

The relationship between selected pelvic biomechanic parameters and hamstring injuries in semi-professional rugby players

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Dedication

To my husband, Lloyd Donald



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Author's contribution

The principle author of this dissertation is Ms. A Donald. The contribution of the co-author involved in this study are summarised in the following table:

Co-Author	Contribution
Prof. S.J. Moss	Supervisor. Co-author, assistance in writing of manuscripts, selection of studies, data extraction, design and planning of manuscripts, interpretation of results.

The following is a statement from the co-author confirming her individual role in each study and giving her permission that the manuscripts may form part of this dissertation.

I declare that I have approved the above mentioned manuscripts, that my role in the study, as indicated above, is representative of my actual contribution and that I hereby give my consent that they may be published as part of the M.A. dissertation of Annarie Donald.

Prof. S.J. Moss

Abstract

The relationship between selected pelvic biomechanical parameters and hamstring injuries in semi-professional rugby players

Hamstring injuries have a high prevalence in rugby union players. Delayed transverse abdominus activation as well as lordosis is associated with hamstring injuries. No literature regarding this relationship in rugby players could have been found. The main purpose of this study was therefore to determine the relationship between pelvic biomechanics (transverse abdominus activation and pelvis tilt) and gluteus maximus, hamstring and erector spinae activation patterns in semi-professional rugby union players as well as the relationship of the above mentioned variables and hamstring injuries. A total of 65 players voluntarily participated in this study. Pelvis tilt (left and right) was assessed by Dartfish version 4.06.0 (Dartfish, Switzerland). Transverse abdominus activation (TrA) was assessed by pressure biofeedback and the mean onset times of the left and right gluteus maximus (GM), biceps femoris (BF), semitendinosus (ST) and lumbar erector spinae (LES) was measured with electromyography (EMG). In order to determine the role of the pelvic biomechanics and activation patterns on hamstring injuries, players were retrospectively grouped in injured and uninjured groups. Differences between the groups were determined with regards to the variables determined. Activation patterns were determined by means of descriptive statistics. The between-group pelvic biomechanic (pelvic tilt and TrA) differences in the muscle (GM, LES and hamstrings) onset times were analysed by determining practical significance by means of effect sizes.

An anterior pelvic tilt on the left side was observed in 64.6% of the participants and on the right side in 83.1% of the participants. TrA testing indicated that 68.4% of participants were classified with bad activation and 31.6% with good activation. No practical significant difference was found in the mean onset times of each muscle relative to the other in the normal and anterior tilted pelvis groups as well as in the bad and good TrA groups.

A total of 24.6% of the rugby players previously suffered from hamstring injuries, 37.5% of those injured participants were suffering from re-injury. No practical significant between group differences were found when the injured and uninjured groups were compared with regards to anterior pelvis tilt values ($d=0.061$) and TrA values ($d=0.189$). EMG results on the right and left side of the injured and uninjured participants present a pattern of the following activation order: LES, GM, BF and lastly ST. No practical significant between groups differences were found in the onset times of the muscles relative to each other in the injured compared to uninjured groups. The conclusions that can be drawn from this study is that semi-professional rugby union players (injured and uninjured) are prone to postural defects such as anterior tilt of the pelvis and bad TrA. Anterior pelvic tilt and bad TrA may be the reason for the earlier activation of the LES and hamstrings muscles relative to the GM in the prone hip extension to stabilize the lumbar spine. These activation patterns were however not influenced by previous hamstring injuries.

Keywords: Hamstring injuries, pelvic tilt, transverse abdominus activation, rugby union players, electromyography

Opsomming

Die verhouding tussen geselekteerde pelvis biomeganiese parameters en hampese beserings in semi-professionele rugbyspelers

Hampese beserings het 'n hoë voorkoms in rugby unie spelers. Vertraagde transverse abdominus aktivering asook lordose word met hampese beserings geassosieer. Geen literatuur oor die verhouding tussen rugby spelers kon gevind word nie. Die hoofdoel van die studie was daarom om die verhouding tussen pelvis biomeganika (transverse abdominus aktivering en pelvis tilt) en gluteus maximus, hampese en erector spinae aktiveringspatrone in semi-professionele rugby unie spelers te bepaal asook wat die verhouding tussen die bogenoemde veranderlikes en hampese beserings is. 'n Totaal van 65 spelers het vrywilliglik aan die studie deelgeneem. Pelvis tilt (links en regs) was geëvalueer deur Dartfish "version" 4.06.0 (Dartfish, Switzerland). Transverse abdominus aktivering (TrA) was bepaal deur 'n "pressure biofeedback" en die gemiddelde aktiveringstye van die linker en regter gluteus maximus (GM), biceps femoris (BF), semitendinosus (ST), en lumbale erector spinae (LES) was met 'n elektromiogram (EMG) gemeet. Om die rol van pelvis biomeganika en aktiveringspatrone op hamstring beserings te bepaal, was die spelers retrospektief in beseerde en onbeseerde groepe gegroepeer. Verskille tussen die groepe was bepaal deur die veranderlikes. Aktiveringspatrone was bepaal deur middel van beskrywende statistiek. Die tussen groep pelvis biomeganika (pelvis tilt en TrA) verskille in die begintye van die spiere (GM, LES en hampese) was ontleed deur die praktiese betekenisvolheid te bepaal met behulp van effekgroottes.

Anterior pelvis tilt was in 64.6% van die deelnemers aan die linkerkant en in 83.1% van die deelnemers aan die regterkant waargeneem. TrA toetsings het aangedui dat 68.4% deelnemers geklassifiseer is met swak aktivering en 31.6% met goeie aktivering. Geen praktiese betekenisvolle verskil was in die gemiddelde

aanvangstye van elke spier relatief tot die ander in die normale- en anterior pelvis tilt groepe, asook in die swak- en goeie TrA groepe gevind nie.

'n Totaal van 24.6% van die rugby spelers het voorheen hampese beserings gehad en 37.5% van daardie beseerde spelers was herbeseer. Geen prakties betekenisvolle tussen groep verskille was tussen die beseerde- en onbeseerde groepe ten opsigte van pelvis tilt waardes ($d=0.061$) en TrA waardes ($d=0.189$) gevind nie. EMG resultate van die regter- en linkerkant van die beseerde en onbeseerde deelnemers het die volgende aktiveringsvolgorde gelever: LES, GM, BF en laaste ST. Geen prakties betekenisvolle tussen groep verskille was in die begintye van die spiere relatief tot die ander in die beseerde- vs onbeseerde groepe gevind nie. Die gevolgtrekkings wat van die studie afgemaak kan word is dat semi-professionele rugby unie spelers (beseer en onbeseer) geneig is tot postuur defekte soos anterior tilt van die pelvis en swak TrA. Anterior pelvis tilt en swak TrA kan die oorsaak wees vir vroeër aktivering van die LES en hampese spiere relatief tot die GM in die “prone hip extension” om die lumbale werwelkolom te stabiliseer. Hierdie aktiveringspatrone is nogtans nie beïnvloed deur vorige hampese beserings nie.

Sleutelwoorde: Hampese beserings, pelvis tilt, transvers abdominus aktivering, rugby unie spelers, elektromiogram

Table of Content

ACKNOWLEDGEMENTS.....	i
AUTHOR'S CONTRIBUTION.....	ii
ABSTRACT.....	iii
OPSOMMING.....	vi
TABLE OF CONTENTS.....	ix
LIST OF TABLES.....	xii
LIST OF FIGURES.....	xv
LIST OF ABBREVIATIONS.....	xvii
 CHAPTER 1.....	 1
Introduction	
1. Introduction.....	1
2. Problem statement.....	2
3. Objectives.....	4
4. Hypothesis.....	5
5. Structure of dissertation.....	5
References.....	7
 CHAPTER 2.....	 11
Overview of pelvic biomechanics and mechanism of hamstring injuries	
1. Introduction.....	11
2. Anatomy and biomechanics.....	12
3. Mechanics of hamstring injury.....	16
3.1 <i>Running cycle phase</i>	16
3.2 <i>Gluteus maximus weakness</i>	17
3.3 <i>Posture in functional activities</i>	17
4. Risk factors associated with hamstring injuries.....	19
4.1 <i>Previous hamstring injuries</i>	19
4.2 <i>Hamstring:Quadriceps muscle strength – and balance</i>	20
4.3 <i>Warm-up</i>	21
4.4 <i>Hamstring muscle fatigue</i>	22
4.5 <i>Hamstring muscle flexibility</i>	23
4.6 <i>Neuromuscular control</i>	24
4.7 <i>Lumbar-pelvic mechanics causing hamstring injuries</i>	25
4.8 <i>Running technique</i>	26

5. Lumbo-pelvic biomechanics and hamstring injuries.....	26
5.1 Lumbo-pelvic instability.....	27
5.1.1 <i>Form and force closure.....</i>	27
5.1.2 <i>Sacroiliac joint dysfunction and hamstring injuries.....</i>	27
5.1.3 <i>The role of SIJ dysfunction on gluteus maximus activation and strength.....</i>	30
6. Transverse abdominus activation in hamstring injuries.....	34
7. Rehabilitation of hamstring injuries.....	37
7.1 Lumbopelvic and neuromuscular control in hamstring injuries.....	38
8. Conclusion.....	39
References.....	41

CHAPTER 3..... 51

Pelvis biomechanics and gluteus maximus, hamstring and erector spinae activation patterns in semi-professional Rugby Union Players.

Abstract.....	52
1. Introduction.....	53
2. Methods.....	54
2.1 <i>Participants.....</i>	54
2.2 <i>Study Design.....</i>	54
2.3 <i>Demographics.....</i>	55
2.4 <i>Pelvic alignment.....</i>	55
2.5 <i>Transverse abdominus activation.....</i>	55
2.6 <i>Electromyography.....</i>	56
2.7 <i>Statistical analysis.....</i>	57
3. Results.....	57
4. Discussion.....	63
5. Conclusion.....	66
References.....	68

CHAPTER 4..... 72

Hamstring injuries in rugby union: the influence of selected pelvic biomechanics, gluteus maximus, hamstring and erector spinae activation patterns.

Abstract.....	73
1. Introduction.....	74
2. Methods.....	75
2.1 <i>Participants.....</i>	75
2.2 <i>Study design.....</i>	76
2.3 <i>Demographics.....</i>	76
2.4 <i>Pelvic alignment.....</i>	76
2.5 <i>Transverse abdominus activation.....</i>	77
2.6 <i>Electromyography.....</i>	77
2.7 <i>Statistical analysis.....</i>	79
3. Results.....	79
4. Discussion.....	82
5. Conclusion.....	86
References.....	88

CHAPTER 5.....	94
Summary, conclusion, limitations and recommendations	
1. Summary.....	94
2. Conclusion.....	96
2.1 Hypothesis 1.....	96
2.2 Hypothesis 2.....	97
3. Limitations and recommendations.....	98
 APPENDIX A: Manual Therapy (Guidelines for authors).....	 101
APPENDIX B: Journal of Biomechanics (Guidelines for authors).....	108
APPENDIX C: Informed Consent Letter.....	115
APPENDIX D: Data Sheet.....	120

List of Tables

CHAPTER 3

Table 1:	Characteristics of the participants.....	58
Table 2:	Frequency of the muscle activation sequence with relation to pelvis tilt and TrA for both the left and right sides.....	60
Table 3:	Mean onset times (ms) of the gluteus maximus, bicep femoris, semitendinosus and lumbar erector spinae for normal and anterior pelvis tilt reporting the means and standard deviation...	62
Table 4:	Mean onset times (ms) of the muscles of participants grouped in bad and good TrA groups.....	63

CHAPTER 4

Table 1:	Characteristics of the participants retrospectively grouped as injured and uninjured.....	80
Table 2:	Mean onset times (ms) of each muscle in the injured and uninjured groups.....	82

List of Figures

CHAPTER 2

Figure 2.1: Hamstrings origin and insertion (Seeley *et al.*, 2000:352)..... 13

Figure 2.2: Attachment of the thoraco-lumbar fascia to latissimus dorsi, which functionally links the hamstrings with the shoulder and upper torso (Hoskins & Pollard, 2005a:98)..... 14

Figure 2.3: Continuation of the biceps femoris to the sacrotuberous ligament which attaches to the thoraco-lumbar fascia (Hoskins & Pollard, 2005a:98)..... 15

Figure 2.4: The relative difference in hamstring muscle length of a normal innominate (solid line) and an anterior tilted innominate (interrupted line) (Cibulka *et al.*, 1986:1222)..... 19

Figure 2.5: Prone hip extension (Sakamoto *et al.*, 2009:107)..... 34

Figure 2.6: Use of pressure biofeedback to assist in recognition of pelvic tilt (Norris, 1995:33)..... 36

CHAPTER 3

Figure 1: The average firing order (percentage) for each muscle tested left and right, presenting the general firing order of the muscles tested in semi-professional rugby players..... 59

CHAPTER 4

Figure 1:	The average muscle activation frequency (percentage) for each muscle tested left and right, presenting the general firing order of the muscles in the injured and uninjured group of the semi-professional rugby players tested.....	81
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List of Abbreviations

ASIS:	Anterior superior iliac spine
BF:	Biceps femoris
CI:	Confidence Interval
cm:	centimeter
EMG:	Electromyography
ES:	Erector spinae
GM:	Gluteus maximus
kg:	kilogram
L:	Left
L1:	First lumbar vertebrae
L3:	Third lumbar vertebrae
L4:	Fourth lumbar vertebrae
L5:	Fifth lumbar vertebrae
LES:	Lumbar erector spinae
ms:	milliseconds
mv:	millivolt
PBU:	pressure biofeedback unit
PHE:	Prone hip extension
PSIS:	posterior superior iliac spine
R:	Right
S1:	First sacral vertebrae

S2:	Second sacral vertebrae
S3:	Third sacral vertebrae
SD:	Standard Deviation
SIJ:	Sacroiliac Joint
ST:	Semitendinosus
TA:	Transverse abdominus
TLF:	Thoracolumbar fascia
TrA:	Transverse abdominus activation

Chapter 1

Introduction

1. Introduction.....	1
2. Problem statement.....	2
3. Objectives.....	4
4. Hypothesis.....	5
5. Structure of dissertation.....	5
References.....	7

1. INTRODUCTION

Hamstring injuries are one of the most common injuries in sport involving the lower body (Orchard *et al.*, 2002:270). It is a common injury in sports where rapid acceleration and running at maximum speed are required (Hoskins & Pollard, 2005a:96). Injury examinations have found hamstring injuries to be very common among rugby union players (Targett, 1998:282). Despite the high incidence of hamstring injuries in professional rugby union players (Brooks *et al.*, 2005:771), evidence-based information on risk factors and injury-prevention strategies is limited (Upton *et al.*, 1996:60).

Earlier studies have investigated risk factors such as previous injury (Hoskins & Pollard, 2005b:2), hamstring:quadriceps muscle imbalance (Heiser *et al.*, 1984:370), warm-up (Verrall *et al.*, 2003:973), muscle fatigue (Woods *et al.*, 2004:37), flexibility (Drezner, 2003:48), neuromuscular control (O'Sullivan *et al.*, 2003:1076), pelvic mechanics such as lordosis (Watson, 1995:293) and running technique (Orchard, 2002:96). Studies investigating the combined effect of pelvic biomechanics such as pelvic tilt, transverse abdominus- and gluteus maximus activation on hamstring injuries could not be found in the

published literature searched for this study. In this dissertation the role of the pelvic biomechanics in relationship to hamstring injuries will be investigated, with Chapter 1 presenting the problem statement, objectives, hypotheses and the structure of the dissertation.

2. PROBLEM STATEMENT

Hamstring injuries have the highest recurrence rate of all football injuries, with more than one in three (34%) injuries recurring within the same season (Orchard & Seward, 2002:44). Verrall *et al.* (2001:437) found that players with a history of hamstring injuries were almost five times more susceptible to re-injury than those who had no injury history. Given the high recurrence rate of hamstring strains, the identification of the underlying risk factors is important for proper treatment of the injury. Several studies have identified risk factors for hamstring injury such as strength imbalances between the hamstring and quadriceps muscles (Coombs & Garbutt, 2002:57), hamstring flexibility (Witvrouw *et al.*, 2003:41), running technique and body mechanics (Hoskins & Pollard, 2005b:4), previous injury and inadequate rehabilitation (Verrall *et al.*, 2001:436), as well as poor lumbo-pelvic strength and stability (Wallden & Walters, 2005:99).

Increased lumbar lordosis, as well as an increase in anterior pelvic tilt, have previously been associated with increased risk of hamstring injury in athletes (Hodges & Mosley, 2003:362; Hennessey & Watson, 1993: 245). When the biomechanics of the lumbo-pelvic area is taken in consideration, research on hamstring injuries should particularly focus on the lumbar spine and pelvic areas. Cibulka *et al.* (1986:1220) suggest that an anterior pelvic tilt elongates the hamstrings and produces a functional tightness in the hip flexors and that an anterior pelvic tilt may be a result of iliopsoas tightness. These findings are supported by a study of Ashmen *et al.* (1996:277) in which they assessed the endurance and activation patterns of the transverse abdominus with a pressure biofeedback device placed under L4 – L5, with the subject lying supine with the hips flexed to 60 degrees and knees flexed to 90 degrees. Transverse abdominus weakness and the use of the iliopsoas muscle to stabilize the spine are observed when the pressure drops from 40 mmHg to 20 mmHg during an early phase of controlled lowering of the legs to the floor. An earlier activation of the biceps

femoris is noted with delayed activation of the transverse abdominus (Hungerford *et al.*, 2003:1596). Lack of muscular control of the pelvic girdle can contribute to overuse or repetitive strain of the hamstrings (Devlin, 2000:281).

