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Lower Limb Fatigue Asymmetry of Preferred and Non-Preferred Legs after a Repeated-Sprint Test in Football Players with Previous Hamstring Injury

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This thesis is submitted in fulfilment of the requirements for Masters by research.

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USE OF THESIS

DECLARATION

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ABSTRACT

Football is the most widely played sport in the world and is thus associated with the highest total number of injuries of all sports. 12% of all football injuries are to the hamstrings, as this muscle group is subjected to constant stress during training and match play performance (Ekstrand, Hägglund, Waldén, 2011; Woods, Hawkins, Maltby, Hulse, Thomas & Hodson, 2004). While the influence of limb dominance has been extensively examined as a risk factor for injury in upper limb-dominant sports (e.g. badminton, tennis and baseball), little research has focussed on the dominance in the lower limbs. Since almost all footballers show a limb preference for kicking, an example of limb dominance, it is possible to speculate that limb-specific injury rates will vary between preferred and non-preferred legs (Brophy, Silvers, Gonzales and Mandelbaum, 2010). Previous research has also shown that injury rates increase with the accumulation of fatigue, and that inter-limb force production variation increases as fatigue progresses. Thus, the possibility exists that increases in inter-limb force production variability after fatiguing exercise would increase injury risk in football players. The purpose of the present research, therefore, was to examine changes in muscle force production and fatigue between preferred and non-preferred legs in football players with and without a history of unilateral hamstring injury (in the preferred kicking leg). In the single leg vertical jump, peak jump force of the preferred leg in the injured group changed by -12% whilst force in the non-preferred leg changed by -5%. Force in the non-injured preferred leg changed by -6% and changed by -8% in the non-preferred leg. These results indicate a clear difference in fatigue response between groups, and that the inter-limb difference in force production is greater in the preferred leg of the injured group. Decline in hamstring torque in the preferred leg of the injured group changed by 98%, and the non-preferred leg changed by 67%. While in the non-injured group, decline in hamstring torque changed by 219% and 852% respectively. The greater changes observed in the non-injured group was due to

minimal fatigue before the fatigue condition (repeated-sprint test). The injured group had a greater fatigue response both before and after the fatigue condition (26.1±18.4 to 51.7±20.9 N preferred leg and 11.6±8.94 to 19.4±20.5 N non-preferred leg) suggesting previous injury has a different effect on fatigue response. Horizontal force production during the repeated-sprint test changed by -14% in the preferred kicking leg and -3% in the non-preferred leg (injured group). This represents the preferred kicking leg having a greater fatigue response. In conclusion, the present study has provided a foundation for comparing the injured and non-injured group and the preferred and non-preferred kicking legs during a single leg vertical jump, isokinetic endurance test and repeated-sprint test. These tests provided evidence that the non-preferred leg had greater force production, the preferred leg had greater fatigue response, and the inter-limb difference in force production after fatigue was greater in the injured group. It can be assumed that the preferred kicking leg of the injured group being the previously injured leg has attributed to these results. These results highlights the need for future research to further understanding of the differences in preferred and non-preferred kicking legs, why they occur, and the influence they have on injury.

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CHAPTER ONE: INTRODUCTION

1.1 Background

Football is the most widely played sport in the world and is thus responsible for the most sport related injuries (Ekstrand & Gillquist, 1982). Hamstring injuries are a common occurrence in football, contributing to 12% of all injuries in the sport and accounting for an average of 90 days and 15 matches missed per club per season in the professional English football leagues (Woods et al., 2004). These injuries can be long standing and injured players are prone to injury recurrence even after rehabilitation; the re-injury rate for hamstrings has been reported to be 12-31% (Woods et al., 2004; Sherry & Best, 2004). Such proneness to recurrence suggests that mechanisms underlying hamstring re-injury differ to that of first-time injury mechanisms (Askling, Tengvar, Saartok & Thorstensson, 2007).

Hamstring anatomical arrangement

Contributing to the susceptibility of hamstring muscles is their anatomical arrangement, being a biarticular muscle group flexing the knee and extending the hip. Many movements made during football require both simultaneous and sequential flexions of the knee and hip, resulting in complex lengthening-shortening load being imposed on the hamstrings (Petersen & Holmich, 2005). While such movements are required for optimal performance in football, Askling, Tengvar, Saartok and Thorstensson (2007) suggest that the variation in requirements and demands of different sports indicate an existence of hamstring injuries with different mechanisms.

Physiological factors influencing injury risk

Despite conflicting evidence as to the factors predisposing hamstring injuries, insufficient warm up, poor flexibility and strength, muscle imbalances, muscle weakness, fatigue, age, dys-synergistic contractions, and incomplete rehabilitation of previous injuries are generally considered to be prominent (Agre, 1985; Worrell, 1994; Alemkinders, 1999; Hawkins & Fuller, 1999; Orchard, 2001). Injuries most often occur in the biceps femoris muscle of the hamstring muscle group with the muscle-tendon junction being the most common site of injury (Garrett, 1996; Garrett, Rich, Nikolaou & Vogler, 1989; Woods, Hawkins, Maltby, Hulse, Thomas & Hodson, 2004), however injury can also occur at the tendon origin, insertion or muscle belly (Garrett, 1996).

Hamstring injuries are also most commonly associated with eccentric muscle contractions during sprinting or running when peak tension in the muscle is evident during lengthening (Stanton & Purdam, 1989). This is most apparent in the final stages of the swing phase in running, with the hamstring contracting eccentrically to decelerate knee extension to prepare for the foot strike (Stanton & Purdam, 1989). Such an action is also evident when kicking a football, with the load in tension exceeding the physiological limit which most often occurs in hamstring strains (Van Don, 1998). With such kicking actions so frequent in football, a significant research effort is required to prevent hamstring injuries in football players.

Leg dominance and underlying asymmetry

While it is assumed that recovery will continue until pre-injury capacity is reached (after the conclusion of an intensive rehabilitation phase), Holder-Powell and Rutherford (1999) concluded that full recovery is frequently not achieved and emphasise the importance of accurate and objective assessment of muscle strength. Through this assessment, decrements in strength of a unilateral lower-limb injury can be found, highlighting the prominence of inter-limb differences (Holder-Powell & Rutherford, 1999). However, while previous research recognises this as a predisposing factor for hamstring injuries, it fails to quantify the difference in muscle force production and fatigue in relation to lower-limb dominance (i.e. preferred versus non-preferred kicking leg).

While most footballers exhibit limb dominance during kicking (i.e. they have a preferred and non-preferred kicking leg), little is known about whether the degree of preference is a predisposing factor for hamstring injuries (Rahnama, Lees & Bambaecichi, 2007). Rahnama, Lees and Bambaecichi (2007) compared strength and flexibility between preferred and non-preferred kicking legs and reported a clear difference in lower extremity strength, despite results showing no difference in flexibility. A clear difference in lower extremity strength would suggest that asymmetry are evident however, little research sought to determine how such asymmetry affect hamstring performance.

Injury risk analysis in football

An analysis of injury risk in outfield players by Rahnama, Reilly and Lees (2002) found that the risk of injury can be related to playing actions (players are most at risk when receiving or making a tackle), period of the game (the first and last 15 minutes of the game reflecting the high intensity levels at the start of the game, and the possible fatigue effects at the end of the game) and specific zones of the pitch (specific attacking and defending areas of the pitch where the ball is most contested). However, no data was provided as to the actions involved in the preferred and non-preferred legs. Given that most football players exhibit limb dominance during football-related skills, the preferred and non-preferred legs are subjected to different muscle activation patterns. This is particularly true during kicking, where one leg kicks the ball while the other acts to support the body’s weight (Brophy, Backus, Pansy, Lyman & Williams, 2007).

Fatigue in football

Football requires the repetitive performance of a range of gross motor skills, including walking, jogging, jumping and sprinting over 90 min of a competitive football match. Effective performance of these skills then allows footballers to accurately perform other motor and technical skills such as passing, shooting, crossing and tackling (Svensson & Drust, 2007; Alghannam, 2012; Nikolaidis, 2014). The ability to repeatedly recover over the game duration is therefore of great importance (Svensson & Drust, 2007; Alghannam, 2012; Nikolaidis, 2014). The decline in muscle force caused by fatigue affects repeated skill performance and is considered to impair technical performance and increase lower-limb injury risk (Reilly, Drust & Clarke, 2008).

Such evidence of a relationship between fatigue, the duration of a competitive football match and injury risk is highlighted by Woods et al., (2004) who found that 47% of all hamstring strains during a professional English football match occurred in the final 15 min of each half (with a half lasting 45 min). Thus, with nearly every second hamstring strain occurring in the latter stages of a football match fatigue can be considered a major contributing factor to these injuries. Gibson and Edwards (1985) define fatigue as the failure to maintain the required or expected force or power output. This reduction in force or power output is more prominent towards the end of a half of football, and in particular the second half (Reilly, Drust & Clarke, 2008).

With players being most susceptible to hamstring injuries towards the end of a competitive football match, Greig (2008) proposed that muscle strength deficiency due to fatigue can cause such injury. The fatigue results in decreased hamstring force, reducing energy absorption capabilities and increasing the injury risk. However, little is known about the effect on game-specific fatigue in muscle force making it unclear whether there is an association with injury. Thus there is a need to further research the effect of muscular fatigue on hamstring injury risk.

Running biomechanical changes due to fatigue

Benjaminse, Habu, Sell, Abt, Fu, Myers and Lephart (2008) suggest that an environment is created during the onset of fatigue in which lower extremity landing strategies are altered to combat fatigue in an attempt to continue effort and performance. Importantly, as the control of body movement decreases during fatigue, non-contact injury rates increase (Chappell, Herman, Knight, Kirkendall, Garrett & Yu, 2008). Sprague and Mann (1983) and Tupa, Gusenov and Mironenko (1995) clearly show biomechanical alterations accompanying fatigue during sprint running, including a decrease in hip flexion and thigh angular velocity and an increase in knee extension during the swing phase of the stride cycle. However, despite such biomechanical alterations being shown in straight-line sprints, possession of a football and frequent jumping and cutting manoeuvres can change the dynamics of a sprint and thus increase the physiological stress further (Hoff, Wisloff, Engen, Kemi and Helgerud, 2002; Askling, Karlsson and Thorstensson, 2003). What is not known, however, is whether potential differences in the rates of fatigue between legs (e.g. preferred versus non-preferred legs in football players) increase injury risk.

Methods of testing muscle function in hamstring injury research

Isokinetic testing is commonly used in the detection of bilateral strength deficits. However, these tests are not specific with regards to movement patterns in football, which are typically open kinetic chain, of high-velocity and stretch-shortening cycle based (Brughelli, Cronin, Mendiguchia, Kinsella, & Nosaka, 2010; Newton, Gerber, Nimphius, Shim, Doan, Robertson, Pearson, Craig, Hakkinen and Kraemer, 2006). Despite this, isokinetic dynamometers have been validated for the study of fatigue, making this an important tool for testing (Sangnier & Tourny-Chollet, 2008). While there are many ways to quantify bilateral strength deficiency, testing that is most similar in movement pattern to the tasks performed in football, such as jumping and running, could be considered more relevant. Thus, research is required that examines bilateral strength, and the resulting change with fatigue, using football specific tests. The relationship between strength deficit, fatigue and injury risk could then be explored.

To ensure that the effect of fatigue is reliable, a sprint-based running performance test is required. The repeated sprints test is used to assess the physical performance of football players in which repeated maximal bouts of short duration (~6s) sprints are performed with brief recovery periods (Rampinini, Bishop, Marcora, Ferrari Bravo, Sassi & Impellizzeri, 2006; Bangsbo, Norregaard & Thorso, 1991; Bangbso, 1994). The repeated sprints test elicits physiological responses similar to the responses that occur during a competitive football match (Wragg, Maxwell & Doust, 2000; Svensson & Drust, 2005; Spencer, Bishop, Dawson & Goodman, 2005). Repeated sprint ability is an important factor influencing football performance and can be used for monitoring footballers' physical fitness and performances. By testing subjects on a treadmill with a repeated sprints test, subjects could be fatigued in a similar manner as they are during a competitive football match. Using data obtained during the test non-injured versus previously-injured subjects could be compared to indicate a link hamstring injuries.

A repeated sprints test can be performed on a non-motorised treadmill, allowing for close replication of physiological and running demands of a competitive football match (Sirotic & Coutts, 2007). By monitoring these demands in a controlled environment, real-time measures of force production, power output and running kinematics can be obtained through instantaneous feedback (Sirotic & Coutts, 2007). A reliability study by Sirotic and Coutts

(2007) found that a 6-s sprint is best for assessing sprint performance on a non-motorised treadmill in team-sport athletes. By using this 6-s sprint in a repeated-sprint test protocol, repeated-sprint performance can be measured in order to partly replicate the repeated-sprint demands in football.

Conclusion

While fatigue and muscle imbalances are clearly defined as physiological factors that increase hamstring injury risk, the combination of both as a risk factor has previously been ignored. The possibility of differing rates of fatigue between muscles groups, preferred and non-preferred kicking legs and injured and non-injured groups have not been thoroughly explored. The present thesis project was designed to compare hamstring muscle function in previously injured and non-injured footballers over a series of tests. Within these tests the quantification of the preferred and non-preferred kicking legs can be made. By comparing the injured and non-injured groups, and the preferred and non-preferred kicking legs within the groups, this study is the first to explore the possibility of the legs fatiguing at different rates. Deficits between the injured and non-injured groups will provide an indication of the effect of previous injury on hamstring muscle function in both fatigued and non-fatigued states.

1.2 Purpose of the Study

The key purpose of this study was to determine whether the injured and non-injured groups show different fatigue magnitudes during a series of tests in which the hamstring muscles are highly active. By examining this, it was possible to explore that the preferred and non-preferred kicking legs fatigue at different rates and also to compare the rates of unilateral strength and performance decrement between previously injured and non-injured subjects (i.e. control). The force production and fatigue profile in the preferred and non-preferred legs of

West Australian State League footballers with (injured group; preferred kicking leg as the previously injured leg) and without prior hamstring injuries (non-injury group) were tested. Fatigue was induced using a repeated-sprint protocol, and lower-limb dynamics and kinematics were monitored to quantify muscle fatigue in a sport-specific manner. The results from this study will help determine whether the preferred and non-preferred legs fatigue differently in football-specific movements (jumping and repeated sprints) and, more importantly, whether the legs of previously injured players fatigue more rapidly (i.e. with an increased bilateral difference). A clearer understanding of this may help to uncover strategies that could reduce the risk of injury in footballers.

1.3 Significance of the Study

No previous research has examined lower limb asymmetry with respect to fatigue in football players. This is also the first study, to the researcher's knowledge, to test the hypothesis that a preference in kicking leg is a risk factor for hamstring injury. Previous research (Brughelli et al., 2010) focussed on lower-limb leg deficiencies in running at 80% of maximum velocity (v_{max}), whereas the present research was designed to test repeated sprint ability at 100% v_{max} attained in 6-s. With most hamstring injuries occurring during the late swing phase of v_{max} running, a repeated-sprint test at such a velocity will mimic normal running performance (Stanton & Purdam, 1989). While a prospective study is ideal, this retrospective study provides the first data potentially linking inter-limb fatigue to hamstring injury risk.

