain a high work-rate throughout a match may gain an advantage over equally skilled players who approach exhaustion towards the end of a game, or after a series of high intensity efforts, resulting in reduced performance (Reilly, 2000).

In addition to the repeated high-intensity movement demands of field-based team sports, further physiological strain is placed on the body as a result of physical contact, either with other players, or when “going to ground” (Gabbett, 2005). For instance, in AF, contact is permitted between players in the form of tackling the player in possession of the ball (between the shoulders and knees); using the body or arm to push, bump or block opposition players within 5 m of the football (shepherding); and that which is incidental to a legitimate marking contest (Gray & Jenkins, 2010). With respect to tackling, this involves wrapping, holding or wrestling a player who has possession of the ball to the ground. The number of “going to ground” instances due to the occurrence of contact reported in an AF game is 8-23 times per game, with rucks and midfielders having the greatest tallies (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004a).

In rugby, a tackle generally refers to when the player carrying the ball is held by one or more opponents and is brought to ground (International Rugby Board, 2008). During a rugby union match, forwards are involved in an average of 17 tackles per match, while backline players are involved in 7 tackles per match (Smart, Gill, & Beaven, 2008). In rugby league, forwards can be involved in 32-55 tackles each
match and backline players 19-29 tackles per match, depending on the level of play (Sirotic, Coutts, Knowles, & Catterick, 2009). Importantly, regardless of the specific sport or mode of tackling, every time a player goes to ground they must expend energy in getting up off the ground in order to run again (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004a), thereby contributing further to the physiological and physical requirements of the game.

In addition to tackling, there are other forms of physical impact experienced during many field-based team sports in the form of bumps and shepherds. In AF, a player can legally bump (also known as a hip-and-shoulder move) any opponent (not just the player in possession) who is within 5 m of the ball. In some cases, both players will charge each other, sometimes from opposite directions, resulting in a high impact collision. Also, a player with the ball may aggressively bump opponents that are attempting to tackle them. Bumps commonly can come from any direction and are normally not expected by the receiver. On the other hand, shepherding is when a player uses their whole body to stop an opponent from reaching a contest, usually to stop an opponent from tackling a teammate or getting to the ball. Dawson and colleagues (2004a) reported approximately 4 shepherds given and received per game, and 9 bumps given and received in elite AF.

In rugby, other forms of physical contact (besides tackling) include rucks (6–17% of total game time), mauls (12–16%), collisions (8–9%) and scrums (2–8%) (Deutsch, Kearney, & Rehrer, 2007). A ruck is formed when a player from each side bind onto each other with the ball on the ground between them (Drewett & Biscombe, 2010). Physical binding in a ruck is usually done by locking shoulders while players face
each other. Players may use their hands to win the ball or they can attempt to push other opponents off the ball or use their feet to hook it back towards their own side. Eaton et al., (2006) reported that an average of 13 rucks were executed by forwards and 6 by outside back players. A scrum is formed when players bind together in three rows to 'engage' the opposition team so that the player's heads are interlocked with those of the other side's front row. Both teams then compete for the ball by trying to hook the ball backwards with their feet. The number of total body contacts (tackles, rucks, scrums) executed by players in a forward role and back role average 55 and 29 collisions per game, respectively (Gissane, White, Kerr, & Jennings, 2001).

1.3 Post Exercise Muscle Soreness

Given the above-mentioned physiological and physical demands of team-sports, together with the demanding training and competition schedules of many team sport athletes, one potential limiting factor after a competitive match is post-exercise muscle soreness, with the resultant stiffness, swelling, reduced range of movement, fatigue and loss of strength all potentially contributing to performance decrements (Cheung, Huma, & Maxwell, 2003).

In general, post-exercise muscle soreness is experienced as a dull, aching sensation. This sensation can be often caused by unaccustomed exercise, primarily exercise that requires eccentric muscle action. Muscle soreness may initially be felt at a concentrated area sensitive to passive manipulation, through active movement when the muscle contracts or when it is stretched (Lieber & Friden, 2002). This early
sensitivity may later be perceived as broad muscle soreness with focal points of
tenderness referred from the active process within the musculotendinous junction
(Gibson, Arendt-Nielsen, & Graven-Nielsen, 2006). Other common signs include
muscle shortening, swelling, decreases in strength and power, localised soreness and
altered proprioception (Proske & Morgan, 2001).

The manifestation of post-exercise muscle soreness usually follows an inverted U-
shaped curve over time (Figure 1), with sensations of pain and tenderness peaking 1–
3 days after exercise, and eventually subsiding within approximately 7 days. On the
other hand, the resultant muscular stiffness and swelling usually peaks 3–4 days after
exercise, resolving within 10 days (McHugh, Connolly, Eston, & Gleim, 2000). For
example, Byrnes and colleagues (1985) reported that muscle soreness steadily
increased when assessed at 6, 18 and 42 h following 30 min of downhill treadmill
running. Similarly, soreness has been shown to peak at 48 h post-exercise in three
separate studies of eccentric exercise of the elbow flexors (Rodenburg, Bar, & de
Boer, 1993; Rodenburg, Steenbeek, Schiereck, & Bar, 1994; Clarkson & Tremblay,
1988).

![Figure 1. Time course of muscle soreness following long-distance running and bench stepping (from Vickers et al., 1997)](image)
With respect to team sport performance, increased post-exercise muscle soreness has been reported following competitive (Ascensão, et al., 2008) and simulated soccer matches (Bailey, et al., 2007; Thompson, et al., 2001), with peak soreness reported immediately after the match, but remaining elevated for 2 (Bailey, et al., 2007) to 3 days (Thompson, et al., 2001).

1.3.1 Causes of Post-Exercise Muscle Soreness

Although the precise cause of post-exercise muscle soreness is currently unclear, it appears that the magnitude of active strain imposed on a muscle fibre, as opposed to absolute force, causes muscle soreness through microtrauma to the muscle fibres. Post-exercise muscle soreness can also be caused by a number of other factors such as minute tears in muscle tissue, muscle spasms, overstretching, tearing of the muscle’s connective tissue harness, acute inflammation, or any combination of these factors (Armstrong, 1984).

Team sports involving repetitive sprinting are particularly taxing on the metabolic and musculoskeletal system. Powerful concentric muscle contractions are required to accelerate the body to maximum speed and eccentric contractions are required to decelerate the centre of mass upon completion of a sprint and during activities involving changes in direction. These muscle contractions create large forces per cross sectional area of muscle, resulting in minor tears in the myofibril structure and inflammation in muscle fibres that is often associated with significant post-match muscle soreness (Dawson, Gow, Modra, Bishop, & Stewart, 2005). Accordingly, the primary cause of post-exercise muscle soreness is probably mechanical disruption of
the contractile units within muscle fibres themselves (Proske & Morgan, 2001; Warren, Hayes, Lowe, Prior, & Armstrong, 1993), which in turn causes swelling and initiates an inflammatory response (Gleeson, Almey, Brooks, & Cave, 1995). This inflammatory response recruits inflammatory cells and cytokines that potentiate the nerve endings and perception of soreness (Smith, et al., 1993). In particular, this may excite nociceptors (receptors capable of transmitting information about pain) (Lieber & Friden, 2002). Hence, when passive manipulation or active movement is carried out, this modifies intramuscular pressures and stimulates mechanoreceptor nerve endings, which contributes to the perception of soreness (Lewis, Ruby, & Bush-Joseph, 2012). Of note, pressure thresholds of the affected muscles seem to decrease when large diameter afferents are blocked by nerve compression induced by swelling (large diameter afferents are nerve cells that conduct information about touch and limb position) (Herbert, de Noronha, & Kamper, 2011).

A more detailed schematic of the events associated with post-exercise muscle soreness (mechanical damage, inflammation and swelling, and free radical proliferation) is presented in Figure 2. Here, micro-injury to the cell membrane triggers a swelling response that leads to the synthesis of prostaglandin and leukotrienes (Connolly, Sayers, & Mchugh, 2003). Prostaglandins can directly cause the sensation of pain by sensitizing type III and IV pain afferents to the effects of chemical stimuli, whereas leukotrienes increase vascular absorbency and attract neutrophils to the site of soreness (Connolly, Sayers, & Mchugh, 2003). The “respiratory burst” of the neutrophils produces free radicals, which can further aggravate damage to the cell membrane (Connolly, Sayers, & Mchugh, 2003). The
movement of cells and fluid from the bloodstream into the interstitial spaces can cause swelling, further contributing to the sensation of soreness.

**Figure 2. Schematic showing possible sequence of injury and treatment of post-exercise muscle soreness (from Connolly et al., 2003).**

This phenomenon of post-exercise muscle soreness is distinct from a muscle strain, which is usually an isolated disruption of the muscle-tendon junction extending across the fibres (Nosaka & Clarkson, 1995). This is important to note because in the early phase after a muscle strain, eccentric muscle contractions can make the soreness worse. In contrast, additional eccentric contractions on subsequent days don’t usually exacerbate post-exercise muscle soreness (Nosaka & Clarkson, 1996). Hence, it is important to appreciate that exercise-induced muscle soreness and muscle strains are different clinical entities and should be treated so.

In addition to the contribution of these internal factors to post-exercise muscle soreness and damage, external factors may also play an important role. For example, in team sports involving body contact such as AF or rugby, post-exercise muscle soreness and damage may be the result of direct physical impact resulting from
tackling, rucking, shepherding or collisions between players. In support of this notion, AF players reported greater soreness post-match as compared to post-training, with one possible difference between matches and training sessions being the level of body contact and resulting muscle contusions (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004a). In games, most marking opportunities and handballs are contested, and the overall level of physical contact is much higher in comparison to training. Accordingly, the lack of physical pressure at training, with little body contact (tackles, bumps, shepherds and spoils) and fewer ground balls being contested, could be a reason why post-exercise muscle soreness is reported to be lower than after competitive match play (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004a). Despite the suggestion that body contact may contribute to muscle damage in team sports, at the time of completion of the research studies that form this thesis (published in 2010 and 2011), no previous research had directly compared the degree of muscle soreness and damage resulting from contact and non-contact team sports.

1.3.2 The Effect of Post-Exercise Muscle Soreness on Subsequent Performance

Regardless of the precise cause of post-exercise muscle soreness, the resultant strength loss, pain, tenderness, stiffness, and swelling (McHugh, Connolly, Eston, & Gleim, 2000) may affect the ability of an athlete to perform optimally. Various studies have detected that exercise induced muscle damage can cause continued reductions in maximal force and EMG activity, ground reaction forces, stretch-reflex sensitivity, muscle and joint stiffness regulation, and drop jump performance (Avela, Kyrolainen, & Komi, 1999; Horita, Komi, Nicol, & Kyröläinen, 1999). This may
have important implications for team sport athletes that compete weekly, where the ability to recover from this soreness and produce maximal efforts is likely to be an important determinant of the outcome of a subsequent game.

With respect to strength, the reductions are most notable in eccentric muscle actions, although concentric and isometric strength losses have also been reported (Eston, Finney, & Baker, 1996). Athletes typically experience strength loss in the affected muscle immediately after exercise or within the first 48 h, with full recovery commonly taking more than 5 days. To demonstrate this, Eston and coworkers (1996) measured isokinetic, eccentric and concentric knee extension peak torque values immediately post-exercise, as well as on the 2nd, 4th and 7th day following muscle soreness-inducing isokinetic exercise. These researchers reported an immediate post-exercise loss in peak strength for all modes of exercise at slow and fast velocities up to the 4th day, returning to normal values between the 4th and 7th day.

With specific reference to team sport exercise, Ingram et al., (2009) reported a reduction in maximal voluntary isometric strength in leg flexion, leg extension and hip flexion 48 h following simulated team sport exercise. Similarly, Duffield et al., (2012) observed a significant reduction in maximal voluntary contraction both immediately and 2 h following an amateur rugby league match compared with pre-game measures. In an elite handball competition, Thorlund et al., (2008) recorded a 10% reduction of maximal voluntary contraction and rate of force development alongside reduced electromyography amplitude of the quadriceps and hamstrings. Taken together, these findings clearly show that team sports involving intermittent
sprint exercise can lead to significant suppression of skeletal muscle force post-match.

This prolonged delay of strength recovery following exercise-induced muscle soreness may have implications for a range of dynamic activities involved in team sport games such as short sprint and vertical jump performance and participation in physical contests. Several researchers have examined changes in physical performance in team-sport athletes after one-off competition (Dawson, Gow, Modra, Bishop, & Stewart, 2005; Hoffman, et al, 2003), periods of intensified training (Coutts, Wallace, & Slattery, 2007), and during tournament situations (Ronglan, Raastad, & Borgesen, 2006; Spencer, Bishop, Dawson, & Goodman, 2005). With respect to the latter, Ronglan et al., (2006) detected a decrease of 2–7% in repeated 20 m sprints and countermovement jump performance in elite female handball players thru a 3-day tournament. Likewise, Spencer et al., (2005) showed that repeated sprint performance decreased in elite male field hockey players over a 4 day hockey tournament.