During sprinting, the hamstrings should act as a transducer of power between the knee and the hip joint and contribute little to hip extension (Jacobs *et al.*, 1996:513). Gluteus maximus inhibition during sprinting may require the hamstrings to contribute more force to hip extension rather than acting in its transducer role, which can cause injury (Hoskins & Pollard, 2005a:100). Although the hamstrings assist in hip extension, recruitment should occur after the prime mover gluteus maximus has been recruited (Devlin, 2000:276). Sakamoto *et al.* (2009:108) analyzed muscle activation in 31 subjects during prone hip extension with electromyography (EMG). The study found that movement was initiated by semitendinosus muscle, followed by the erector spinae and then the gluteus maximus was recruited. The gluteus maximus onset time showed that the gluteus maximus' anticipated activation occurs before the initiation of movement. In another study, Lewis *et al.* (2009:40) also analyzed muscle activation during prone hip extension with the use of EMG testing, and a reduction of maximum gluteus maximus strength resulted in increased activation of the semimembranosus.

The activation of the deep lumbo-pelvic muscles, such as the transverse abdominus and multifidus assists in controlling the movement of the lumbar spine and pelvis in order to provide a stable foundation from which the hamstring can function (O'Sullivan *et al.*, 1998:114). According to Devlin (2000:283), earlier activation of the hamstring and erector spinae muscles occurs in subjects where the gluteus maximus is inhibited. These compensations may lead to hamstring and erector spinae overuse, causing back and hamstring injuries (Sahrmann, 2002:15).

Treatment of hamstring injuries should be aimed at both the local hamstring injury and the non-local functional deficiency or aetiological factors responsible for the overload, causing injury (Hoskins & Pollard, 2005a:102). A cause of hamstring injuries can often be associated with non-local factors including lumbo-pelvic dysfunctions (Hoskins & Pollard, 2005a:103), asymmetric range of motion at the

hip (Cibulka *et al.*, 1998:1009), earlier activation of biceps femoris during forward flexion and altered lumbo-pelvic stabilization (Hungerford *et al.*, 2003:1593), and past groin injuries and osteitis pubis (Verrall *et al.*, 2001:436). According to Sakamoto *et al.* (2009:106), it is unknown at this point what the normal activation patterns are in activities that use the gluteus maximus muscles, even in healthy sporting subjects

From these findings in the literature the following research question can be asked: What is the activation pattern of the erector spinae, hamstring, gluteus maximus and transverse abdominus, how are they related to each other and what is the relationship between selected pelvic biomechanical parameters and hamstring injury in semi-professional rugby union players?

The results of this study will contribute to the understanding of the role of pelvic biomechanics, transverse abdominus activation and activation patterns of gluteus maximus, hamstring and erector spinae muscles in hamstring injuries of young rugby union players. Effective rehabilitative exercises to prevent hamstring injuries can be implemented from the results obtained in this study. With prehabilitation and effective rehabilitation, the recurrence rate of injury may be decreased. Information of the pelvic biomechanics may also increase return to play and prevent re-injury.

3. OBJECTIVES

The objectives of this study are to determine:

- The relationship between pelvic biomechanics (transverse abdominus activation and pelvic tilt) and gluteus maximus, hamstring and erector spinae activation patterns in semi-professional rugby union players.
- The relationship between pelvic biomechanics (transverse abdominus activation and pelvic tilt) and gluteus maximus, hamstring and erector spinae activation patterns and hamstring injuries in semi-professional rugby union players.

4. HYPOTHESIS

The study is based on the following hypotheses:

- Pelvic biomechanics (transverse abdominus activation and pelvic tilt) are positively related to gluteus maximus, hamstring and erector spinae activation patterns in semi-professional rugby union players.
- A positive relationship exists between pelvic biomechanics (transverse abdominus activation and pelvis tilt) and gluteus maximus, hamstring and erector spinae activation patterns and hamstring injuries in semi-professional rugby union players.

5. STUCTURE OF DISSERTATION

The results of this dissertation will be presented in the format of two individual research articles. Each article will consist of unique aims and conclusions. The articles will be submitted for publication in accredited scientific journals as indicated in the next section.

Chapter 1: Introduction. This is the introductory chapter where the problem statement, aim and hypotheses of the study will be stated. The list of references is presented at the end of the chapter according to the Harvard style as prescribed by the North-West University.

Chapter 2: Literature review: Overview of pelvic biomechanics and mechanisms involved in hamstring injuries. In this literature review chapter, an overview of the anatomy and biomechanics of hamstring injury, mechanisms of hamstring injuries, risk factors for hamstring injuries, lumbo-pelvic biomechanics, transverse abdominus activation, gluteus maximus activation and rehabilitation of hamstring injuries will be presented. The list of references is presented at the end of the chapter according to the regulations of the Harvard style of referencing, as prescribed by the NWU.

Chapter 3: Research article 1. Pelvis biomechanics and gluteus maximus, hamstring and erector spinae activation patterns in semi-professional Rugby Union Players. This article investigates the influence of selected biomechanical

characteristics and muscle activation patterns in rugby union players. This article will be presented for publication to the journal, *Manual Therapy*. The list of references at the end of the chapter will be presented according to the guidelines for authors as indicated by *Manual Therapy*. See Appendix A (Guidelines for authors) at the end of this dissertation.

Chapter 4: Research article 2. Hamstring injuries in rugby union: The influence of selected pelvic biomechanics, gluteus maximus, hamstring and erector spinae activation patterns. This is an article that identifies the pelvic biomechanical risk factors that predict hamstring injury in semi-professional rugby union players. This article will be prepared for submission to the *Journal of Biomechanics*. The list of references at the end of the chapter will be presented according to the guidelines to the author, which is attached as Appendix B (Guidelines for authors) at the end of this dissertation.

Chapter 5: Summary, conclusions, limitations and recommendations. In this chapter the findings of this study will be summarised and conclusions made. The limitations of the study will be presented with the necessary recommendations made to improve future studies in this area. The list of references is presented at the end of the chapter according to the regulations of the Harvard style of referencing, as prescribed by the NWU.

The method and results of this study will be incorporated in Chapters 3 and 4. Therefore, no separate method and results chapter will be presented in this dissertation.

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Chapter 2

Overview of pelvic biomechanics and mechanisms involved in hamstring injuries

1.	Introduction.....	11
2.	Anatomy and biomechanics.....	12
3.	Mechanics of hamstring injury.....	16
4.	Risk factors associated with hamstring injuries.....	19
5.	Lumbo-pelvic biomechanics and hamstring injuries.....	26
6.	Transverse abdominus activation and hamstring injury.....	34
7.	Rehabilitation of hamstring injuries.....	37
8.	Conclusion.....	39
	References.....	41

1. INTRODUCTION

A high proportion of hamstring injuries are recurrences (Orchard & Seward, 2002:42). The high incidence of recurrence suggests either an inherent susceptibility of the muscle group to injury, or mismanagement or ineffective treatment of the injury (Wallden & Walters, 2005:100). This could be because of a lack of high-quality research into the methods of treatment, rehabilitation and prevention of hamstring injuries (Hoskins & Pollard, 2005c:3).

Biomechanical principles dictate that restriction or tension in one part of a kinetic chain will create increased load on other parts of the same chain (Sahrman, 2002:14). This may result in instant micro trauma, or the cumulative effect of increased load which is repetitive micro trauma, culminating in eventual injury. The recurrent nature of hamstring injuries could be the result of tension or restriction elsewhere in the same functional chain of muscles (Wallden & Walters, 2005:100). To analyze the entire kinetic muscular chain, of which the hamstrings are a component, would be a complex task.

Hamstrings play an important role in lumbo-pelvic rhythm and the hip extensor mechanism (Magee, 2002:51). It has been postulated that hamstring injuries may have a biomechanical basis (Woods *et al.*, 2004:39). Therefore, it is reasonable to suggest that assessment of hamstring injury should include a biomechanical evaluation, especially at the lumbar spine, pelvis and sacrum (Woods *et al.*, 2004:39). Significant excessive lumbar lordosis has been found in athletes with previous hamstring injury when compared to a group with no injury (Hennessey & Watson, 1993:243). This indirectly suggests that improving lumbar-pelvic biomechanics may play a role in the treatment and prevention of hamstring injury. Therefore in this chapter an overview of the anatomy and biomechanics of hamstring injury, mechanisms of hamstring injuries, risk factors for hamstring injuries, lumbo-pelvic biomechanics, transverse abdominus activation, gluteus maximus activation and rehabilitation of hamstring injuries will be presented. This overview will determine whether there is a possible connection between hamstring injuries and the combined factors such as anterior pelvic tilt, transverse abdominus- and gluteus maximus activation.

2. ANATOMY AND BIOMECHANICS

The hamstring muscle group consists of the semimembranosus and semitendinosus medially and biceps femoris, short and long heads, laterally. All muscles attach proximally to the ischial tuberosity, except for the short head of biceps femoris which originates at the linea aspera and supracondylar line of the femur (Seeley *et al.*, 2000:352). Semitendinosus attaches to the medial surface of the superior tibia, semitendinosus to the posterior part of the medial condyle of the tibia and the oblique popliteal ligament, while biceps femoris attaches to the lateral side of the fibula (Seeley *et al.*, 2000:352) (Figure 2.1).

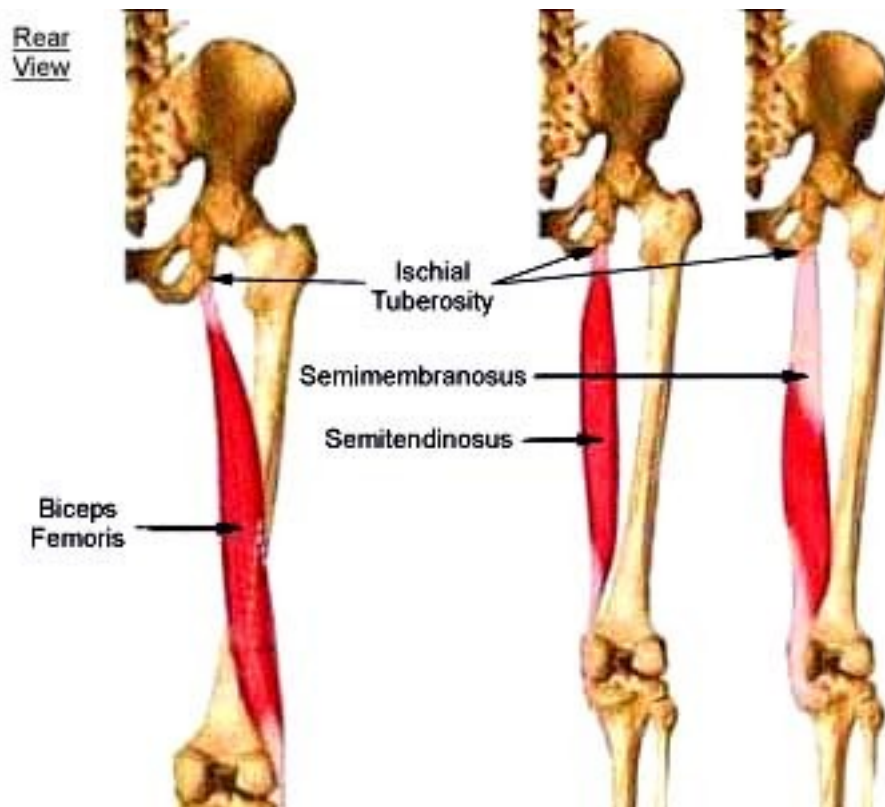


Figure 2.1: Hamstrings origin and insertion (Seeley *et al.*, 2000:352).

In order to thoroughly study the thoraco-lumbar fascia (TLF) due to its connection to the hamstrings, the anatomy of the TLF has to be understood. The TLF attaches to the latissimus dorsi, transverse abdominus, internal oblique and rhomboid muscles, splenius capitis, cervicus tendons, lumbar vertebrae and posterior superior iliac spines (Barker & Briggs 1999:1760). Through these attachments, the TLF functionally connects the hamstrings to the lumbar-pelvic spine, upper torso, shoulder and skull (Vleeming *et al.*, 1995:129) (Figure 2.3). In cadaver specimens, contracture of the muscular attachments of the TLF is capable of causing the TLF's displacement (Barker *et al.*, 2004:130). Hamstring tension can tighten the TLF and reduce motion at the sacroiliac joint (SIJ) (Van Wingerden *et al.*, 2004:200).

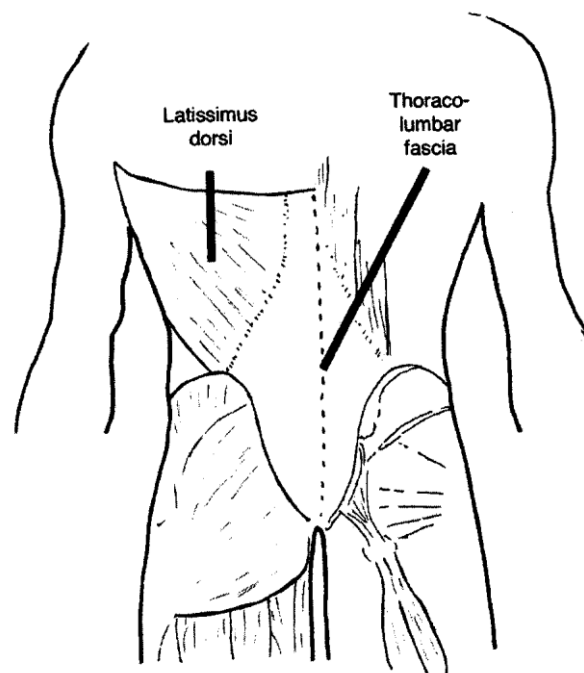


Figure 2.2: Attachment of the thoraco-lumbar fascia to latissimus dorsi, which functionally links the hamstrings with the shoulder and upper torso (Hoskins & Pollard, 2005a:98)

The extensive attachments of the transverse abdominus to the TLF, makes it one of the most capable of all muscles tensioning the TLF (Hodges and Richardson, 1998:53). The aponeurosis of the transverse abdominus is continuous with the middle portion of the TLF (McGill & Norman, 1988:316). These fibres are then continuous with the lateral raphe and thus the internal oblique muscles (Vleeming *et al.*, 1995:754). It has been found that low levels of tension are effectively transmitted between the transverse abdominus and TLF (Barker *et al.*, 2004:130). At the ischial tuberosity, the tendon of the long head of biceps femoris is continuous with the superficial and distal part of the sacrotuberous ligament, which passes across the sacrum, and attaches to the TLF (Vleeming *et al.*, 1995:753) (Figure 2.2). The effect of TLF tension is transmitted to the SIJ from the deep fibres which are connected to the sacrotuberous ligaments (Vleeming *et al.*, 1995:755). Tension in the TLF could generate forces perpendicular to the SIJ that would stabilize the joint (Vleeming *et al.*, 1995:756). Earlier activation of the biceps femoris is noted with delayed transverse abdominus activation (Hodges &

Richardson, 1998:51). A previous study has found that dysfunction in the lumbar spine, pelvis and SIJ are risk factors for hamstring injury (Verrall *et al.*, 2001:439).

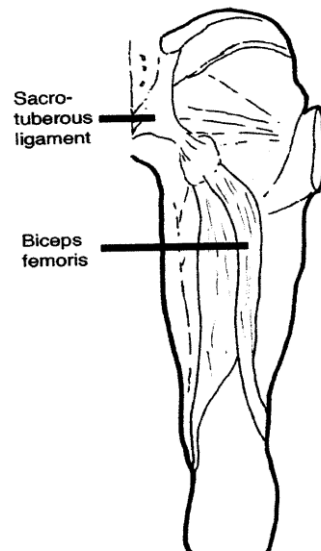


Figure 2.3: Continuation of the biceps femoris to the sacrotuberous ligament which attaches to the thoraco-lumbar fascia (Hoskins & Pollard, 2005a:98)

Due to the anatomical link between the hamstrings, lumbar spine, pelvis and sacrum, it has been recommended that the biomechanics of these structures be assessed when evaluating hamstring injury (Woods *et al.*, 2004:39). From these studies it seems that the stabilizing muscles of the pelvis are all connected to the TLF and through this connection they stabilize the pelvis. It seems if one muscle part of this connection does not function properly, another muscle must take over the function, causing overloading. For instance, if the activation of the transverse abdominus is delayed then the biceps femoris must activate earlier to take over its stabilizing function, resulting in overloading of the hamstring. This overloading may consequently result in hamstring injuries (Verrall *et al.*, 2001:439) .

3. MECHANISMS OF HAMSTRING INJURY

High incidences of hamstring muscle strains are associated with sports that involve stretch-shortening cycle activities, such as sprinting, high-intensity running, stopping, starting, quick changes of direction and kicking (Verrall *et al.*, 2005:363). Video analysis of the events leading to hamstring injuries in Australian Rules football indicate that injury was most likely to occur when players were running at high speed and, in particular, when the body was leaning forward. (Verrall *et al.*, 2005:364). It is important to identify the phase of the running cycle when hamstring injuries occur. It is also important to identify why mechanisms such as gluteus maximus weakness and posture could possibly cause hamstring injuries in activities such as sprinting, stopping, starting, quick changes of direction and kicking.

3.1 Running cycle phase

Occurrence of hamstring muscle injuries often take place during eccentric contraction of the hamstring muscles (Woods *et al.*, 2004:40). Schache *et al.* (2009:337) indicated that the swing phase rather than the stance phase of running is the most likely time of injury. This is for several reasons. Firstly, the hamstrings appear to be biomechanically most exposed during the terminal swing. Most of the inertial force acting about the knee joint at this time, is imparted onto the hamstrings as they attempt to decelerate the swinging lower leg. Hamstrings are also responsible for generating hip extensor torque (<50%). The hamstrings must change from functioning eccentrically to decelerate knee extension in the late swing, to concentrically, becoming an active extensor of the hip joint. The rapid changeover from eccentric to concentric function of the hamstring is when the muscle is most vulnerable to injury (Arnold *et al.*, 2005:2184). Secondly, peak hamstring electromyography activity during sprinting has been shown to occur during the terminal swing (Thelen *et al.*, 2005:109). Thirdly, the hamstring muscle-tendon unit undergoes an active lengthening contraction during terminal swing. Eccentric contractions, rather than concentric contractions, have been shown to produce some muscle fibre damage (Thelen *et al.*, 2005:109).