1.4 Research Questions

1. Is there a difference between the preferred and non-preferred legs in (i) peak jump force and height during a single leg vertical jump (SLVJ); (ii) mean knee extensor and flexor torque and change (percent) in quadriceps and hamstring torque during an isokinetic endurance test (IET); and (iii) mean vertical and horizontal force production, power output, contact time, flight time, stride frequency and stride length in a repeated-sprint test (RST)?
2. Is there evidence that the preferred and non-preferred legs fatigue at different rates during a repeated-sprint running protocol?
3. Do previously injured players display a greater fatigue response in the preferred kicking leg (in all cases, this is the previously injured leg), when compared to the non-preferred kicking leg, and is the inter-limb difference in force production after fatigue greater than in non-injured subjects?

1.5 Research Hypotheses

1. There will be a difference between the preferred and non-preferred legs in which the non-preferred leg will be established as the stronger leg; the force and power is expected to be greater than that of the preferred leg. In turn, the preferred leg is expected to fatigue at a greater rate.
2. The preferred leg will fatigue at a greater rate during a repeated-sprint running protocol.
3. The previously injured players are expected to have a greater fatigue response in the preferred kicking leg and a greater inter-limb force production difference.

CHAPTER TWO: LITERATURE REVIEW

2.1 Hamstring anatomy

The hamstring muscle group consists of biceps femoris (long and short head), semimembranosus and semitendinosus (Kumazaki, Ehara, Sakai, 2012; Abebe, Moorman, Garrett, 2012). The long head of biceps femoris originates from the lateral portion of the ischial tuberosity and the sacrotuberous ligament and attaches distally at the fibular head, shared with the short head (Carlson, 2008). The short head originates from the lateral intermuscular septum and the distal third of the lateral femoral cortex (Carlson, 2008). The semimembranosus and semitendinosus share both origins and attachments originating from the mid-portion of the ischial tuberosity and attaching distally at the posteromedial tibia (Carlson, 2008), thus there are three biarticular heads and one unilateral head.

2.2 Hamstring injury classification

The degree to which the muscle fibres have been injured classifies the degree of muscle strain that has occurred (Agre, 1985). At one end of the scale, first degree strains occur through the stretching of the musculotendinous units resulting in minimal loss of strength and function with only minor swelling and discomfort. At the other end of the scale, third degree strains present as a complete rupture across the musculotendinous unit resulting in total functional disability (Kujala, Orava & Jarvinen, 1997; Drezner, 2003; Petersen & Holmich, 2005). The degree of classification dictates the functional disability and rehabilitation time, highlighting the importance of testing previously significant hamstring injuries.

2.3 Hamstring injury risk factors

Risk factors associated with hamstring injury include competition participation (versus practice), decreased quadriceps flexibility, older age (which has been shown to be associated with increased hip flexor tightness and increased body weight), over-striding during sprint acceleration, imbalances between muscle groups (especially the hamstring to quadriceps ratio), muscle fatigue, hamstring tightness and decreased tendon compliance and muscular fatigue. Additionally, previous injury is consistently rated as one of the strongest predictors of injury risk (Petersen & Homlich, 2005; Carlson, 2008); the incidence of recurrent injury runs between 12 and 14% in football players (Petersen & Homlich, 2005; Carlson, 2008).

2.4 Anatomy of the hamstring

Having multiple attachments allows the hamstring to impact function throughout the pelvis and lower extremities; flexion and extension of the knee, pelvic tilt and rotation, sacral rotation and extension and rotation of the hip (Carlson, 2008; Thelen, Chumanov, Sherry, Heiderschiet, 2006). Hip extension and knee flexion are the two primary activities of the hamstring group, however the muscles also function to control hip flexion and knee extension, emphasising the eccentric action of the hamstring (Abebe, Moorman, Garrett, 2012). The biarticular structure of the hamstring muscles enables the ability to localise contractions to one joint by allowing movement to occur at the other, if either antagonists contract (Koulouris & Connell, 2003).

2.5 Hamstring injury rates and severity

Repeated hamstring injury rates have ranged from 16-60% in a number of sports including; football, rugby union, American football, track and field and Australian rules football (Brooks et al., 2006). Injury recurrence is arguably the most troubling aspect of hamstring injuries, as recurring injuries often result in a greater loss in playing time than the original injury (Brooks et al., 2006; Ekstrand et al., 2011; Koulouris and Connell, 2006). This is particularly true of hamstrings as after injury the hamstrings remain at an elevated risk of injury recurrence for longer than any other muscle strained (Orchard and Best, 2002). Previous research highlights this, providing evidence of a significant rate of recurrence of hamstring injuries over consecutive seasons (Carling et al., 2011; Hagglund et al., 2006; Verrall et al., 2006). This previous research would suggest that injury prevention and rehabilitation practices are not as effective as athletes and coaches require them to be, highlighting the need to further research the understanding of hamstring injuries.

More than 90% of all muscle injuries in football occur in the four major lower limb muscle groups: hamstrings, adductors, quadriceps and gastrocnemius (Ekstrand, Healy, Waldén, Lee, English, & Hägglund, 2011; Ekstrand, Hägglund, Waldén, 2011). Hamstring injuries have been reported to be the most common injury subtype, representing 12% of all injuries recorded (Ekstrand et al., 2011; Ekstrand, Hägglund, Waldén, 2011). An epidemiological study conducted by Ekstrand et al. (2011) estimated that each professional football team (25 players in a squad) would average approximately 5 hamstring injuries per season, totalling over 80 days lost to injury.

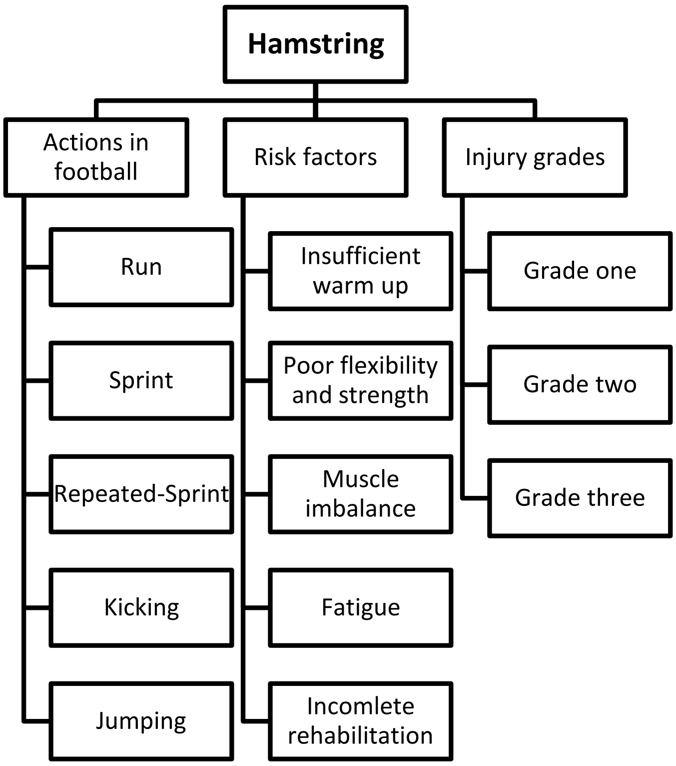


Figure 1. The role of the hamstring in; actions in football, risk factors and injury grades.

2.6 Hamstring injury mechanism

Hamstring injuries occur when the force applied to the contracted muscle exceeds the physiological limit of the muscle-tendon unit (Abebe, Moorman, Garrett, 2012). This occurs when the muscle group resists a powerful eccentric load when contraction combined with the lengthening of the muscle takes place (Abebe, Moorman, Garrett, 2012). It is at this time when the muscle lengthens and the resulting force applied to the muscle contraction exceeds physiological limit that an injury will occur (Speer, Lohnes, Garrett, 1993; Abebe, Moorman, Garrett, 2012). From this it is clear as to why hamstring are particularly vulnerable to injury during eccentric loading (Heiderscheit, Hoerth, Chumanov, Swanson, Thelen, Thelen, 2005; Carlson, 2008; Abebe, Moorman, Garrett, 2012).

Previous research suggests that there are at least two different injury mechanisms, with the predominant type occurring during high-speed running and the other occurring during movements resulting in extensive lengthening of the hamstring (Askling, Tengvar, Saartok &

Thorstensson, 2000; Askling, Saartok & Thorstensson, 2006; Askling, Tengvar, Saartok & Thorstensson, 2007; Askling, Tengvar, Saartok & Thorstensson, 2008). Movements causing extensive lengthening of the hamstring include kicking and slide tackling, both frequently used while playing football (Askling, Tengvar, Saartok & Thorstensson, 2000; Askling, Saartok & Thorstensson, 2006; Askling, Tengvar, Saartok & Thorstensson, 2007; Askling, Tengvar, Saartok & Thorstensson, 2008). High-speed running requires a high intensity of stretch-shortening cycles in order to perform rapid changes of direction and jumping and landing tasks (Croisier, Ganteaume, Binet, Genty & Ferret, 2008). Performance of these movements can cause a sudden forcible contraction of the muscles to take place against resistance, causing excessive eccentric overloaded resulting in injury to the hamstring (Gidwani & Bircher, 2007). Epidemiological studies show that a higher rate of injury occurs in the biceps femoris during high-speed running (Thelen, Chumanov, Sherry & Heiderschiet, 2006; Thelen, Chumanov, Hoerth, Best, Swanson, Li, Young & Heiderscheit, 2005; Brooks, Fuller, Kemp & Reddin, 2006; Woods, Hawkins, Maltby, Hulse, Thomas & Hodson, 2004). As football can reduce induce injury through both mechanisms (high-speed running and movements resulting in extensive lengthening of the hamstring), the performance of both modes of injury the need to further research hamstring injuries and test during movements that may induce both modes of injury is of great importance.

2.7 Effect of activation pattern on hamstring injury

The hamstring muscle group is recruited differently depending on the activity performed, which has implications for injury propensity (Carlson, 2008). Dancers are frequently injured during partner-assisted static stretches (Askling, Saartok & Thorstensson, 2006). Ice hockey players are thought to develop hamstring problems from poor core muscle strength (Carlson, 2008); such core weakness allows an anterior pelvic tilt which places the hamstrings at a mechanical disadvantage, due to reduced moment arm, that can lead to overuse injury

(Carlson, 2008). Hamstring fatigue, measured as a decrease in maximum eccentric force, has been shown in marathon runners over the course of a race resulting in an increased risk of injury (Koller, Sumann, Schobersberger, Hoertnagl & Haid, 2006). Football and Australian Rules football are the two most frequently epidemiologically researched sports regarding hamstring strains (Brooks, Fuller, Kemp & Reddin, 2006; Woods, Hawkins, Maltby, Hulse, Thomas & Hodson, 2004; Gabbe, Finch, Bennell & Wajwelner, 2005; Gabbe, 2006; Volpi, 2004). Both sports demand frequent bursts of sprinting over prolonged periods of time, resulting in a higher incidence of muscular fatigue. The kicking action involved in both sports also predispose to muscle injury as forces driving the hip into flexion during the acceleration phase of kicking is relatively greater. Likewise, the eccentric braking action of the hamstrings is greater during the kicking action. While some previous research has examined such effects of the kicking action (generally associated with a preferred kicking leg), no previous research has investigated differences between the preferred and non-preferred kicking legs.

2.8 Hamstring action during running

While sprinting, the hamstring lengthens maximally during the end of the swing phase of gait just prior to foot contact when the hip is flexed and the knee flexion moment is decreasing (Thelen, Chumanov, Best, Swanson & Heiderscheit, 2005). The rapid lengthening of the hamstring muscle group at this point allows the muscle to become vulnerable to injury. The initial swing phase in sprinting allows the hip flexors to generate power to propel the thigh forward (Lee, Reid, Elliot & Lloyd, 2009). This provides for the transfer of thigh angular momentum to the shank resulting in rapid knee extension during the second half of the swing phase (Lee, Reid, Elliot & Lloyd, 2009). From this point the hamstrings act eccentrically, absorbing power to control knee extension (Lee, Reid, Elliot & Lloyd, 2009). The hamstring also acts as a spring, lengthening under load and reusing the swing through stance

(Malliaropoulos, Mendiguchia, Pehlivanidis, Papadopoulou, Valle, Malliaras & Maffulli, 2012).

2.9 Physiological demands in football

During an elite competitive 90-min football match players are physically challenged, averaging 10-13 km in total distance covered, 220 high speed runs and frequent changing of activity and direction (Vigne, Dellal, Gaudino, Chamari, Rogowski, Alloatti, Wong, Owen & Hautier, 2013; Greco, da Silva, Camarda & Denadai, 2013). The demand for such physical performance induces fatigue resulting in impaired performance, which becomes more prominent in the second half and particularly in the final 15-min (Greco, da Silva, Camarda & Denadai, 2013). Impaired performance is particularly evident in decreased eccentric strength, which is thought to increase hamstring injury risk (Greig, 2008; Small, MacNaughton, Greig & Lovell, 2008). Previous research has detailed the levels of fatigue after a competitive match, with jump ability, sprint ability (Magalhaes, Rebelo, Oliveira, Silva, Marques & Ascensao, 2013) and repeated sprint performance (Krustrup, Zebis, Jensen & Mohr, 2010) being found to be significantly reduced. No previous research, however, has compared these deficits between the preferred and non-preferred kicking legs.

2.10 Muscular fatigue and decline in knee flexor and extensor torque

High incidences of hamstring injury in all levels of football have been linked to muscular fatigue (Steffen, Myklebust, Olsen, Holme and Bahr, 2008; Arnason, Andersen, Holme, Engebretsen and Bahr, 2008; Petersen, Thorborg, Nielsen, Budtz-Jørgensen and Holmich, 2011). Previous research have reported reductions in knee flexor (hamstring) and knee extensor (quadriceps) maximal torque during and after actual and simulated football match play (Delextrat, Gregory and Cohen, 2010). Gray and Chandler (1989) reported a 47.7%

decline in concentric hamstring and quadriceps torque highlighting the importance of continued testing in the decline of torque. Previous research has yet to compare the preferred and non-preferred kicking legs and the difference in the decline in torque between legs.

2.11 Inter-limb difference in function and fatigue

Rahnama, Lees and Bambaecichi (2007) compared strength and flexibility between preferred and non-preferred kicking legs and reported a clear difference in lower extremity strength, despite showing no difference in flexibility. The authors suggested that the performance of skills with a limb preference during football training and match play was a cause of the difference in strength between limbs. This could result in asymmetry in the lower limb extremities as functional discrepancies increase (Rahnama, Lees & Bambaecichi, 2007). The possibility of asymmetry has yet to be fully explored and could give insight into hamstring injuries in team sports that require particular use of the lower limbs such as football.

Most footballers have a clear preference in the leg they use to kick the ball. During kicking the non-preferred kicking leg is used to support the body, providing the platform of support for the preferred kicking leg to swing through and make contact with the ball (Ball, 2013). Lees, Asai and Andersen (2010) suggest that a stronger support leg (non-preferred kicking leg) can provide greater stabilisation for the kick and enabling greater forces to be generated. Consideration needs to be given to the effects of the resulting inter-limb asymmetries between the preferred and non-preferred kicking legs. At this stage, there is no consensus as to the quantification of difference between the legs that is needed to be considered an injury risk. Thus, there is a need to determine asymmetries in both previously injured and a healthy control group and comparing such asymmetries in taking the first step in identifying the kicking legs as an injury risk factor.