Furthermore, there is evidence of a reduction in joint range of motion during periods of severe muscle soreness, and a reduction in shock attenuation (Cheung, Huma, & Maxwell, 2003). For instance, Paschalis and colleagues (2007) reported that muscle soreness significantly modified the range of motion at the knee joint during stance and the swing phases of walking and running. These significant decreases in knee joint range of motion also caused increased pelvic rotation and a decreased pelvic tilt. The occurrence of such alterations has been suggested to be speed dependent and work as a self-protection mechanism to prevent further damage to the joint. Tsatalas
et al., (2010) reported considerably different effects of exercise-induced muscle damage on the range of motion at the knee and ankle at higher movement speeds. These researchers suggested that soreness resulting from exercise-induced muscle damage causes athletes to make speed-dependent biomechanical adaptations when performing movements at varying speeds to compensate for insufficient strength of the surrounding support muscles. Athletes may also make these adaptations to maintain balance and avoid exertion during the swing phase, and most importantly to ease soreness over the entire movement cycle in order to allow them to still perform at an optimal level during competition.

The combination of impaired muscular strength and reduced range of motion likely has implications for activities requiring high power outputs such as sprinting, throwing, and jumping (Byrne, Twist, & Eston, 2004). Additionally, the ability of an athlete to produce power after exercise-induced muscle damage is an aspect of human muscle function and exercise performance that has received limited attention (Eston, Byrne, & Twist, 2003). Byrne and Eston (2002a) reported an immediate and prolonged reduction of 12-15% in peak power during a 30 s Wingate cycle test performed 1 h after 100 repetitions of the eccentric phase of the barbell squat exercise (10 sets x 10 reps at 80% concentric one-repetition maximum). Of note, the temporal pattern of recovery of peak power was different to that of isometric strength. Isometric strength demonstrated a linear recovery over the next 7 days after an initial decline 1 h post-exercise, whereas peak power demonstrated further decrements between day 1 and 2 after exercise (~6 to 7%), before recovering linearly over the subsequent four days. Accordingly, it is possible that muscle power, unlike
strength, may be affected by the inflammation caused by exercise-induced muscle damage.

In summary, several performance aspects of team sports may be impaired by exercise-induced muscle damage. Post-exercise muscle damage elevates physiological responses and increases the subjective effort, which in turn would likely impair an athlete’s training and game performance. It is therefore important that coaches recognise the potential functional limitations when these situations arise, and training and competition should be structured to accommodate prior exposure to exercise-induced muscle damage to ensure that an athlete is performing to their maximum capability (Eston, Byrne, & Twist, 2003).

1.4 Assessment of Muscle Soreness and Damage

A number of methods are employed by coaches and sports scientists to assess the degree of muscle soreness and damage following exercise. These include self-reporting of perceived soreness by athletes, the assessment of pressure or pain threshold, or more objective measures of the circulating levels of blood markers of muscle damage such as creatine kinase, myoglobin and lactate dehydrogenase.

1.4.1 Assessment of Perceived Soreness

Perceived soreness is typically assessed using a 10-point Likert Scale (Appendix D). This allocates quantitative values (numbers) to qualitative (the nature, perception or quality of something) data to allow for comparison and analysis (Likert, 1952). The
Likert scale is one of the most extensively used scaling techniques (Polit, Beck, & Owen, 2007) and is regularly used in a range of stress and health research studies (Svensson, Sjostrom, & Haljamae, 2001). With specific respect to assessing perceived soreness, athletes’ are required to rank their perception of soreness on a scale of 0 to 10, with 0 being “normal”, 3 being “uncomfortable”, 5 being “sore”, 8 being “very sore” and 10 being “extremely sore”. This scale has been widely used by researchers as a non-invasive method to monitor changes in perceived soreness following muscle damaging protocols (Horita, Komi, Nicol, & Kyröläinen, 1999; Vaile, Gill, & Blazevich, 2007).

Benefits of using the Likert scale to assess perceived muscle soreness include its ease of administration and comprehension by both the researcher and the respondent. Another possible advantage of the Likert score is that it avoids the difficulty of pain “calibration” which may be necessary when using other subjective measures of soreness such as a visual analogue scale. In the visual analogue scale there is a horizontal or vertical line, typically 10 cm in length, anchored by textual descriptors at each end (Figure 3). Athletes are asked to indicate a point along the line that represents their perception of soreness. At the left, the endpoint of the descriptor will be marked as ‘no pain’ (a score of 0) and ‘worst pain imaginable’ or ‘worst possible pain’ (a score of 10) is marked at the right end. Then soreness will be determined by measuring the distance in cm from the left end of the line to the point that the athlete indicates (McCarthy, et al., 2005). However, some athletes may not have a good register of how a specific level of pain compares with no pain and with the worst pain possible. Also, previously sedentary subjects may not have had a wide
range of soreness experiences and therefore may not be able to judge a particular level of soreness relative to extreme soreness.

On the other hand, it is important to acknowledge that a possible limitation with using the Likert scale is that wording of the descriptive categories might not be sufficient to describe a complex continuous, subjective phenomenon (Vickers, Livingston, Umeris, & Holden, 1999). Furthermore, too many response categories may lead to difficulties in choosing and too few may not provide enough choice or sensitivity, forcing the respondent to choose an answer that does not represent the person’s true intent. Therefore, when designing Likert scales there are a few points that may need to be considered. In particular, they should avoid “anchoring” the lowest Likert score to zero pain by using phrases such as “no or almost no soreness” in place of those such as “a complete absence of soreness” (Vickers, Livingston, Umeris, & Holden, 1999).

Another method of evaluating the degree of perceived soreness in the athlete involves the use of a pressure pain Algometer. This is a hand-held device which is used to apply force (in kg.cm\(^{-2}\)) to the tissues via a small metal probe which has a 1 cm\(^2\) pressure application surface. This metal probe is placed perpendicular to the tissue surface at specific trigger points and pressure is applied steadily at a constant rate of 1 kg.cm\(^{-2}\).s\(^{-1}\) (Fischer, 1990) or 10 N.s\(^{-1}\) (Ylinen, Nykanen, Kautiainen, &
Hakkinen, 2007) to increase reliability (Jensen, Anderson, Olesen, & Lindblom, 1986). Compression should be performed slowly enough to allow the subject time to react when pain is felt. When the subject reports feeling pain, the action of pressure is stopped and the force that is recorded is referred to as the pressure pain threshold (PPT).

Many studies in the literature have used the algometer to monitor perceived soreness (Newhan, McPhail, & Mills, 1983; Hasson, Mundorf, Barnes, Williams, & Fujii, 1990). This methodology has been shown to have good inter-rater and intra-rater reliability when the measurements are performed once or repeatedly (2-50 repetitions) on a single day, at weekly intervals (1-5 weeks), or at longer intervals (8-12 weeks) (Vatine, Shapira, Magora, Adler, & Magora, 1993; Kosek & Ekholm, 1995). The algometer is particularly reliable over consecutive days when the same examiner obtains the measurements (Nussbaum & Downes, 1998). However, it is important to make sure that the probe is placed on the exact same bodily location every time the reading is taken.

1.4.2 Assessment of Blood Markers of Muscle Damage

In addition to the above-mentioned methods of assessing perceived muscle soreness, many researchers have attempted to quantify the degree of muscle damage by measuring markers in the blood. This is based on the premise that exercise-induced muscle damage results in a substantial increase in myocellular protein levels in the blood (Takarada, 2003). These include creatine kinase (CK), lactate dehydrogenase (LDH), myoglobin (Mb) and C-reactive protein (CRP). Importantly, studies have co-
related soreness to these biological markers and have shown strong correlations between the time course and the intensity of perceived soreness and the elevation of these biomarkers in the blood (Hirose, et al., 2004). For this reason, many researchers have used these blood markers as more objective markers of muscle damage after exercise, given that the levels of these factors in the blood are not altered by external application of heat, menthol or other analgesics – unlike the perception of soreness. The assessment of blood markers of muscle damage also provides very useful information relative to the “time course of the healing process” (Petrofsky, et al., 2012).

1.4.2.a Creatine Kinase

Creatine Kinase (CK) is an enzyme expressed by various tissues and cell types that is commonly used as a marker of muscle damage. CK is composed of two polypeptide subunits, M (muscle type) and B (brain type). These subunits are further divided into three tissue-specific isoenzymes: CK-MM, CK-MB and CK-BB. CK-MM is located primarily in the skeletal muscles, whereas CK-MB is localized to the heart and CK-BB is mostly found in the brain (Baird, Scott, Julien, & Gordon, 2012). Given that skeletal muscle contains almost entirely CK-MM, with a small amount of CK-MB, CK is released into the blood stream when fibres surrounding the muscle are disrupted, thus causing an increase in serum concentrations of CK following exercise-induced muscle damage (Ehlers, Ball, & Liston, 2002).

The normal reference range for serum CK is 55 to 170 IU/L for males, and 30 to 135 IU/L for females (Ward & Williams, 2003). After exercise-induced damage to
skeletal muscle fibres, particularly at the level of the sarcolemmal membrane (Lee, et al., 2002), the circulating levels of CK become elevated (Nosaka & Clarkson, 1996), and may rise as high as 40 000 IU/L following eccentric exercise (Nosaka & Clarkson, 1992). CK may remain elevated in the bloodstream for several days after exercise (Nosaka & Clarkson, 1995), normally peaking 24 h after a prolonged exercise bout and remaining elevated for 48 h (Brancaccio, Maffulli, & Limongelli, 2007).

The extent of damage to the sarcolemmal membrane, and accompanying increase in CK in the blood, is probably relative to the duration and intensity of the muscle contraction, which is in turn related to the severity of muscle soreness (Brancaccio, Maffulli, & Limongelli, 2007). With specific reference to team sport exercise, Coelho and colleagues (2011) observed peak serum CK concentrations 12-20 h following a competitive soccer game in professional soccer players, with concentrations returning to normal within 60-65 h. Similarly, Suzuki and coworkers (2004) reported a significant increase in serum CK immediately after Rugby Union match play and the magnitude of increase was most apparent 24 h post-match. Of interest, Hunkin and colleagues (2013) noted elevations in CK in elite AF players prior to weekly matches throughout the season compared with baseline values in the rested state, suggesting inadequate recovery or residual muscle damage from the previous week before the next game. Elevated pre-match CK was also associated with impaired subsequent match performance in these players.

There is also some evidence to suggest that the elevation in CK following team sport games may be contributed to (at least in part) by the high-impact collisions received
by players in various contact sports (Cunniffe, Hore, & Whitcombe, 2010; Gill, Beaven, & Cook, 2006; Takarada, 2003). For instance, Takarada (2003) observed positive correlations between peak CK concentrations and the number of tackles in a competitive rugby match, suggesting that the direct impact of tackles contributes to muscle damage. Likewise, Smart and colleagues (2008) reported a significant increase in CK in a position-specific manner following an elite rugby match, with a large proportion of the change in CK accounted for by physical impact in the form of rucks, mauls, tackles, collisions and scrums. McLellan and colleagues (2011) also observed a significant correlation between the number of severe impacts experienced by players during elite rugby league match play with increases in plasma CK. Finally, Cunniffe and coworkers (2010) also found that CK activity following an international rugby match was correlated with the number of tackles and game contact events.