3.2 Gluteus maximus weakness

Gluteus maximus has a major functional importance in the early stance phase of walking, where 60% of body weight is transferred in 0.02 seconds, resulting in abrupt loading of the forward limb (Anderson & Pandy, 2003:163). When comparing runners with hamstring injuries to non-injured runners, a significant loss of hip extensor torque was found in the early support phase of injured runners (Schache *et al.*, 2009:337). Gluteus maximus demonstrates increased electromyography activity just prior to foot contact, which was proposed to assist the hamstrings in decelerating the swinging thigh (Mann *et al.*, 1986:506).

Hamstring injury may also occur at the initial stage of the stance phase of gait, when hamstring muscle activity is high (Orchard, 2002:93). This method of injury could be more likely in athletes with poor running technique or gluteus maximus weakness or -activation problems. Gluteus maximus should be the primary hip extensor in sprinting (Simonson *et al.*, 1985:530). During sprinting, the hamstrings should act as a transducer of power between the knee and hip joint and contribute little to hip extension (Jacobs *et al.*, 1996:522).

Altered hip extensor recruitment is known to occur with chronic lower back pain during walking, causing the gluteus maximus to be inhibited and hamstrings to become overactive (Vogt *et al.*, 2003:24). Gluteus maximus inhibition during sprinting may require the hamstrings to contribute more force to hip extension rather than acting in its transducer role, potentially predisposing injury (Hoskins & Pollard, 2005a:100). From these findings we may come to a conclusion that gluteus maximus weakness and –activation problems may definitely play a role in hamstring injuries in functional activities. No evidence to support this conclusion could be obtained in the literature.

3.3 Posture in functional activities

The normal biomechanics of walking and running consist of coordinated movement patterns of the hip, pelvis and lumbar spine (Saunders *et al.*, 2005:784). A strong correlation has been reported during running between increased anterior pelvic tilt and increased lumbar lordosis (Schache *et al.*,

2002:287). Specifically increased anterior pelvic tilt has been identified as a predisposing factor for hamstring injuries in runners (Brukner & Khan, 2002:52).

It has been reported that with increasing walking and running velocities, increases are observed in stride length, peak anterior tilt, and lumbar lordosis (Saunders *et al.*, 2005:784). One would expect that with increased running speeds, the peak hip extension torques would increase with the increases in anterior pelvic tilt and lumbar lordosis, but close examination reveals that increases in hip extension torques are very small (Franz *et al.*, 2009:497).

Limitations in hip extensor torques with increased running speed could be caused by limitations in structural tissues (Franz *et al.*, 2009:495). Shortened psoas and quadriceps muscles are associated with an anterior tilted pelvis (Petty & Moore, 2001:40). This causes a limitation in hip extension mobility and causes an increased anterior pelvic tilt (Lee & Kerrigan, 2004:658). To maintain a reasonable stride length in the presence of limited hip extension mobility, one must compensate with an increased anterior pelvic tilt (Franz *et al.*, 2009:495).

As mentioned previously, an increased anterior pelvic tilt and increased lumbar lordosis are associated in the literature with an increased risk of hamstring injury (Hodges & Mosley, 2003:362). An increase in lumbar lordosis and anterior pelvic tilt results in the ischium being moved further away from the distal insertion of the hamstrings. The mechanical stress and strain in the hamstrings during function is therefore increased (Hunter & Speed, 2007:266). It seems from these studies that in athletes with an increased anterior pelvic tilt, the hamstrings are elongated causing a constant strain during functional activities. Thus, the hamstrings are not in its normal length-tension-relationship, causing it to be weak and in constant strain because it is constantly trying to regain its normal length. Apart from these mechanisms there may also be risk factors causing hamstring injuries.

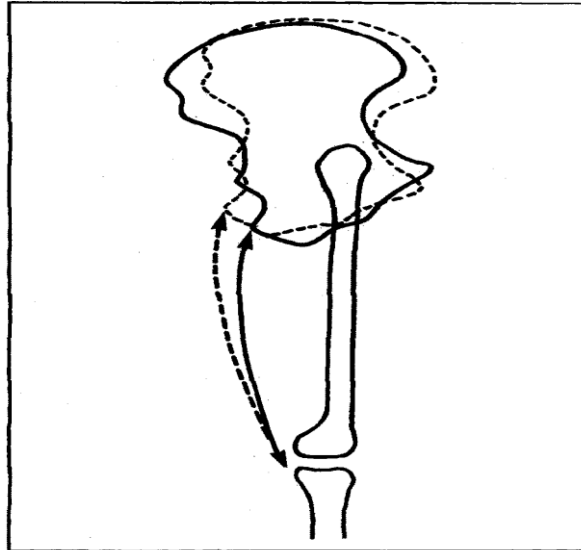


Figure 2.4: The relative difference in hamstring muscle length of a normal innominate (solid line) and an anterior tilted innominate (interrupted line) (Cibulka *et al.*, 1986:1222)

4. RISK FACTORS ASSOCIATED WITH HAMSTRING INJURIES

4.1 Previous hamstring injury

Previous injury is the most recognized risk factor for future injury (Hoskins & Pollard, 2005c:2). Previous injury was found to be a significant risk factor independent of other variables such as muscle strength or -imbalance (Bennell *et al.*, 1998:313). This is indicated by the fact that recurrent hamstring injuries commonly occur (34% of recurring hamstring injuries) (Orchard & Seward, 2002:42). Verrall *et al.* (2001:437) found that football players with a history of hamstring injuries were almost five times more susceptible to re-injury than those who had no history of injury.

Re-injury can result from the inability to assess the severity of initial damage and premature return to competition as athletes return during the remodelling phase of repair (Hoskins & Pollard, 2005a:101). During this remodelling phase of repair, realignment of the collagen fibres that make up the scar tissue takes place. This is a long-term process. With increased stress and strain of rehabilitation, the collagen fibres realign in a position of maximum efficiency parallel to the lines of

tension. The tissue gradually assumes normal appearance and function, although a scar is rarely as strong as the normal injured tissue. After a period of 3 weeks a stronger scar exists (Prentice, 2004:25). Thus, if the football player returns before 3 weeks with a severe hamstring injury, his/her risk for re-injury is much higher.

Orchard and Best (2002:1) noted that, when football players return to the field, they remain at risk for re-injury for many weeks. Re-injuries are likely to occur in the first week of return. This suggests that whatever structural changes occurred in the muscle after rehabilitation, it remains there for long periods. Another reason could be because previously injured muscle is more susceptible to eccentric damage than uninjured muscle (Brockett *et al.*, 2004:383). Hamstrings contract eccentrically to slow down the forward swing of the leg, to prevent over-extension of the knee and flexion of the hips. Such movement occurs during sprinting and kicking. With ineffective treatment, scar tissue and adhesions will accumulate and increase the risk of re-injury (Hoskins & Pollard, 2005a:101). This could be due to ineffective range of motion and strengthening exercises which should facilitate tissue remodelling and realignment during the remodelling phase (Prentice, 2004:24). According to these factors, players should be prevented from returning to the field too early after severe hamstring injury, due to the remodelling phase of repair that could be incomplete.

4.2 Hamstring:quadriceps muscle strength- and balance

Several authors suggested injury to be related to weakness and hamstring:quadriceps muscle imbalance (Christiensen & Wiseman, 1972:39; Heiser *et al.*, 1984:370). This ratio compares concentric or eccentric strength of hamstrings to the same mode of contraction of the quadriceps. Comparison of one mode of agonist muscle contraction to the opposite mode of the antagonist muscle contraction has been put forward as a more functionally relevant measure (Aagaard *et al.*, 1998:236). This functional strength ratio compares eccentric hamstring strength to concentric quadriceps strength, more closely simulating the practical relationship.

Various hamstring:quadriceps strength ratios have been investigated, but it remains unclear whether strength disorders are the cause of injury, or the

consequence of injury, or both. It is unclear what testing is best, concentric or the more functional eccentric testing method (Aagaard *et al.*, 1998:235). However, eccentric testing may not be as reliable as injury can occur and cause sub-maximal efforts as a protective mechanism (Orchard *et al.*, 2001:275). The ratio can also differ for athletes across different sports, because different sports require different power requirements (Read & Bellamy, 1990:181).

A previous study has shown strength deficiencies to be significantly associated with injury (Yamamoto, 1993:197). In a larger study by Bennell *et al.* (1998:312) no significant differences were found between the injured and non-injured football players for any variables of muscle strength and –imbalance. Another study found strength deficits to exist in athletes with a history of recurrent injuries (Crosier *et al.*, 2002:201). This may be due to ineffective rehabilitation (not enough range of motion and strengthening exercises in the remodelling phase of repair). Dysfunction in the lumbar spine, sacroiliac joint or pelvis (anterior pelvic tilt) which remained uncorrected could also be a contributing factor because the hamstrings may be weak since they function in an elongated position. However, another study has reported normal strength after hamstring injury (Worrell *et al.*, 1991:125).

In a study by Cameron *et al.* (2003:164) it was found that hamstring strength and previous injury were individually not significant predictors of hamstring injury. Cameron *et al.* (2003:164) found that increased quadriceps strength rather than decreased hamstring strength is responsible for the reduced hamstring:quadriceps ratio. According to the above-mentioned conflicting findings, there is insufficient evidence to suggest that hamstring weakness or hamstring:quadriceps imbalance is a risk factor for injury.

4.3 Warm-up

Despite proper warm-up before activity, hamstring injuries still occur (Verrall *et al.*, 2003:973). The application of a moist heat pack, which may simulate a warm-up situation, has been found to not affect hamstring muscle flexibility significantly (Sawyer *et al.*, 2003:289). This provides indirect evidence for a kinetic chain dysfunction causing injury and not a local cause of injury (Hoskins & Pollard, 2005a:101).

Lumbar spine flexibility has been found to increase with warm-up procedures, but it can be lost by twenty minutes of sitting (Green *et al.*, 2002:1076). This has implications for the attachment of the hamstrings to the TLF. By increasing the flexibility of the lumbar spine, the flexibility of the TLF is increased. As previously explained, the hamstrings are connected to the TLF through the biceps femoris which is connected to the sacrotuberous ligament. When the flexibility of the TLF is increased, the flexibility of the hamstrings is also increased due to the extended time that the hamstrings will need to function in an elongated position. Athletes particularly affected are those taking a half-time break or sitting on the bench for interchange during play (Hoskins & Pollard, 2005a:101). From these findings the conclusion may be drawn that players will benefit from doing lower back warm-up exercises during a half time break or while waiting on the bench.

A decrease in muscle stiffness with warm-up is known to occur (Noonen *et al.*, 1993:521). It increases the muscle length to failure, making the muscle more resistant to stretch-induced injuries. Warm-up procedures could be beneficial for injury prevention, but a lack of literature exist identifying the best warm-up methods (Hoskins & Pollard, 2005a:101).

4.4 Hamstring muscle fatigue

Most of the hamstring injuries occur in the last third of the first or second halves of a match, implicating muscle fatigue (Woods *et al.*, 2004:37). Multiple factors are associated with muscle fatigue, including the neural system, specifically the dual innervations of the two heads of biceps femoris (Foreman *et al.*, 2006:107). The long head is innervated by the tibial portion of the sciatic nerve (L5, S1 – S3), whereas the short head is innervated by the common peroneal division (L5, S1 – S2). These dual innervations can be implicated as a cause of injury because of uncoordination of contraction of the two heads with muscle fatigue (Devlin, 2000:275; Agre, 1985:23).

Another factor contributing to muscle fatigue could be poor running style (Devlin, 2000:281). Poor running style on the other hand could be caused by repeated efforts to maximal sprint running which causes a significant change in running

technique, causing a poorly coordinated running style (Devlin, 2000:281; Pinniger *et al.*, 2000:647).

Fatigued muscle is less able to produce force than non-fatigued muscle and is more susceptible to stretch injury in eccentric contractions (Mair *et al.*, 1996:141). A Previous study also found that fatigued muscles absorb less energy in the early stages of stretch than do non-fatigued muscles (Mair *et al.*, 1996:141). Fatigue is also known to result in decreased lower extremity and lumbar-pelvic proprioceptive acuity, which could contribute to hamstring injury through deficient neuromuscular motor control and inappropriate muscular contraction (Taimela *et al.*, 1999:1325). Changes in training or coaching may address these muscle fatigue causing factors. High volumes of training in the week preceding a match were identified as possible risk factors for match injuries, which supports previous reports that high training volumes can increase the risk of sustaining hamstring injury (Crosier, 2004:685).

4.5 Hamstring muscle flexibility

There is little evidence for poor flexibility as a hamstring injury predictor (Bennell *et al.*, 1999:106). Lack of flexibility has not yet been conclusively linked to the risk of hamstring injuries (Hennessey & Watson, 1993:243). Previous evidence seems unable to establish whether decreased muscle flexibility is a potential risk factor for injury, or just a consequence of it (Drezner, 2003:48).

Hamstring stretching was shown to increase torque generated in isokinetic tests, suggesting that stretching plays a greater role in performance enhancement than in injury prevention (Worrell *et al.*, 1994:158). Strength increases were due to increased muscle compliance and increased ability to store potential energy. Stretching acts to increase absorbed force prior to injury (Devlin, 2000:284). In a study by Hennessey and Watson (1993:245) there was no difference in flexibility between subjects with a history of hamstring injury and subjects with no history of hamstring injury. In another study it was found that players who regularly performed static hamstring stretching as well as strengthening exercises, present with the same type of match and training hamstring injuries as players who only performed strengthening exercises (Brooks *et al.*, 2006:1303). In the study by

Hennessey and Watson (1993:245) it was found that there was a difference in the degree of lumbar lordosis between the uninjured group and the group with hamstring injuries. This is an indication that posture abnormalities rather than flexibility can be linked to hamstring injury (Hennessey & Watson, 1993:245) .

A lack of neural extensibility is likely to decrease range of motion (Agre, 1985:31). Therefore, the slump test should also be used alongside other range of motion tests to identify exactly which structure is limiting movement (Turl & George, 1998:20). It may be that decreased flexibility in the hamstring muscles is connected to lumbar lordosis. Again, when the lumbar lordosis is decreased, the hamstring muscles will regain their normal length.

4.6 Neuromuscular control

Altered neuromuscular control can be caused by a number of factors, namely lack of proper warm-up, poor training and muscle fatigue where the neural activity pattern change (Agre, 1985:28), neural tension due to lack of flexibility, or a protective reflex mechanism following injury (Bennell *et al.*, 1999:107). Another important contributing factor is proprioceptive defects existing in lower back pain populations contributing to hamstring injury through alterations in neuromuscular control of the pelvis muscles (O'Sullivan *et al.*, 2003:1076).

Considering the composite nature of the interaction of the thigh muscles during activities of the lower limb, poor neuromuscular control of any part of the thigh muscles complex may predispose one to hamstring injury (Devlin, 2000:280). Proprioception, both afferent and efferent information for the whole limb, was tested by Cameron *et al.* (2003:160). In this study, Cameron *et al.* (2003:160) tested the movement discrimination of the backward swinging leg, whilst weight bearing on the other side, in order to create a functional movement as close as possible to the movement of injury. The study found players with poor lower limb proprioception and motor control to be at risk of hamstring injury. Throughout the running cycle there are many challenging acts, for example, to control hip and knee motion in late swing phase and to provide hip extensor torque in early stance phase of running. During sprinting, these actions occur over a very short period of time, and if the control and coordination are inadequate, then muscle strain may

result (Bennell *et al.*, 1999:107). Thus, improvement of the combined neuromuscular control of the pelvis, hip and lower leg in rehabilitation exercises may decrease the risk for hamstring injuries.

4.7 Lumbar-pelvic mechanics causing hamstring injuries

Aberrant lumbar-pelvic mechanics have been linked to possibly playing a role in hamstring injuries. Significant excessive lumbar lordosis has been found in a group of athletes with previous hamstring injury when compared to a control group with no injury history (Hennessey & Watson, 1993:245). In a prospective study, excessive lumbar lordosis and sway back were related to thigh muscle strains (hamstrings, quadriceps, and adductor) and defects in body mechanics were associated with the site of injury (Watson, 1995:293).

A muscular imbalance known as the lower crossed syndrome, which occurs with tightness of the hip flexors and lumbar erector spinae and weak, inhibited gluteal and abdominal muscles, can result in an anterior tilt, increased hip flexion and a hyperlordosis of the lumbar spine (Janda, 1996:97). The altered biomechanics of an anterior pelvic tilt will change the hamstring biomechanics and function in that the ischium is moved further away from the distal insertion of the hamstrings, thus increasing the mechanical stress and strain in the hamstrings during movement (Hunter & Speed, 2007:266). Decreased hip flexor and quadriceps flexibility has been identified as a risk factor for hamstring injury.

If the rectus femoris is very tight, the acceleration of hip flexion and knee extension is increased during the mid- to late swing phase of running. This action must be counteracted by the eccentric contraction of the hamstrings. Thus, a greater load is placed on the hamstring muscles, increasing their chance of injury (Gabbe *et al.*, 2005:108). However, even if proven to be a risk factor for injury, it is unclear as to whether improving lumbar-pelvic mechanics will result in prevention of injury, although one case report did produce positive results from improving body and lumbar-pelvic mechanics in association with hamstring soft tissue treatment (Hoskins & Pollard, 2005c:1).