2.12 The importance of treadmill testing

Before treadmill running tests could be reliably conducted, researchers had great difficulties in conducting accurate and specific running tests. Comparisons of vertical ground reaction forces made between overground running and treadmill running by Kluitenberg, Bredeweg, Zijlstra and Buist (2012) validated the use of treadmills in measuring ground reaction forces. One difficulty for researchers is the difficulty in getting representative ground reaction force measurements of a repeated-sprint test with a traditional force platform. While traditional force platforms only allow for limited measurements of kinetic and kinematic patterns, treadmill testing provides a continuous analysis of such patterns (Kluitenberg, Bredeweg, Zijlstra & Buist, 2012; Riley, Dicharry, Franz, Della Croce, Wilder & Kerrigan, 2008), particularly important while conducting a repeated-sprint test. This provides more accurate data results and allows researchers to provide greater analysis of running kinetic and kinematic patterns.

To further improve testing environments, the use of non-motorised treadmills has increased in order to replicate the running performance and physiological changes specific to a particular sport (Sirotic & Coutts, 2006; Riley, Dicharry, Franz, Della Croce, Wilder & Kerrigan, 2008). Non-motorised treadmills allow near maximal velocities to be obtained, instantaneous changes in running velocity, and provide real-time measures of power output (Sirotic & Coutts, 2006). From this, simulation of physiological demands and running kinetics specific to particular sports can be achieved (Sirotic & Coutts, 2006). Several studies have already described the reliability and validity of the use of non-motorised treadmills in the simulation of team-sports and running performance (Tong, Bell, Ball & Winter, 2001; Hughes, Doherty, Tong, Reilly & Cable, 2006; Sirotic and Coutts 2006).

2.13 Conclusion

The importance of further hamstring injury research is highlighted by the fact that it is the most common injury subtype in football (12%; Ekstrand et al., 2011). The hamstring muscle group also has the highest re-injury rate, suggesting that proper rehabilitation is of great importance (Brooks et al., 2006). Continued research into hamstring injury risk factors could potentially further our understanding of why hamstring injuries occur. Such research could help attribute to reducing hamstring injury and re-injury rates in the future. While an extensive research effort has shown that lower- limb asymmetry and fatigue are risk factors for hamstring injuries (Petersen & Homlich, 2005; Carlson, 2008), consideration of the interplay between asymmetry and fatigue rates has in relation to hamstrings injury has not been published. By testing injured and non-injured subjects and comparing the differences in leg asymmetry and fatigue, the first steps of examining lower-limb fatigue asymmetry are taken.

CHAPTER THREE: METHODOLOGY

3.1 Approach to the Problem

To assess leg fatigue asymmetry in both healthy and previously injured Western Australian State League footballers, players were asked to perform a single leg vertical jump (SLVJ) and an isokinetic knee extension/flexion endurance test (IET) before and after a repeated-sprint test (RST) on a non-motorised treadmill. Comparisons were made between preferred and non-preferred legs as well as between the injured and non-injured groups. Leg asymmetry was quantified before and after a RST in which mean jump force, height and impulse during the SLVJ and both mean knee extension and flexion torque and the percent decline in knee extension and knee flexor torque during the IET was assessed. The resulting decreases in force and power production were calculated as a percent change to index fatigue rates. Ground reaction force production was also measured on the non-motorised treadmill during the RST, and changes in horizontal force production, vertical force production, power output, contact time, flight time, stride frequency and stride length were recorded as indicators of fatigue and running technique.

3.2 Subjects

40 footballers currently playing in the Western Australia State League (semi-professional) volunteered for the study. All footballers have had at least 2 years of playing experience in the State League, and playing experience in football for at least 5 years. Players were assigned to either an injured group (IG) or non-injured group (NG) based on the following criteria: (a) injury history of one or multiple hamstring injuries to one leg only (a unilateral hamstring injury); (b) the injury caused the athlete to miss at least 1 week of training (the injury was significant): (c) the injury occurred less than 2 years prior to testing (the injury

was recent enough for some deficiencies to potentially remain). All subjects in the injured group experienced their unilateral hamstring injury on the preferred kicking leg. Before data collection, each subject completed a questionnaire to determine their suitability for inclusion in the study. The questionnaire was used to determine whether or not the inclusion criteria were met for injured and non-injured groups and provide the subject's playing history, preferred and non-preferred legs and contact details. Following the completion of the questionnaire, anthropometric measurements of standing height (cm) (Detecto, United States of America) and body mass (kg) (Tanita, United States of America) as well as performance in a sit and reach test (cm) (Sanming, China) were recorded.

3.3 Experimental Procedure

Familiarisation of the SLVJ, IET and RST tests were completed over two familiarisation sessions, as suggested by Martin, Diedrich and Coyle (2000). This ensured that subjects understood what was expected of them in order to produce stable and consistent results. The seating position of each subject on the isokinetic dynamometer was recorded during familiarisation and repeated during testing. Testing was performed over three sessions separated by a week at the same time of day to allow for sufficient recovery. The subjects were asked to maintain a normal diet and refrain from participating in any strenuous exercise 48 h prior to testing. Before the commencement of testing a 5-min warm-up on a non-motorised treadmill at 2 $m.s^{-1}$ (i.e. jog) was completed with the subjects given the opportunity to perform dynamic stretches after the warm up for a total of 2 min. Once the warm-up and dynamic stretching were completed the subjects followed one of three protocols, as described below.

3.4 Protocol 1: Isokinetic Endurance Test (non-fatigued condition)

The subject was seated on the isokinetic dynamometer (System 3; Biodex Medical Systems, Shirley, NY) with a hip joint angle of 85° (0° = full extension). To minimise any extraneous movement, two diagonal straps were secured across the chest and a seatbelt applied across the hips. Alignment of each knee was maintained visually by altering the dynamometer chair position allowing for the knee axis of rotation (tibio-femoral joint) to be aligned with the axis of rotation of the dynamometer's attachment arm. The subject's legs were secured to the attachment arm (2.5 cm above the lateral malleolus of the ankle) using wide velcro straps. The contralateral leg was not secured in order to prevent any influence on the development of strength on the leg being tested. For the maximal strength test the subject performed three maximal concentric contractions (concentric contractions are used so this test protocol can be used in-season with minimal delayed onset muscle soreness) using both the preferred and non-preferred legs as described by Sangnier and Tourny-Chollet (2008). The dynamometer velocity was calibrated to an angular velocity of $180°\cdot s^{-1}$, through a 90° range of motion. Sangnier and Tourny-Chollet (2007) showed a divergence in fatigue between the quadriceps and hamstrings using $180°\cdot s^{-1}$, so this speed was used in the present study. The starting test leg order was randomised between subjects and the mean of the three trials for each leg was recorded and used as the subject's maximal strength. (Sangnier & Tourny-Chollet, 2008).

The subjects remained seated on the dynamometer for 3 min before a fatigue test was performed. Subjects performed 50 consecutive knee extension and flexion concentric contractions with maximal force. The fatigue test was performed on each leg with a 1-min rest between the tests. The subjects were instructed to exert the greatest force possible during the test; if 95% of maximal strength was not achieved during one of the first 5 repetitions the test was stopped and then repeated after a 3-min rest (Sangnier & Tourny-Chollet, 2008). The loss of strength in the hamstrings and quadriceps was measured over the 50 repetitions and the decline in torque production (as a percentage) over 50 contractions was calculated by using the following equation: $D\% = ([MT_{1\text{-}5} - MT_{46\text{-}50}]/MT_{1\text{-}5}) \times 100$, where $MT_{1\text{-}5}$ represents the MT of the 1^{st} to 5^{th} repetitions and $MT_{46\text{-}50}$ represents the MT of the 46^{th} to 50^{th} repetitions. The rate of decline in strength was compared between muscle groups of the same leg and between the preferred and non-preferred legs (Sangnier & Tourny-Chollet, 2008). The subjects were not informed of their results during testing in order to prevent feedback effects.

3.5 Protocol 2: Isokinetic Endurance Test (fatigued condition)

Each subject completed the RST followed by the IET. This testing was designed to use the RST to fatigue the subject before completing the IET in a fatigued state. As repeated sprints are prominent in football, the RST is designed to replicate fatigue in replicating a competitive football match. The subjects completed the same warm up conducted in Protocol 1 and completed the RST on a non-motorised treadmill (Curve Treadmill Dynamometer, Woodway, Waukesha, Wisconsin, USA). The test required ten 6-s running bouts to be performed at maximum velocity with 25 s of active recovery (jog at 2 $m.s^{-1}$) between each sprint. Feedback of running speed and time was provided by the Pacer Performance System software (Innervations Solutions, Joondalup, Australia). The subject was instructed to build to their maximum velocity as quickly as possible as the acceleration phase of the sprint was included in the 6-s sprint data collection period. The subject was given verbal encouragement to perform maximally throughout the repeated sprints. Calibration of the non-motorised treadmill was conducted before each testing session using a range of known loads according to the manufactures guidelines.

After 3-min of recovery from the RST, the subject followed the same IET protocol as followed in Protocol 1. The declines in force and power during the IET resulting from the RST when compared to the non-fatigued condition (Protocol 1) were used as measures of fatigue.

3.6 Protocol 3: Jump Test (fatigued and non-fatigued conditions)

The subject followed the SLVJ protocol designed by Ceroni, Martin, Delhumeau and Farpour-Lambert (2012). The subject placed their foot of the designated test leg, in a randomised order, on a portable force platform (400 Series Performance Plate, Fitness Technology, Adelaide, Australia) and squatted approximately to a 70-80° knee angle (0° = full extension) as quickly as possible and then explosively jumped with maximal effort as high as possible. The subject was asked to keep their hands on their hips to minimise potential contribution from their arms, and to flex the opposing knee as parallel as possible with the ground to keep balance during the descent of the jump. In the familiarisation session, the subject was to perform the SLVJ on each leg as many times as deemed necessary until they felt comfortable with the technique and proper form had been demonstrated. During testing, the SLVJ was performed three times on each leg, alternating between preferred and non-preferred legs with a 10-s passive rest between. The three SLVJ heights for each leg were performed before and after the RST to determine the magnitude of fatigue (ie. decrease in jump height), and also averaged to provide an individual subject mean. Jump height (JH) was calculated as $\frac{1}{2}\, g(t/2)^2$, where $g = 9.81\ m.s^{-1}$ and t = time in the air. Time in the air was defined as the period between take-off and contact after flight (Moir, 2008).

Three minutes after the SLVJ test the subject performed the RST as described in Protocol 2, then recovered for 3 min before again completing the SLVJ test protocol. The decline in force and power during the SLVJ resulting from the RST was used as a measure of fatigue.

3.7 Statistical Analysis

Data was analysed using SPSS statistical software (SPSS 19, Chicago, I11). Means and standard deviations were calculated as measures of centrality and spread of data for all dependent variables. Outcome measures were analysed using a repeated measures ANOVA, with 'leg' (preferred and non-preferred kicking leg), 'time' (before and after the isokinetic endurance test and single leg vertical jump) or 'sprint' (sprint number during the repeated-sprint test) as between subject variables with the between-group factor of 'group' (with two levels; injured and non-injured). Intra-class Correlation Coefficients (ICC) were conducted to confirm reliability of the Woodway Curve non-motorised treadmill. Statistical significance was accepted at an alpha level of 0.05.

CHAPTER 4: RESULTS

4.1 Single Leg Vertical Jump

4.1.1 Peak Jump Force

A significant difference was observed in the injured group (p = 0.003) and the non-injured group (p = 0.005) in peak jump force of the preferred and non-preferred kicking legs during the single leg vertical jump test (before and after the repeated-sprint test) (Table 1). In the injured group, force production in the preferred kicking leg decreased from 3371±370 to 3000±374 N (-12% change), and decreased in the non-preferred kicking leg from 3907±516 to 3717±677 N (-5% change). In the non-injured group, force production in the preferred kicking leg decreased from 3037±354 to 2863±322 N (-6% change), and decreased in the non-preferred kicking leg from 3379±410 to 3117±380 N (-8% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0.014).

4.1.2 Peak Jump Height

A significant difference was observed in the injured group (p = 0.004) in peak jump height of the preferred and non-preferred kicking legs during the single leg vertical jump (before and after the repeated-sprint test) (Table 1). In the injured group, jump height in the preferred kicking leg decreased from 0.105±0.012 to 0.091±0.013 N (-15% change), and decreased in the non-preferred kicking leg from 0.129±0.024 to 0.116±0.019 N (-11% change). In the non-injured group, jump height in the preferred kicking leg decreased from 0.095±0.014 to 0.088±0.013 N (-7% change), and decreased in the non-preferred kicking leg from 0.110±0.015 to 0.101±0.014 N (-8% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0. 038).

Table 1. Mean (± *SD*) and percent change in peak jump force and height of preferred and non-preferred kicking legs in injured and non-injured groups during the single leg vertical jump.

	Before	After	% Change
Peak Jump Force (N)			
Injured Group			
Preferred Leg	3371±370*	3000±374*	-12%
Injured Group			
Non-Preferred Leg	3907±516*	3717±677*	-5%
Non-Injured Group			
Preferred Leg	3037±354*	2863±322*	-6%
Non-Injured Group			
Non-Preferred Leg	3379±410*	3117±380*	-8%
Peak Jump Height (m)			
Injured Group			
Preferred Leg	0.105±0.012*	0.091±0.013*	-15%
Injured Group			
Non-Preferred Leg	0.129±0.024*	0.116±0.019*	-11%
Non-Injured Group			
Preferred Leg	0.095±0.014	0.088±0.013	-7%
Non-Injured Group			
Non-Preferred Leg	0.110±0.015	0.101±0.014	-8%

* = p < 0.05, ** = p < 0.001; N = newtons; m = metres.

4.2 Isokinetic Endurance Test

4.2.1 Knee Extensor Torque

A significant difference was observed in the injured group (p = 0.001) and the non-injured group (p = 0.025) in knee extensor torque of the preferred and non-preferred kicking legs during the isokinetic endurance test (before and after the repeated-sprint test) (Table 2). In the injured group, torque production in the preferred kicking leg decreased from 85.2±7.4 to 77.4±8.4 N (-10% change), and decreased in the non-preferred kicking leg from 87.8±8.4 before to 84.3±6.6 N (-4% change). In the non-injured group, torque production in the preferred kicking leg increased from 81.0±13.1 to 82.9±12.8 N (2% change), and decreased in the non-preferred kicking leg from 94.3±14.6 to 85.3±16.5 N (-10% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0. 000).

Table 2. Mean (± *SD*) and percent change in knee extensor and flexor torque of preferred and non-preferred kicking legs in injured and non-injured groups during the isokinetic endurance test.

	Before	After	% Change
Knee Extensor Torque (N)			
Injured Group			
Preferred Leg	85.2±7.4**	77.4±8.4**	-10%
Injured Group			
Non-Preferred Leg	87.8±8.4**	84.3±6.6**	-4%
Non-Injured Group			
Preferred Leg	81.0±13.1*	82.9±12.8*	2%
Non-Injured Group			
Non-Preferred Leg	94.3±14.6*	85.3±16.5*	-10%
Knee Flexor Torque (N)			
Injured Group			
Preferred Leg	35.1±9.1**	23.3±12.5**	-50%
Injured Group			
Non-Preferred Leg	54.2±6.0**	50.5±11.7**	-7%
Non-Injured Group			
Preferred Leg	43.1±10.2*	28.5±12.7*	-51%
Non-Injured Group			
Non-Preferred Leg	44.8±10.2*	33.5±11.1*	-33%

* = p < 0.05, ** = p < 0.001; N = newtons.