1.4.2.b Lactate Dehydrogenase

Lactate dehydrogenase (also called lactic acid dehydrogenase or LDH) is an enzyme found in almost all body tissues and is important for ATP production, given its role in catalyzing the interconversion of pyruvic acid and lactic acid (Brancaccio, Lippi, & Maffulli, 2010). There are a number of different isoenzymes of LDH found in different tissues of the body (Table 1). Regardless, given that LDH is an intracellular enzyme; cellular damage causes its release into the circulation where levels are normally very low. Resting levels for LDH level have been reported as 200 mg per liter of blood (Petrofsky, et al., 2012).
Table 1. Types of isoenzymes and subunits of lactic acid dehydrogenase
(from Brancaccio et al., 2010)

<table>
<thead>
<tr>
<th>LDH</th>
<th>Subunits</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDH-1</td>
<td>(4H)</td>
<td>Found in the heart and in red blood cells</td>
</tr>
<tr>
<td>LDH-2</td>
<td>(3H1M)</td>
<td>Found in the immune system</td>
</tr>
<tr>
<td>LDH-3</td>
<td>(2H2M)</td>
<td>Found in the lungs</td>
</tr>
<tr>
<td>LDH-4</td>
<td>(1H3M)</td>
<td>Found in the kidneys, placenta, and pancreas</td>
</tr>
<tr>
<td>LDH-5</td>
<td>(4M)</td>
<td>Found in the liver and skeletal muscle</td>
</tr>
</tbody>
</table>

Strenuous exercise has been shown to increase the concentration of total LDH in the bloodstream (Rumley, et al., 1985), specifically the isoenzymes LDH-1, LDH-2, and LDH-5 (Mena, Maynar, & Campillo, 1996). This is likely caused by an increase in muscle cell membrane permeability, which occurs as the cell becomes energy depleted and is damaged by exercise. Levels of LDH have been reported to rise within 12-24 h of prolonged endurance exercise, reaching peak levels within 48-72 h, and possibly remaining elevated for up to 10 days (Kobayashi, Takeuchi, & Hosoi, 2005). Blood LDH levels are much higher after an eccentric bout of exercise (compared with concentric), with the levels reported to increase between the third and the fifth day after exercise (Nosaka & Clarkson, 1992), and sometimes even after the seventh day post-effort (Brown, Day, & Donnelly, 1999).

With respect to team sports, variations in LDH serum activity appear to correlate with different field positions and intensities of physical exercise (Mashiko, Umeda, & Nakaji, 2004). The physical demands of different positions in the field may liberate LDH by inducing different rates of muscular inflammation, or by increasing
the permeability of the muscle cell membrane in different situations (Flynn, Pizza, &
Boone, 1994). For instance, Mashiko and coworkers (2004) reported that the
magnitude of change in serum LDH during a summer training camp for college
rugby players was significantly greater for the forwards than for the backs. This was
attributed to the forwards experiencing more physical contact, executing more
physically strenuous exercise, and exhibiting higher levels of muscular damage.

1.4.2.c **Myoglobin**

Myoglobin (Mb) is a protein found in muscle that binds iron and oxygen together to
provide extra oxygen for the muscles during brief periods of oxygen deficit. The
normal level of Mb is between 0 and 85 nanograms per milliliter of blood. However,
exercise-induced muscle damage is associated with increased release of Mb into the
bloodstream (Clarkson & Hubal, 2002). Levels can rise within two to three hours of
muscle damage post exercise, reaching peak concentrations within 8 to 12 h, before
returning to normal within one day of performing the exercise (Mair et al., 1994). In
fact, one reason for measuring Mb as a key marker of muscle damage is its
appearance in the bloodstream much faster than other blood markers such as CK,
LDH and C-reactive protein. Therefore, in acute situations post-exercise, Mb may be
a more sensitive marker of immediate muscle damage (Huerta-Alardin, Varon, &
Marik, 2005). In contrast, CK persists in the blood long after the athlete exhibits
symptoms and may unnecessarily prolong a return to activity if used to assess an
athlete’s ability to return to play. Levels of Mb may therefore be a better biochemical
marker to determine immediate post-exercise effects and an athlete’s return to
participation (Kahanov, Eberman, Townsend, & Gurovich, 2012).
Different types of exercises can cause Mb to be released at different rates. Martínez-Amat and colleagues (2010) tested 23 male athletes in (13 rugby and 10 handball players) in their chosen sport. Blood samples were taken from them at rest before and immediately after rugby and handball matches by the respective athletes. These researchers reported that Mb levels were significantly higher after the rugby match compared with the handball match, possibly because the rugby match involved more physical strain and body contact. Similarly, Takarada (2003) recorded positive and significant correlations between the number of tackles and blood Mb concentration following a rugby match, which peaked 45 min post-match.

1.4.2.d C-reactive protein

C-reactive protein (CRP) is a part of the body’s inflammatory process, aiding in activating neutrophils, preventing platelet accumulation and assisting cytotoxic reactions (Das, 2001). It is produced by the liver in response to inflammation, as signaled by the secretion of interleukin-1 (IL-1), and interleukin-6 (IL-6) by adipose, muscle and other tissues following exercise-induced muscle damage (Febbraio & Pederson, 2002). During an acute phase inflammatory response after exercise, elevations of CRP begin within 4 to 6 h, remaining elevated while the inflammatory response persists, with peak levels reached within 24 to 48 h, before declining rapidly once the acute inflammation is terminated (Ridker & Rifai, 2001). Accordingly, normal levels are restored within 2 to 7 days post-exercise. For instance, Gleeson et al., (1995) reported no change in CRP levels immediately after 40 min of bench stepping; however, 24 h post-exercise, CRP levels were at their peak at 3.9 mg/L, before returning to basal levels 2-3 days post exercise.
With specific reference to team sport exercise, Pointon and Duffield (2012) found elevated blood CRP levels 24 h after completing a 2 × 30 min intermittent sprint exercise protocol with either tackling or no tackling in rugby players. Similarly, Cunniffe et al., (2011) observed increases in serum CRP (at 38 h post-exercise) following an international rugby union game. Elevated CRP levels 24 h post-game after a soccer match were also recorded by Ispirlidis et al., (2008).

1.5 Testing Team Sport Performance

As mentioned above, one potential limiting factor after a competitive match is muscle soreness and damage, and the direct physical impact resulting from tackling, rucking, shepherding or collisions between players may be an important contributing factor to this soreness (Takarada, 2003). Surprisingly, no previous research has compared the degree of muscle soreness and damage resulting from contact and non-contact team sports. To investigate this issue, researchers must first be able to reliably quantify team-sport performance. This is a difficult task, given the complex nature of competitive team-sport games.

In an effort to monitor the effect of training or various interventions (i.e. ergogenic aids, dietary manipulations, recovery strategies) on team sport performance under more controlled conditions than a real game situation, a variety of protocols have been devised to simulate the activity patterns of such sports (Bishop & Claudius, 2005; Drust, Cable, & Reilly, 2000; Glaister, Howatson, Pattison, & McInnes, 2008; Sirotic & Coutts, 2007). These protocols have been specifically designed to reflect the activity patterns of team sports, by including quick multi-directional, high-
intensity movements, combined with medium and low intensity periods repeated over long periods. Such protocols may be employed to replicate game demands, for the purpose of talent identification, to measure an athlete’s physiological capabilities and physiological state throughout a season, or to monitor key performance indicators in response to training or other interventions. These protocols can be divided into two broad types: laboratory simulations and field-based simulations. The benefits and limitations of both laboratory-based testing and field-based testing protocols are discussed below.

1.5.1 Laboratory-Based Simulation of Team Sport Performance

Laboratory simulations of the physiological requirements of team sport games are often performed by using specialist equipment in a controlled laboratory environment to reduce the impact of extraneous variables that may influence the relationship between the variables that a researcher is examining (i.e. ambient temperature/humidity and the influence of team tactics) (Sirotic & Coutts, 2007). To simulate team sport performance, a variety of ergometers, including motorised (Drust, Cable, & Reilly, 2000) and non-motorised treadmills (Thatcher & Batterham, 2004), as well as cycle ergometers (Bishop & Claudius, 2005) have been used.

Using a motorised treadmill, Drust et al., (2000) developed a 45 min soccer-specific intermittent exercise protocol involving repeated bouts of walking, jogging, cruising, and sprinting to represent one half of a soccer match. Specifically, this protocol was divided into two 22.5 min cycles, with each cycle comprising 23 isolated bouts of movement: six bouts of both walking and jogging, three “cruises” and eight sprints.
Speeds for each of these activities were based on time motion analyses during a soccer game: walking 6 km.h\(^{-1}\), jogging 12 km.h\(^{-1}\), cruising 15 km.h\(^{-1}\) and sprinting 21 km.h\(^{-1}\) (Van Gool, Van Gerven, & Boutmans, 1988). The order of these bouts was randomised to reproduce the non-cyclical nature of the exercise patterns observed in a soccer game. Between each 22.5 min cycle, athletes were allowed 71 s of standing recovery on the treadmill. This duration of this static recovery was based on half of the total time players stood still during a 90 min game (Reilly & Thomas, 1976). Mean heart rate observed during this intermittent protocol was approximately 170 bpm, similar to heart rates observed during soccer match-play in university athletes (Van Gool, Van Gerven, & Boutmans, 1988).

While the above-mentioned protocol reflects the activity patterns of soccer, and the use of the motorised treadmill allows for specific control over the speed/total amount of work completed, other researchers have employed non-motorised treadmills to allow individual athletes to self-select the speed at which they work during laboratory-based simulations. This approach can allow for monitoring of fatigue within the athlete over the course of the protocol. Furthermore, achieving a specific target speed may be faster when using a non-motorised treadmill as it can take some time for motorised treadmills to effect changes in speed.

Using a non-motorized treadmill, Abt et al., (2003) developed a protocol consisting of two 45 min halves involving a variety of movements (standing, walking, jogging and striding) with different timings to allow for a total distance of approximately 11 km to be covered. Instructions to change speed were given by audio beeps and verbal prompts from a computer, with a screen placed at eye level to display the target
speed as well as current speed. Likewise, Thatcher and Batterham (2004) devised a soccer-specific exercise protocol consisting of two bouts of 9 x 5 min repeated cycles (separated by a 15 min rest period considered as half-time) on a non motorised treadmill. Each 5 min cycle consisted of 8 different types of activities (standing, walking forwards and backwards, jogging forwards, backwards and sideways, running and sprinting forwards), resulting in a total distance covered of ~10 km to be consistent with observations in English Premier League soccer games. Similar to Abt et al., (2003), visual cues were given on a computer that displayed both target speeds and actual treadmill speeds. The mean heart rate response was 166 bpm, equating to 83 % HR$_{max}$. Importantly, the mean HR during actual soccer games can range from 81.7 - 93.6% HR$_{max}$ or 156 – 167 bpm (Thatcher & Batterham, 2004).

Another commonly-used method to simulate the repeated sprint aspect of team sport performance in a laboratory setting involves the use of a front access cycle ergometer (Bishop, Spencer, Duffield, & Lawrence, 2001; Fitzsimons, Dawson, Ward, & Wilkinson, 1993). Although not specific to sprint running, the use of this type of ergometer provides an alternative to field testing that allows for the quantification of total work and power output, keeps the participant stationary to facilitate blood sampling, and allows the performance of maximal sprints in an upright position (when using a front access ergometer). On this basis, Bishop and Claudius (2005) developed a protocol to simulate the average sprint profile of a field hockey match. Participants performed intermittent activities on a front access cycle ergometer for two 36 min halves. Each half was divided into ~2-min blocks, consisting of periods of sprinting (4 s), active recovery (100 s at a power output of
35% VO\textsubscript{2} max) and passive rest (20 s). This protocol has been used in other studies to simulate the demands of team sport games (Schneiker, Bishop, Dawson, & Hackett, 2006; Pongson, Wallman, Bishop, & Morton, 2012).

While the above-mentioned protocols employ the use of laboratory ergometers for exercise testing, other researchers have tried to replicate the demands of multiple-sprint sports in the laboratory using indoor over-ground running. Nicholas et al., (2000) designed the Loughborough Intermittent Shuttle Test to simulate the activity patterns observed during a soccer match under controlled conditions. The protocol comprised two parts: Part A consisted of a fixed period of variable-intensity shuttle running over a distance of 20 m, and Part B consisted of continuous running, alternating every 20 m between 55% and 95% VO\textsubscript{2}max, until volitional fatigue. The total distance covered (~12.4 km), repeated sprints and turns involved, and physiological and metabolic responses (mean heart rate of 170 bpm) were intended to be similar to those reported in soccer games (Ali & Farrally, 1991; Reilly, 1994; Tumilty, 1993).

In summary, these laboratory-based team sport simulations appear to be able to replicate the activity patterns, speeds/workloads and distances found during team sport games. The controlled laboratory conditions facilitate the collection of physiological and performance data that generally has high reliability as all measures showed low coefficients of variation of ≤10%. On the other hand, one potential limitation of performing a laboratory-based team sport exercise protocol is that athletes are often restricted to moving in a straight line only, with limited or no agility or change of direction movements, despite their frequency and importance in
team sports (Svensson & Drust, 2005). The omission of this component of team sport performance may alter the effect of fatigue in these laboratory-based protocols.

1.5.2 Field-Based Simulation of Team Sport Performance

Field-based simulations of team sport performance allow researchers to incorporate over-ground running, skill tasks and aspects of agility and change of direction into their assessments, increasing the specificity of the test, as the data can be collected in the same context as real match play (Wragg & Maxwell, 2000). In addition to being very sports specific, field tests often require little equipment and can be carried out almost anywhere (Svensson & Drust, 2005). However, efforts to standardise the surface (grass, bitumen, rubberized track, etc) used for testing as well as environmental conditions (e.g. wind speed/temperature/humidity) are important to ensure reasonable repeatability of the data collected.