4.8 Running technique

Running technique plays a significant role in hamstring injury. Injury occurs when the body is leaning forward trying to maintain or produce extra speed, resulting in over-striding (Orchard, 2002:96). Gluteus maximus weakness results in a characteristic forward lean lurch, which may result in over-striding. Leaning forward causes hamstring injury by increasing its relative length. Also, gluteus maximus weakness during sprinting may require the hamstrings to contribute more force to hip extension than it normally does and this will increase the injury risk (Hoskins & Pollard, 2005a:103).

This links optimal lumbar-pelvic function to injury prevention. It suggests that improving motor patterns and running technique by increasing lumbar-pelvic stability and gluteus maximus strength to prevent the forward lurch, may play a role in the management of hamstring injury.

5. LUMBO-PELVIC BIOMECHANICS AND HAMSTRING INJURIES

The causes of hamstring injuries as presented in the previous sections, are multi-factoral. There is evidence to suggest that hamstring injuries are caused by lumbo-pelvic imbalances (Hoskins & Pollard, 2005c:4). These imbalances increase the functional load on the hamstring by decreasing gluteus maximus activation and increasing the tensile stress on the biceps femoris (Panayi, 2009:5).

One may speculate that this may explain why hamstring injuries have such a high recurrence rate. A significant risk of injury recurrence exists in the first few weeks following return to play, with the risk for re-injury for the remainder of the season being 30,6% (Orchard & Best, 2002:1). Also, football players with a previous back injury have been found to have a significant risk for hamstring injury (Verrall *et al.*, 2001:438). These findings have important implications for the possibility of a biomechanical factor that may require a different approach, that has yet to be introduced. The efforts to decrease recurrence rates for hamstring injuries will be unsuccessful if the possibility of a biomechanical factor is excluded (Hoskins & Pollard, 2005c:1). This suggests that assessment of hamstring injury should include a biomechanical evaluation, especially that of the lumbar spine, pelvis and

sacrum (Woods *et al.*, 2004:39). Such assessment will include investigating the influence of lumbo-pelvic stability, form and force closure and sacroiliac joint (SIJ) function on gluteus maximus- and transverse abdominus activation. Furthermore it will be interesting to investigate whether these factors could be part of the multi-factoral causes of hamstring injuries.

5.1 Lumbo-pelvic instability

“The neuromuscular activation of the muscles in the pelvic region plays a primary role for the physiologic coordination and interaction of pelvis, spine and lower limb movements in human gait” as stated by Panjabi (1992:387). Hamstring injuries may occur due to poor functioning of the lumbar spine. In people with lower back pain and injury, restricted range of motion and decreased extensibility of the hamstrings exist (Halbertsma *et al.*, 2001:238). Increased muscle tone due to lumbo-pelvic instability, lumbar spine or sacroiliac joint dysfunction may also be a predisposing factor (Devlin, 2000:281). In a study by Wallden & Walters (2005:106) it was found that 80% of the subjects who had a history of lumbo-pelvic dysfunction, were associated with hamstring injuries.

5.1.1 Form and force closure

A primary function of the pelvis is to transfer the loads generated during standing, walking, sitting and other functional tasks. Effective load transfer requires optimal force and form closure of the sacroiliac joint (SIJ). Form closure refers to the stable situation of the SIJ due to closely fitting joint surfaces where no extra forces are needed to maintain stability (Pool-Goudzwaard *et al.*, 1998:13). Force closure refers to the stability of the SIJ produced by surrounding myofascia, particularly with a fibre direction perpendicular to the SIJ, such as the gluteus maximus (Pool-Goudzwaard *et al.*, 1998:13). Active compression of the pelvic articulations via the muscles and fascia of the lumbo-pelvic region is therefore required to stabilize intrapelvic motion during transfer of loads between the spine and lower limbs (Snijders *et al.*, 1998:210).

5.1.2 Sacroiliac joint dysfunction and hamstring injuries

The sacroiliac joint (SIJ) is the link between the lower extremities and the spine (Brolinson *et al.*, 2003:47). Also, the SIJ is fully integrated in the spine-pelvis-leg

mechanism (Snijders *et al.*, 1993:289). For the SIJ to function properly, this mechanism needs stability over the pelvis and the sacroiliac joints. Effective load transfer across the sacroiliac joints requires specific action of a variety of muscles, leading to sufficient compression of the sacroiliac joint and preventing shear forces (Snijders *et al.*, 1993:287). In enlarging compression, the biceps femoris and gluteus maximus muscles are important. Both muscles are attached to the sacrotuberous ligament, which functionally bridges the SIJ (Snijders *et al.*, 1993:291).

SIJ dysfunction has been defined as pelvic asymmetry between the left and right innominates, involving an anterior pelvic tilt on one side and a posterior pelvic tilt on the other side (Pool-Goudzwaard *et al.*, 1998:19). During athletic activities the SIJ sustains higher loads than normal, predisposing dysfunction (Brolinson *et al.*, 2003:47). Ideally in walking, when performing hip flexion, the innominate on the same side rotates in a posterior and inferior direction (using the posterior superior iliac spine as the point of reference), moving the ischial tuberosity (hamstrings' origin) anterior and reducing hamstring strain. If the innominate is fixed in an anterior rotation, the innominate will not rotate posterior during hip flexion and the ischial tuberosity will not move anterior. This will increase stress at the origin of the hamstrings in that the origin is moved further away from the insertion, causing the hamstring to elongate more than usual. This kind of stress is particularly increased in sports involving rapid acceleration during running and sprinting (Gabbe *et al.*, 2005:108).

Researchers have noted a high correlation between hamstring muscle injuries and an anterior tilt of the innominate bones associated with sacroiliac dysfunctions (Hoskins & Pollard, 2005c:2). They concluded that mobilizing the SIJ reduced the tilts of the innominates, releasing stress on the previously elongated biceps femoris. They also found that by manipulating the SIJ joint, hamstring strength improved due to the improved length-tension relationship (Hoskins & Pollard, 2005c:2; Cibulka *et al.*, 1986:1220). More recent research has also found SIJ mobilization to increase hamstring flexibility (Fox, 2006:29). Hoskins and Pollard (2005c:2) found that improving lumbar-pelvic biomechanics, including SIJ mobilization, played a role in treatment and prevention of hamstring injury in

footballers. This shows us that altered pelvic biomechanics such as an increased anterior pelvic tilt could be an important factor decreasing hamstring flexibility and strength. It is, however, important to not only investigate the injured hamstring muscle, as the cause of injury is not always at the site of injury or pain. The origin could be a biomechanical dysfunction of the pelvis.

The anterior tilt of the innominate bones could also possibly contribute to altered muscle activation of the muscles surrounding the pelvis. When a subject is standing and flexes a left hip, the distribution of vertical forces between the spine and lower limbs will alter with the initiation of the task. Weight is shifted to the left to increase the vertical force required for lateral transfer of the centre of mass toward the right supporting leg (Rogers & Pai, 1990:398). Displacement of body mass is preceded and accompanied by muscle activation to provide postural support for load transfer to the new single leg support. Stability of intrapelvic motion for transference of loads is controlled by co-contraction of the transverse abdominus, internal obliques and multifidus via connections to the posterior layer of the thoraco-lumbar fascia (TLF) (Vleeming *et al.*, 1995:136).

A study by Hungerford *et al.* (2003:1595), found that when subjects with no sacroiliac joint pain flex their hip in standing, the onset of the internal obliques, transverse abdominus and multifidus electromyography (EMG) activity on the side of the standing leg occurred before initiation of the task. Internal obliques, transverse abdominus, gluteus maximus, latissimus dorsi and lumbar erector spinae increase compressive forces of the SIJ (Snijders *et al.*, 1998:206). These muscles fire before the initial alteration to vertical ground reaction forces. By contrast, the EMG onsets of internal obliques, transverse abdominus, multifidus and gluteus maximus were significantly delayed on the symptomatic side of the subjects with sacroiliac joint pain. In these subjects the onset of the biceps femoris occurred significantly earlier to compress the SIJ (Hungerford *et al.*, 2003:1596). The earlier activation of the biceps femoris could result in an overloaded bicep femoris, as its usual function is not to stabilize the spine.

5.1.3 The role of SIJ dysfunction on gluteus maximus activation and strength

In an anterior tilted pelvis, the iliopsoas and quadriceps muscles become shortened (Janda, 1996:101). In SIJ dysfunction, hamstring injuries are associated with an anterior tilt of the innominates (Cibulka *et al.*, 1986:1220). A shortened iliopsoas muscle is associated with a tightened anterior hip capsule (Yerys *et al.*, 2002:222). Visible muscle wasting of the gluteal muscles is often seen when tightness in the iliopsoas is present. The cause of this problem is that the gluteus maximus is inhibited each time the hip extends against its restrictive barrier of motion, decreasing the hip extension range (Panayi, 2009:4).

Since the gluteus maximus is a prime mover in hip extension, the inhibition of the muscle places an increased load on hamstring synergists (Sahrman, 2002:139). Inappropriate activation of the gluteus maximus in gait has been found to cause lower back pain, resulting in a deficiency in the shock absorption mechanism at the sacroiliac joint (Hossain & Noakes, 2005:280). In subjects where the gluteus maximus is inhibited, earlier activation of the hamstrings and erector spinae muscles occur to stabilize the lumbar spine (Sahrman, 2002:37). Mobilizations performed on the anterior hip capsule have shown to increase gluteus maximus strength (Yerys *et al.*, 2002:223). Muscle weakness may therefore be influenced by inhibition related to capsular hypomobility of the hip joint. Therefore, if the innominates of the pelvis are not anterior tilted, the gluteus maximus will function properly as the prime hip extensor and pelvis stabilizer in gait. The hamstrings can act as a synergist in hip extension as it is supposed to.

To determine the order of muscle firing of the erector spinae, hamstrings and gluteus maximus, the prone hip extension test is used. The prone hip extension test was developed by Janda (1996:99) and involves having a subject lie prone and alternatively lift each leg behind his/her body into the air (Figure 2.5). An examiner attempts to determine, either by palpation or observation, the order of activation of the ipsilateral gluteus maximus, ipsilateral hamstring, ipsilateral erector spinae, and contralateral erector spinae muscles. This movement was thought to simulate hip extension while in a standing position. It was proposed that if an “abnormal” muscle activation pattern was used, for instance if the erector

spinae and hamstrings are first to be activated and the activation of the gluteus maximus delayed, it could be a risk factor for lower back pain and dysfunction (Janda, 1996:101).

The validity and reliability of determining the order of muscle activation, either by palpation or observation, during performance of the prone hip extension test has never been investigated (Bruno *et al.*, 2008:5). It has also been demonstrated that both lower back pain and non-lower back pain subjects are not consistent with regard to the activation orders they use when performing this movement over a series of repetitions. The original contention that a delay in gluteus maximus activation is abnormal for this movement has been challenged by several studies as it appears that gluteus maximus is most commonly the final muscle to become active in prone hip extension (Sakamoto *et al.*, 2009:108; Bruno & Bagust, 2007:76). The study of Sakamoto *et al.* (2009:108) found that the firing order for prone hip extension is as follows: first the semitendinosus, followed by the contralateral erector spinae, ipsilateral erector spinae, and finally by the gluteus maximus. Sakamoto *et al.* (2009:108) indicated that in 82% of the cases, the gluteus maximus was the last muscle to be activated. Bruno and Bagust (2007:76) also found that in subjects with or without lower back pain, the hamstrings, contralateral erector spinae and ipsilateral erector spinae became active before the gluteus maximus, with the differences in the onset times of the first three muscles being quite insignificant. In a study by Lewis *et al.* (2009:36) subjects started with the hip joint angle at 10° of hip flexion in the prone hip extension test. They did this to prevent hip hyperextension as it was previously found in a study that in prone hip extension the hip is in hyperextension (Sahrman, 2002:32). This could cause the hamstrings and ES to activate first in the studies by Sakamoto *et al.* (2009:108) and Bruno and Bagust (2007:76). Currently the PHE is the only standardised method for determining hip extension.

However, Sahrman (2002:15) stated that when too much delay is seen in gluteus maximus activation during prone hip extension, hip extension is achieved primarily by the hamstring muscles. This compensatory action causes a compensatory anterior pelvic tilt and therefore lumbar hyperlordosis. Bruno and Bagust (2007:76) also found that the onset time of the gluteus maximus relative to the onset of leg

movement was significantly delayed in patients with lower back pain. These findings may suggest that, although the gluteus maximus muscle is usually the final muscle to become active, the timing of its activation may be an important indicator of the motor control utilized during this movement (Bruno *et al.*, 2008:5). Motor control parameters are important as they represent the body's ability to provide the necessary stability around the spine during movement to prevent tissue injury (Murphy *et al.*, 2006:375).

Takasaki *et al.* (2009:487) also found that when compression force was applied across the pelvis, the onset delay of the gluteus maximus was reduced. The gluteus maximus compresses the SIJ to provide stability of the pelvis, causing force closure (Hossain & Noakes, 2005:279). A lack of control of the pelvis may further increase the movement of an already mobile lumbar spine segment (McConnell, 2002:185). It was found that especially medial compression force on the pelvis increases force closure at the SIJ (Pel *et al.*, 2008:1881). Mens *et al.* (2006:125) found that medially applied pelvis force at the level of the anterior superior iliac spines produced significant less SIJ laxity. Takasaki *et al.* (2009:488) found that the stronger the force application across the pelvis, the earlier the onset of gluteus maximus activation occurred during the prone hip extension. If lumbo-pelvic dysfunction is reduced by the force closure of the trunk muscles responsible for SIJ compression, the onset of the gluteus maximus activation will occur earlier. It could be that the other three muscles become active first in order to stabilize the lumbar spine and knee before the gluteus maximus becomes active to extend the hip. If this is the case, then it is possible that a delay in the gluteus maximus activation could cause the other muscles such as the hamstrings and erector spinae to compensate, not by contracting earlier, but, rather by contracting with greater force (Bruno & Bagust, 2007:76).

Oh *et al.* (2007:323) looked at the effects of doing an abdominal drawing-in manoeuvre during prone hip extension on activation in back and hip extensor muscles. It is known that the abdominal drawing-in manoeuvre activates the transverse abdominus (Norris, 1995:33). The EMG signal amplitude decreased significantly for erector spinae and increased significantly for gluteus maximus and medial hamstrings when the subjects performed the abdominal drawing-in

manoeuvre prior to hip extension. The angle of anterior pelvic tilt also reduced when subjects performed the abdominal drawing-in. In a study by Chance-Larson *et al.* (2009:4) when the subjects performed the abdominal drawing in manoeuvre, the gluteus maximus activation delay was reduced, relative to the biceps femoris. It also reduced the angle of anterior pelvic tilt. Studies have linked hamstring injuries to lumbar lordosis (Hennessey & Watson, 1993:245). The abdominal drawing in manoeuvre could have an effect on the length-tension relationships within the biceps femoris, as an increased lumbar lordosis, associated with an increased anterior pelvic tilt, elongates the hamstrings, increasing the mechanical stress and strain in the hamstrings (Hunter & Speed, 2007:266). If this abdominal drawing-in action can increase gluteus maximus activation relative to biceps femoris, the gluteus maximus could contribute more in controlling hip momentum, and thereby reducing the imposed demands on hamstrings (Chance-Larson *et al.*, 2009:4).

From these studies the conclusion can be drawn that there is a possible connection between the abdominal drawing-in manoeuvre and transverse abdominus activation (TrA) and a decreased anterior pelvic tilt. There could also be a connection between transverse abdominus activation and a decreased anterior tilt and earlier gluteus maximus activation in the prone hip extension. There could also be a connection between the earlier gluteus maximus activation and delayed erector spinae and hamstrings activation in the prone hip extension test. Therefore it is possible that there could be a combined connection between all these factors and that they could possibly influence one another.

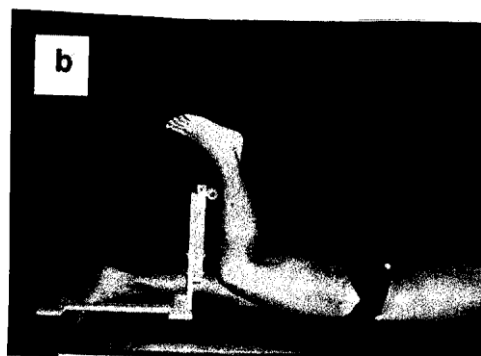


Figure 2.5: Prone hip extension (Sakamoto *et al.*, 2009:107)

6. TRANSVERSE ABDOMINUS ACTIVATION IN HAMSTRING INJURY

The origin of the transverse abdominus muscle is the inner surfaces of the cartilage of the lower six ribs, the thoraco-lumbar fascia (TLF), the anterior, internal lip of the iliac crest, and the lateral third of the inguinal ligament. The muscle fibres run transversely to insert into the linea alba, pubic crest and pecten pubis (Seeley *et al.*, 2000:334). The action of this muscle flattens the abdominal wall and compresses the abdominal viscera (Seeley *et al.*, 2000:334).

The transverse abdominus is the deepest of the abdominal muscles and it contributes primarily to the stabilization of the spine. This occurs through either its role in the development of intra-abdominal pressure, or tension in the thoracolumbar fascia (Cresswell *et al.*, 1994:340; Tesh *et al.*, 1987:508). The aponeurosis of the transverse abdominus is continuous with the middle portion of the thoracolumbar fascia. These fibres are then continuous with the lateral raphe of the thoracolumbar fascia and hence the internal obliques muscles (Vleeming *et al.*, 1995:134). The extensive attachments of the transverse abdominus to the thoracolumbar fascia makes it one of the most capable of all muscles in tensioning the thoracolumbar fascia (Hodges & Richardson, 1998:53).