4.2.2 Knee Flexor Torque

A significant difference was observed in the injured group (p = 0.000) and the non-injured group (p = 0.005) in knee flexor torque of the preferred and non-preferred kicking legs during the isokinetic endurance test (before and after the repeated-sprint test) (Table 2). In the injured group, torque production in the preferred kicking leg decreased from 35.1±9.1 to 23.3±12.5 N (-50% change), and decreased in the non-preferred kicking leg from 54.2±6.0 to 50.5±11.7 N (-7% change). In the non-injured group, torque production in the preferred kicking leg decreased from 43.1±10.2 to 28.5±12.7 N (-51% change), and decreased in the non-preferred kicking leg from 44.8±10.2 to 33.5±11.1 N (-33% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0. 019).

4.2.3 Decline in Quadriceps Torque (%)

A significant difference was only observed in the injured group (p = 0.006) in the decline in quadriceps torque of the preferred and non-preferred kicking legs during the isokinetic endurance test (before and after the repeated-sprint test) (Table 3). In the injured group, percent decline in torque production in the preferred kicking leg increased from 6.5±7.41 to 19.6±17.7 N (201% change), and decreased in the non-preferred kicking leg from 11.4±10.7 to 6.3±16.5 N (-44% change). In the non-injured group, percent decline in torque production in the preferred kicking leg decreased from 20.5±6.9 to 16.4±10.4 N (-20% change), and decreased in the non-preferred kicking leg from 16.2±4.2 to 11.1±17.3 N (-32% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0. 012).

Table 3. Mean (± *SD*) and percent change in decline in quadriceps torque in preferred and non-preferred kicking legs in injured and non-injured groups during the isokinetic endurance test.

	Before	**After**	**% Change**
Decline in Quadriceps Torque (%)			
Injured Group Preferred Leg	6.5±7.1*	19.6±17.7*	201%
Injured Group Non-Preferred Leg	11.4±10.7*	6.3±16.5*	44%
Non-Injured Group Preferred Leg	20.5±6.9	16.4±10.4	20%
Non-Injured Group Non-Preferred Leg	16.2±4.2	11.1±17.3	32%

* = p < 0.05, ** = p < 0.001; % = percent.

4.2.4 Decline in Hamstring Torque (%)

A significant difference was only observed in the injured group (p = 0.006) in the decline in hamstring torque of the preferred and non-preferred kicking legs during the isokinetic endurance test (before and after the repeated-sprint test) (Figure 2). In the injured group, percent decline in torque production in the preferred kicking leg increased from 26.1±18.4 to

51.7±20.9 N (98% change), and increased in the non-preferred kicking leg from 11.6±8.94 to 19.4±20.5 N (67% change). In the non-injured group, percent decline in torque production in the preferred kicking leg increased from 7.3±4.34 to 23.3±13.4 N (219% change), and increased in the non-preferred kicking leg from 2.1±8.0 before to 20.0±35.7 N (852% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0.046).

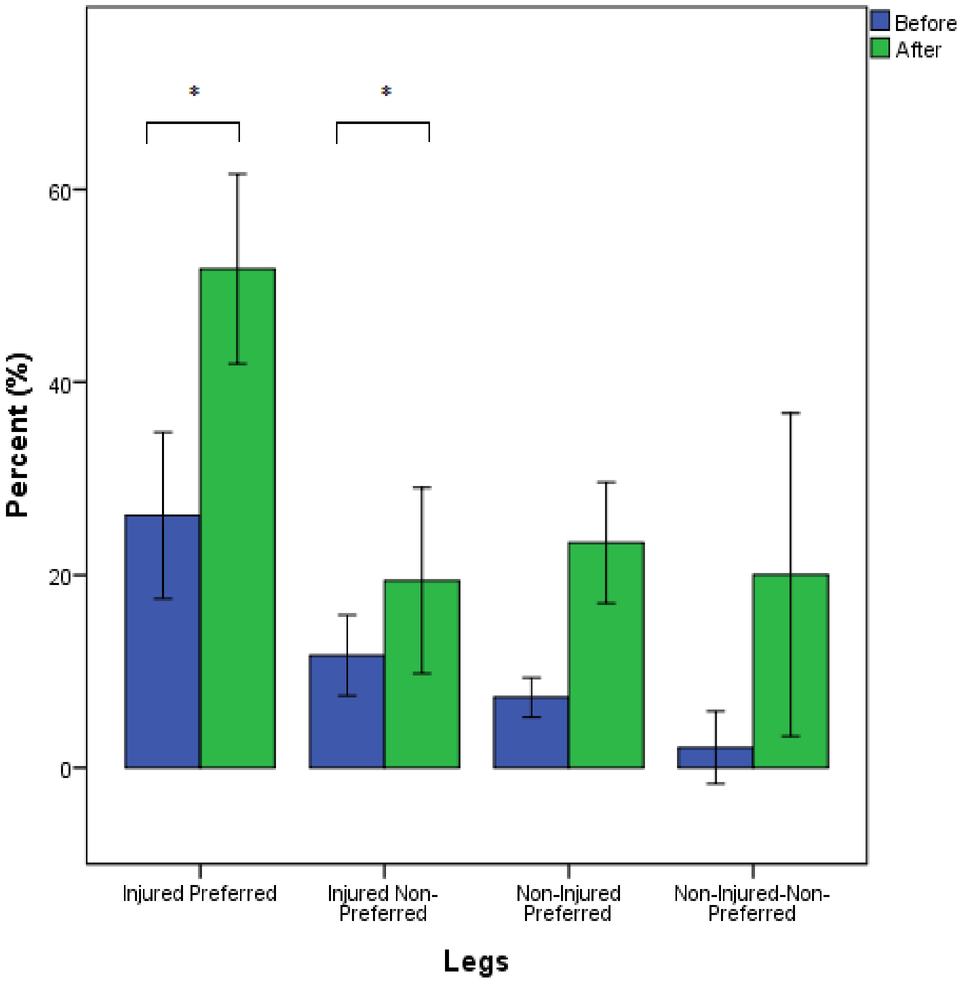


Figure 2. Decline in hamstring torque in preferred and non-preferred kicking legs in injured and non-injured groups during the isokinetic endurance test.

4.3 Repeated-Sprint Test

4.3.1 Vertical Force

A significant difference was only observed in the injured group ($p = 0.000$) in mean vertical force production in the preferred and non-preferred kicking legs during the repeated-sprint test (Figure 3). In the injured group, mean vertical force production in the preferred kicking leg decreased from 2043±167 to 1979±104 N (-3% change), and decreased in the non-preferred kicking leg from 2000±145 to 1974±108 N (-1% change). In the non-injured group, mean vertical force production in the preferred kicking leg decreased from 1669±104 to 1658±73 N (-0% change), and decreased in the non-preferred kicking leg from 1714±81 to 1710±73 N (-0% change).

A)

B)

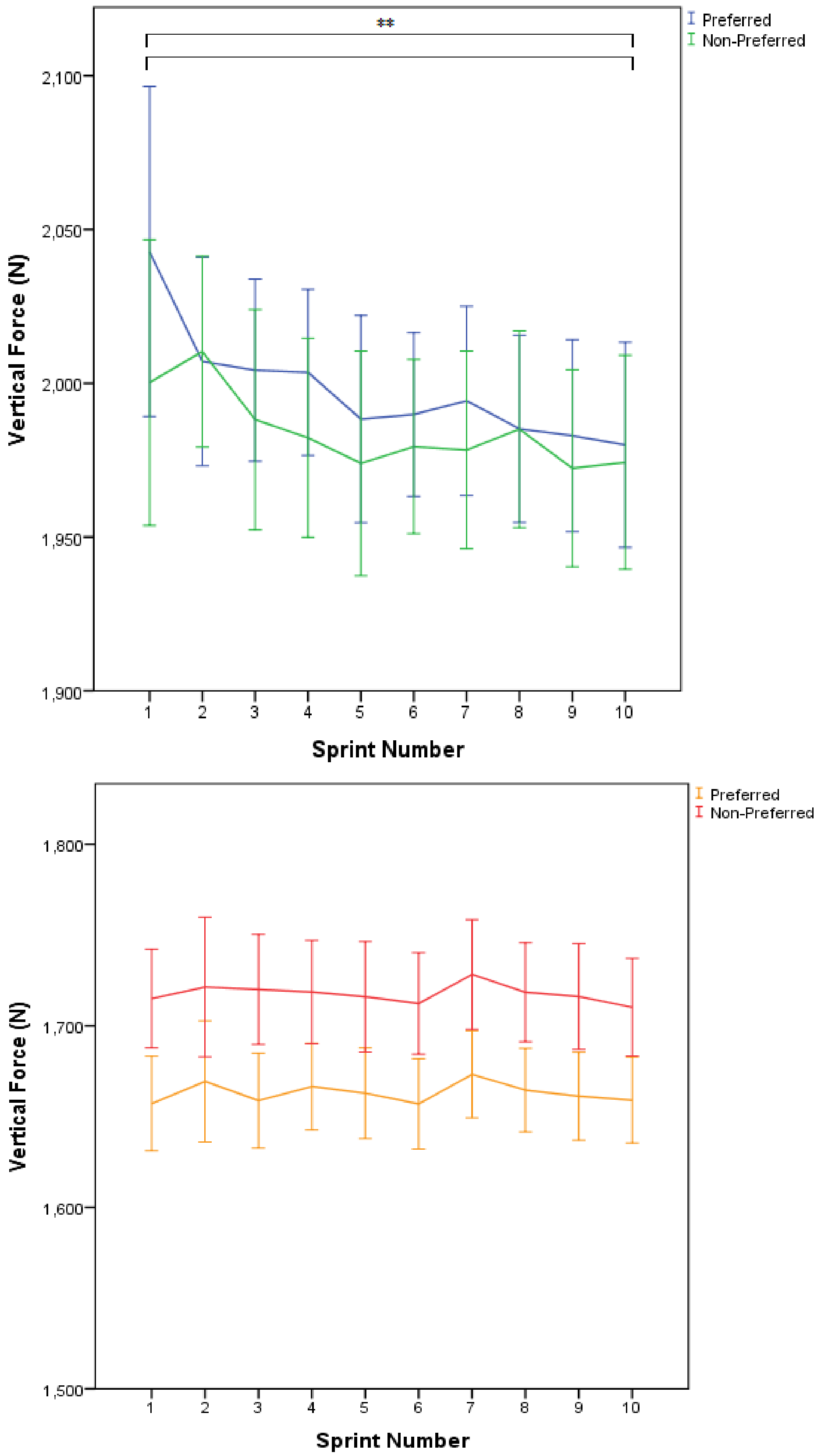


Figure 3. Changes in mean vertical ground reaction force of the preferred and non-preferred kicking legs in the **A)** injured group ($p < 0.001$) and **B)** non-injured group during the repeated-sprint test. * = $p < 0.05$, ** = $p < 0.001$.

4.3.2 Horizontal Force

A significant difference was observed in the injured group ($p = 0.000$) and the non-injured group ($p = 0.001$) in mean horizontal force production in the preferred and non-preferred kicking legs during the repeated-sprint test (Figure 4). In the injured group, mean horizontal force production in the preferred kicking leg decreased from 165.9±11.7 to 145.1±7.8 N (-14% change), and decreased in the non-preferred kicking leg from 159.8±18.8 to 154.8±11.3 N (-3% change). In the non-injured group, mean horizontal force production in the preferred kicking leg decreased from 124.1±10.3 to 119.4±6.5 N (-3% change), and decreased in the non-preferred kicking leg from 123.1±354 to 120.6±322 N (-2% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0. 000).

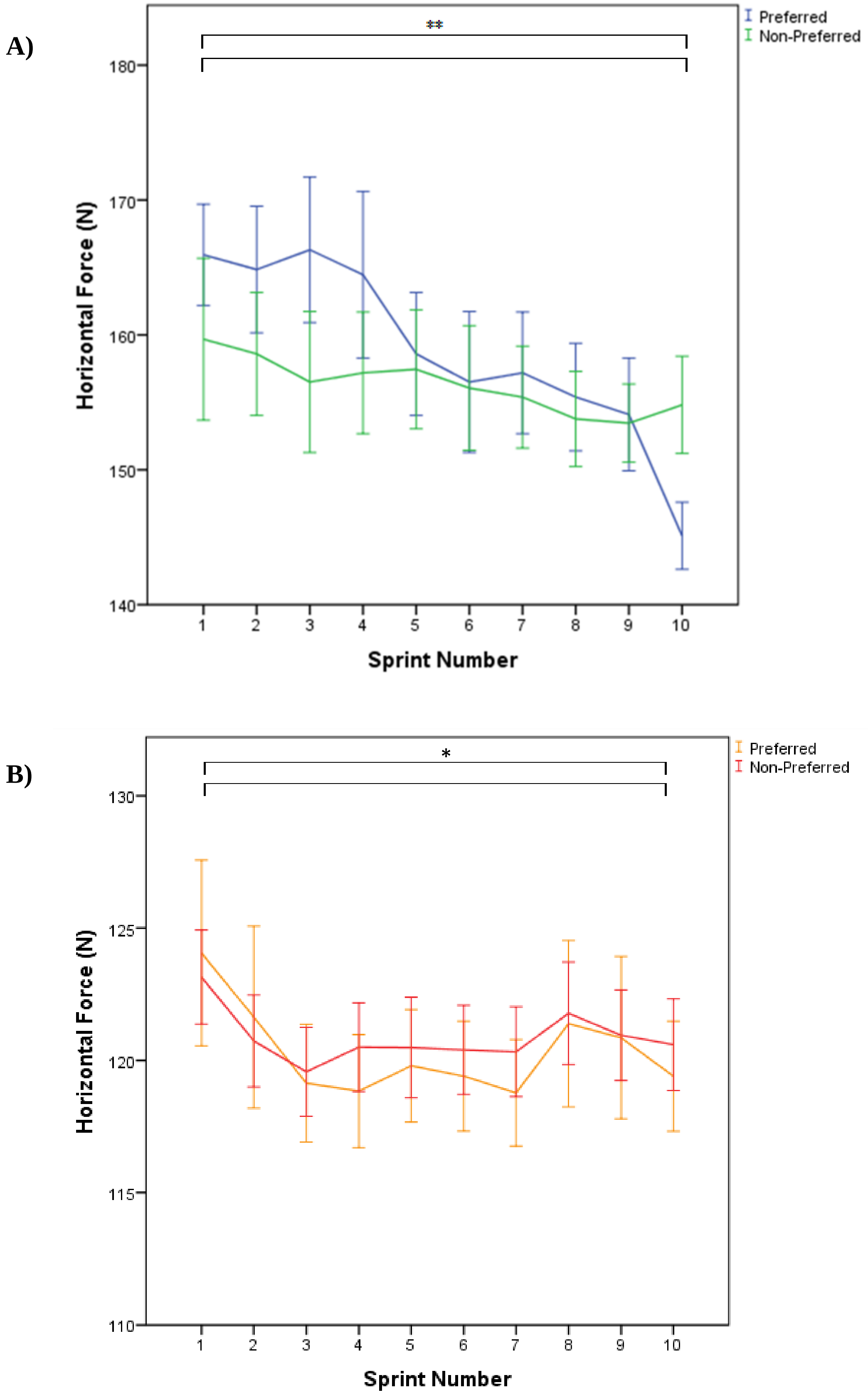


Figure 4. Changes in mean horizontal ground reaction force of the preferred and non-preferred kicking legs in the **A)** injured group and **B)** non-injured group during the repeated-sprint test. * = $p < 0.05$, ** = $p < 0.001$.