Green et al., (2011) developed a field test protocol to assess linear speed (LS), change of direction speed (COD) and reactive agility speed (RAS) in rugby union players. The protocol was performed on two separate occasions (three days apart) to assess test reliability. For LS, 10 and 30 m times were recorded across three trials, with 3 min of rest between each. For COD speed, athletes had to sprint forward 5 m then perform a 45° change of direction maneuver to pass through either a left or right finish gate. For RAS measures, the COD protocol was again used, but athletes were required to visually scan for a “flashing” finish gate and then sprint through it. In both the COD and RAS trials, each direction maneuver was performed three times (3 trials each to the right and left), with 3 min of rest allowed in between trials. The
results demonstrated good reliability for measuring these abilities of rugby union players (ICC = 0.87-0.97 for LS; ICC = 0.87 for COD; ICC = 0.88 for RAS), and compare well with similar studies using rugby union players (Gabbett, Kelly, & Sheppard, 2008; Oliver, Armstrong, & Williams, 2009). However, this protocol fails to replicate other physiological aspects of field sports, such as cardiovascular endurance.

A more holistic simulation of team-sport exercise was developed by Bishop et al., (2001). This protocol was originally developed to assess the validity of a frequently used laboratory test of repeated sprint ability - the 5 x 6 s cycle test. This field-based protocol consisted of four sets of 15 min of intermittent running (with 5 min of recovery between sets) around a circuit, replicating the movement patterns observed in team sports (Figure 4). Each circuit lap included three maximal sprints, an agility (zig-zag) section, plus some walking, jogging, striding and a deceleration to a stop immediately after a sprint. Each circuit took 46-52 s to complete; allowing ~8-14 s rest before the next circuit (on a 1 min cycle), with 15 circuits performed per 15 min set. This protocol has since been adapted by others for the purpose of replicating team sport games (Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; King & Duffield, 2009) with additional performance measures including an initial 15 m sprint time, countermovement vertical jump height, heart rate, time to complete each circuit and also measurement of oxygen consumption.
While such field-based protocols allow for the duration, activity patterns and physiological demands of team sport games to be simulated, their reliability may be limited due to changes in weather and surface conditions, and the presence of other factors such as opponents and coaches (Wragg & Maxwell, 2000). Furthermore, physiological (i.e., VO$_2$, blood markers) and performance (i.e., power output) variables cannot be as easily measured in outdoor testing sessions (Sirotic & Coutts, 2007). Accordingly, the use of field tests may restrict the analysis of underlying physiological mechanisms, since less physiological data can be measured in the field.

1.5.3 *Simulation of Body Contact*
Another potential limitation of both the laboratory and field-based team sport simulations described above is the lack of ‘body contact’ to simulate the tackling, rucking, shepherding (body checking) and collisions that are commonly encountered in field-based team sports. The inclusion of contact in simulated team game protocols may be important given that Australian football players tend to complain of greater soreness post-match compared with post-training (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004b) and one likely difference between games and training sessions is the level of body contact and the resulting muscle contusions that commonly occur during matches (Dawson, Gow, Modra, Bishop, & Stewart, 2005; Takarada, 2003). Likewise, it has been suggested that direct impact between opposing players may account for much of the muscle damage observed following competitive rugby matches (Gill, Beaven, & Cook, 2006). Given that testing for team sports should replicate real game activities as closely as possible, protocols are required that incorporate a ‘body contact’ component.

Stuart et al., (2005) addressed this issue with a field-based team sport simulation protocol based on the time motion analysis of a first class rugby union game. This protocol comprised two 40 min periods of intermittent activities (with a 10 min half-time rest) to simulate a game situation. Each half consisted of 7 repetitions of a circuit, with each circuit comprised of 11 stations of different rugby simulated activities such as sprinting (offensive, defensive and tackle sprints), peak power generation in two consecutive drives and agility movements (Table 2). Athletes started at station 1 and proceeded through to station 11 at 30 s intervals, with a 2 min break allowed after activity 4 and activity 11. With respect to body contact, the ‘offensive sprint’ station required athletes to perform a swerving run, while carrying
Table 2. Performance tasks at each station in the simulated rugby test (from Stuart et al., 2005).

<table>
<thead>
<tr>
<th>Station</th>
<th>Task</th>
<th>Task Description</th>
<th>Performance Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20-m sprint</td>
<td>20-m straight-line sprint</td>
<td>Time</td>
</tr>
<tr>
<td>2</td>
<td>Offensive sprint</td>
<td>22-m agility sprint</td>
<td>Time</td>
</tr>
<tr>
<td>3</td>
<td>Walk</td>
<td>Walk to next station</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Drive 1</td>
<td>Dynamic drive</td>
<td>Peak power</td>
</tr>
<tr>
<td>5</td>
<td>Walk</td>
<td>Walk to next station</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Defensive sprint</td>
<td>33-m agility sprint</td>
<td>Time</td>
</tr>
<tr>
<td>7</td>
<td>Walk</td>
<td>Walk to next station</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Tackle sprint</td>
<td>31-m agility sprint</td>
<td>Time</td>
</tr>
<tr>
<td>9</td>
<td>Passing accuracy</td>
<td>Ball passing at a target</td>
<td>Number of hits</td>
</tr>
<tr>
<td>10</td>
<td>30-m sprint</td>
<td>30-m straight-line sprint</td>
<td>Time</td>
</tr>
<tr>
<td>11</td>
<td>Walk</td>
<td>Walk to Station 1</td>
<td></td>
</tr>
</tbody>
</table>

In the time since the research studies for this thesis were published (2010 and 2011), some other protocols incorporating ‘body contact’ into field-based simulations of team sport games have been reported (Pointon & Duffield, 2012; Roberts, Stokes, Weston, & Trewartha, 2010; Sykes, Nicholas, Lamb, & Twist, 2013). For instance, Roberts and colleagues (2010) developed the Bath University Rugby Shuttle Test (BURST), consisting of 16 x 315 s exercise bouts grouped into 4 x 21 min quarters, with 4 min breaks following quarters 1 and 3 and a 10 min break to simulate half time. Each 315 s exercise bout consisted of 20 m shuttles at walking and cruising speeds, interspersed with 10-m jogs, incorporating simulated scrummaging, rucking, or mauling exercises and also standing rests. The timings of these movements were dictated by an audio CD with spoken commands. With respect to ‘contact’ the protocol involved a simulated ruck carrying a 20 kg tackle bag 5 m, a scrum that required athletes to push against a 120 kg one-man scrummaging machine and a
maul that involved 5 s grappling with an opponent to gain possession of a ball. Of note, the coefficient of variation value for mean heart rate, 15 m sprint time and time to complete an anaerobic game-specific agility test were all $\leq 2.2\%$.

Sykes et al., (2013) also developed a protocol intended to simulate the movement patterns and contact demands of rugby league. This protocol lasted for 86.8 min, divided into two halves with a 10 min half-time break. Each half comprised 20 identical cycles each lasting 2 min 10 s, with periods designed to replicate typical player movement patterns when the ball is in play (40.4 s cycle performed twice) and when the ball is out of play (lasting 49.3 s). The activity patterns during these periods are summarised in Figure 5.

![Figure 5. Schematic representation of the exercise pattern of the rugby league match simulation protocol (RLMSP) (from Sykes et al., 2012)](image)

In order to simulate ‘contact’, Sykes et al., (2013) required athletes to lie prone on the ground after the deceleration from each sprint before regaining their feet as rapidly as possible. These movements were included (in place of actual physical
contact) in an effort to replicate the physical exertion of contact in a controlled and reproducible manner, given that getting up from the ground after a tackle is anecdotally reported to be a very physically taxing component of match play (Sykes, Ceri, & Lamb, 2012). However, it must be acknowledged that the lack of actual contact (either with other bodies or tackle bags) is a limitation of this study, as less muscle contusions are likely to have resulted when performing this protocol.

Finally, Pointon and Duffield (2012) simulated the requirements of a team sport game using 2 x 30 min bouts of intermittent sprint exercise. This consisted of a 15-m sprint repeated every minute separated by self-paced bouts of hard running, jogging and walking for the remainder of the minute around a circuit. In addition, after every sixth maximal sprint the participants received five lower body tackles from a trained research assistant. Here, athletes were required to run hard for 10 m before making contact with the tackler, who aimed to direct shoulder contact into the middle of the athletes’ lower leg, forcing them to the ground. The exercise protocol was successful in causing a significant loss in muscle function (as evidenced by reductions in maximal voluntary contraction and voluntary activation for up to 24 h post-exercise), together with significant elevations in blood markers of muscle damage (CK and CRP). Additionally, a reduction in subsequent intermittent-sprint exercise performance was noticed as a direct result of the repeated body contacts.
1.6 Summary and Aims of the Thesis

In summary, high-intensity, multiple-sprint team sports such as hockey, soccer, rugby and AF place intense demands on the body’s musculoskeletal, nervous, immune and metabolic systems. Consequently, participating in these sporting activities can cause substantial muscle fatigue, soreness and damage, which may diminish the subsequent performance level of an athlete, whether at training or in further competition. As testing and training for team sports should replicate real game activities as closely as possible, plus some evidence that the direct impact between opposing players may account for much of the muscle soreness and damage observed following contact sports, the purpose of this thesis was to firstly assess the reliability of a simulated team game circuit with and without ‘contact’ for repetitive performance measures. This was intended to help to determine whether such a protocol could replicate game demands and monitor key performance indicators in response to training or other interventions (i.e. ergogenic aids, dietary manipulations, and recovery strategies) under more controlled conditions than a real game situation.

Once the reliability of such a protocol was confirmed, the second study of the present thesis aimed to compare the effect of the simulated team sport activity circuit (based on the activity demands of Australian football) both with and without ‘contact’, on perceived muscle soreness, blood markers of muscle damage, and performance when the same team sport circuit was repeated 48 h later.

Taken together, these studies may provide a reliable option for assessing team game performance parameters for both contact and non-contact sports, with the choice of
test depending on the specific sport itself and whether body contact is involved. Furthermore, the findings of the studies may have implications for training and recovery, since minimising subsequent performance decrements may be vital in determining the outcome of the next competitive match.
CHAPTER 2

Reliability of a Contact and Non-Contact Simulated Team Game Circuit

Based on a manuscript published in the

*Journal of Sports Science and Medicine, 9: 638-642, 2010*
2.1 Abstract

Most team sports are characterised by repeated short maximal sprint efforts interspersed with longer periods of active recovery or rest. Although a variety of testing protocols have been devised to simulate these activity patterns under controlled conditions, a common limitation is the lack of ‘body contact’ to simulate the tackling efforts seen in contact sports. Therefore, the purpose of this study was to assess the reliability of a simulated team game protocol with and without ‘contact’.

Eleven male, team-sport athletes (mean ± SD; age 22 ± 2 yr; BMI 23.0 ± 1.7 kg/m²) completed four separate testing trials; two ‘non-contact’ trials (NCON) and two ‘contact’ (CON) trials of a simulated game to determine the reliability of a range of team sport performance indicators including repeated 15-m sprint time, vertical jump height, heart rate response and ratings of perceived exertion (RPE). The team game protocol involved four sets of 15-min of intermittent running around a circuit replicating the movement patterns observed in team sports, either with or without simulated contact. Within-subject reliability of each performance measure was determined by expressing the typical error of measurement as the coefficient of variation, as well as by determining intra-class correlations. Both CON and NCON produced reliable results for a variety of team sport performance indicators, including repeated 15-m sprint time, vertical jump height, heart rate response and RPE. Repeated sprint and jump performance declined over time throughout the simulated game (p<0.05), while heart rate and RPE increased. There was no difference in these performance measures between CON and NCON protocols. As such, these simulated game protocols provide reliable options for assessing team
game performance parameters in response to training or other interventions under controlled conditions.