Contraction of the transverse abdominus has been found to be the first trunk muscle to be activated before lower limb movement and it is independent of the directions of movement (Hodges & Richardson, 1997:1221). This feedforward mechanism limits excessive tissue loading (Chance-Larson *et al.*, 2009:4). Panjabi (1992:387) proposed a hypothesis of spinal stability based upon the concept of a neutral zone – a region of intervertebral motion around a neutral position where little or no resistance from the supporting spinal structures occurs. Spinal stability can be enhanced by facilitating a co-contraction of the muscles surrounding the lumbar spine (Richardson *et al.*, 1990:7). The transverse abdominus, especially, is able to control the neutral zone both in the lumbar spine and at the sacroiliac joint (Barker *et al.*, 2004:137). Therefore, delayed activation of the transverse abdominus will cause increased movement at the sacroiliac joint and cause earlier

activation of the biceps femoris, which will increase the compression of the sacroiliac joint (Hungerford *et al.*, 2003:1596).

Transverse abdominus activation is measured by the use of a pressure biofeedback unit. The biofeedback unit consists of a rubber bladder and pressure gauge similar to a sphygmomanometer. The pressure biofeedback unit is a tool developed to aid the retraining of the stabilizing muscles using specific exercises, and detects movement of the lumbar spine in relation to an air-filled reservoir (Jull *et al.*, 1992:192). In the crook lying position, the bladder of the unit is placed beneath the subject's lumbar spine between L1 and L5. It is then inflated to show a constant pressure of 40 mmHg.

Abdominal hollowing has shown to produce muscle activity suitable for lumbar stabilization (Richardson *et al.*, 1990:7). This action has shown to dissociate activity in the internal obliques and transverse abdominus from that of the rectus abdominus (Richardson *et al.*, 1992:111). Abdominal hollowing is achieved by patients drawing in the abdomen, without allowing significant lumbar flexion. This is easier if they are asked to focus their attention on the umbilicus, this area becoming the focus for movement control. Patients are instructed to pull their umbilicus in and up while breathing normally (Norris, 1995:33). Restoration of the abdominal hollowing mechanism can be enhanced by the use of pressure biofeedback (Chattanooga Group Limited, Bicester, UK). The subject is instructed to contract the abdominal muscles without performing a posterior tilt. If the lordosis is unchanged, a constant pressure is shown on the pressure unit (Figure 2.6). Increasing pressure shows flattening of the lumbar lordosis (lumbar flexion) while reducing pressure shows an increased lordosis (lumbar extension) (Figure 2.6). Excessive motion in either direction represents loss of lumbar stability (Norris, 1995:33).

Common errors in the execution of this exercise include holding the breath and practicing a valsalva manoeuvre. Patients often inhale and raise the rib cage to make the abdomen appear flatter. Posterior pelvic tilting and depression of the anterior rib cage is indicative of unwanted rectus abdominus activity (Norris, 1995:33). Previous research has indicated that specific testing using the pressure

biofeedback was reliable in identifying the presence of transverse abdominus dysfunction (Richardson & Jull, 1995:6; Richardson *et al.*, 1992:108). Thus, this is an indication that the pressure biofeedback unit can be used to identify whether transverse abdominus activation is dysfunctional. It can identify whether subjects are using their rectus abdominus and oblique muscles rather than the transverse abdominus for stabilization of their neutral zone.

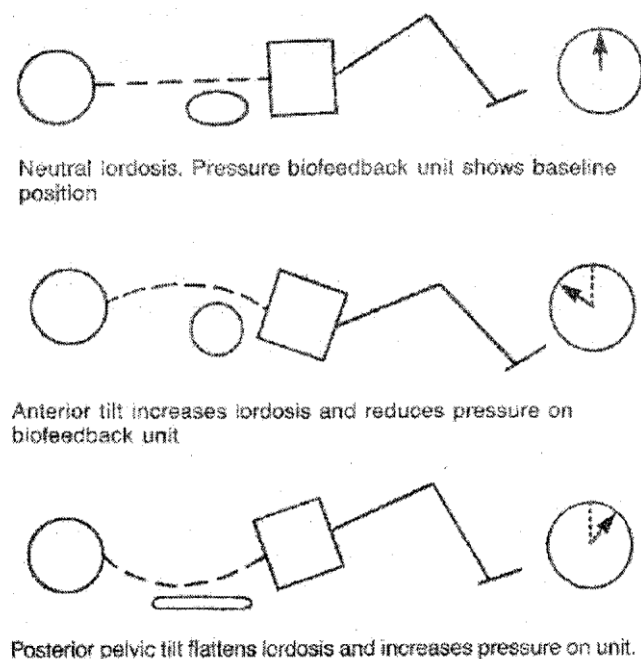


Figure 2.6: Use of pressure biofeedback to assist in recognition of pelvic tilt (Norris, 1995:33)

7. REHABILITATION OF HAMSTRING INJURIES

No consensus exists for the rehabilitation of hamstring injuries. This may be due to the lack of knowledge of the aetiological and predisposing factors for injury (Hoskins & Pollard, 2005b:186). Watson (1983:237) found that the degree of lumbar lordosis increased during the course of two seasons in football players. Some exercises have been identified to increase lumbar lordosis (Watson, 1983:237). Kicking and abdominal strengthening exercises with straight legs have been identified as possible contributors to lumbar lordosis. The anatomical reason

seems to be that the iliopsoas muscle group is primarily involved in kicking and straight leg raising or straight leg sit-up exercise and these exercises contribute to strengthening the iliopsoas. Lumbar lordosis is a risk factor for hamstring injuries (Watson, 1983:237). Therefore, it is possible that certain athletic activities and training methods may exacerbate postural defects which may predispose the players to injury (Hennessey & Watson, 1993:245).

The hamstring and quadriceps co-contract during the early stance phase of running as the knee flexes after ground contact and then extends. If quadriceps force during this co-contraction is in excess of the hamstring muscles' capacity, then hamstring injury may be possible. For instance, during rehabilitation it is possible that players continue to strengthen their uninjured quadriceps and that this strengthening may further reduce their hamstring:quadriceps ratio, which has been suggested as a risk factor for injury (Crosier, 2004:689). This may occur by increasing the number of lower limb strength exercises, where the players are unaware that they are increasing their uninjured quadriceps muscles without activating the hamstring muscles (Cameron *et al.*, 2003:104).

It is agreed for rehabilitation that it is important to restore strength, endurance and flexibility prior to return to competition (Hoskins & Pollard, 2005b:186). Isokinetic normalization by rehabilitation has shown to reduce hamstring muscle re-injury (Crosier *et al.*, 2002:202). Functional rehabilitation incorporating coordination, skill patterns, power and agility to progress the athlete to sport-specific activities should be incorporated in rehabilitation (Lephart & Henry, 1995:579). If sprint drills are utilized, it should be on an adequate foundation of general fitness and implemented slowly from walking drills with maintenance of pelvic stability. Specific training will include sprint and running retraining for all playing positions. Players need to progress the sprint drills to more difficult drills while maintaining abdominal control (Devlin, 2000:285). It has been suggested that return to full speed running and training should only occur when normal hamstring strength (>90% of the uninjured side) and range of motion have returned (Heiser *et al.*, 1984:370). Research is needed to clarify the best return-to-play protocol for hamstring injury (Hoskins & Pollard, 2005b:186).

7.1 Lumbopelvic and neuromuscular control in hamstring injuries

Sherry and Best (2004:122) conducted a clinical trial that produced evidence that rehabilitative exercises targeting neuromuscular control of muscles in the lumbopelvic region (eg. abdominal obliques, erector spinae, iliopsoas) along with progressive agility should be included in hamstring rehabilitation programs. Their study compared two hamstring rehabilitation programs where one group were given static stretching, isolated progressive hamstring resistance exercises and the other group was given a programme of progressive agility and trunk stabilization exercises. The trunk stabilization exercises consists of prone abdominal body bridge, supine extension bridge and side bridge which target static and dynamic control of the lumbopelvic-hip region (Sherry & Best, 2004:120). There was no significant difference between the groups with regard to the time required to return to sport, but there was a significant difference in the re-injury rate after two weeks and after one year. The group of athletes that had trunk stability exercises had no recurrence of hamstring injury at two weeks and only one recurrence at one year, whereas for the athletes in the other group, six had a recurrence of their injury within two weeks and ten had reported a recurrence at one year follow up (Sherry & Best, 2004:121).

Hoskins and Pollard (2005c:2) studied the effect on hamstring injuries by improving the muscle activation of multifidus, transverse abdominus and internal obliques in two Australian Rules football players. Both case reports finished the season without re-injury. This suggests that a lack of neuromuscular control of the trunk and pelvis may contribute to hamstring injuries. Neuromuscular control and proprioceptive defects as determined by lumbar-pelvic position sense are known to exist in lower-back pain populations (O'Sullivan *et al.*, 2003:1076). This may contribute to hamstring injury through deficiency in neuromuscular motor control of the hamstring muscles or lumbar-pelvic functional instability (O'Sullivan *et al.*, 2003:1076). Therefore players suffering from recurrent hamstring injuries could have a neuromuscular motor control problem of the pelvic stabilizing muscles. Improving the neuromuscular control of the pelvis by strengthening the transverse abdominus, gluteus maximus, internal obliques and multifidus could reduce the risk for re-injury.

8. CONCLUSION

Although lumbar-pelvic or body mechanics has proven to be risk factors for hamstring injuries, it is unclear as to whether improving factors, such as lumbar lordosis, improving lumbar-pelvic stabilizers and gluteal strength, will decrease the risk for hamstring injury (Hoskins & Pollard, 2005a:103). Successful resolution of hamstring injury may involve the following improvements: firstly lengthening myofascial components that contribute to excessive lumbar lordosis, anterior pelvic tilt, and pelvic obliquity; secondly, mobilizing the sacroiliac joint/anterior hip joint to stimulate joint receptors and facilitate gluteus maximus and the hamstrings; thirdly, incorporating balance-challenging exercises to further stimulate joint proprioceptor activity and enhance gluteal strength; and fourthly, incorporating strengthening exercises for the lumbar-pelvic stabilizer muscles to create and maintain a balanced pelvis (Panayi, 2009:5). Only one case report could be identified, which provided positive results from improving body and lumbar-pelvic mechanics (Hoskins & Pollard, 2005c:4). Sherry and Best (2004:125) also produced positive results with their study where they compared two rehabilitation programs, one with stretching and hamstring resistance exercises and one with trunk stability and agility exercises. Only one re-injury occurred in the group with the trunk stability exercises whereas a couple of re-injuries occurred in the other group. Prospective studies assessing the effectiveness of improving lumbar-pelvic mechanics and looking at the relationship of body posture, pelvic tilt, leg length and scoliosis are still needed (Hoskins & Pollard, 2005a:103). Methods for improving neuromuscular control and lumbar-pelvic proprioception for the rehabilitation of hamstring injuries also need to be identified (Hoskins & Pollard, 2005b:13).

Due to the findings of various studies of the gluteus maximus muscle to be activated last, future research should examine whether the prone hip extension can be used as a valid assessment of pathological muscle coordination or the evaluation of intervention strategies in the pelvic hip region (Bruno & Bagust, 2007:76). Also, prone hip extension is an open kinetic chain, non-weight bearing position performed by concentric muscle contraction. Joint afferent activity and recruitment strategies will be different from those in gait (Vogt *et al.*, 2003:22).

Further studies should also be performed to investigate whether an earlier onset of gluteus maximus during hip extension actually leads to enhanced stability in the pelvic region (Bruno *et al.*, 2008:11).

No previous studies have investigated the influence of excessive anterior pelvic tilt, causing abnormal lumbar lordosis, on gluteus maximus and transverse abdominus activation in rugby players, neither has previous research been done on the influence of delayed transverse abdominus and gluteus maximus activation and anterior pelvic tilt on hamstring injury in rugby players. Chance-Larson *et al.* (2009:4) found that with intervention exercise of abdominal hollowing during the prone hip extension test, the gluteus maximus activation delay was significantly reduced relative to the biceps femoris activation. It is known that the abdominal drawing-in manoeuvre activates the transverse abdominus (Norris, 1995:33). The angle of anterior pelvic tilt also reduced when subjects performed the abdominal drawing-in (Oh *et al.*, 2007:323). Studies investigating the influence of a combination of factors such as anterior pelvic tilt, transverse abdominus- and gluteus maximus activation on hamstring activation in the prone hip extension test and hamstring injuries are needed.

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Chapter 3

Pelvis biomechanics and gluteus maximus, hamstring and erector spinae activation patterns in semi-professional Rugby Union Players

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ABSTRACT

Delayed gluteus maximus (GM) activation during hip extension causes earlier activation of the hamstring and erector spinae (ES) muscles to stabilize the spine. Transverse abdominus activation (TrA) was found to be activated before lower limb movement starts. The transverse abdominus (TA) activated by the abdominal drawing-in maneuver, resulted in a prevention of anterior tilt and delayed GM activation during prone hip extension (PHE). This study investigated the activation patterns of GM, hamstrings and ES and the influence of TrA and pelvic tilt on the muscle activation patterns of young semi-professional rugby union players. A total of 65 players voluntarily participated in this study. Anterior pelvis tilt (left and right) was assessed by Dartfish (Dartfish Switzerland). TrA was assessed by pressure biofeedback (Chattanooga UK) and the mean onset times of the left and right GM, biceps femoris (BF), semitendinosus (ST) and lumbar ES was recorded with surface electromyography (EMG) (Noraxon USA). Activation patterns were determined by means of descriptive statistics of the firing order of the muscles. The mean onset of each muscle was calculated for participants with normal and anterior pelvis tilt as well as for participants with good and bad TrA. The between-group differences in the muscle onset times were analysed by determining practical significance by means of effect sizes (Cohenn d). An anterior pelvis tilt on the left side was observed in 64.6% of the participants and on the right side in 83.1% of the participants. TrA activation testing indicated that 68.4% of the participants were classified as presenting with bad and 31.6% with TrA good activation. The activation pattern observed in this study for the muscles measured was in order of: ES, GM, BF and ST. To conclude, there is some preliminary evidence to suggest that semi-professional rugby union players in this co-hort tested are inclined to present with an anterior tilted pelvis and bad TrA that may influence the activation patterns of the ES, GM and hamstrings in the PHE.

Keywords: Pelvis biomechanics, electromyography, rugby union

1. INTRODUCTION

“The neuromuscular activation of the muscles in the pelvic region plays a primary role in the physiologic coordination and interaction of the pelvis, spine and lower limb” (Panjabi 1992). Transverse abdominus activation (TrA) was found to be initiated before lower limb movement starts (Hodges & Richardson 1997). This finding is supported by the results obtained with electromyography (EMG) measurements during hip flexion in standing, where the transverse abdominus (TA) activation on the side of the supporting leg occurred before movement of the free leg to hip flexion (Hungerford et al., 2003). Delayed TA activation was found to cause increased sacroiliac joint (SIJ) movement and cause earlier activation of the biceps femoris to stabilize the SIJ due to its attachment through the sacrotuberous ligament on the SIJ (Hungerford et al., 2003).

Janda (1996) developed the prone hip extension test to determine the firing order of the erector spinae (ES), hamstrings and gluteus maximus (GM). An “abnormal” activation pattern is considered when the ES and hamstrings are activated first and the GM activation delayed. This “abnormal” activation pattern has been challenged by several studies (Sakamoto et al., 2009; Bruno & Bagust 2007). The ES and hamstring muscles were found to be activated first and the GM activation delayed in the prone hip extension (Bruno & Bagust 2007; Sakamoto et al., 2009). However, Sahrman (2002) stated that when too much delay is seen in gluteus maximus activation during prone hip extension, hip extension is achieved by the hamstring muscles. Delayed gluteus maximus activation during prone hip extension causes earlier activation of the hamstrings and ES muscles in order to stabilize the lumbar spine. This adjusted activation pattern resulted in a compensatory anterior tilt and hyperlordosis of the lumbar spine (Sahrman 2002). Increased anterior pelvis tilt has been specifically identified as a risk factor for hamstring injuries in runners (Brukner & Khan 2002). The lower crossed syndrome, which occurs with tightness of the iliopsoas and ES and weak inhibited gluteal- and abdominal muscles, result in an anterior tilt and hyperlordosis of the lumbar spine (Janda 1996). The GM then compresses the SIJ to provide stability of the pelvis (Hossain & Noakes 2005). When a compressive force was applied

across the pelvis in the prone hip extension the GM onset delay was significantly reduced (Takasaki et al., 2009). When the TA was activated by the abdominal drawing-in maneuver, the anterior pelvis tilt and GM activation delay relative to the ES and hamstring muscles during prone hip extension was reduced (Norris 1995; Oh et al., 2007).

No previous studies have investigated the influence of pelvis tilt and transverse abdominus activation (TrA) on GM, hamstrings and ES activation patterns in young semi-professional rugby union players. Biomechanical principles dictate that restriction or tension in one part of a kinetic chain will create increased load on other parts of the same chain (Sahrman 2002). According to Sahrman (2002), delayed GM activation in hip extension will cause the hamstrings and ES muscles to activate earlier than usual, stabilizing the lumbar spine with the resulting overloading. The purpose of this study was to determine the role of the pelvis biomechanics (pelvis tilt and TrA) on the activation patterns of the GM, hamstrings and ES in semi-professional rugby union players of the Rugby Institute of the North-West University.

2. METHODS

2.1 Participants

Participants for this study were recruited from the 80 rugby union players of the U/19 and U/21 teams of the Potchefstroom Rugby Institute via the rugby coaches of the North-West University (Potchefstroom Campus). Players with injuries were excluded from this study. A total of 65 players voluntarily gave informed consent to be tested. Before participating in the study each participant read a study information sheet and signed an informed consent form. Ethical approval was obtained from the Ethics Committee of the North-West University.