4.3.3 Power Output

A significant difference was observed in the injured group (p = 0.000) and the non-injured group (p = 0.004) in mean power output (of each sprint number) in the preferred and non-preferred kicking legs during the repeated-sprint test (Figure 5). In the injured group, mean power output in the preferred kicking leg decreased from 728.7±105.6 to 702.7±48.8 N (-3% change), and decreased in the non-preferred kicking leg from 736.3±62.6 to 725.6±73.3 N (-1% change). In the non-injured group, mean power output in the preferred kicking leg decreased from 618.0±48.8 to 606.5±25.7 N (-1% change), and decreased in the non-preferred kicking leg from 636.4±29.1 to 635.6±26.4 N (-0% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0. 026).

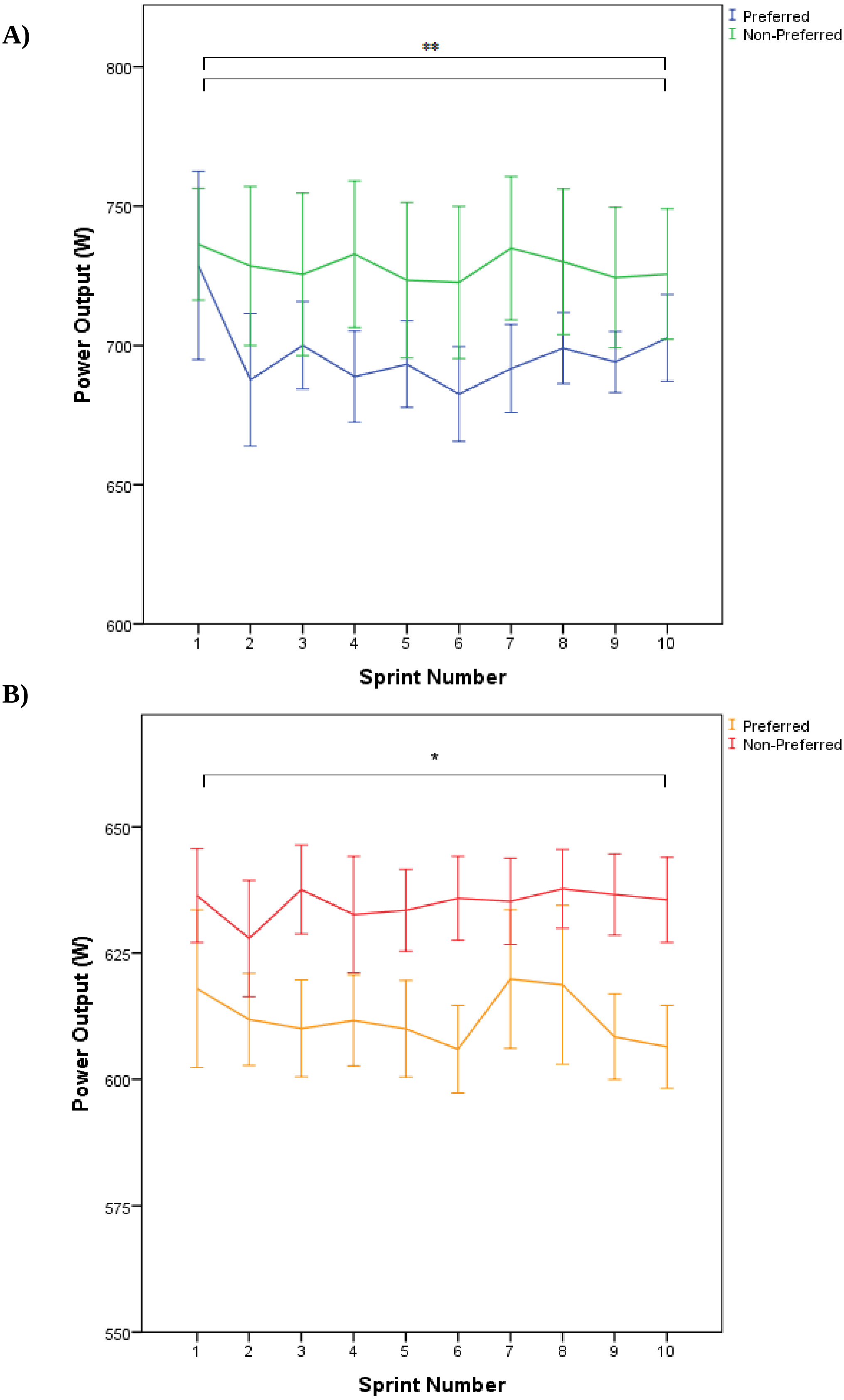
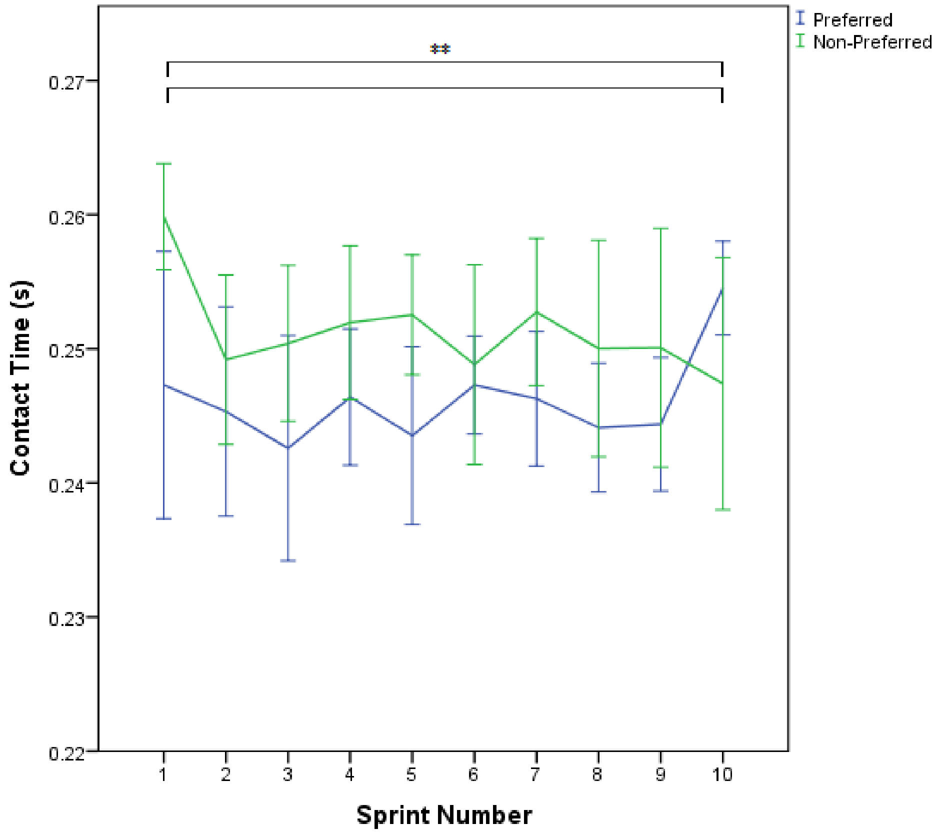


Figure 5. Changes in mean power output of the preferred and non-preferred kicking legs in the **A)** injured and **B)** non-injured group during the repeated-sprint test. * = $p < 0.05$, ** = $p < 0.001$.

4.3.4 Contact Time

A significant difference was observed in the injured group ($p = 0.000$) and the non-injured group ($p = 0.002$) in mean contact time in the preferred and non-preferred kicking legs during the repeated-sprint test (Figure 6). In the injured group, mean contact time in the preferred kicking leg increased from 0.247±0.031 to 0.254±0.011-s (2% change), and increased in the non-preferred kicking leg from 0.260±0.012 to 0.247±0.029-s (-5% change). In the non-injured group, mean contact time in the preferred kicking leg increased from 0.147±0.008 to 0.150±0.007-s (2% change), and increased in the non-preferred kicking leg from 0.147±0.009 to 0.148±0.008-s (0% change). A significant difference was also observed when comparing between groups (injured and non-injured) ($p = 0.000$).

A)



B)

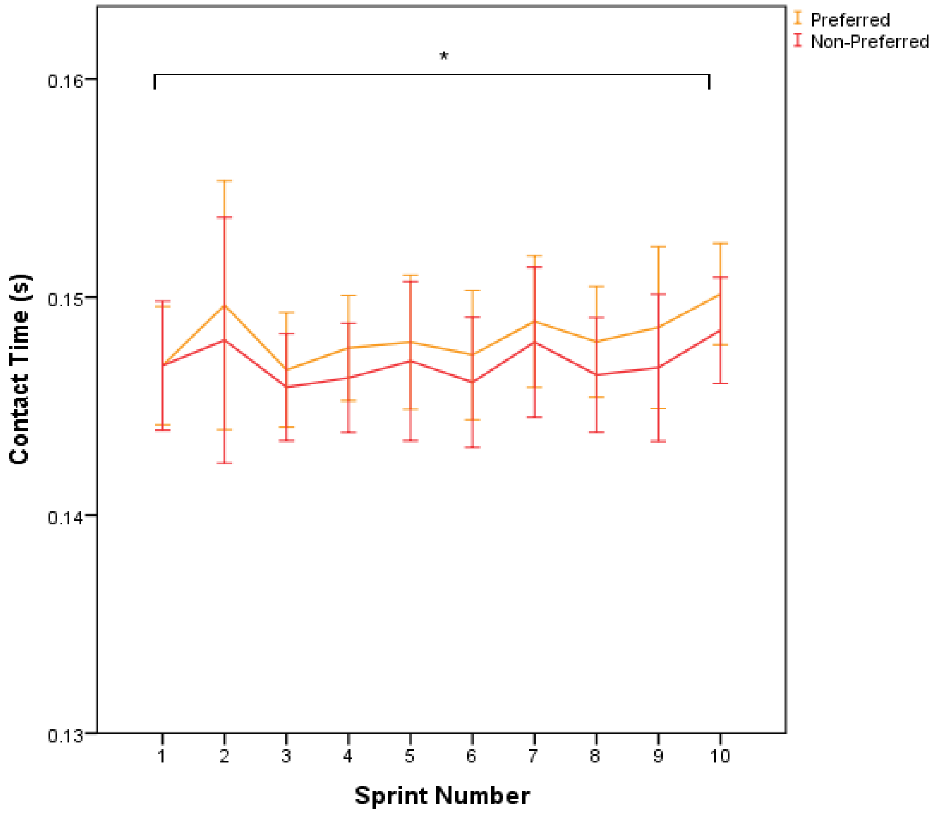
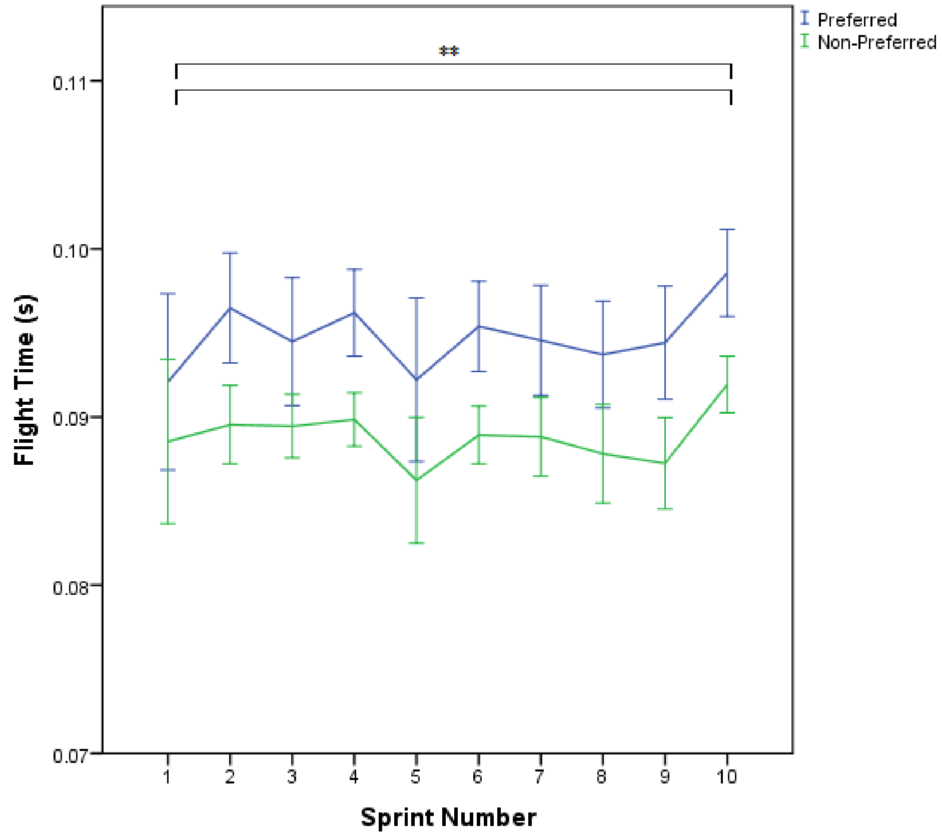


Figure 6. Changes in mean contact time of the preferred and non-preferred kicking legs in the **A)** injured and **B)** non-injured group during the repeated-sprint test. * = $p < 0.05$, ** = $p < 0.001$.

4.3.5 Flight Time

Flight time was differentiated by the time of the end of foot contact to the start of foot contact of the same leg. A significant difference was only observed in the injured group ($p = 0.000$) in comparing mean flight time in the preferred and non-preferred kicking legs during the repeated-sprint test (Figure 7). In the injured group, mean flight time in the preferred kicking leg increased from 0.092±0.016 to 0.099±0.008-s (7% change), and increased in the non-preferred kicking leg from 0.088±0.015 to 0.091±0.005-s (3% change). In the non-injured group, mean flight time in the preferred kicking leg increased from 0.065±0.006 to 0.066±0.004-s (1% change), and increased in the non-preferred kicking leg from 0.060±0.004 to 0.062±0.005-s (3% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0. 004).