2.2 Introduction

Most team sports are characterised by short maximal sprint efforts, interspersed with longer periods of active recovery or rest, repeated over a prolonged period of time (Bishop, Spencer, Duffield, & Lawrence, 2001). In an effort to monitor the effect of various interventions on team sport performance under more controlled conditions than a real game situation, a variety of protocols have been devised to simulate the activity patterns of such sports (Bishop & Claudius, 2005; Drust, Cable, & Reilly, 2000; Glaister, Howatson, Pattison, & McInnes, 2008; Sirotic & Coutts, 2007). However, a potential limitation of these protocols is the lack of ‘body contact’ to simulate the tackling, rucking, shepherding (body checking) and collisions that are commonly involved in contact sports. The inclusion of contact in simulated team game protocols may be important given that Australian Rules football players tend to complain of greater soreness post-match as compared to post-training (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004b). One possible difference between games and training sessions is the level of body contact and the resulting muscle contusions that commonly occur during a match (Dawson, Gow, Modra, Bishop & Stewart, 2005; Takarada, 2003). Likewise, it has been suggested that the direct impact between opposing players accounts for much of the muscle damage observed following competitive rugby matches (Gill, Beaven, & Cook, 2006). This is supported by positive correlations between the number of tackles during a competitive rugby match and blood markers of muscle damage including peak...
myoglobin (Mb) concentration \( r = 0.85 \) and peak creatine kinase (CK) activity \( r = 0.92 \) (Takarada, 2003). Given that testing and training for team sports should replicate real game activities as closely as possible, protocols are required that incorporate a ‘body contact’ component. However, there is no data on the reliability of including contact in such protocols. Therefore, the purpose of this study was to assess the reliability of a simulated team game circuit with and without ‘contact’ to determine whether it may be suitable for monitoring key performance indicators in response to training or other interventions.

### 2.3 Research Design and Methods

#### 2.3.1 Experimental Design

Using a within-subjects experimental design, male team sport athletes attended a grass track (temperature 24 ± 3°C, humidity 60 ± 1%) on five occasions, first for familiarisation with the simulated team game protocol (both with and without simulated contact), followed by four testing trials; two ‘non-contact’ (NCON) and two ‘contact’ (CON) to determine the reliability of a range of performance measures, including repeated sprint speed and vertical jump height. Trials were conducted seven days apart at the same time of day (±1 h) in a randomised crossover design. Participants maintained their normal diet (self-reported) and abstained from training and caffeine in the 48 h prior to each trial.

#### 2.3.2 Participants

Eleven male, recreational, team-sport athletes (Mean ± SD; age 22 ± 2 yr; body mass 74.4 ± 7.4 kg; height 1.79 ± 0.06 m; BMI 23.0 ± 1.7 kg/m\(^2\)) were recruited as
participants. They were involved in a range of sports at the time of testing (rugby, hockey and Australian football), but all had previous experience with contact sports. Testing was conducted during the pre-season period to minimise any potential influence of competition (and hence body contact) on performance measures. The study was approved by the Human Ethics Committee of The University of Western Australia and written informed consent was obtained prior to testing (Appendix A).

2.3.3 Procedures

All sessions were commenced after jogging six circuits and stretching. The circuit involved a modified version of the simulated team-sport circuit developed by Bishop and colleagues (2001). It involved four sets of 15 min of intermittent running, replicating the movement patterns observed in team sports (Figure 6), with 5 min of rest between sets (Bishop, Spencer, Duffield, & Lawrence, 2001). This protocol has also been adapted by others for the purpose of replicating team sport games (Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; King & Duffield, 2009). The only difference between CON and NCON was the inclusion of a tackle bag, to be taken to ground every three circuits (20 tackles in total), together with bump pads to provide three contacts to each side of the legs at the end of each set (12 contacts to each side of the legs in total). With respect to the tackle bag, a target line was marked at the level of the hip on the bag. Participants were then instructed to tackle the bag at this level, following a 10 m maximal sprint run up, bringing it to ground with maximum force. In addition, strong verbal encouragement was provided with each tackle. The circuit was completed in pairs on a staggered start so that the bump pads could be utilised at the end of each period of intermittent running. Here, one participant would kneel in a braced position with the bump pads, while the other was required to run in
to receive 3 maximal ‘contacts’ to each side of the legs, before swapping. The number of contacts provided was based on various time-motion analyses from Australian football (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004a), rugby union (Duthie, Pyne, & Hooper, 2005; Takarada, 2003) and rugby league (Sirotic, Coutts, Knowles, & Catterick, 2009). Each circuit took ~50 s; allowing ~10 s rest before the next circuit (on 1 min) with 15 circuits per set.

Performance was quantified by timing the initial 15 m of the first sprint in the circuit from a stationary start (SMART SPEED, Fusion Sports, Wales, UK). From this, the best sprint time and mean sprint time were determined. Vertical jump performance was also measured (Yardstick, Swift Performance Equipment, NSW, Australia) to determine the best vertical jump and mean vertical jump in each set. In addition, heart rate (HR; Polar, Finland) and ratings of perceived exertion (RPE) were recorded (Borg, 1982) at the end of each set.

### 2.3.4 Statistical Analyses

Within-subject reliability of performance was determined by expressing the typical error of measurement as the coefficient of variation (CV), along with 90% confidence intervals (CI) and intra-class correlations (ICC) from log-transformed raw data using the online spreadsheet of Hopkins (2000). In addition, differences between protocols (CON and NCON) were assessed using two-way (set x protocol) repeated measures ANOVA, with statistical significance accepted as $p \leq 0.05$. Cohen’s $d$ effect sizes were also calculated for this purpose.
Figure 6. Simulated Team-Game Protocol modified from Bishop et al., 2001.

Both CON and NCON involved four sets of 15-min of intermittent running around a circuit replicating the movement patterns observed in team sports, with three maximal sprints, an agility section; walking, jogging, striding and a deceleration to a stop immediately prior to a vertical jump. The only difference between CON and NCON was the inclusion of a tackle bag, to be taken to ground every three circuits, together with bump pads to provide three standard contacts to each side of the legs at the end of each set. The circuit was completed in pairs on a staggered start so that one participant could hold the bump pads while the other received the “contact” before swapping. Each circuit took ~50 s; allowing ~10 s rest before the next circuit (on 1 min) with 15 circuits performed per set.
2.4 Results

The CV between trials for best sprint time was 0.9% (90% CL, 0.7–1.4%; ICC r = 0.97) for CON and 2% (90% CL, 1.4 –3.1%; ICC r = 0.93) for NCON (Table 3). For mean sprint time, the CV was 1.7% (90% CL, 1.3–2.7%; ICC r = 0.89) for CON and 3.7% (90% CL, 2.7–6.0%; ICC r = 0.75) for NCON. There was a main effect of set on both best sprint time (p < 0.001) and mean sprint time (p < 0.001) within protocols, but no difference between CON and NCON protocols. Small effect sizes were observed for the differences in best sprint time and mean sprint time for CON (0.12 and 0.01 respectively) and NCON (0.21 and 0.36 respectively).

For best vertical jump, the CV between trials was 3.1% (90% CL, 2.3-4.9%; ICC r = 0.97) for CON and 2.7% (90% CL, 2.0-4.3%; ICC r = 0.99) for NCON (Table 3). For mean vertical jump, the CV was 4.1% (90% CL, 3.0-6.4%; ICC r = 0.96) for CON and 4.3% (90% CL, 3.1-6.9%; ICC r = 0.96) for NCON. Best vertical jump was maintained across sets, while mean vertical jump declined (p = 0.024); however, there was no difference between CON and NCON. Small effect sizes were observed for the differences in best vertical jump and mean vertical jump for CON (0.00 and 0.37 respectively) and NCON (0.00 and 0.12 respectively).

For heart rate, CV was 1.2% (90% CL, 0.9-1.8%; ICC r = 0.88) for CON and 1.0% (90% CL, 0.7-1.6%; ICC r = 0.97) for NCON (Table 3). Heart rate increased (p = 0.002) across sets within both protocols, and there was a significant interaction between protocols and sets (p < 0.001), although post hoc analysis failed to reach significance. The CV of RPE was 2.7% (90% CL, 2.0-4.3%; ICC r = 0.86) for CON.
and 3.4% (90% CL, 2.5-5.5%; ICC r = 0.77) for NCON (Table 3). RPE increased across sets (p = 0.000), but was not different between CON and NCON protocols. Similarly, small effect sizes were observed for both HR and RPE in both conditions.
Table 3. Mean (±SD) performance measures during a simulated game protocol with “contact” (CON) and without “contact” (NCON) (n=11)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Trial</th>
<th>SET 1</th>
<th>SET 2</th>
<th>SET 3</th>
<th>SET 4</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CON</td>
<td>NCON</td>
<td>CON</td>
<td>NCON</td>
<td>CON</td>
</tr>
<tr>
<td>Best Sprint Time (s)*</td>
<td>T1</td>
<td>2.56</td>
<td>2.60</td>
<td>2.56</td>
<td>2.62</td>
<td>2.60</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>2.53</td>
<td>2.58</td>
<td>2.55</td>
<td>2.60</td>
<td>2.59</td>
</tr>
<tr>
<td>Mean Sprint Time (s)*</td>
<td>T1</td>
<td>2.70</td>
<td>2.79</td>
<td>2.78</td>
<td>2.82</td>
<td>2.80</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>2.70</td>
<td>2.69</td>
<td>2.76</td>
<td>2.74</td>
<td>2.81</td>
</tr>
<tr>
<td>Best Vertical Jump (cm)</td>
<td>T1</td>
<td>46</td>
<td>46</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>46</td>
<td>45</td>
<td>45</td>
<td>46</td>
<td>43</td>
</tr>
<tr>
<td>Mean Vertical Jump (cm)*</td>
<td>T1</td>
<td>41</td>
<td>43</td>
<td>41</td>
<td>41</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>42</td>
<td>42</td>
<td>41</td>
<td>42</td>
<td>40</td>
</tr>
<tr>
<td>HR(bpm)* †</td>
<td>T1</td>
<td>177</td>
<td>181</td>
<td>180</td>
<td>178</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>178</td>
<td>178</td>
<td>181</td>
<td>181</td>
<td>181</td>
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<tr>
<td>RPE*</td>
<td>T1</td>
<td>15</td>
<td>14</td>
<td>15</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>15</td>
<td>14</td>
<td>15</td>
<td>15</td>
<td>17</td>
</tr>
</tbody>
</table>

*: Indicates significant main effect of sets on performance
†: Indicates significant interaction effect of set and trial on performance

(HR: Heart Rate, RPE: Rating of Perceived Exertion)
2.5 Discussion

The purpose of this study was to evaluate the reliability of both a contact (CON) and non-contact (NCON) version of a simulated game protocol based on a circuit originally developed by Bishop and colleagues (2001). Both CON and NCON produced reliable results for assessing a variety of team sport performance indicators including sprint time, vertical jump height, heart rate response and ratings of perceived exertion (Bishop, Spencer, Duffield, & Lawrence, 2001). Furthermore, the reliability of CON and NCON is comparable to other team sport simulations. Sirotic and Coutts (2007) reported a CV of 2.0% and 2.7% for total distance and sprint distance covered in their protocol utilising a non-motorised treadmill. Similarly, Bishop and Claudius (2005) reported a CV of 2.5% for mean sprint power output during their cycle ergometer team game simulation. In addition, the RPE during CON and NCON is comparable to that observed by Drust and colleagues (2000) with their soccer-specific protocol, although the heart rate response was higher in the present study compared to previous research (Bishop & Claudius, 2005; Drust, Cable, & Reilly, 2000; Sirotic & Coutts, 2007).