2.2 Study design

This is a once-off subject availability study with the pelvic biomechanics (TrA and pelvic tilt) and muscle (GM, ES and hamstring) activation patterns being measured before the start of the rugby season of 2010. In order to determine the influence of

pelvic tilt and TrA on muscle activation patterns, participants were grouped according to normal and abnormal results for anterior pelvis tilt and good and bad TrA.

2.3 Demographics

The stature of each participant was measured to the nearest 0.1 cm, with a stadiometer (Seritex) using the stretch stature method (ISAK 2001). Body mass was measured to the nearest 0.1 kg with an electronic weighing scale (Micro) (ISAK 2001).

2.4 Pelvic alignment

Pelvic alignment was measured by placing bright orange markers, 1 cm in diameter, on the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS). Digital photos were taken of the left and right lateral view of each participant. The camera was positioned 2.5 meters from the subject. Pelvis tilt angle was then analysed for each player from the digital photo making use of Dartfish computer software program version 4.06.0 (Dartfish, Switzerland). Pelvic tilt is defined by the angle formed between the line connecting the ASIS with the PSIS and the line horizontal with the floor (Sprigle et al., 2003). Normal pelvic tilt angle is indicated to be between 7 – 15 degrees (Magee 2002) and reported to the nearest 1 degree.

2.5 Transverse abdominus activation

Transverse abdominus activation (TrA) was determined by a pressure biofeedback unit (PBU) (Chattanooga Group limited, Bicester, UK) (Richardson & Jull 1995). With the TrA activation assessment the PBU was placed beneath the lower back (L4 – L5) and inflated to 40 mmHg while the participant's hips and knees were flexed to 90 degrees (Ashmen et al., 1996). The participants had to maintain the pressure at 40 mmHg on the cuff while slowly lowering their legs to the floor until both the knees and hips were fully extended (Ashmen et al., 1996). Athletes with good TrA patterns and strength will be able to maintain the pressure at 40 mmHg

until their hips and knees are fully extended (Ashmen et al., 1996). When the pressure on the cuff started to decrease, even after the first warning to maintain the correct posture, the hip angle was measured with a goniometer and recorded. TrA was classified as follows using the measured hip angle when pressure on the cuff started to drop: 0 = 90 - 75° (Very bad), 1 = 74 - 60° (bad), 2 = 59 - 45° (Average), 3 = 44 - 30° (Good), 4 = 29 - 15° (Very Good), 5 = 14 - 0° (Excellent) (Kendall et al., 2005). For statistical analysis the groups were reduced to a bad and a good TrA group. The very bad, bad and average groups were recorded as the bad TrA group and the good, very good and excellent groups were grouped as the good TrA group.

2.6 Electromyography

Activation patterns of the left and right gluteus maximus, semitendinosus, biceps femoris and erector spinae muscles were analysed with an electromyograph (EMG) (MyoTrace 400, Noraxon USA, Inc., Scottsdale, Arizona). Latency was measured in time (ms) and muscle activation in microvolt (mV). Skin preparations involved shaving the hair on the surface and swabbing the skin with alcohol. Markers indicating anatomical landmarks were placed on the first and last sacral vertebrae, medial and lateral femoral condyle and greater trochanter (Konrad 2005). Two pre-gelled self-adhesive active Ag/AgCl surface electrodes (1 cm in diameter) were placed 2 cm apart, parallel to the muscle fiber direction (Chance-Larson et al., 2009). For measurements, electrodes were placed midpoint between the last sacral vertebrae and greater trochanter, for gluteus maximus, medially on mid-distance between the gluteal fold and medial condyle, for semitendinosus, on mid-distance between the greater trochanter and lateral condyle, for biceps femoris, parallel to the lumbar spine at L3, 2 cm lateral to the spinal processes, for erector spinae (Sakamoto et al., 2009). The total movement performed by the participant was captured on video ensuring visibility of the placed markers. For EMG testing participants were prone on a plinth with the knee to be tested, flexed to 90 degrees (Sakamoto et al., 2009). A marker was placed 15 cm above the foot to ensure a consistent range of motion with hip extension. The participant extended his leg on the command "Contract!" During each extension

the participant's foot touched the marker before relaxing back to the plinth. Three trials were performed of which the best trial was used for statistical analyses.

The EMG signals were full wave rectified, low and high-pass filtered, with cut-off frequencies of 500 and 10 Hz, respectively, and recorded at a sampling rate of 1000 Hz (Sakamoto et al., 2009). Muscle activation patterns were described after determining the EMG onset for each muscle. The computer-identified data points for muscle activity were determined by visual inspection. The visual onset was identified at the point where the EMG activity clearly deviated from the baseline (Marshall & Murphy 2003). Hodges and Bui (1996) found that visual determination of EMG onset was highly repeatable. The onset of muscular activity was considered to occur when the value exceeded two standard deviations from the mean value observed at baseline for a 50 ms period (Hodges & Bui 1996; Brindle et al., 1999).

2.7 Statistical analysis

Data were analyzed using SPSS (Statistical Package for the Social Sciences) version 17 (SPSS Inc. Chicago, Illinois, USA). Descriptive statistics were performed to describe the characteristics of the participants reporting means and standard deviations. The description of the activation patterns was calculated with frequencies. The mean onset of each muscle was calculated for the normal and anterior pelvis tilt groups as well as for the good and bad TrA groups. The between-group differences in the muscle onset times were analysed by determining practical significance by means of effect sizes ($d=0.2$ small, $d=0.5$ medium, $d=0.8$ large) (Cohen 1988). The statistical analyses were performed by the Statistical Consultation Services of the North-West University.

3. RESULTS

The results of this study that investigated the muscle activation patterns of the gluteus maximus, biceps femoris, semitendinosus and erector spinae muscles related to the hip together with pelvis biomechanics were performed in the semi-professional rugby players. The results of the participant's characteristics are presented in Table 1.

Table1: Characteristics of the participants

	N	Mean	Std. Deviation
Age (years)	65	19.12	1.18
Stature (cm)	65	182.81	8.38
Body mass (kg)	65	92.54	13.07

The majority of the participants was dominant in the right leg (86.2%) and 56.9% played in one of the forward positions in the game of rugby union. The results of the pelvis tilt measurement indicated that an anterior tilt on the left side was observed in 64.6% of the participants and on the right side in 83.1 % of the participants.

TrA activation testing by means of the PBU indicated that 68.4 % of the participants were classified as having bad TrA activation and 31.4% of the participants were classified as having good TrA (Kendall et al., 2005). Results of the muscle activation patterns (Figure 1) as tested with EMG on the right and left side of the participants presented the following muscle activation order: ES, GM, BF and ST.

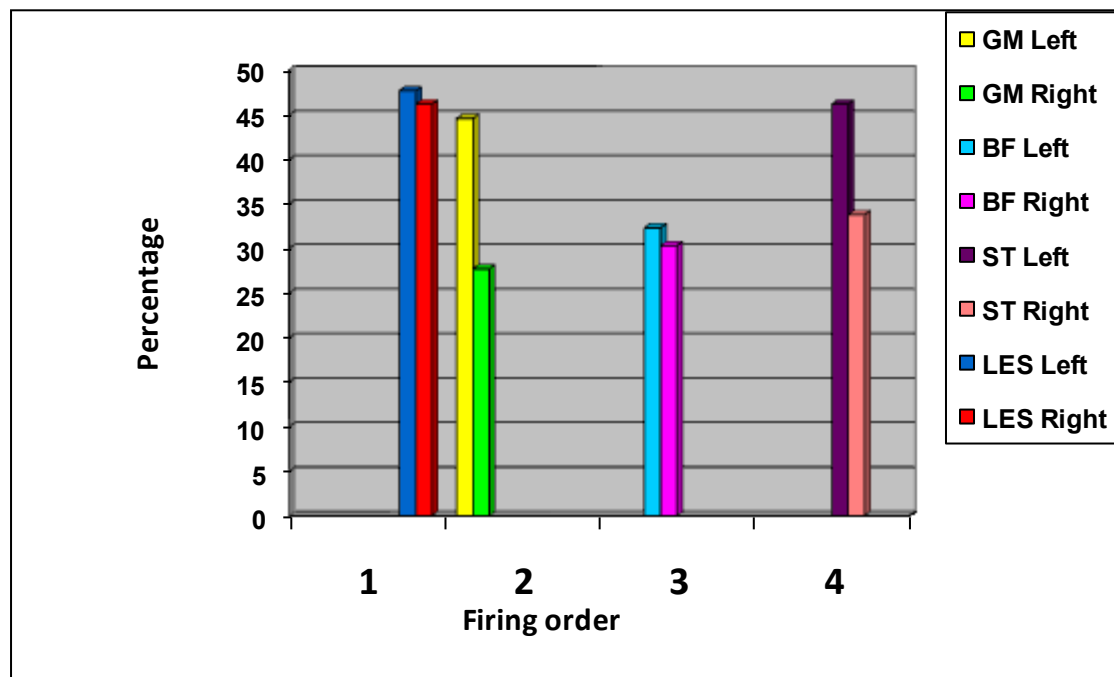


Figure 1: The average firing order (percentage) for each muscle tested left and right, presenting the general firing order of the muscles tested in the semi-professional rugby players tested. (GM = gluteus maximus, BF = Biceps femoris, ST = Semitendinosus, LES = Lumbar Erector spinae)

When the general activation pattern for all participants (frequency of activation (%)) of the muscles was analysed for participants with normal and anterior pelvic tilt (Table 2) the results indicate that there is not a practical significant difference in the frequency of activation of the muscles in the normal pelvic tilt group compared to the anterior pelvic tilt groups left. The LES being activated first, GM second, BF third and ST last. However, the results for activation frequency were exactly the same for all the muscles tested in the anterior pelvic tilt group left with the activation order of LES, GM, BF and ST equally activated third (25%). On the right side the frequency of activation in the normal and anterior pelvic tilt groups was slightly different. The GM was mostly activated third (27.8%) in the anterior pelvic tilt groups. In the right side of the normal pelvic tilt group the BF activated third most of the time (54.5%). Results also indicated equal activation frequency on the right side with the GM, BF and ST in the normal pelvic tilt group (27.3%) and in the anterior pelvic tilt group (27.8%).

When the frequency of activation patterns were compared for the participants, divided into a good TrA and bad TrA group (Table 2), the results indicate that LES was activated first in both groups for left and right. The GM activated second in participants with bad and good TrA left but the frequency differed for the right side. In participants with bad TrA the firing order right was: LES, BF, GM and ST. In participants with good TrA the firing order was: LES, ST, BF and with GM activated last with only 20%.

Table 2: Frequency of the muscle activation sequence with relation to pelvic tilt and TrA for both the left and right sides

Activation sequence	Frequency of muscle activation							
	Pelvis tilt (L)		Pelvis tilt (R)		TrA (L)		TrA (R)	
	Normal	Anterior	Normal	Anterior	Bad	Good	Bad	Good
First								
GM %	16.0	27.5	18.2	16.7	28.9	10.0	11.1	30.0
BF %	8.0	12.5	0.0	20.4	11.1	10.0	15.6	20.0
Sem %	24.0	15.0	18.2	20.4	13.3	30.0	22.2	15.0
LES %	52.0	45.0	63.6	42.6	46.7	50.0	51.1	35.0
Second								
GM %	56.0	37.5	27.3	27.8	40.0	55.0	28.9	25.0
BF %	12.0	22.5	27.3	27.8	22.2	10.0	33.3	15.0
Sem %	8.0	12.5	27.3	27.8	11.1	10.0	24.4	35.0
LES %	24.0	27.5	18.2	18.5	26.7	25.0	15.6	25.0
Third								
GM %	16.0	25.0	36.4	27.8	22.0	20.0	31.1	25.0
BF %	44.0	25.0	54.5	25.9	33.3	30.0	28.9	35.0
Sem %	24.0	25.0	0.0	22.2	20.0	35.0	17.8	20.0
LES %	20.0	25.0	9.1	24.1	24.4	20.0	22.2	20.0
Fourth								
GM %	12.0	10.0	18.1	27.7	8.9	15.0	28.9	20.0
BF %	36.0	40.0	18.2	25.9	33.4	50.0	22.2	30.0
Sem %	44.0	47.5	54.5	29.6	55.7	25.0	35.6	30.0
LES %	4.0	2.5	9.1	14.8	2.2	5.0	11.1	20.0

The percentages were calculated in 65 rugby union players. Each subject performed 1 set of 3 repetitions. (GM= Gluteus maximus, BF = Biceps femoris, Sem = Semitendinosus, LES = Lumbar Erector Spinae).

An analysis of the muscle activation onset times (Table 3), comparing the means of the participants with normal pelvic tilt to participants with an anterior pelvic tilt, indicated that, although no practical significance in different onset times were reported for normal compared to anterior tilt, in most of the instances of normal pelvis tilt the mean onset time of the muscles on the right side were delayed compared to the mean onset time of the muscles on the left side, except for the lumbar erector spinae. In the participants with an anterior pelvis tilt the onset times presented with a different pattern compared to the participants with a normal tilt. The mean onset time of the muscles on the right side were delayed compared to the mean onset time of the muscles on the left side, except for the ST. When the onset times in the two groups were compared no large delay in the mean onset times was indicated, except for the ST and Lumbar ES. The Lumbar ES right and ST left mean onset times were delayed compared to the mean onset times of the normal pelvis tilt group. The mean onset times of the Lumbar ES left and ST right were delayed compared to mean onset times of the anterior pelvis tilt group.

Table 3: Mean onset times (ms) of the gluteus maximus, bicep femoris, semitendinosus and lumbar erector spinae for normal and anterior pelvic tilt reporting the means and standard deviation

Mean Onset times (ms)			
Pelvis Tilt			
	Normal	Anterior	d
Glut Max L			
Mean (SD)	90.7(47.2)	96.8(53.3)	0.11
Glut Max R			
Mean (SD)	114.8(41.3)	119.5(77.4)	0.06
Biceps Fem L			
Mean (SD)	128.8(95.0)	125.1(94.70)	0.04
Biceps Fem R			
Mean (SD)	130.4(66.8)	145.2(156.8)	0.09
Semiten L			
Mean (SD)	125.5(118.6)	141.8(165.70)	0.10
Semiten R			
Mean (SD)	139.8(72.1)	117.5(84.8)	0.26
Lumbar ES L			
Mean (SD)	117.3(204.9)	73.8(46.9)	0.21
Lumbar ES R			
Mean (SD)	73.2(46.1)	110.5(146.8)	0.25

The means and standard deviations were calculated from 65 rugby union players. Each player performed a set of three repetitions. The between-group differences in the muscle onset times were analysed by determining practical significance by means of effect sizes (d). (Glut max = gluteus maximus, biceps fem = biceps femoris, semiten = semitendinosus, Lumbar ES = Lumbar Erector Spinae, L = left, R = right)

Table 4 shows the mean onset times for each muscle in participants with bad and good TrA. Although no practical significance in different onset times were reported for bad compared to good TrA, in most of the cases in participants with bad TrA the mean onset times for the right side muscles were delayed compared to left side muscles except for semitendinosus. The mean onset times of the muscles in participants with good TrA group slightly different in that the right side onset times of the muscles were still delayed compared to the left side in all the muscles except for the biceps femoris where the left side was delayed compared to the right side. When the onset times in the two groups were compared no large delay in the mean onset times was indicated in the GM left and right. In all the other muscles there was a more obvious delay in the mean onset times in the muscles

of the bad and good TrA groups. The mean onset times were delayed in participants with good TrA compared to participants with bad TrA, except for biceps femoris right and semitendinosus left where the mean onset time was delayed compared to participants with normal TrA.

Table 4 Mean onset times (ms) of the muscles of participants grouped in bad and good TrA groups.

	Onset times (ms)		
	TrA		
	Bad	Good	d
Glut Max L			
Mean (SD)	96.2(54.1)	90.7(43.2)	0.10
Glut Max R			
Mean (SD)	117.5(58.2)	121.5(98.7)	0.04
Biceps Fem L			
Mean (SD)	122.2(95.0)	136.4(93.5)	0.15
Biceps Fem R			
Mean (SD)	149.2(159.1)	127.8(109.6)	0.14
Semiten L			
Mean (SD)	143.9(158.3)	116.7(125.6)	0.17
Semiten R			
Mean (SD)	115.7(73.4)	134.0(101.6)	0.18
Lumbar ES L			
Mean (SD)	75.7(44.1)	123.7(230.0)	0.21
Lumbar ES R			
Mean (SD)	92.3(95.4)	130.9(199.3)	0.20

The means and standard deviations were calculated from 65 rugby union players. Each player performed a set of three repetitions. The between-group differences in the muscle onset times were analysed by determining practical significance by means of effect sizes (d). (Glut Max = Gluteus Maximus, Biceps Fem = Biceps Femoris, Semiten = semitendinosus, Lumbar ES = Lumbar Erector spinae, L = left, R = right)

4. DISCUSSION

In this study the activation order of the muscles for the prone hip extension (PHE) in young semi-professional rugby players was determined as follows: ES, GM, BF, and ST. This is different from the firing order found in the study of Sakamoto et al. (2009) reporting the firing order for PHE as: first the semitendinosus (ST), followed by the contralateral erector spinae (ES), ipsilateral ES, and finally by the gluteus

maximus (GM). Bruno and Bagust (2007) also found that in PHE in subjects with or without low back pain, the hamstrings and ES become active before the GM with differences in the onset times quite small. The ES activation in this study correlates with the study of Sakamoto et al (2009) and Bruno and Bagust (2007), but in this study the GM was activated second and the hamstrings last, whereas in the other two studies the hamstrings were activated second and the gluteus maximus last. The studies of Sakamoto et al. (2009) and Bruno and Bagust (2007) analysed the activation patterns of the general population and not those of rugby players, whereas in this study the activation patterns of rugby players were analysed.