A)



B)

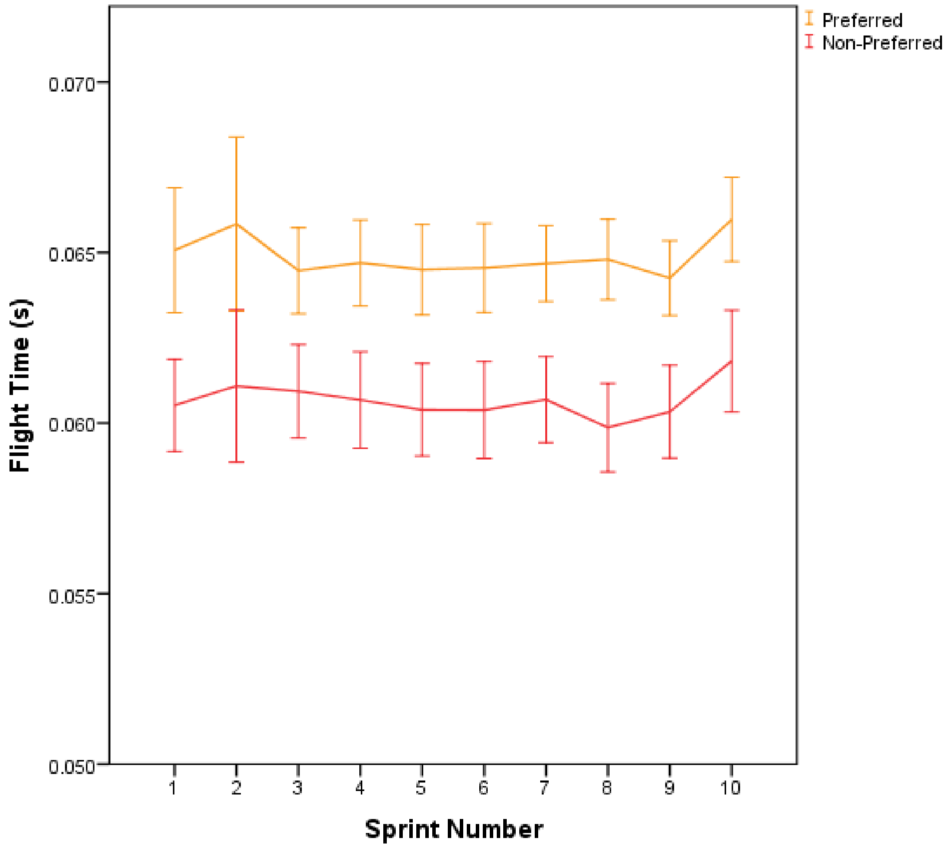


Figure 7. Changes in mean flight time of the preferred and non-preferred kicking legs in the **A)** injured and **B)** non-injured group during the repeated-sprint test. * = $p < 0.05$, ** = $p < 0.001$.

4.3.6 Stride Frequency

A significant difference was observed in the injured group ($p = 0.000$) and the non-injured group ($p = 0.000$) in mean stride frequency in the preferred and non-preferred kicking legs during the repeated-sprint test (Figure 8). In the injured group, mean stride frequency in the preferred kicking leg increased from 3.7±0.156 to 3.9±0.693 N (5% change), and increased in the non-preferred kicking leg from 3.6±0.219 to 3.8±0.353 N (5% change). In the non-injured group, mean stride frequency in the preferred kicking leg increased from 6.2±0.397 to 6.4±0.504 N (3% change), and decreased in the non-preferred kicking leg from 6.4±0.595 to 6.3±0.435 N (-1% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0. 000).

A)

B)

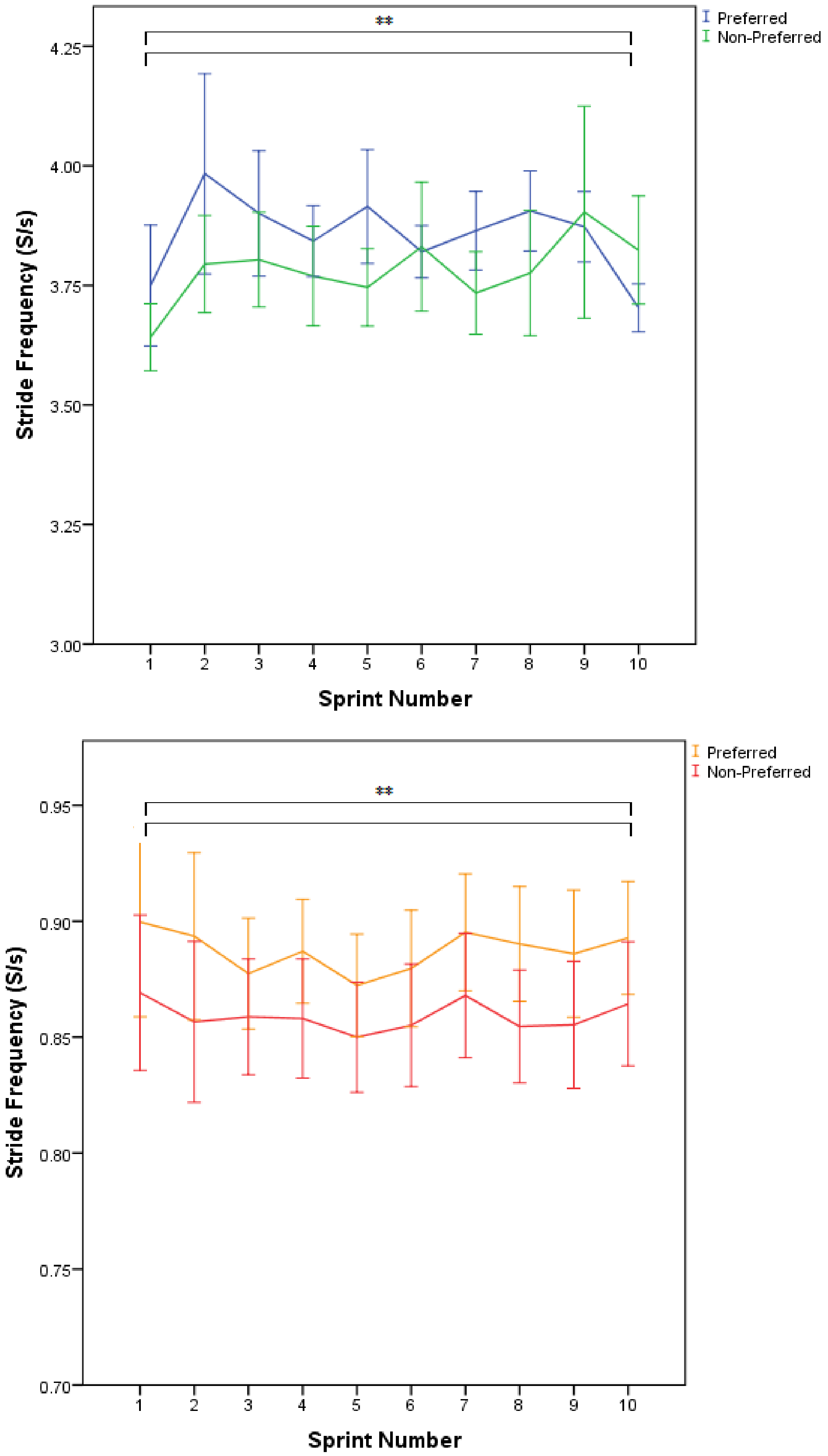
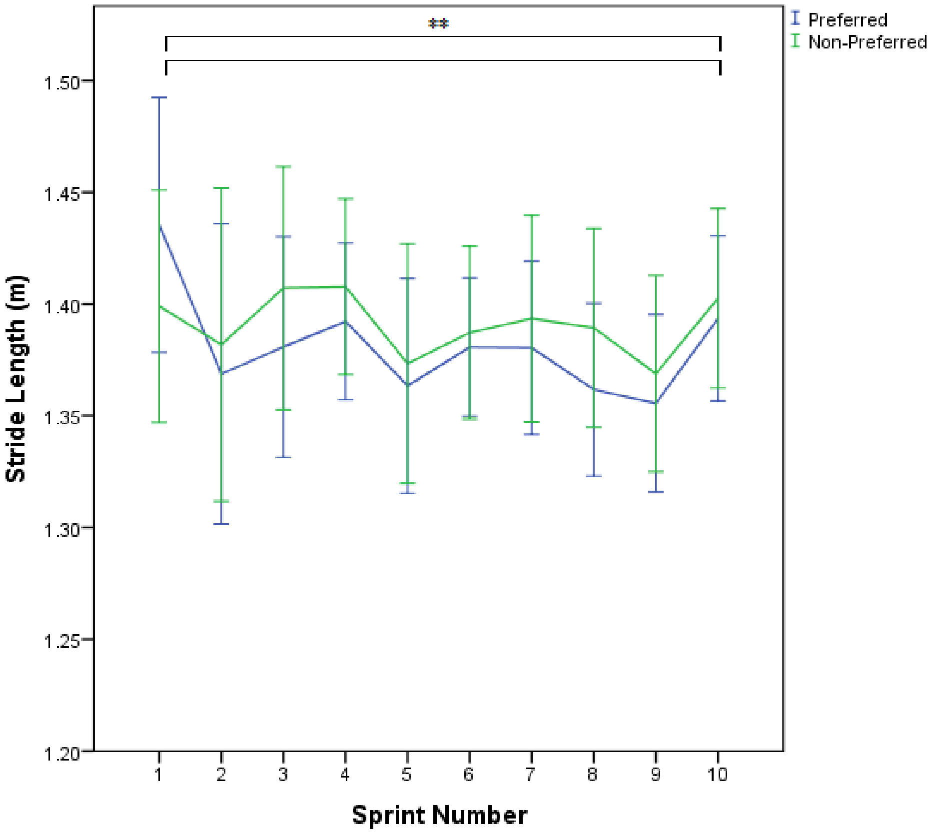


Figure 8. Changes in mean stride frequency of the preferred and non-preferred kicking legs in the **A)** injured and **B)** non-injured group during the repeated-sprint test. * = $p < 0.05$, ** = $p < 0.001$.

4.3.7 Stride Length

A significant difference was observed in the injured group (p = 0.000) and the non-injured group (p = 0.041) in mean stride length in the preferred and non-preferred kicking legs during the repeated-sprint test (Figure 9). In the injured group, mean stride length in the preferred kicking leg decreased from 1.43±0.178 to 1.39±0.116 N (-2% change), and decreased in the non-preferred kicking leg from 1.40±0.162 to 1.40±0.125 N (-0% change). In the non-injured group, mean stride length in the preferred kicking leg increased from 0.899±0.128 to 0.893±0.076 N (-0% change), and decreased in the non-preferred kicking leg from 0.869±0.105 to 0.864±0.084 N (-0% change). A significant difference was also observed when comparing between groups (injured and non-injured) (p = 0. 000).

A)



B)

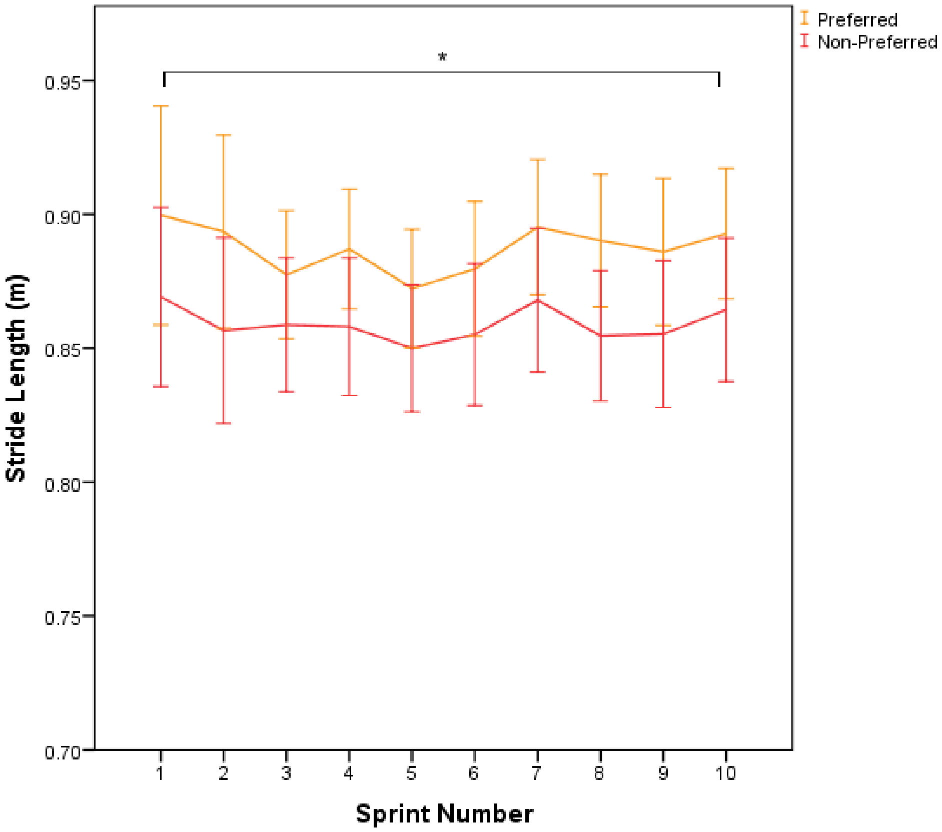


Figure 9. Changes in mean stride length of the preferred and non-preferred kicking legs in the **A)** injured and **B)** non-injured group during the repeated-sprint test. * = $p < 0.05$, ** = $p < 0.001$.

4.4 Reliability

4.4.1 Repeated-Sprint Test on the Woodway Curve Non-Motorised Treadmill

Intraclass correlation coefficients (ICC) were computed to determine the reliability of vertical and horizontal ground reaction forces, power output, contact time, flight time, stride frequency and stride length measured on the Woodway Curve non-motorised treadmill during a repeated-sprint test. The ICC for stride frequency was very good (0.8-0.9) while vertical and horizontal forces, power output, contact time, flight time and stride length were excellent (> 0.9). These results support the use of the Woodway Curve non-motorised treadmill during the repeated-sprint test.

Table 4. Intraclass correlation coefficients (ICC) for variables derived from the Woodway Curve non-motorised treadmill during the repeated-sprint test.

Variables	Intraclass Correlation Coefficient (r)
Vertical Force (N)	0.965**
Horizontal Force (N)	0.960**
Power Output (W)	0.962**
Contact Time (s)	0.984**
Flight Time (s)	0.988**
Stride Frequency (S/s)	0.818*
Stride Length (m)	0.932**

* = very good correlation (0.8-0.9), ** = excellent correlation (> 0.9).

CHAPTER FIVE: DISCUSSION, DIRECTIONS FOR FUTURE RESEARCH AND CONCLUSIONS

5.1 Discussion

This is the first study, to the researcher's knowledge, that has compared injured and non-injured subjects and the effect of fatigue on force production in preferred and non-preferred kicking legs in footballers. The purpose of this study was to (1) compare the preferred and non-preferred kicking legs from kinetic and kinematic data obtained during the repeated-sprint test, peak torque and the fatigue related decrease in torque measured during the isokinetic endurance test, and force production and jump height measured during the single leg vertical jump; (2) compare the fatigue profiles of the injured and non-injured group through a repeated-sprint protocol; and (3) compare the fatigue response of the injured and non-injured groups and the resulting inter-limb force production. A main finding from this study was that a greater significant difference was observed in the injured group when comparing the preferred and non-preferred kicking legs. This provided evidence that the non-preferred kicking leg had greater force production, the preferred kicking leg (previously injured leg) had a greater fatigue response and the inter-limb difference in force production after fatigue was greater in the injured group. Investigation into this could help to uncover new strategies to reduce the risk of hamstring injuries in particular in football.

5.2 Single Leg Vertical Jump

The single leg vertical jump test was designed to imitate a footballer jumping for a header. A single leg is often used during take-off in the jump to head the ball; such preference is also seen in other sports as well (Stephens, Lawson & Reiser, 2005). By testing before and after fatiguing exercise, examination of the effect of fatigue on each leg can be undertaken. Single-leg vertical jumps are also considered the most sensitive tool to detect muscle strength imbalance (Ceroni, Martin, Delhumeau & Farpour-Lambert, 2012).