Of interest, there was no statistical difference in performance measures between CON and NCON. This was surprising given the greater amount of work involved in CON. It is possible that the addition of contact does not acutely impair performance measures, but rather results in a greater decrement in subsequent performance (i.e. after limited recovery 24 or 48 hr later) due to the resulting muscle damage (Gill, Beaven, & Cook, 2006; Takarada, 2003). Alternatively, it must be acknowledged that the ‘contact’ involved in the current study was simulated. Despite our best
efforts to ensure that each tackle was maximal, it is likely that the ‘contact’
experienced with a tackle bag and bump pads may be less physically damaging than
actual body-on-body contact. However, true contact is not feasible within the context
of a simulated performance test and the current protocol should be preferable to
previous protocols used to simulate the activity patterns of team games that have
neglected to include any contact component at all. Perhaps future studies could
attempt to quantify the degree of impact experienced with simulated (i.e. tackle bags
and bump pads) versus actual body-on-body contact. In a case of insufficient contact,
the number of simulated contacts in the current protocol could be increased to
compensate for any possible reduction in the ‘intensity’ of contact. Nonetheless, both
CON and NCON appear reliable for assessing aspects of team sport performance. As
such, these tests may provide additional options for assessing team game
performance parameters, with the type of test used depending on the specific sport
itself and whether ‘contact’ is involved.
CHAPTER 3

A comparison of muscle damage, soreness and performance following a simulated contact and non-contact team sport activity circuit

Based on a manuscript published in the

*Journal of Science and Medicine in Sport, 14: 441–446, 2011*
3.1 Abstract

Objectives: To compare the effect of a simulated team sport activity circuit (reflective of the activity demands of Australian football) either with or without body ‘contact’ on muscle soreness, damage, and performance when the circuit was repeated 48 h later. Methods: Eleven male, team-sport athletes completed a ‘non-contact’ (NCON) and a ‘contact’ (CON) version of the team sport activity circuit in a crossover design with at least 1 week between trials. The effect of CON and NCON on repeated 15 m sprint and vertical jump performance was assessed by completing the same version of the circuit 48 h after the initial trial. The effect on perceived soreness and blood markers of muscle damage and inflammation was also determined. Results: Subsequent performance was affected to a greater extent by CON, with both best and mean sprint times significantly slower 48 h following CON (p < 0.05), while performance was maintained after NCON. Best and mean vertical jump performance was significantly impaired following CON (p < 0.05), while only best vertical jump was affected by NCON (p < 0.05). Perceived soreness and pressure sensitivity were elevated following both NCON and CON (p < 0.001); however, the increase in soreness was greater with CON (p = 0.012). Both CON and NCON resulted in elevated serum creatine kinase, myoglobin and lactate dehydrogenase, while C-reactive protein increased following CON but not NCON. Conclusions: Greater perceived soreness and decrements in performance of the simulated team sport activity circuit when repeated 48 h later were observed following CON.
3.2 Introduction

Many team-sport athletes are required to compete weekly, leaving limited time for full recovery before the next training session or competitive event (Dawson, Gow, Modra, Bishop, & Stewart, 2005). One potential limiting factor after a competitive match is muscle soreness and damage, with the resultant skeletal muscle stiffness, swelling, reduced range of movement, muscle fatigue and loss of strength, all contributing to performance decrement (Cheung, Huma, & Maxwell, 2003). Although the precise cause of post-exercise muscle soreness is unclear, it is typically attributed to internal mechanical strain or injury imposed on muscle fibres during intense or repeated muscular contractions. External factors may also be an important cause of post-exercise muscle soreness. For example, in team sports such as Australian football, soreness and damage may be the result of direct physical impact resulting from tackling, rucking, shepherding or collisions between players. Indeed, Australian football players report greater soreness post-match as compared to post-training (Dawson, Gow, Modra, Bishop, & Stewart, 2005), and one possible difference between matches and training sessions is the level of body contact and resulting muscle contusions (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004b). Likewise, it has been suggested that direct impact between opposing players accounts for much of the muscle damage observed following competitive rugby (Gill, Beaven, & Cook, 2006). This is supported by positive correlations between the number of tackles during a rugby match and blood markers of muscle damage (Takarada, 2003).
Despite the suggestion that body contact may contribute to post-exercise muscle soreness, no previous research has directly compared the degree of muscle soreness and damage resulting from contact and non-contact team sports. It is possible that non-contact sports mainly invoke symptoms of acute muscle soreness, while contact sports result in additional muscle damage due to direct body contact when tackling and contesting the ball. Therefore, the purpose of this study was to compare the effect of a simulated team sport activity circuit (reflective of the activity demands of Australian football) with and without ‘contact’ on perceived muscle soreness, blood markers of muscle damage, and performance when the same team sport circuit was repeated 48 h later.

### 3.3 Research Design and Methods

#### 3.3.1 Experimental Design

Using a within-subject, repeated-measures design, each participant completed a familiarisation session during which they were introduced to the simulated team sport activity circuit to be used in the subsequent experimental trials. The familiarisation required a walk-through with the experimenter explaining all requirements, prior to jogging six laps of the circuit and then completing the full protocol (explained below). Each participant completed two separate experimental trials; one ‘non-contact’ version (NCON) of the simulated team sport activity circuit and one ‘contact’ version (CON) of the protocol, performed at least one week apart (mean 12 ± 3 days) at the same time of day (± 1 h) in a counterbalanced crossover design. The effect of each protocol on subsequent repeated sprint and vertical jump
performance was assessed by completing the same version of the test 48 h later. In addition, the effect of CON and NCON on perceived soreness and blood serum markers of muscle damage was determined. All trials were conducted outdoors (temperature 24 ± 3°C, humidity 56 ± 6%; no difference between trials; p > 0.05) on a grass oval to replicate competitive match-play and participants were required to maintain their normal diet and abstain from training and caffeine on the day prior to and in the 48 h following initial testing.

3.3.2 Participants

Eleven moderately-trained (club level), healthy, male, team-sport athletes (age 22 ± 2 years; height 179 ± 6 cm; body mass 74.4 ± 7.6 kg; mean ± SD) gave written informed consent to participate in this study, which was approved by The University of Western Australia Human Ethics Committee (Appendix A). The participants were involved in a range of sports at the time of testing (rugby, hockey and Australian football), but all had previous experience with contact sports. Every participant was tested during the pre-season of their respective sport to minimise any potential influence of competition on performance. Additional exclusion criteria were an age > 30 years and any musculoskeletal injury that might impair performance or impact post-exercise muscle soreness.

3.3.3 Procedures

The simulated team sport activity circuit involved a modified version of the circuit developed by Bishop and colleagues (Bishop, Spencer, Duffield, & Lawrence,
2001). It involved four periods of 15 min of intermittent running, with 5 min of rest between each period. This protocol has also been adapted by others for the purpose of replicating team-sports (Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; King & Duffield, 2009). Each circuit included three maximal sprints (20 m, 10 m, 10 m), a 12 m agility section, 10 m of walking, 15 m of jogging, a 20 m striding effort and a deceleration to a stop immediately prior to a counter-movement vertical jump (see Appendix E). Each individual circuit took approximately 50 s to complete, allowing ~10 s rest before the next circuit (on 1 min) with 15 circuits completed per period. All sessions were commenced with an active warm up involving jogging six laps of the circuit, followed by active stretching and then 5 min of rest before the commencement of the full protocol.

The only difference between CON and NCON was the addition of a tackle bag to be taken to ground every three circuits at the end of the third sprint (10 m) of each circuit, together with the use of bump pads at the end of each 15 min period to provide three standard contacts to each side of the legs at the end of each period (see Appendix E). With respect to the tackle bag, a target line was marked at the level of the hip on the bag and participants were instructed to tackle the bag at this level bringing it to ground with maximum force. Testing was conducted in pairs (on a 30 s staggered start) so that the bump pads could be utilised at the end of each period. One participant would kneel in a braced position with the bump pads, while the other was required to run in at maximal speed to receive 3 ‘contacts’ to each side of the legs, before swapping. The number of contacts provided was based on various time-motion analyses from AFL (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004a), rugby union (Takarada, 2003; Duthie, Pyne, & Hooper, 2005) and rugby
league (Sirotic, Coutts, Knowles, & Catterick, 2009). Both CON and NCON have previously been shown to be reliable for assessing team sport performance variables, including repeated sprint times and vertical jump height (Singh, Guelfi, Landers, Dawson, & Bishop, 2010).

3.3.3.a Performance Measures and Quantification of Muscle Soreness

Repeated sprint performance was quantified in all trials by timing the initial 15 m of the first sprint in each circuit from a stationary start (SMART SPEED, Fusion Sports, Wales, UK) to determine the best (fastest) and mean sprint time for each period. Vertical jump performance was also measured (Yardstick, Swift Performance Equipment, NSW, Australia) to determine the best (highest) and mean vertical jump height in each period. In addition, HR and RPE were recorded.

A 10 point Likert scale was used to assess perceived soreness (with 0 being ‘normal’ and 10 being ‘extremely sore’) at baseline and 1, 24 and 48 h post-exercise (Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; Vaile, Gill, & Blazevich, 2007). At the same time points, lower-limb soreness (pressure sensitivity) was assessed using an algometer (Wagner Force Dial™, Wagner Instruments, Greenwich, CT) applied to mid-belly sites on the quadriceps, hamstrings and gastrocnemius (posteriorly and medially) of the dominant leg. These sites were marked on the participant’s body using an indelible pen in order to ensure that the same sites were subsequently assessed. During this assessment, each participant was instructed to relax the muscle, while pressure was gradually applied (~1 kg·s⁻¹) via the algometer until the participant verbally indicated that the pressure had become ‘uncomfortable’ (Ali,
Creasy, & Edge, 2010). Each site was pressure tested for muscle soreness three times and the mean recorded.

3.3.3.b **Blood Sampling and Analysis**

Venous blood samples (5 mL) were collected from a superficial forearm vein pre-exercise and 1, 24 and 48 h post-exercise to measure creatine kinase (CK), lactate dehydrogenase (LDH), myoglobin (Mb) and C-reactive protein (CRP). All samples were collected directly into serum separator tubes, with the serum separated by centrifugation at 3,000 rpm for 10 min at 10°C before being stored at -80°C until later analysis. The CK, LDH, and Mb assays were made using an Architect ci8200 using ABBOTT Diagnostics reagents, while CRP was assayed by immunochemical reaction (BNII analyser, Dade Behring Marburg GmbH, Germany). The reference ranges for each of these is < 5 mg/L for CRP; 30 – 190 U/L for CK in males >17 years of age; 120 - 250 U/L for LDH; < 78 ng/mL for Mb in males.

3.3.3.c **Statistical analysis**

Statistical analysis was performed using the Statistical Package for Social Sciences Version 17.0 (SPSS Inc. Chicago, IL) with a significance level of $p \leq 0.05$. Two way (trial x circuit period) repeated-measures ANOVA were used to assess any decrements in performance variables following CON and NCON respectively, with post hoc pairwise comparisons (paired samples t-tests) performed as appropriate. In addition, two way (protocol x time) repeated-measures ANOVA were used to compare muscle soreness and damage between CON and NCON over time.
3.4 Results

The effects of NCON and CON on sprint performance are presented in Table 4. There was a main effect of protocol period on repeated 15 m sprint performance for both NCON and CON, with best and mean sprint times slowing as the protocol progressed. When the exercise protocol was repeated 48 h following NCON, both best and mean 15 m sprint times were similar to those obtained in the initial trial (p = 0.140; p = 0.460 respectively). In contrast, best and mean sprint times were significantly slower in the second trial following CON (p = 0.002; p = 0.037 respectively).

With respect to vertical jump performance, when the exercise protocol was repeated 48 h following NCON, best vertical jump performance was significantly lower than that obtained in the initial trial (p = 0.031), while mean vertical jump performance was maintained (p = 0.904). In contrast, both best and mean vertical jump performances were significantly lower in the second trial following CON compared to that obtained in the initial trial (p = 0.006; p = 0.011 respectively).

For both HR and RPE, there was a main effect of protocol period, with increases observed as both NCON and CON protocols progressed (p < 0.001). However, when the protocol was repeated 48 h following NCON, the HR response was similar to that obtained in the initial trial (p = 0.949). In contrast, following CON the HR response to the protocol was elevated (p = 0.024). With respect to RPE, values were higher when the exercise protocol was repeated after both NCON and CON (p = 0.007; p = 0.000 respectively).
There was a significant interaction effect of protocol and time on perceived muscle soreness (p < 0.05). Perceived muscle soreness was elevated from baseline following both NCON and CON (p < 0.001; Table 5). However, the increase in soreness was greater with CON compared to NCON (p = 0.012), specifically at 1 and 24 h post exercise (p = 0.007; p = 0.005 respectively). With respect to pressure sensitivity, a significant increase was noted at all sites following both NCON and CON (p < 0.001; p < 0.001 respectively; Table 5). The increase was similar between NCON and CON at the mid-hamstring, mid-quadriceps and medical calf sites, while the interaction effect of time and protocol approached significance at the mid-calf site (p = 0.087), with greater soreness at 24 h after CON (p = 0.009).