The different activation patterns may be influenced by the postural defects that were found in this population of rugby players indicating pelvis tilt abnormalities. Watson (1983:237) found that the degree of lumbar lordosis increased during the course of two seasons in football players. Some exercises have been identified to increase lumbar lordosis (Watson, 1983:237). Kicking and abdominal strengthening exercises with straight legs have been identified as possible contributors to lumbar lordosis. The anatomical reason seems to be that the iliopsoas muscle group is primarily involved in kicking and straight leg raising or straight leg sit-up exercises and these exercises contribute to strengthening the iliopsoas. Therefore, it is possible that certain athletic activities and training methods may exacerbate postural defects which may predispose the players to injury (Hennessey & Watson, 1993:245). It is known that a tight iliopsoas causes an anterior pelvis tilt (Janda 1996). Although some participants were identified with normal pelvis tilt, it could be that the iliopsoas and ES are still overactive relative to the GM and hamstring muscles due to the training programmes of the participants. Therefore, we could suggest that the exercise programmes of high performance athletes may cause muscle imbalances causing altered activation patterns compared to subjects not participating in sport on a high level.

Although there was no practical significance in the difference in the mean onset times of all the muscles tested when participants with normal and anterior pelvis tilt were compared in this study, most of the participants were identified with an anterior pelvis tilt (left and right). The lower crossed syndrome, which occurs with tightness of the iliopsoas and ES and weak inhibited gluteal and abdominal

muscles, results in an anterior tilt and hyperlordosis of the lumbar spine (Janda 1996). The ES mean onset time in participants with normal pelvis tilt was delayed compared to the ES mean onset time in participants with an anterior pelvis (right) in this study. The average anterior pelvis tilt was larger on the right side than the left side in this study. This shows that an anterior pelvis tilt could cause the ES to be activated earlier than in participants with normal pelvis tilt. In a study by Chance-Larson *et al.* (2009) when the subjects performed an abdominal drawing-in manoeuvre (which activates the TA), the angle of anterior pelvic tilt reduced. The GM activation delay was reduced, relative to the ES and biceps femoris. Therefore, it could be that an anterior pelvis tilt causes the ES to shorten and the GM to be inhibited and this could cause the GM activation to be delayed relative to the ES muscles which were activated first in most of the participants in this study. However, in a study by Bruno and Bagust (2007), the original contention that a delay in GM activation is abnormal for the PHE has been challenged as it appears that GM is most commonly the last activated muscle. In a study by Vogt and Banzer (1997) the PHE was initiated by the ipsilateral ES, followed by ST, contralateral ES and lastly the GM muscles. The researchers justified the activation of the lumbar ES during the pre-movement phase as preparation to stabilize the trunk to control the pelvis during leg lifting (Vogt & Banzer 1997). However, Sahrman (2002) stated that when too much delay is seen in gluteus maximus activation during prone hip extension it causes a compensatory anterior pelvic tilt and, therefore, lumbar hyperlordosis. Delayed gluteus maximus activation during PHE causes earlier activation of the hamstrings and ES muscles in order to stabilize the lumbar spine. In this study the GM was activated before the hamstrings most of the times and, therefore, it could be that delayed GM activation caused the ES muscles to activate earlier to stabilize the lumbar spine in PHE.

Furthermore, in this study most of the participants were identified with bad TrA and, although no practical significant between group differences were found in the mean onset times of all the muscles tested when participants with good and bad TrA were compared, we could suggest that bad TrA has an effect on the activation order (ES, GM and hamstrings). The ES mean onset time in participants with good TrA was delayed compared to the ES mean onset time in participants bad TrA.

This could suggest that bad TrA causes the ES to activate earlier than usual. A previous study found significant between group differences in the GM mean onset times relative to the ES and hamstring muscles in groups who performed an abdominal drawing-in maneuver prior to PHE and the group which did not (Oh et al., 2007). The abdominal drawing-in maneuver activates the transverse abdominus (Norris 1995). In the group which performed the abdominal drawing-in maneuver the GM delay in onset time was significantly reduced relative to the hamstring and ES muscles compared to the group which did not perform the abdominal drawing-in maneuver (Oh et al., 2007). In a study by Bruno and Bagust (2007) it was found that in subjects with or without low back pain, the ES and hamstrings become active before the GM in PHE with differences in the onset times quite small. It is known that subjects with low back pain are associated with delayed TrA (Hungerford et al., 2003). However, they found that the onset time of the GM relative to the onset of leg movement was significantly delayed in patients with low back pain. This study also did not exclude participants with low back pain, therefore, it could be that the participants in this study suffered from low back pain due to their training programmes or the physical nature of the game of rugby.

Future studies can determine if muscle activation patterns will differ for the GM, ES and hamstrings in the PHE relative to hip extension in a weight-bearing position, especially in athletes. In this study timing of contraction is only one aspect of function, and no data investigating force or torque generated were collected. Future studies can investigate if force and torque with which the GM or hamstring contracts in hip extension are different in subjects with injury compared to subjects without hamstring injuries.

5. CONCLUSION

The conclusion that can be drawn from this study is that this co-hort of semi-professional rugby union players tested are prone to postural defects such as anterior tilt of the pelvis and that they are prone to present with bad TrA. Most of the participants were identified with an anterior pelvis tilt and bad TrA and according to the literature. We expected these findings to have an effect on the

onset times of the ES, GM and hamstrings in the PHE. However, no practical significant relationship was found when the onset times of participants with an anterior and normal pelvis tilt, and participants with bad and good TrA were compared. The general activation order that occurred in this study was as follows: LES, GM and lastly the hamstrings. We could, however, suggest that the GM delay in the PHE is caused by an anterior pelvis tilt and bad TrA.

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Chapter 4

Hamstring injuries in rugby union: the influence of selected pelvic biomechanics, gluteus maximus, hamstring and erector spinae activation patterns

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ABSTRACT

Hamstring injuries are common in the rugby union. Evidence-based information on risk factors and injury-prevention strategies is limited. Increased lumbar lordosis and anterior pelvis tilt are identified as risk factors for hamstring injuries. With delayed Transverse abdominus activation (TrA) biceps femoris is activated earlier to stabilize the lumbar spine. Gluteus maximus (GM) inhibition during sprinting also requires the hamstrings to contribute more force to hip extension rather than acting in its transducer role, increasing the risk for injury. This study investigates the relationship between pelvis biomechanics (TrA and pelvis tilt) and GM, erector spinae (ES) and hamstring activation patterns and hamstring injuries in semi-professional rugby union players. A total of 65 players voluntarily participated in this study. Left and right pelvis tilt was assessed by Dartfish. TrA was assessed by pressure biofeedback. The mean onset times of the left and right GM, biceps femoris (BF), semitendinosus (ST) and lumbar ES was recorded with electromyography (EMG). The mean onset of each muscle was calculated for participants with normal and anterior pelvic tilt as well as for participants with good and bad TrA. At the end of the 2010 rugby season participants were retrospectively grouped as injured and uninjured and the variables measured pre-season were compared. The between-group differences in the muscle onset times were analysed by determining practical significance by means of effect sizes (Cohen d). The results of this study indicate that no practical significant between group differences were found between the injured and uninjured groups when participants with normal and anterior pelvis tilt right were retrospectively compared ($d=0.061$). No practical significant between group differences were found between the injured and uninjured groups when participants with bad and good TrA were retrospectively compared ($d=0.189$). Therefore, could we conclude that pelvic tilt and TrA may have some effect on the activation patterns of the ES, GM and hamstrings that may lead to hamstring injuries in semi-professional rugby union players.

Keywords: Hamstring injuries, Pelvis tilt, Transverse abdominus activation, Electromyography, Muscle activation patterns

1. Introduction

Hamstring injuries are one of the most common injuries of sport involving the lower body (Orchard et al., 2002) specifically in sports where rapid acceleration and running at maximum speed are required (Hoskins and Pollard, 2005b). Injury surveillances have found hamstring injuries to be very common in rugby union (Targett, 1998). The highest recurrence rate of all football injuries with more than one in three (34%) injuries recurring within the same season is found in the hamstrings (Orchard and Seward, 2002). Verrall et al. (2001) found that players with a history of hamstring injuries were almost five times more susceptible to re-injury than those who had no history of injury. Despite the high incidence of hamstring injuries in professional rugby union (Brooks et al., 2005), evidence-based information on risk factors and injury-prevention strategies is limited (Upton et al., 1996).

Increased lumbar lordosis, as well as an increase in anterior pelvis tilt, has previously been associated with an increased risk of hamstring injury in athletes (Hodges and Mosley, 2003; Hennessey and Watson, 1993). Cibulka et al. (1986) suggest that an anterior pelvic tilt elongates the hamstrings in that it is further away from its origin point, the ischial tuberosity, producing a functional tightness in the hip flexors. A lack of muscular control of the pelvic girdle such as the activation of transverse abdominus may contribute to overuse or repetitive strain of the hamstrings (Devlin, 2000). Transverse abdominus activation (TrA) is known to occur before limb movement (Hodges and Richardson, 1997). The transverse abdominus (TA) and internal obliques attach to the thoracolumbar fascia (TLF) and low level contraction can tension the TLF to stabilize intersegmental lumbar motion (Barker et al., 2004). The biceps femoris (BF) has an indirect connection through the sacrotuberous ligament to the TLF (Woods et al., 2004). With delayed TrA earlier BF activation occurs to stabilize the TLF and thus the lumbar spine (Hungerford et al., 2003). Oh et al. (2007) also found that when an abdominal drawing-in manoeuvre was performed prior to prone hip extension the subjects' anterior tilt was reduced significantly. The BF onset time was also delayed relative to the gluteus maximus. The abdominal drawing-in manoeuvre is known to activate the TA (Norris, 1995) and, therefore, with TrA the BF onset time was delayed.

During sprinting, the hamstrings should act as a transducer of power between the knee and the hip joint and contribute little to hip extension (Jacobs et al., 1996). Although the hamstrings assist in hip extension, recruitment should occur after the prime mover gluteus maximus (GM) has been recruited (Devlin, 2000). When comparing runners suffering hamstring injuries with non-injured runners, a significant loss of hip extensor torque was found in the early support phase of injured runners (Schache et al., 2009). Limitations in hip extensor torques with increased running speed could be caused by limitations in structural tissues (Franz et al., 2009). Shortened psoas and quadriceps muscles are associated with an anterior tilted pelvis (Panayi, 2009). This causes a limitation in hip extension mobility (Lee and Kerrigan, 2004). This also causes the GM to be inhibited each time the hip extends (Panayi, 2009). The GM inhibition during sprinting may require the hamstrings to contribute more force to hip extension rather than acting in its transducer role, which can cause overloading and injury (Hoskins and Pollard, 2005b).

These findings may suggest that improving certain lumbar-pelvic biomechanics may play a role in the treatment and prevention of hamstring injuries. No previous studies have investigated the role of certain pelvic biomechanics such as pelvis tilt, TrA and GM activation on hamstring injuries in healthy, young rugby players. Therefore, this study aims to investigate the effect of these selected pelvic biomechanics (TrA and pelvis tilt) and gluteus maximus, erectors spinae and hamstring activation patterns on hamstring injuries in semi-professional rugby union players.

2. Methods

2.1 Participants

Participants from a group of 80 rugby union players of the U/19 and U/21 teams of the Potchefstroom Rugby Institute was recruited via the rugby coaches of the North-West University (Potchefstroom Campus) to participate in this study. Players with a current injury during baseline measurement were excluded from this study. A total of 65 players voluntarily gave informed consent to participate in this study. Before participating in the study each subject read a study information

sheet and signed an informed consent form. Ethical approval was obtained from the Ethics Committee of the North-West University.

2.2 Study design

This is a retrospective once-off subject availability study with the pelvic biomechanics and muscle activation patterns of LES, GM, ST and BF measured before the rugby season started. Injury rates of the participants that were measured at the start of the season were recorded for the total duration of the rugby union season from February 2010 to September 2010. The pelvic tilt, transverse abdominus activation and gluteus maximus, erector spinae, and hamstring firing order of the participants that were injured during the season were compared to those of the participants that were not injured during the season.

2.3 Demographics

The stature of each player was measured to the nearest 0.1 cm, with a stadiometer (seritex) using the stretch stature method (ISAK, 2001). Body mass was measured to the nearest 0.1 kg with an electronic weighing scale (micro) (ISAK, 2001). Participants completed an information sheet recording their age, position of play and dominant leg. Participants that were treated for hamstring injuries by a medical professional and who missed one or more weeks of practice or more than one game, was reported as being injured. The injury was recorded in terms of the left or right limb and whether it was a new or repeated injury.

2.4 Pelvic alignment

Pelvic alignment was measured by placing bright orange markers, 1 cm in diameter, on the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS) of the participant. The camera was positioned 2.5 meters from the subject. Digital photos were taken of the left and right lateral view of each participant. Pelvis tilt angle was then analysed for each player from the digital photo making use of Dartfish computer software program version 4.06.0 (Dartfish,

Switzerland). Pelvic tilt is defined by the angle formed between the line connecting the ASIS with the PSIS and the line horizontal with the floor (Sprigle et al., 2003). Normal pelvic tilt angle is indicated to be between 7 – 15 degrees (Magee, 2008). The pelvic tilt angle was determined to the nearest one degree.

2.3 *Transverse abdominus activation*

Transverse abdominus activation (TrA) was determined by a pressure biofeedback unit (PBU) (Chattanooga Group limited, Bicester, UK) (Richardson and Jull, 1995). With the TrA activation assessment the PBU was placed beneath the lower back (L4 – L5) and inflated to 40 mmHg while the participant's hips and knees were flexed to 90 degrees (Ashmen et al., 1996). The participants had to maintain the pressure at 40 mmHg on the cuff while slowly lowering their legs to the floor until both the knees and hips were fully extended (Ashmen et al., 1996). Athletes with good TrA and strength will be able to maintain the pressure at 40 mmHg until their hips and knees are fully extended (Ashmen et al., 1996). When the pressure on the cuff started to decrease, even after the first warning to maintain the correct posture, the hip angle was measured with a goniometer and recorded. TrA was classified as follows using the measured hip angle when pressure on the cuff started to drop: 0 = 90 - 75° (Very bad), 1 = 74 - 60° (bad), 2 = 59 - 45° (Average), 3 = 44 - 30° (Good), 4 = 29 - 15° (Very Good), 5 = 14 – 0° (Excellent) (Kendall et al., 2005). For statistical analysis the groups were reduced to a bad and a good TrA group. The very bad, bad and average groups were recorded as the bad TrA group and the good, very good and excellent groups were grouped as the good TrA group.

2.4 *Electromyography*

Activation patterns of the left and right gluteus maximus, semitendinosus, biceps femoris and erector spinae muscles were analysed with an electromyograph (EMG) (MyoTrace 400, Noraxon USA, Inc., Scottsdale, Arizona). Latency was measured in time (ms) and muscle activation in microvolt (mV). Skin preparations involved shaving the hair on the surface and swabbing the skin with alcohol.

Markers indicating anatomical landmarks were placed on the first and last sacral vertebrae, medial and lateral femoral condyle and greater trochanter (Konrad, 2005). Two pre-gelled self-adhesive active Ag/AgCl surface electrodes (1 cm in diameter) were placed 2 cm apart, parallel to the muscle fiber direction (Chance-Larson et al., 2009). For measurements, electrodes were placed midpoint between the last sacral vertebrae and greater trochanter, for gluteus maximus, medially on mid-distance between the gluteal fold and medial condyle, for semitendinosus, on mid-distance between the greater trochanter and lateral condyle, for biceps femoris, parallel to the lumbar spine at L3, 2 cm lateral to the spinal processes, for erector spinae (Sakamoto et al., 2009). The total movement performed by the participant was captured on video ensuring visibility of the placed markers. For EMG testing participants were in a prone position on a plinth with the knee to be tested, flexed to 90 degrees (Sakamoto et al., 2009). A marker was placed 15 cm above the foot to ensure a consistent range of motion with hip extension. The participant extended his leg on the command "Contract!". During each extension the participant's foot touched the marker before relaxing back to the plinth. Three trials were performed of which the results of the best trial were used for statistical analysis.

The EMG signals were full wave rectified, low- and high-pass filtered, with cut-off frequencies of 500 and 10 Hz, respectively, and recorded at a sampling rate of 1000 Hz (Sakamoto et al., 2009). Muscle activation patterns were described after determining the EMG onset for each muscle. The computer-identified data points for muscle activity were determined by visual inspection. The visual onset was identified at the point where the EMG activity clearly deviated from the baseline (Marshall and Murphy, 2003). Hodges and Bui (1996) found that visual determination of EMG onset was highly repeatable. The onset of muscular activity was considered to occur when the value exceeded two standard deviations from the mean value observed at baseline for a 50 ms period (Hodges and Bui, 1996; Brindle et al., 1999).

2.7 Statistical analysis

Data were analyzed using SPSS (Statistical Package for the Social Sciences) version 17 (SPSS Inc. Chicago, Illinois, USA). Descriptive statistics were performed to describe the characteristics of the participants reporting means and standard deviations. The description of the injury prevalence and activation patterns was calculated with frequencies. The differences in pelvic tilt and TrA in the injured and uninjured groups were analysed by determining practical significance by means of effect sizes ($d=0.2$ small, $d=0.5$ medium, $d = 0.8$ large) (Cohen, 1988). The mean onset of each muscle was calculated for participants with normal and anterior pelvic tilt as well as for participants with good and bad TrA in the injured and uninjured groups. The between-group differences in the muscle onset times were analysed by determining practical significance by means of effect sizes (Cohen, 1988). The statistical analysis for this study was performed by the Statistical Consultation Services of the North-West University.