5.2.1 Peak jump height and force

The fatigue response between the preferred and non-preferred kicking legs of the non-injured group differed to that of the injured group in both peak jump height and force. While the non-injured group demonstrated greater peak jump force and height, the injured group displayed a greater fatigue response in the preferred kicking leg (see Table 1). This suggests that the previous injury to the preferred kicking leg has resulted in a different fatiguing mechanism as deficiencies are evident directly due to the injury. As these results show an obvious difference in fatigue response (the injured group’s force production reduced while the non-injured group’s force production increased), whether this is evidence of this particular test potentially detecting injury risk in footballers due to such a different response is unknown. Potential future retrospective designs would be able to see clear differences between before and after injury and whether the fatigue response functions have changed due to injury.

5.3 Isokinetic Endurance Test

The use of isokinetic dynamometry is a validated test of fatigue (Eichner, 1995). This testing can target specific muscles of limbs to test strength and fatigability; of which the isokinetic endurance test in the present study tested the quadriceps and hamstrings of the preferred and non-preferred kicking legs. Previous epidemiological studies (Chomiak, Junge, Peterson & Dvorak, 2000; Hawkins, Hulse, Wilkinson, Hodson, & Gibson 2001; Woods et al., 2004) have documented a rise in number of injuries occurring at the end of a competitive fixture suggesting that fatigue is a major risk factor of injury (Eichner, 1995).

5.3.1 Knee extensor and flexor torque

The present research, concentric knee extension and knee flexion testing was completed before and after the repeated-sprint test, where subjects were to be fatigued in a football-specific manner in a way that could be used in-season. The change in knee extensor torque was similar between the preferred kicking leg of the injured group and the non-preferred kicking leg of the non-injured group (10%) (see Table 2). Change in knee flexor torque was greater in the preferred kicking leg of both the injured and non-injured group (50 and 51% respectively). While knee flexor torque of the preferred kicking leg in the non-injured group was slightly greater than the injured group, an imbalance in fatigue response between each leg was significantly greater in the injured group (50% change in the preferred leg and 7% change in the non-preferred leg (43% imbalance) compared to the non-injured group (51% change in the preferred and 33% in the non-preferred leg (18% imbalance)). It can be assumed that such variation between groups is due to the previously injured status of the subjects in the injured group.

5.3.2 Decline in quadriceps and hamstring torque

Decline in quadriceps and hamstring torque was analysed by comparing the last 5 repetitions with the first 5 repetitions during knee flexion and extension. The greatest decline in quadriceps torque was observed in the preferred kicking leg of the injured group (201%) (see Table 3). While the greatest decline in hamstring torque was observed in the non-injured group in the non-preferred kicking leg (32%), the preferred kicking leg of the injured group produced the greatest decline in hamstring torque both before and after the repeated-sprint test (26.1±18.4 to 51.7±20.9 N) (see Figure 2). This represents the preferred kicking leg of the injured group having a greater fatigue response over the course of the 50 repetitions in the isokinetic endurance test both before and after the fatigue condition (repeated-sprint test).

While the non-preferred leg had a considerably greater change (2.1±8.0 to 20.0±35.7 N), this was due to the fact that there was little fatigue before the fatigue condition. This would suggest that the preferred kicking leg in the injured group had a greater fatigue response during the isokinetic endurance test both before and after the fatigue condition.

Such findings in the present research suggest that previous injury could have affected knee extensor and knee flexion torque production and fatigue response (the decline in quadriceps and hamstring torque) in the preferred kicking leg. Such a suggestion is supported by previous research by Opar, Williams, Timmins, Dear and Shield (2013) where rates of force development were reduced in previously strained hamstrings, even after rehabilitation, in comparison to the uninjured limb. This shows that previous hamstring injury may affect function and that underlying differences between lower limbs exist after injury. This highlights the importance of furthering research into the comparisons between injured and non-injured groups, and their differences in preferred and non-preferred kicking legs.

5.3.3 Loss in hamstring strength

It is believed that a lack of sufficient hamstring strength is considered to be a major cause of injury (Sangnier & Tourny-Chollet, 2007). As apparent in the present study, muscle imbalances induced by fatigue because of the greater loss in hamstring strength reduces the regulatory capacity of the hamstring muscles, in turn resulting in greater vulnerability to non-contact injury (Sangnier & Tourny-Chollet, 2008). Such decreases in hamstring strength could also explain the increased number of muscle injuries, particularly of the hamstrings, at the end of matches (Sangnier & Tourny-Chollet, 2008). Discrepancies specifically between the preferred and non-preferred kicking legs however have not been previously examined. As the preferred kicking leg (previously injured leg) arguably has a greater fatigability within the present study; that particular leg could potentially be at greater risk to injury as a greater loss in hamstring strength is apparent. With a greater vulnerability to injury the preferred kicking leg in itself could potentially be a risk factor if the loss in muscular strength is great enough.

5.4 Repeated-Sprint Test

Subjects performed the repeated-sprint test on a non-motorised treadmill (Woodway Curve), which allows for the quantification of running kinetics and kinematics. Previous research has confirmed the validity of measurements on overground running by comparing data obtained to that obtained during overground running (Kluitenberg, Bredeweg, Zijlstra, Zijlstra & Buist, 2012), and reliability of kinetic and kinematic variables on non-motorised treadmills has been presented previously (Hughes, Doherty, Tong, Reilly & Cable, 2006). While a previous study confirmed the reliability of anaerobic performance (using mean and peak velocity, mean and peak power and relative mean and peak power) on the Woodway Curve treadmill (Gonzalez, Emerson, Robinson, Edward, Wells, Hoffman, Stout, Fragala, Mangine, McCormack, Townsend & Jajtner 2013) little research has explored the reliability of running kinetics and kinematics on the Woodway Curve treadmill. In the present study, intraclass correlation coefficient values ranging from 0.818 to 0.988 were obtained across a spectrum of kinetic and kinematic variables (see Table 4), which suggests that highly reliable data can be obtained using the Woodway Curve treadmill.

5.4.1 Vertical force

Previous research has investigated the running velocity effect on vertical force production, and have broadly found that vertical forces remain constant for speeds greater than approximately 60% maximum velocity (Brughelli, Cronin & Chaouachi, 2011). The present study observed similar findings as velocity force production over the course of the repeated-sprint tests remained consistent (Figure 3). A fatigue response is evident in the previously injured group (3% change in the preferred kicking leg and 1% change in the non-preferred kicking leg, compared to a 0% change in both preferred and non-preferred legs in the non-injured group) which suggests that injury to the preferred kicking leg has effected vertical force production. With vertical force production being the predominant mechanism used to attain faster maximum velocity (Weyand, Sternlight, Bellizzi & Wright, 2000), variation in the vertical force production seen in the injured group (Figure 3) suggests a potential cause of injury as the non-injured subjects were unable to maintain their vertical force production consistently. While there is some variation in the literature regarding the point at which vertical forces remain constant (Brughelli, Cronin & Chaouachi, 2011), being around 60% of maximum velocity in Australian rules footballers and starting at 70% in sprinters (Kuitunen, Komi & Kyrolainen, 2002), the increase in vertical force production to the point of it becoming consistent is evident throughout the literature. This could be due to variation in vertical force production between individuals dictating the degree of maximum velocities obtained. The present study however tested maximum velocity attained in 6-s (acceleration) of which a greater discrepancy was found in the injured group compared to the non-injured group (conforming to the discrepancy of injured and non-injured legs in Brughelli, Cronin and Chaouachi (2010)). However, it is not clear how the discrepancy affects causes of injury, an important area for future study.

5.4.2 Horizontal force

The present data indicated that horizontal forces were significantly different between legs during the repeated-sprint test (Figure 4). The preferred kicking leg in both injured and non-injured groups produced the greatest change in horizontal force (14% and 3% respectively). This suggests that the fatigue response in horizontal force is greater in the preferred kicking leg and significantly greater in the injured group. It can be assumed that the preferred kicking leg had the greatest change in horizontal force due to previous injury however; no previous research has examined the differences between the preferred and non-preferred kicking legs during a repeated-sprint test to determine whether such fatigue is a common response regardless of previous injury. This makes it difficult to determine why the fatigue response of the preferred kicking leg was greater than the non-preferred kicking leg in both previously injured and uninjured subjects in a repeated-sprint test.

One possibility is because the non-preferred kicking leg is stressed more in football supporting body weight during kicking action it has built a greater resistance to fatigue mechanisms. Brughelli et al. (2010) reported significantly less (46%) horizontal force production in the injured leg in comparison to the uninjured leg. The differences between preferred and non-preferred kicking legs were not considerable in the present study possibly due to the differences in the stage of running data was collected. In the present study, data were collected from the first 6 s of the sprint (the acceleration phase) whereas Brughelli et al. (2010) collected data from 3-8 s in the sprint (80% of maximum velocity) and thus minimised data collection during acceleration. However, the findings of Brughelli et al. (2010) findings are similar to those of the present study in that the greatest change in horizontal force was due to previous injury in a particular leg. Force production and fatigue response mechanisms have shown to differ between legs and the fact that the fatigue response is greater in the previously injured leg (preferred kicking leg) would suggest it is due to previous injury.

5.4.3 Power output

The effect of power output on repeated-sprint ability has previously been difficult to investigate. To the researcher's knowledge, little information is available on the importance of power output on repeated-sprint ability due to the difficulty in obtaining power output profiles during repeated-sprints. However the use of non-motorised treadmills would remove such difficulty and allow power output performance to be recorded during repeated-sprints. While several studies have confirmed the reliability of such testing on non-motorised treadmills (Lim & Chia, 2007; Tong, Bell, Ball & Winter, 2001), power output performance in repeated-sprint ability has yet to be investigated in depth.

While previous research reported a decrease of 21% in mean power output after ten (Holymard, Cheetham, Lakomy, & Williams, 1988) and five (Wootton & Williams, 1983) 6 s sprints with 30 s recovery, the greatest fatigue response found in the present study was 3% (Figure 5) in the preferred kicking leg of the injured group. Discrepancy in results between different research could be explained by differences in training status of participants and also in protocols. This is particularly true in comparison with Mendez-Villanueva, Hamer and Bishop (2008) where results showed a 28% decrease in mean power output the participants were recreationally active in various sports. With the preferred kicking leg producing less power over the 10 sprints, the non-preferred kicking leg could potentially be producing greater power to compensate for the preferred kicking leg. This is also seen in horizontal force production, particularly of the injured group (Figure 4A), as there is a significant decrease in force production of the preferred leg there is a small increase in force production of the non-preferred leg. Whether or not these factors attribute to injury is unknown as the present study is the first to investigate power output leg asymmetry between the preferred and non-preferred kicking legs.

5.4.4 Contact and flight time

The injured group displayed greater variance between preferred and non-preferred kicking legs in contact and flight times (see Figure 6 and 7). This suggests that previous injury could have potentially affected contact and flight times while running. While the non-preferred kicking leg in the injured group had the greatest change in contact time (5%), the preferred kicking leg of the injured group had the greater change in flight time (7%). These findings could potentially interplay with each other, as contact time should affect flight time as velocity increases (as contact time decreases, flight time should increase in order to increase velocity). However if there is a greater change in a particular leg in contact time, a greater change should be evident in the opposite leg for flight time (as one leg should dictate the time of the other leg) as seen in the present study. The greater changes in the injured group in contact and flight times could suggest that previous injury to the preferred kicking leg effected resulting times. Figure 6 also shows a great increase in contact time of the preferred kicking leg of the injured group on the 9th repeated sprint (sprint number 10) suggesting a significant fatigue effect. While this is the only evidence of an increase in contact time of fatigue in both groups, this could suggest that the preferred and non-preferred kicking legs have different fatigue responses and the resulting inter-limb force production is reduced in the preferred kicking leg when fatigued.

While contact and flight time data from the curved treadmill were strongly correlated (Table 4), no previous research has examined the difference in contact or flight time between the curved belt on the non-motorised treadmill and a flat treadmill belt. With foot contact being made at a higher point on the treadmill belt in comparison to a flat treadmill it could be possible that times are affected. Seneli, Edlbeck, Myatt, Reynolds and Snyder (2011) examined the same theory with stride length and found no differences. With no differences in the length of the stride it could be assumed that there would be no difference in contact and flight time also. Brughelli, Cronin and Chaouachi (2011) reported that as running velocity increased from 40% to 100% maximum, contact times decreased with it. This is explained as during the increment of velocity foot contact time decreases while flight time increases in order to build velocity (Brughelli Cronin & Chaouachi, 2011).

5.4.5 Stride length and frequency

During running there is never an overlap between the stance phases of the right and left legs, instead, there are periods when both feet are off the ground (flight phase) (Schubert, Kempf and Heiderscheit, 2014). Previous research has failed to explore the importance of comparing the preferred and non-preferred kicking legs from the stance phase to flight phase during running. Findings from the present study showed that stride length of the preferred kicking leg in the injured group reduced by 2% while the non-preferred kicking leg failed to fatigue (0%). Both preferred and non-preferred kicking legs also failed to show any representations of fatigue (0%). This could be a representation of the fact that the previously injured leg (preferred kicking leg) having a greater fatigability. Stride frequency increased by 5% in both preferred and non-preferred kicking legs in the injured group while stride frequency in the non-injured group increased by 3% in the preferred kicking leg and reduced by 1% in the non-preferred kicking leg. As little is known as to why such differences are apparent between preferred and non-preferred kicking legs, these findings highlight the importance for further investigation into the difference between the preferred and non-preferred kicking legs during stride length and frequency.

The present study suggests that there is interplay between stride length and stride frequency as the injured group demonstrates less stride frequency and a longer stride length and (Figure

8 and 9 respectively). The non-injured group had the opposite effect, with less stride length and greater stride frequency. This could be best explained as a greater stride length results in a lesser stride per second while running. It is also important to note that these results are reflective of an individual’s acceleration as acceleration requires a decreased stride length and increased stride frequency to build running velocity up. While running velocity increases it can be assumed that stride length would increase while stride frequency would decrease (a decrease in stride frequency with an increase in stride length is used to increase velocity). This is supported by Schubert, Kempf and Heiderscheit (2014) who found that increased stride rate resulted in decreased stride length affecting impact peak, kinematics and kinetics and therefore could be considered as a mechanism to influence injury risk and recovery in a runner. Significant variations in both stride length and frequency evident in the injured group suggests that injury could have potentially caused such variations.

The present study observed that the injured group had greater stride length. With the ability to potentially produce force rapidly reduced due to the preference in greater stride length, the ability to maintain force could be questioned. The horizontal force of the preferred kicking leg in the injured group in particular had the greatest change (14%), with a great decrement in force production undertaken during the last sprint. The interplay between the reduction in horizontal force producing capabilities and stride length could lead to injury, or increase the susceptibility to re-injury. However as before injury capabilities are unknown it can only be speculated that these could be potential reasons for injury or re-injury.

No previous research has examined the dribbling capabilities between legs in relation to stride length. This is something that future research could examine through manipulation of stride lengths in football players. It is unknown whether or not the resulted stride lengths of the injured group are greater in the non-preferred kicking leg due to injury. Variance is also apparent in stride length as initially the preferred kicking leg is greater than the non-preferred kicking leg until the first repeated sprint (sprint number 2). While it can be assumed that this is a result of fatigue, again it is difficult to make substantial claims as stride frequency and length before injury is unknown.