There was no interaction effect of protocol and time on the circulating levels of CK, LDH, Mb and CRP. However, there was a main effect of time on CK (p = 0.006; Figure 7), with levels elevated from baseline at 1 and 24 h following both NCON and CON (p < 0.05). Likewise, Mb was significantly increased at 1 and 24 h following both NCON and CON (p < 0.05), with levels returning to baseline by 48 h after CON, but not NCON (p = 0.033). Levels of CRP were elevated from baseline at 24 and 48 h following CON (p = 0.027; p = 0.027 respectively), but not NCON. There was also a main effect of time on LDH (p = 0.001), with levels elevated from baseline 1 h after both NCON (p = 0.003) and CON (p = 0.011).
Figure 7. Mean (± SE) response of (A) Creatine Kinase, (B) Myoglobin, (C) Lactate Dehydrogenase and (D) C-Reactive Protein to a simulated team sport activity circuit with ‘contact’ (CON■) and without ‘contact’ (NCON□). * Indicates significant difference from pre-exercise concentrations (p < 0.05).
Table 4. Mean (±SD) performance measures during a simulated team sport activity circuit involving 4 x 15 min periods either with “contact” (CON) or without “contact” (NCON); trials 1 and 2 were separated by 48 h (n=11).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Trial</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Period 4</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CON</td>
<td>NCON</td>
<td>CON</td>
<td>NCON</td>
<td>CON</td>
</tr>
<tr>
<td><strong>Best Sprint</strong></td>
<td>1</td>
<td>2.54 ± 0.13</td>
<td>2.58 ± 0.19</td>
<td>2.55 ± 0.12</td>
<td>2.60 ± 0.18</td>
<td>2.59 ± 0.11&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Time (s)</strong></td>
<td>2</td>
<td>2.62 ± 0.15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.59 ± 0.14</td>
<td>2.64 ± 0.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.63 ± 0.16</td>
<td>2.72 ± 0.12&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Mean Sprint</strong></td>
<td>1</td>
<td>2.70 ± 0.14</td>
<td>2.69 ± 0.17</td>
<td>2.76 ± 0.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.74 ± 0.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.81 ± 0.14&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Time (s)</strong></td>
<td>2</td>
<td>2.76 ± 0.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.70 ± 0.15</td>
<td>2.81 ± 0.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.76 ± 0.17</td>
<td>2.94 ± 0.19&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Best Vertical</strong></td>
<td>1</td>
<td>46 ± 7</td>
<td>45 ± 8</td>
<td>45 ± 8</td>
<td>46 ± 10</td>
<td>43 ± 8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Jump (cm)</strong></td>
<td>2</td>
<td>42 ± 7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45 ± 9</td>
<td>42 ± 7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45 ± 10</td>
<td>40 ± 7</td>
</tr>
<tr>
<td><strong>Mean Vertical</strong></td>
<td>1</td>
<td>42 ± 7</td>
<td>42 ± 7</td>
<td>41 ± 8</td>
<td>42 ± 8</td>
<td>40 ± 7&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Jump (cm)</strong></td>
<td>2</td>
<td>39 ± 7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>42 ± 8</td>
<td>38 ± 7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>42 ± 8</td>
<td>36 ± 7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>HR (bpm)</strong></td>
<td>1</td>
<td>178 ± 7</td>
<td>178 ± 11</td>
<td>181 ± 6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>181 ± 9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>181 ± 7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>180 ± 7</td>
<td>177 ± 10</td>
<td>182 ± 8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>180 ± 10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>183 ± 7&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>RPE</strong></td>
<td>1</td>
<td>15 ± 1</td>
<td>14 ± 1</td>
<td>16 ± 1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15 ± 1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17 ± 1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>16 ± 1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15 ± 1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17 ± 1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>16 ± 1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>18 ± 1&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Indicates significant difference from trial 1 (p < 0.05); <sup>b</sup> Indicates significant difference from period 1 (p < 0.05); HR: Heart Rate; RPE: Rating of Perceived Exertion; Trial 2 was performed 48 h following trial 1.
<table>
<thead>
<tr>
<th></th>
<th>Pre Exercise</th>
<th>1 h Post Exercise</th>
<th>24 h Post Exercise</th>
<th>48 h Post Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CON</td>
<td>NCON</td>
<td>CON</td>
<td>NCON</td>
</tr>
<tr>
<td>Perceived soreness</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>6 ± 2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3 ± 1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Relative change</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in Pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial Calf</td>
<td>0</td>
<td>0</td>
<td>-2.3 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-1.8 ± 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mid Calf</td>
<td>0</td>
<td>0</td>
<td>-2.1 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-1.7 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mid Hamstring</td>
<td>0</td>
<td>0</td>
<td>-1.9 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-1.6 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mid Quadriceps</td>
<td>0</td>
<td>0</td>
<td>-1.9 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-2.0 ± 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>: Indicates significant difference from pre-exercise (p < 0.05)
<sup>b</sup>: Indicates significant difference from NCON (p < 0.05)
3.5 Discussion

The purpose of this study was to compare muscle soreness and markers of muscle damage, together with repeated sprint and vertical jump performance, following a simulated team sport activity circuit performed with and without ‘contact’ (replicated through the use of a tackle bag and bump pads). Both NCON and CON resulted in significant increases in muscle soreness and blood serum markers of muscle damage, although the increase in perceived soreness was greater with CON. With respect to performance, both best and mean 15 m sprint times were significantly slower 48 h following CON, while performance was maintained after NCON. Likewise, best and mean vertical jump performance was significantly impaired following CON, while only best vertical jump was affected by NCON.

The greater impairment of repeated sprint and vertical jump performance following CON may be attributed to greater levels of muscle damage and soreness resulting from the direct impact of the tackles and bumps experienced. Indeed, we observed significantly greater levels of overall perceived soreness following CON compared to NCON. However, there was no difference in pressure sensitivity at various sites on the lower limb between trials, except for a greater decline at the mid-calf site noted 24 h post CON. It is also interesting to note that perceived muscle soreness was not higher at 24 or 48 h post-exercise compared to 1 h post-exercise, yet the change in pressure sensitivity appeared to increase following the 1 h post-exercise assessment. The lack of consistency between the perceived soreness and pressure sensitivity measures raises the
possibility that the greater perceived soreness following CON may be a psychological effect due to the participants expecting to feel greater soreness when experiencing more contact. Nonetheless, the finding of greater perceived soreness following CON compared to NCON is consistent with Australian football players reporting greater soreness post-match as compared to post-training, which usually involves a lesser degree of body contact (Dawson, Gow, Modra, Bishop, & Stewart, 2005). It has also been suggested that the direct impact between opposing players accounts for much of the muscle damage observed following competitive rugby matches (Gill, Beaven, & Cook, 2006).

Of interest, both CON and NCON resulted in muscle damage as indicated by significant increases in CK, Mb and LDH. The extent of these changes was similar between CON and NCON. In addition, we observed significantly elevated CRP at 24 and 48 h following CON, but not NCON. No previous studies have compared the response of blood markers of muscle damage or inflammation between CON and NCON team sports. However, with respect to the role of contact, Takarada (2003) observed positive correlations between both peak Mb and CK concentrations and the number of tackles in a competitive rugby match, suggesting that the direct impact of tackles is a major cause of muscle damage (Takarada, 2003). Likewise, Cunniffe and coworkers found that CK activity following an international rugby match was correlated with the number of tackles and game contact events (Cunniffe, Hore, & Whitcombe, 2010). Smart and colleagues also reported a significant increase in CK in a position-specific manner following an elite rugby match, with a large proportion of the change in CK accounted
for by physical impact (Smart, Gill, & Beaven, 2008). The apparent effect of contact in these studies, compared to the present study, may be related to the nature of contact (real versus simulated). Despite our best efforts to ensure that each tackle was maximal, it is likely that the contact experienced with a tackle bag and bump pads is less physically damaging than actual body-on-body contact experienced in a real match situation. However, true contact is not feasible (or ethical) within the context of a simulated performance test and the current protocol should be preferable to previous protocols that have neglected to include any contact component at all. Future studies could attempt to quantify the degree of impact experienced with simulated versus actual body-on-body contact, with the number of simulated contacts increased to compensate for any possible reduction in the ‘intensity’ of contact.

The greater impairment in repeated sprint and vertical jump performance following CON compared to NCON is likely due to greater levels of muscle damage and soreness resulting from the simulated ‘contact’. However, an alternative explanation may be the greater amount of work involved (i.e. energy expended) in completing the CON protocol. The only difference between CON and NCON was the addition of the tackle bag to be taken to ground every three circuits, together with the use of bump pads to provide three contacts to each side of the legs at the end of each period. Perhaps the extra energy expenditure required to complete these tackles and bumps resulted in higher levels of fatigue, and therefore a greater duration of time required to recover performance, compared to NCON. In support of this notion, the HR response to CON
was significantly higher when the protocol was repeated 48 h later, while the HR response to NCON was similar for both trials.

The observation of a greater impairment in performance following CON compared to NCON may have implications for optimising recovery from team sports. Numerous research studies have sought to examine the benefits of various recovery modalities such as cold water immersion, static stretching, massage and low-intensity aerobic exercise for accelerating the post-exercise recovery process (Dawson, Gow, Modra, Bishop, & Stewart, 2005; Cheung, Huma, & Maxwell, 2003; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; King & Duffield, 2009; Vaile, Gill, & Blazevich, 2007). Of interest, the benefits of such recovery strategies for performance are often found to be small or negligible. However, a possible limitation of these studies is the use of non-contact exercise protocols. If non-contact sports mainly invoke sensations of acute muscle soreness, while contact sports result in additional muscle damage due to direct body contact when tackling and contesting the ball, it is possible that significant benefits of some recovery modalities (i.e. cold water immersion) may become more evident following contact team sports. Therefore, future studies investigating recovery strategies should employ exercise protocols specific to the sport of interest, including simulated contact, if the sport of intended application involves body contact.
3.6 Conclusion

In summary, the addition of ‘contact’ to a simulated team sport activity circuit resulted in greater levels of perceived soreness, together with a greater impairment in subsequent repeated sprint and vertical jump performance 48 h later. These observations are likely to be the result of additional muscle trauma resulting from the addition of ‘contact’ itself. The greater reduction in performance following CON may have implications for training and recovery, since minimising subsequent performance decrements may be vital in determining the outcome of the next competitive match.
CHAPTER 4

General Discussion
4.1 Summary

Several exercise protocols have been devised to simulate the activity patterns of team sports. These protocols may be used by the sport scientist, conditioning staff, coach and athlete in training to replicate game demands, or at intervals throughout the season to monitor key performance indicators in response to training or other interventions (i.e. ergogenic aids, dietary manipulations, recovery strategies) under more controlled conditions than a real game situation. However, a potential limitation of many of these protocols is the lack of ‘body contact’ to simulate the tackling, rucking, shepherding (body checking) and collisions that are commonly involved in contact sports.

Given that testing and training for team sports should replicate actual game activities as closely as possible, plus evidence that direct impact between opposing players accounts for much of the post-exercise muscle damage observed (Gill, Beaven, & Cook, 2006; Takarada, 2003), the study described in Chapter 2 provides a reliable option for assessing team game performance parameters for both contact and non-contact sports. More specifically, both CON and NCON produced reliable results for assessing a variety of team sport performance indicators, including sprint time, vertical jump height, heart rate response and ratings of perceived exertion. The reliability of CON and NCON was comparable to other reported team sport simulations (Sirotic & Coutts, 2007; Bishop & Claudius, 2005).
Using this simulated team game protocol, the second study of the current thesis (Chapter 3) compared the effect of CON and NCON on perceived muscle soreness and blood markers of muscle damage, together with performance when the same team sport circuit was repeated 48 h later. Overall, the addition of ‘contact’ to the simulated team sport activity circuit (CON) resulted in greater levels of perceived soreness, increased c-reactive protein in the blood, and a greater impairment in subsequent repeated sprint and vertical jump performance 48 h later. These observations are likely the result of additional muscle trauma resulting from the addition of ‘contact’ itself. The greater reduction in performance following CON may have implications for training and recovery, since minimising subsequent performance decrements may be vital in determining the outcome of the next competitive match.

4.2 Practical Implications

4.2.1 Chapter 2

- The simulated team sport circuit involving 4 x 15 min periods of intermittent running, both with (CON) and without body contact (NCON), is a reliable option for assessing a variety of team sport performance indicators.

- These types of tests can provide reliable options for assessing team game performance parameters at intervals throughout the season to monitor key performance indicators in response to training or other interventions (i.e.
ergogenic aids, dietary manipulations, recovery strategies). The tests provide more controlled conditions than a real game situation, with the type of test used depending on the specific sport itself and whether “contact” is involved.

4.2.2 Chapter 3

- The inclusion of simulated ‘body contact’ when attempting to replicate team game demands is important given the increased level of perceived muscle soreness and blood markers of muscle damage experienced following CON versus NCON.

- The addition of simulated ‘contact’ to team sport exercise impairs subsequent performance to a greater degree than when there is no contact.

4.3 Limitations & Direction for Future Research

It must be acknowledged that the ‘body contact’ involved in the current study was only simulated. Despite our best efforts to ensure that each tackle was maximal, the intensity of the impact between the athletes and the tackle bag/bump pads could not be quantified, such that it is likely that the ‘contact’ experienced with a tackle bag and bump pads may be less physically damaging than actual body-on-body contact during actual match play. Furthermore, while true body contact is often not feasible within the context of a simulated performance test, future studies may consider the introduction of alternative
‘contact’ options. Such actions might involve tackling and pushing back a bespoke ‘contact sled’ (Figure 8) which has been used in other sports such as American football to simulate contact situations in exercise training and testing protocols (Hoffman & Hamilton, 2002).

![Figure 8. The bespoke “contact sled” designed for simulating contact or collision (from Pointon et al., 2012)](image)

Alternatively, the approach of Pointon and Duffield (2012) may be considered, in which athletes receive actual contact/tackles from a trained research assistant. Future studies may also attempt to quantify the degree of impact experienced with simulated (i.e. tackle bags and bump pads) versus actual body-on-body contact. If simulated contact is shown to be lacking in intensity, the number of simulated contacts in the current protocol could be increased to compensate for any possible reduction in the intensity/impact force of contact. Regardless, the current protocol is preferable to previous protocols used to simulate the activity patterns of team games that have
neglected to include any contact component, and is a reliable option for assessing aspects of team sport performance.

A final point for future research relates to the observation of a greater impairment in performance following CON compared to NCON. This may have implications for optimising recovery from team sport training and competition. Although numerous studies have examined the benefits of various recovery modalities (i.e. cold water immersion, static stretching, massage) for accelerating the post-exercise recovery process, the effects of such modalities are often studied following non-contact exercise protocols. It is possible that any benefits of such recovery strategies for performance may be magnified following exercise that involves a ‘contact’ component, given the additional damage and perceived soreness and greater performance decrements. Future studies should compare the effect of recovery modalities following CON and NCON.
References


Appendices
Appendix A

Participant Information Sheets and Consent Forms
PARTICIPANTS INFORMATION SHEET (CHAPTER 2)
Reliability of a contact and non-contact simulated team game circuit

PURPOSE
This study is being carried out to assess the reliability (repeatability) of a simulated team game exercise protocol. If found to be reliable, this exercise protocol can be used in future research studies.

PROCEDURES
You will be required to visit the School of Human Movement and Exercise Science for 5 separate trials each separated by at least a week. Your first visit will involve familiarisation with the simulated game protocols to be tested for reliability. After the familiarisation session, you will participate in four separate testing trials; two of a non-contact simulated game protocol and two of a contact protocol (Table 1). All trials that you will participate in will be conducted 7 days apart.

All visits will involve a specific warm up involving jogging through six laps of a circuit and stretching. Both the contact and non-contact protocols involve four periods of 15 min of intermittent running around a circuit with a 5 min rest in between periods. The circuit replicates the typical movement patterns observed during a team game, with each circuit includes three maximal sprints, an agility section, four periods of walking, two periods of jogging, one striding effort, decelerating to a stop and a vertical jump. The only difference between the contact and non-contact protocols will be the addition of a tackle bag that you will bring to ground every three circuits and bump pads to be used at the end of each 15 min period in the contact condition. With a partner, you will be required to pick up the bump pads and provide 3 standard contacts to each side of the legs and then swap over with your partner and do the same. Your performance will be measured by timing the initial 20 m sprint time (using electronic timing gates), vertical jump height (using a Vertec) and also the time taken to complete each circuit (using electronic timing gates). In addition, you will have to wear a heart rate monitor and rate how hard you feel the exercise to be (RPE).
By repeating the protocol, we will be able to see how repeatable (reliable) the performance measures are.

**RISKS**
It is possible that as a result of the simulated exercise protocol you may develop delayed onset muscle soreness (DOMS), minimal bruising from the bump pads or suffer a muscular injury. If there are any serious illnesses or injuries, you will be able to get appropriate medical attention at any time.

**BENEFITS**
The benefits of this study are that you will find out about your performance in various areas that are involved in the simulated exercise protocol.

**TIME COMMITMENTS**
You will be required to attend at the School of Human Movement and Exercise Science on 5 different occasions approximately 7 days apart. You are not allowed to engage in any sporting activities or training the day before your simulated exercise protocol. Complete rest will be required before you come in and do the same protocol for the second time. Estimated time of each session will be about one and a half hours.

Your participation in this study does not prejudice any right to compensation, which you may have under statute or common law.

The participant is free at any time to withdraw consent to further participation without prejudice in any way. The participant need give no reason or justification for such a decision. In such cases, the record of that participant is to be destroyed, unless otherwise agreed by the participant.

**CONTACT DETAILS**
If you have any queries throughout the testing procedures you can contact:

Dr Kym Guelfi
School of Human Movement and Exercise Science
Ph: 08 6488 2602
Email: kym.guelfi@uwa.edu.au

Tarveen Kaur Ragbir Singh
School of Human Movement and Exercise Science
Ph: 0430 181 844
Email: tarveenlonj@gmail.com
PARTICIPANT INFORMATION SHEET (CHAPTER 3)

A comparison of muscle damage, soreness and performance following a simulated contact and non-contact team sport activity circuit

PURPOSE
The purpose of this study is to compare the levels of muscle soreness and damage after a simulated non-contact team game to that experienced after a simulated team game with contact.

PROCEDURES
You will be required to visit the School of Human Movement and Exercise Science for 3 separate trials each separated by at least a week. Your first visit will involve familiarisation with the simulated game protocols. After this familiarisation session, you will participate in two separate testing trials; one involving a non-contact simulated game protocol and one involving a contact simulated game protocol (Table 1).

The protocol will be completed in pairs. Firstly, you will do a specific warm up involving jogging through six laps of a circuit and stretching. Both the contact and non-contact exercise protocols involve four periods of 15 min of intermittent running around a circuit with a 5 min rest in between periods. The circuit replicates the typical movement patterns observed during a team game, with each circuit includes three maximal sprints, an agility section, four periods of walking, two periods of jogging, one striding effort, decelerating to a stop and a vertical jump. The only difference between the contact and non-contact protocols will be the addition of a tackle bag that you will bring to ground every three circuits and bump pads to be used at the end of each 15 min period in the contact condition. With a partner, you will be required to pick up the bump pads and provide 3 standard contacts to each side of the legs and then swap over with your partner and do the same. Your performance will be measured by timing the initial 20 m sprint time (using electronic timing gates), vertical jump height (using a Vertec) and also the time taken to complete each circuit (using electronic timing gates). In addition, you will have to wear a heart rate monitor and rate how hard you feel the exercise to be (RPE).
After both the simulated contact and non-contact game protocols, you will be required to repeat the exercise protocol 48h later. The same performance measure will be recorded. In addition, assessments of muscle soreness and damage will be performed before and after the simulated game protocol, 24h later, and before and after the repeat of the simulated game protocol 48h later. The assessment for the muscle soreness and damage will involve three techniques; using an Algometer (an instrument used to measure pressure threshold and pain tolerance by applying slight pressure to designated areas), blood markers and a likert scale (a scale where you will tell the examiner your pain ratings from 0-10). Blood samples will be taken from the vein in the crease of the elbow by a trained phlebotomist.

Table 1: Experimental Design Indicating Familiarisation Session and Two Testing Sessions and Two Performance Test

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<td>Simulated Non-contact Team Game (performance test)</td>
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<td>REST</td>
<td>Simulated Contact Team Game</td>
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<td>Simulated Contact Team Game (performance test)</td>
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</table>

RISKS

It is possible that as a result of the simulated exercise protocol you may develop delayed onset of muscle soreness (DOMS), minimal bruising from the bump pads or suffer a muscular injury. There is also the potential for minimal bruising at the site of venous blood sampling. If there are any serious illnesses or injuries, you will be able to get appropriate medical attention at any time.
**BENEFITS**
This study will provide a better understanding about muscle soreness and damage resulting from contact and non-contact team games. The findings of this study will allow athletes, coaches, trainers and medical staff to make informed decisions regarding the recovery strategies they adopt when it comes to these different types of team games.

**TIME COMMITMENTS**
You will be required to attend at the School of Human Movement and Exercise Science on 7 different occasions (as described in Table 1). You are not allowed to engage in any sporting activities or training the day before your simulated exercise protocol and the day after. Complete rest will be required before you come in and do the same protocol for the second time. The time spend for each session is different; for the simulated game protocol and the assessments will take 1 and half hours, the blood sampling the next day will take 15 min and the performance testing will take about 1 and half hours.

Your participation in this study does not prejudice any right to compensation, which you may have under statute or common law.

The participant is free at any time to withdraw consent to further participation without prejudice in any way. The participant need give no reason or justification for such a decision. In such cases, the record of that participant is to be destroyed, unless otherwise agreed by the participant.

**CONTACT DETAILS**
If you have any queries throughout the testing procedures you can contact:

Dr Kym Guelfi  
School of Human Movement and Exercise Science  
Ph: 08 6488 2602  
Email: kym.guelfi@uwa.edu.au

Tarveen Kaur Ragbir Singh  
School of Human Movement and Exercise Science  
Ph: 0430 181 844  
Email: tarveenlonj@gmail.com
CONSENT FORM (Chapter 2)

Reliability of a contact and non-contact simulated team game circuit

Investigator responsibilities – Participant rights

• As a subject you are free to withdraw your consent to participate at any time without prejudice.

• The researchers will answer any questions you may have in regard to the study at any time. Questions concerning the study can be directed to:

Tarveen Kaur Ragbir Singh
School of Human Movement
and Exercise Science
Ph: 0412 147 901
Email: tarveenlonji@gmail.com

Dr Kym Guelfi
School of Human Movement
and Exercise Science
Ph: 08 6488 2602
Email: kym.guelfi@uwa.edu.au

I, (print your name) _____________________________________________________________

Acknowledge that I have read the above statement and information sheet that explains the nature, purpose and risks of the investigation and that the information has been explained to my satisfaction. I understand that signing this form does not withdraw my right to withdraw from this study at any time without affecting my relationship with staff members at the University of Western Australia.

I understand that all information provided is treated as strictly confidential and will not be released by the investigator unless required to by law.

I agree that research data gathered for the study may be published provided my name or other identifying information is not used.

Signature of participant _______________________     Date__________________________

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar’s Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.
CONSENT FORM (Chapter 3)

A COMPARISON OF MUSCLE DAMAGE, SORENESS AND PERFORMANCE FOLLOWING A SIMULATED CONTACT AND NON-CONTACT TEAM SPORT ACTIVITY CIRCUIT

Investigator responsibilities – Participant rights

- As a subject you are free to withdraw your consent to participate at any time without prejudice.

- The researchers will answer any questions you may have in regard to the study at any time. Questions concerning the study can be directed to:

  Tarveen Kaur Ragbir Singh
  School of Human Movement and Exercise Science
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  Email: tarveenlonj@gmail.com

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Appendix B

Chapter 2 Data Collection Sheets
# RELIABILITY OF A CONTACT AND NON-CONTACT SIMULATED TEAM GAME CIRCUIT

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* S.TI\(\text{ME} \) : \text{SPRINT TIME}  \quad  V.J. : \text{VERTICAL JUMP}  \quad  R.P.E. : \text{RATINGS OF PERCEIVED EXERTION}  \quad  H.R. : \text{HEART RATE}  \quad  W.C. \text{T}\(\text{I\(\text{ME}\) : WHOLE CIRCUIT TIME}  \)
Appendix C

Chapter 3 Data Collection Sheets
**A COMPARISON OF MUSCLE DAMAGE, SORENESS AND PERFORMANCE FOLLOWING A SIMULATED CONTACT AND NON-CONTACT TEAM SPORT ACTIVITY CIRCUIT**

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**S.TIME**: SPRINT TIME  
**V.J.**: VERTICAL JUMP  
**R.P.E**: RATINGS OF PERCEIVED EXERTION  
**H.R**: HEART RATE  
**W.C.TIME**: WHOLE CIRCUIT TIME
# MUSCLE SORENESS MEASURES

*ALGOMETER & LIKERT SCALE SHEET*

Name:

Time Set: Pre-exercise

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<th>Likert Scale</th>
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Time Set: 1 h post-exercise

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Time Set: 24 h post-exercise

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Time Set: 48 h post-exercise

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Appendix D

Likert Scale
LIKERT SCALE

10  EXTREMELY SORE
9
8  VERY SORE
7
6
5  SORE
4
3  UNCOMFORTABLE
2
1
0  NORMAL
Appendix E

Chapter 2 and 3 Simulated Team Game Exercise

Protocol
SIMULATED TEAM-GAME EXERCISE CIRCUIT (NON-CONTACT VERSION)

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TIMING GATES
VERTICAL JUMP VJ
SIMULATED TEAM-GAME EXERCISE CIRCUIT (CONTACT VERSION)
Appendix F

Sample of Participants Study 1 (Chapter 2)

Diary Sheet
## PARTICIPANT DIARY SHEET

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### REST
* Complete rest and no vigorous or strenuous activities encouraged.

### TESTING
**Time:**

### Activities:

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### REST
* Complete rest and no vigorous or strenuous activities encouraged.

### TESTING
**Time:**

### Activities:
Appendix G

Publications Arising from this Thesis

NOTE: Journal articles removed due to copyright issues.