5.5 Football related reasons for differences in kicking legs

It can be assumed that the workload of football training has attributed to musculoskeletal modification (Sangnier & Tourny-Chollet, 2008). Football training can have athletic and technical-tactical components of which athletic preparations develop strength and aerobic and anaerobic capacities which place similar demands on both preferred and non-preferred kicking legs (Sangnier & Tourny-Chollet, 2008). Technical-tactical training prompts specific actions of which the load on preferred and non-preferred kicking legs differs. Such actions include tackling, jumping, dribbling, changing direction and striking the ball (Sangnier & Tourny-Chollet, 2008). Over years of training such actions are repeated countless times and as a consequence results in a divergent load between the preferred and non-preferred kicking legs (Sangnier & Tourny-Chollet, 2008). The present study shows examples of such divergent loads of which the repetitions of technical-tactical actions have potentially affected the capacity of muscle resistance (Sangnier & Tourny-Chollet, 2008). This prompts the notion of imbalance between not only muscle groups but also the preferred and non-preferred kicking leg, as seen when comparing injured and non-injured groups in the present study

5.6 Limitations

Limitations exist within this study, the most prominent being the fact that this study is of retrospective design. Without lower-limb leg asymmetry measurements taken before injury, it is difficult to determine whether or not resulting asymmetries are the result of hamstring injury or not. Also, by not measuring different levels of football the study can only be true of the level of football played within this study. As previously discussed, due to technical-tactical training within football, different levels of football warrant different levels of training intensity. This could further impose lower limb asymmetry at a higher level due to the greater intensity and frequency in training of technical-tactical training which in most cases warrant different movements and activations between the preferred and non-preferred kicking leg depending on the activity.

5.7 Conclusion

In conclusion, the present study has provided a basis for comparing the injured and non-injured group and the preferred and non-preferred kicking legs during a single leg vertical jump, isokinetic endurance test and repeated-sprint test. From the battery of tests, evidence of the non-preferred leg having greater force production, the preferred kicking leg having a greater fatigue response (more prominently in the injured group of which the preferred kicking leg was the previously injured leg), and the inter-limb difference in force production after fatigue was greater in the injured group. As the preferred kicking leg displayed a greater magnitude of fatigue and the non-preferred kicking leg showed greater unilateral strength and performance, lower limb asymmetry as a potential risk factor for hamstring injury should not be ignored. Future research could help further understanding of the differences between the preferred and non-preferred kicking legs, why they occur, and the influence they have on injury. This could possibly be done through a prospective study following a particular football team over a period of time and taking note of any hamstring injuries in particular and comparing hamstring function mechanisms in both preferred and non-preferred kicking legs from before injury to after full recovery. This would investigate the players more susceptible to injury through their lower leg asymmetry and resulting differences before and after injury of hamstring function mechanisms. Continuing to research hamstring injuries could potentially go a long way in reducing the number of the most common lower limb injury in football.

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APPENDIX ONE

Ethics Approval

25th March 2013

Mr Cameron Lord

9 Shoalhaven Place

WAIKIKI, WA, 6169

Dear Mr Lord

I am pleased to write on behalf of the Higher Degrees Committee to advise that your master's research proposal has been approved – **Lower Limb Fatigue Asymmetry of Preferred and Non-Preferred Legs After a Repeated-Sprint Test in Football Players with Previous Hamstring Injury.**

I also wish to confirm that your proposal complies with the provisions contained in the University's policy for the conduct of ethical research, and your application for ethics has been approved. Your ethics approval number is **9302** and the period of approval is **20 March 2013 to 31 October 2013.**

Approval is given for your supervisory team to consist of:

Principal Supervisor: A/Prof Anthony Blazevich - ECU

Associate Supervisor: Dr Fadi Ma'Ayah - ECU

The examination requirements on completion are laid down in *Part VI of The University (Admissions, Enrolment and Academic progress) Rules for Courses Requiring the Submission of Theses* available at:

Additional information and documentation relating to the examination process can be found at the Graduate Research School website: http://research.ecu.edu.au/grs/

Please note: the Research Students and Scholarship Committee has resolved to restrict Master by Research

(1 year) theses to a maximum of 40,000 words or a Master by Research (2 year) theses to a maximum of 60,000 words. Under special circumstances a candidate may seek approval from the Faculty Research and Higher Degrees Committee for an extension to the word length (RSSC 33/04).

I would like to take this opportunity to offer you our best wishes for your research and the development of your thesis.

Yours sincerely

Shelley Huts

Research Assessment Coordinator

Research Assessments- SSC

Principal Supervisor: A/Prof Anthony Blazevich - ECU

Associate Supervisor: Dr Fadi Ma'Ayah - ECU

HDR FCHS

APPENDIX TWO

Subject Eligibility Form

Name: ____ Age: _____ Gender: M / F

Contact Mobile Number: _________________________

Contact E-Mail: ____

Preferred kicking leg: Left / Right

Currently fully fit?: Yes / No

Preferred playing position: _________________________

Current State League club (and division): ____

Number of years' experience in the State League: _____

Club history in the State League (and division):

____

____

____

____

Previous injury history (if applicable, please be specific as to what was injured and the period of time injured for):

____

____

____

____

____

Rehab history (if applicable, please be specific as to what rehab, if any, was performed for each injury/how long the rehabilitation program went for):

____

APPENDIX THREE

Subject Consent Form

LOWER LIMB FATIGUE ASYMMETRY OF PREFERRED AND NON-PREFERRED LEGS AFTER A REPEATED-SPRINT TEST IN FOOTBALL PLAYERS WITH PREVIOUS HAMSTRING INJURY

I ______________________________ (the participant) have been informed about all aspects of the research project and agree to participate in the project, realising that I can withdraw at any time.

I have been informed that some fatigue and delayed onset of muscle soreness (DOMS) could be a result of performing this test.

I agree that research data gathered for this project may be published provided I am not identifiable.

Participant Signature: ____________________ Date: _______________

Researcher Signature: ____________________ Date: _______________

APPENDIX FOUR

Medical Questionnaire

Pre-exercise Medical Questionnaire

The following questionnaire is designed to establish a background of your medical history, and identify any injury and/ or illness that may influence your testing and performance. If you are under 18 then a parent or guardian should complete the questionnaire on your behalf or check your answers and then sign in the appropriate section to verify that they are satisfied the answers to all questions are correct to the best of their knowledge.

Please answer all questions as accurately as possible, and if you are unsure about anything please ask for clarification. All information provided is strictly confidential.

Personal Details

Name:____

Date of Birth (DD/MM/YYYY):___________________ Gender: Female/ Male

PART A

1. Are you a male over 45 yr, or female over 55 yr or who has had a hysterectomy or are postmenopausal?

Y N If YES, please provide details

2. Are you a regular smoker or have you quit in the last 6 months? Y N ________________

3. Did a close family member have heart disease or surgery, or stroke before the age of 60 years? Y N Unsure ________________

4. Do you have, or have you ever been told you have blood pressure above 140/90 mmHg, or do you current take blood pressure medication? Y N Unsure ________________

5. Do you have, or have you ever been told you have, a total cholesterol level above 5.2 mmol/L (200 mg/dL)? Y N Unsure ________________

6. Is your BMI (weight/height^2) greater than 30 kg/m^2? Y N Unsure ________________

PART B

1. Have you ever had a serious asthma attack during exercise? Y N ______________________

2. Do you have asthma that requires medication? Y N ______________________

3. Have you had an epileptic seizure in the last 5 years? Y N ______________________

4. Do you have any moderate or severe allergies? Y N ______________________

5. Do you, or could you reasonably, have an infectious disease? Y N ______________________

6. Do you, or could you reasonably, have an infection or disease that might be aggravated by exercise? Y N ______________________

7. Are you, or could you reasonably be, pregnant? Y N ______________________

PART C

1. Are you currently taking any prescribed or non-prescribed medications?

Y N ______________________

2. Have you had, or do you currently have, any of the following?

			If YES, please provide details
Rheumatic fever	Y	N	______________________
Heart abnormalities	Y	N	______________________
Diabetes	Y	N	______________________

Epilepsy	Y	N	______________________
Recurring back pain that would make exercise problematic, or where exercise may aggravate the pain .	Y	N	______________________
Recurring neck pain that would make exercise problematic, or where exercise may aggravate the pain	Y	N	______________________
Any neurological disorders that would make exercise problematic, or where exercise may aggravate the condition	Y	N	______________________
Any neuromuscular disorders that would make exercise problematic, or where exercise may aggravate the condition	Y	N	______________________
Recurring muscle or joint injuries that would make exercise problematic, or where exercise may aggravate the condition	Y	N	______________________
A burning or cramping sensation in your legs when walking short distances	Y	N	______________________
Chest discomfort, unreasonable breathlessness, dizziness or fainting, or blackouts during exercise	Y	N	______________________

PART D

Have you had flu in the last week?	Y	N	______________________
Do you currently have an injury that might affect, or be affected by, exercise?	Y	N	______________________

*Is there any other condition not previously mentioned that may affect your ability to participate in this study?

Y N ____

Medical Questions that are directly related to the research techniques:

Have you ever experienced injury to the hamstrings? Y N ____________________

Have you ever experienced injury to the quadriceps? Y N ____________________

Have you ever experienced injury while running? Y N ____________________

Have you ever experienced injury while squatting? Y N ____________________

Are you currently fully fit? Y N ____________________

Declaration (to be signed in the presence of the researcher)

I acknowledge that the information provided on this form, is to the best of my knowledge, a true and accurate indication of my current state of health.

Participant

Name:______________________ Date (DD/MM/YYYY):______________

Signature:_________________________

Researcher:

Signature:__________________________

Date (DD/MM/YYYY):_______________

Parent/ Guardian (only if applicable)

I, ____, as parent / guardian of Mr/ Miss ____, acknowledge that I have checked the answers provided to all questions in the medical questionnaire and verify that they are correct to the best of my knowledge.

Signature: ______________________________________

Date (DD/MM/YYYY): __________________________

Practitioner (only if applicable)

I, Dr ____________________________________ have read the medical questionnaire and information/ consent form provided to my patient Mr/Miss/ Ms__________________________________, and clear him/ her medically for involvement in exercise testing.

Signature:______________________________________

Date (DD/MM/YYYY):__________________________

APPENDIX FIVE

Information Letter

Edith Cowan University
School of Exercise and Health Sciences
270 Joondalup Drive
JOONDALUP WA 6027
Phone: 6304 2170
Fax: 6304 2661

LOWER LIMB FATIGUE ASYMMETRY OF PREFERRED AND NON-PREFERRED LEGS AFTER A REPEATED-SPRINT TEST IN FOOTBALL PLAYERS WITH PREVIOUS HAMSTRING INJURY.

The purpose of this research is to examine changes in muscle force production and fatigue between preferred and non-preferred kicking legs in Western Australian State League football players with and without a history of unilateral hamstring injury. In particular, force production and resulting fatigue will be measured during a single leg vertical jump and isokinetic endurance test before and after a repeated-sprint test on a non-motorised treadmill. Not only is this study the first to examine differences in fatigue between preferred and non-preferred kicking legs in footballers, but could also be the first protocol to allow footballers to have their hamstring functions tested during a competitive season, allowing them to train and play the same week of any testing.

This study will involve volunteering State League footballers to first complete a short questionnaire to determine eligibility for this study. Eligible participants will be determined based on previous injury history; divided between a lack of injury history for a 'non-injured group' and a sufficient injury history of the hamstring within 2 years of the study for an 'injured group'. Rehabilitation of the injury will also come into consideration when selecting participants. It is a necessity that all participants are currently fully fit to complete the study. Eligible participants will conduct two familiarisation sessions to give them an understanding of testing protocols before testing commences; over three sessions separated by a week at the same time of day to allow for sufficient recovery. Days of testing sessions will be worked around the footballer's schedule to ensure that they will be able to continue to train at least once a week and play on the Saturday. It is anticipated that this study will enable more in-season testing which in turn could aid injury prevention.

Testing will vary between each session to meet the protocol for the study. The first session will involve participants completing an isokinetic endurance test on an isokinetic dynamometer. The second session will involve participants completing a repeated-sprints test on a non-motorised treadmill followed by the same isokinetic endurance test. The third and final session will involve participants completing single leg vertical jumps before and after the same repeated-sprint test as in session 2. Each session will take a maximum of 1 hour. Participants are expected to experience some fatigue during testing, and it is possible delayed onset of muscle soreness could be experienced after. If by chance any pain or injury is experienced during testing emergency procedures are in place to stop testing immediately for all participants' safety.

This study is beneficial to provide a protocol to allow for hamstring functional testing during a competitive football season. It will also provide potential insight into the different mechanisms in preferred and non-preferred kicking legs in relation to hamstring injuries. Information gained from testing participants will provide insight to these benefits. All testing results will only be accessed by the principal investigator which will be password protected. Subjects will be coded to ensure confidentiality and that the use of any personal details or information will not be used due to legal limits. Data will be stored at Edith Cowan University and by the principal investigator; data will remain coded however to ensure confidentiality throughout the minimum 5 year storage period.

Results of the study will be published for the thesis of this Masters study and also presented at conferences. All results will remain coded and all personal details and information will not be presented to ensure confidentiality. Participants will have their test results readily available. While all results will be coded, through this coding results can be re-identifiable to provide individual feedback for all involved in testing.

This testing is voluntary and will remain voluntary throughout. Participants are free to withdraw their consent for further involvement in the study at any time. By withdrawing from the research any testing information already collected will be withdrawn also.

If there are any more questions please e-mail the principal investigator Cameron Lord: clord0@our.ecu.edu.au for quickest response.

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

This study has been approved by the ECU Human Research Ethics Committee.

Thank you for your time,

Principal Investigator: Cameron Lord.
0433499694
clord0@our.ecu.edu.au

Supervisor: Dr Fadi Ma'ayah
6304 2596
f.maayah@ecu.edu.au

School of Exercise and Health Sciences
Sports Science and Football (Soccer)

APPENDIX SIX

Final Checklist

Final Checklist for Participant Sheet

		Please circle one	
1.	**Are you aware that if you feel uncomfortable with any testing procedure you should tell the researcher immediately, and that YOU CAN STOP your participation at any time?**	**YES**	**NO**
1.	Are you aware that, although very rare, maximal exercise can result in fainting, severe exhaustion or cardiac events leading to death?	YES	NO
2.	Are you aware that the fatigue caused by the exercise can impair your ability to perform tasks such as driving for a short while after the cessation of exercise?	YES	NO
3.	Have you been given the opportunity to view the photos outlining the maximal exercise testing techniques?	YES	NO
4.	Have you fasted for longer than 6 hours?	YES	NO

Name of volunteer: ___________________________

Signature of volunteer: ________________________ Date: _______________

Name of witness: ___________________________

Signature of witness: ________________________ Date: _______________

APPENDIX SEVEN

Emergency Contact Form

Participant's Name: __________________________

In case of an emergency please contact:

1)

Emergency Contact Name: __________________________

Emergency Contact Number: __________________________

Relationship to Participant: __________________________

2)

Emergency Contact Name: __________________________

Emergency Contact Number: __________________________

Relationship to Participant: __________________________