3. Results

The results of this study that investigated the influence of pelvis biomechanics (TrA and pelvic tilt) and muscle activation patterns (GM, LES and hamstring) on hamstring injuries were performed in semi professional rugby players. The results of the participant characteristics indicating the average age, stature and body mass of the injured and uninjured participants are presented in Table 1. A total of 20.0% participants were injured in the 2010 rugby season, with 61.5% of those injuries on the right side of the player. A total of 61.5% of the 2010 injured participants was previously injured, mostly on the left side (38.5%) of the player. A total of 24.6% of the rugby players previously suffered from hamstring injuries, 37.5% of those injured participants were suffering from re-injury, mostly on the left side (25%). The majority of the injured (92.3%) and uninjured (84.6%) participants were right leg dominant and 56.9% played in one of the forward positions in the game of rugby union.

Of the 24.6% injured participants, 62.5% were identified with an anterior pelvis tilt on the left side and 75.0% were identified with an anterior pelvis tilt on the right side and 68.8% were identified with bad TrA. Of the uninjured participants, 63.3% were identified with an anterior pelvis tilt on the left side and 85.7% were identified with an anterior pelvis tilt on the right side and 69.4% were identified with bad TrA. Of the 37.5% participants who suffered re-injury, 66.7% was identified with an anterior pelvis tilt on the left side and 83.3% was identified with an anterior pelvis tilt on the right side. No practical significant between group differences were found between the injured and uninjured groups when participants with normal and anterior pelvis left were compared ($d=0.053$). No practical significant between group differences were found between the injured and uninjured groups when participants with normal and anterior pelvic tilt right were compared ($d=0.061$). No practical significant between group differences were found between the injured and uninjured groups when participants with bad and good TrA were compared ($d=0.189$).

Table 1: Characteristics of the participants retrospectively grouped as injured and uninjured in the 2010 season

	Injured		Uninjured	
	N	Mean $\pm$ Std	N	Mean $\pm$ Std
Age	13	20.0 $\pm$ 1.58	52	18.90 $\pm$ 0.96
Stature (cm)	13	182.73 $\pm$ 6.95	52	182.83 $\pm$ 8.76
Body Mass (kg)	13	93.64 $\pm$ 14.74	52	92.27 $\pm$ 12.76

Results of the muscle activation patterns (Figure 1) as tested with EMG on the right and left side of the participants present the following activation pattern: LES, GM, and then the hamstrings in the injured and uninjured players.

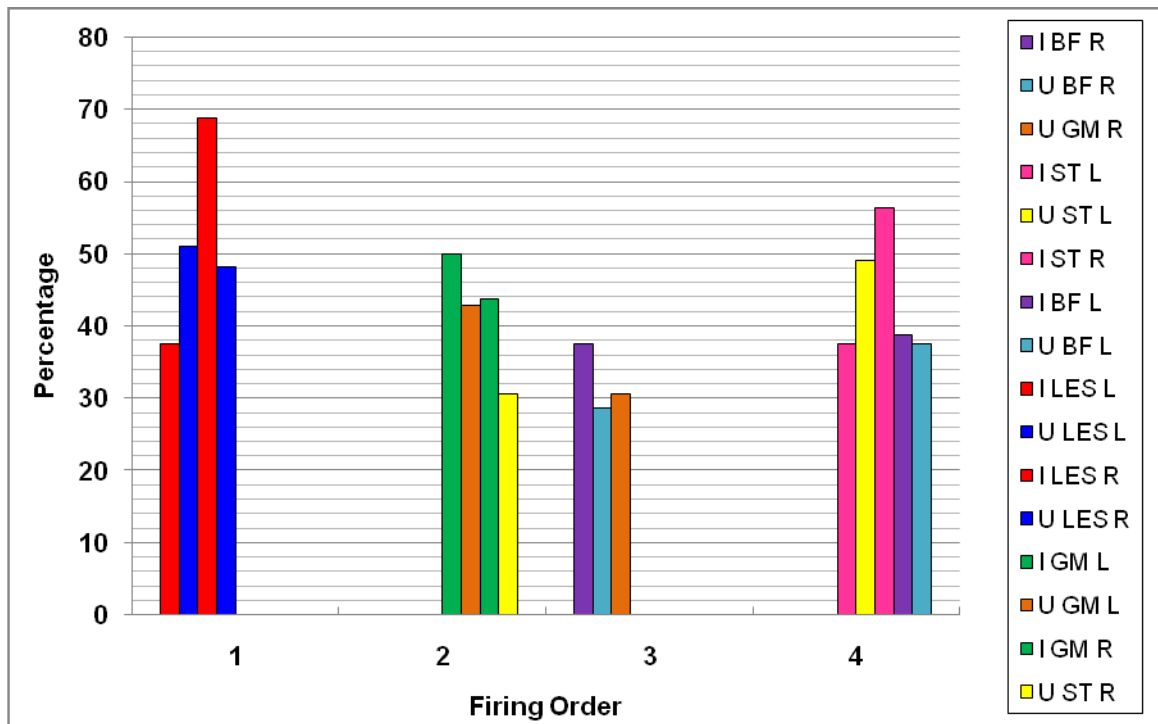


Figure 1: The average muscle activation frequency (percentage) for each muscle tested left and right, presenting the general firing order of the muscles in the injured and uninjured group of the semi-professional rugby players tested. (I = injured, U = uninjured, GM = Gluteus maximus, BF = biceps femoris, ST = semitendinosus, LES = Lumbar Erector spinae, L = Left, R = Right).

An analysis of the muscle activation onset times (Table 2) comparing the means of injured participants to participants with no injury indicated that although no practical significance in different onset times was reported for injured compared to uninjured participants, in most of the instances for uninjured participants the mean onset time of the muscles on the right side were delayed compared to the mean onset time of the muscles on the left side, except for the ST. The patterns were different in the injured players with the mean onset time on the right delayed compared to the left in the GM and BF muscles, but it was the opposite in the ST and LES muscles. The results indicate that the GM and LES mean onset time in the uninjured group occurred after the mean onset time of the GM and LES in the injured group. In the hamstrings it was just the opposite with the mean onset time in the injured group occurring after the mean onset time in the uninjured group.

Table 2 Mean onset times (ms) of each muscle in the injured and uninjured groups

	Mean onset times (ms)		
	Injured	Uninjured	d
Glut max L			
Mean (SD)	83.7(45.4)	98.0(52.3)	0.27
Glut max R			
Mean (SD)	109.0(48.0)	121.9(78.8)	0.16
Biceps Fem L			
Mean (SD)	132.0(92.7)	124.7(95.4)	0.08
Biceps Fem R			
Mean (SD)	140.4(45.6)	143.4(165.7)	0.02
Semiten L			
Mean (SD)	168.9(234.0)	124.7(108.8)	0.19
Semiten R			
Mean (SD)	130.0(68.9)	118.5(87.2)	0.13
Lumbar ES L			
Mean (SD)	80.7(43.6)	93.7(150.8)	0.09
Lumbar ES R			
Mean (SD)	75.2(48.9)	113.7(152.9)	0.25

The means and standard deviations were calculated from 65 rugby union players. Each player performed a set of three repetitions. The between-group differences in the muscle onset times were analysed by determining practical significance by means of effect sizes ($d = 0.8$). (Glut max = gluteus maximus, biceps fem = biceps femoris, semiten = semitendinosus, Lumbar ES = Lumbar Erector Spinae, L = left, R = right).

4. Discussion

The increase in anterior pelvis tilt to the right could be the reason for the majority of injuries reported for the right hamstring during the 2010 rugby season. Additional to larger anterior pelvis tilt abnormalities in the injured participants, most of the injured participants were also identified with bad TrA.

An increased anterior pelvic tilt has been identified as a predisposing factor for hamstring injuries (Brukner and Khan, 2002). Hodges and Mosley (2003) also found that an increased anterior pelvis tilt and lumbar lordosis are associated with an increased risk of hamstring injury. According to the literature, an increase in lumbar lordosis and anterior pelvic tilt results in the ischium being moved further away from the distal insertion of the hamstrings. The mechanical stress and strain

in the hamstrings during function is therefore increased (Hunter and Speed, 2003). It seems from these studies that in athletes with an increased anterior pelvic tilt the hamstrings are not in their normal length-tension-relationship, causing the hamstring to be weak and in constant strain because it is constantly trying to regain normal length. In another study a delayed TrA resulted in a significant earlier onset of the biceps femoris to compress the SIJ (Hungerford et al., 2003). The earlier activation of the biceps femoris could result in an overloaded bicep femoris, as its usual function is not to stabilize the spine.

In this study most of the uninjured participants were also identified with an anterior pelvis tilt, with the consequence that no practical significant difference in pelvis tilt was found when the injured participants were compared with the uninjured participants. Previous studies have found that athletes with previous hamstring injury appear to have excessive lordosis compared to a group with no injury (Hennessey and Watson, 1993). The lower crossed syndrome, which occurs with tightness of the iliopsoas and ES and weak inhibited gluteal- and abdominal muscles, results in an anterior tilt and hyperlordosis of the lumbar spine (Janda, 1996). Watson (1983) found that the degree of lumbar lordosis increased during the course of two seasons in football players. Some exercises have been identified to increase lumbar lordosis (Watson, 1983). Kicking and abdominal strengthening exercises with straight legs have been identified as possible contributors to lumbar lordosis. The anatomical reason seems to be that the iliopsoas muscle group is primarily involved in kicking and straight leg raises or straight leg sit-up exercises and these exercises contribute to strengthening the iliopsoas. It is known that a tight iliopsoas cause an anterior pelvis tilt (Janda, 1996). Therefore, it is possible that certain athletic activities and training methods may exacerbate postural defects which may predispose the players to injury (Hennessey and Watson, 1993). The small difference observed in pelvis tilt between the injured and uninjured group could be caused by the exercise and gym programmes which are not individualised for each player. It could be that the iliopsoas and ES are most commonly the muscles to activate than the GM during the lower body gym programme for example squat, causing the iliopsoas and ES to become tight and causing a resultant anterior pelvis tilt.

Although the uninjured group was not injured during the 2010 season, they could be at risk for injury in future.

In this study most of the uninjured players were also identified with bad TrA. When TrA was compared in the injured and uninjured group, no practical significant difference was found. The reason for this could be that the TrA does not play such a significant role in the mechanism involved in hamstring injury. Participants with low back pain might have been included in this study, as only current hamstring injury was an excluding factor for participation. It is known that subjects with low back pain are associated with delayed TrA (Hungerford et al., 2003). It could be that the participants in the injured and uninjured group in this study could suffer from low back pain due to their training programmes in the gym and the fact that rugby is a physical sport with high impact on the body especially the back. Therefore could the TrA be bad with no practical significance in the TrA difference in both groups due to lower back pain. Previous studies found that transverse abdominus activation (TrA) is connected to hamstring injuries in that the biceps femoris is activated earlier when TrA is delayed (Hodges and Richardson, 1998). Although bad TrA was identified in most of the participants in this study, the ES was mostly activated first and the BF last. TrA has been found to be the first trunk muscle to be activated before onset of lower limb movement (Hodges and Richardson, 1997). In a study by Hungerford et al. (2003) it was found that when subjects flex their hip in standing and the onset of the transverse abdominus (TA) was delayed, the onset of the biceps femoris occurred significantly earlier. Earlier activation of the biceps femoris occurs to stabilize the sacroiliac joint (SIJ) through its connection to the sacrotuberous ligament, instead of the TA stabilizing the SIJ (Hungerford et al., 2003). Hoskins and Pollard (2005a) found that by improving the muscle activation of the multifidus, TA and internal obliques Australian Rules football players finished the season without hamstring re-injury.

As seen in a previous study significant between group differences in the GM mean onset times relative to the ES and hamstring muscles were found in groups who performed an abdominal drawing-in manoeuvre prior to PHE and the group which did not (Oh et al., 2007). The abdominal drawing-in manoeuvre activates the

transverse abdominus (Norris, 1995). In the group which performed the abdominal drawing-in manoeuvre the GM delay in onset time was significantly reduced relative to the hamstring and ES muscles compared to the group which did not perform the abdominal drawing-in manoeuvre (Oh et al., 2007). In this study the activation pattern for the muscles tested similar for the injured and uninjured groups. Bad TrA was also identified in both the injured and uninjured participants. These findings could suggest that TrA has an effect on the activation patterns of the ES, GM and hamstrings and that it could possibly be a risk factor for hamstring injuries in rugby players in that the GM activation is delayed with bad TrA.

The muscle activation patterns as tested with EMG in prone hip extension (PHE) for the uninjured participants present an activation order of: LES, GM and last hamstrings for both injured and uninjured players (left and right sides). A study of Sakamoto et al. (2009) on healthy subjects found the firing order for PHE to be: ST, contralateral ES, ipsilateral ES and finally GM. In a study by Vogt and Banzer (1997) the PHE was initiated by the ipsilateral ES, followed by ST, contralateral ES and lastly the GM muscles. They justified the activation of the lumbar ES during the pre-movement phase as preparation to stabilize the trunk to control the pelvis during leg lifting (Vogt and Banzer, 1997). However Sahrman (2002) stated that delayed gluteus maximus activation during PHE causes earlier activation of the hamstrings and ES muscles in order to stabilize the lumbar spine. The ES activation in this study correlates with the other three studies but in this study the GM was activated second and the hamstrings last, whereas in the other two studies the hamstrings was activated second and the gluteus maximus last. Not one of the other studies analysed the activation patterns of high-performance athletes, whereas in this study the muscle activation patterns of semi-professional rugby players were analysed (Sakamoto et al., 2009; Bruno and Bagust, 2007). In this study there was not practical significant between group differences in the GM, LES and hamstring mean onset times in the injured and uninjured groups. In a study by Bruno and Bagust (2007) it was found that in subjects with or without low back pain, the hamstrings and ES to become active before the GM in PHE with differences in the onset times quite small. The reason that no practical difference was found in the onset times between the injured and uninjured groups

could be that the iliopsoas and LES are still overactive relative to the GM and hamstring muscles due to their training programs.

The results of this study suggest that an anterior pelvis tilt could result a GM activation delay and cause the LES to activate earlier to stabilize the lumbar spine in semi-professional rugby players.

Future studies should determine if muscle activation patterns will differ for the GM, LES and hamstrings in the PHE relative to hip extension in a weight-bearing position, especially in athletes. In this study timing of contraction is only one aspect of function, and no data investigating force or torque generated were collected. Future studies should investigate if force and torque with which the GM or hamstring contracts in hip extension are different in subjects with injury compared to subjects without hamstring injuries.

5. Conclusion

The conclusions that can be drawn from this study are that semi-professional rugby union players (injured and uninjured) are more prone to postural defects such as anterior tilt of the pelvis and bad TrA. Pelvis tilt (anterior and posterior) and TrA (bad and good) were similar in most of injured and uninjured rugby players. According to the literature these postural defects and altered TrA activation pattern will increase the risk for hamstring injuries. However, in this study no practical significant difference was found in pelvic tilt, TrA and muscle activation patterns of the injured and uninjured participants. Although no practical significant differences were observed in pelvis tilt, TrA and muscle activation patterns of the injured compared to the uninjured rugby players, earlier activation of the ES relative to the GM in the PHE were observed probably to stabilize the lumbar spine. Therefore, we conclude that pelvic tilt and TrA may have some effect on the activation patterns of the ES, GM and hamstrings that may be related to hamstring injuries in semi-professional rugby union players.

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Chapter 5

Summary, conclusion, limitations and recommendations

1. SUMMARY.....	94
2. CONCLUSION.....	96
3. LIMITATIONS AND RECOMMENDATIONS.....	98

1. SUMMARY

The main purpose of this study is to determine the relationship between selected pelvic biomechanical parameters (pelvis tilt, transverse abdominus and gluteus maximus activation) and hamstring injuries in semi-professional rugby union players.

In Chapter 1 the problem statement, aim and hypothesis of the study are stated and the structure of the study explained. In Chapter 2 the literature related to the aim of this study is reviewed. In the literature review the anatomy and biomechanics of hamstring injury, mechanics of hamstring injuries, transverse abdominus activation, gluteus maximus activation and rehabilitation of hamstring injuries are presented. A review of the literature indicated that hamstring injuries have a biomechanical basis. According to researchers, by improving the neuromuscular control of the pelvis by strengthening the transverse abdominus, gluteus maximus, internal obliques and multifidus reduces the risk for re-injury significantly. The literature review also emphasizes the need for a biomechanical evaluation of the lumbar spine, pelvis and sacrum when hamstring injuries are assessed. There is evidence to suggest that hamstring injuries are caused by lumbo-pelvic imbalances which increase the functional load on the hamstring by decreasing gluteus maximus activation and increasing the tensile stress on the biceps femoris. Lumbo-pelvic imbalances such as anterior tilt and lumbar lordosis are associated with increased risk for hamstring

injuries. This results in the ischium being moved further away from the distal insertion of the hamstrings, which causes elongation of the hamstrings during function and this is causing overloading on the muscle and subsequent injury.

The literature indicated that when too much delay is present in gluteus maximus activation during prone hip extension, hip extension is achieved primarily by the hamstring muscles. Most studies challenge this statement in that the gluteus maximus was activated last in most studies which tested the activation patterns of the gluteus maximus, erector spinae and hamstrings in prone hip extension. There were, however, studies which found a decrease in gluteus maximus activation delay relative to the other muscles when an abdominal drawing-in manoeuvre (which activates the TA) was performed prior to prone hip extension (PHE). This abdominal drawing-in manoeuvre also decreased the anterior tilt of the pelvis. Not one of the other studies analysed the activation patterns of high-performance athletes, whereas in this study the muscle activation patterns of semi-professional rugby players were analysed.

This resulted in the formulation of the research question for this study: What is the relationship between selected pelvic biomechanical parameters (TrA, pelvis tilt) and GM, BF and ES activation and hamstring injuries in semi-professional rugby union players?

In Chapter 3 the results investigating the effect of selected biomechanical characteristics (pelvis tilt and transverse abdominus activation) on gluteus maximus, hamstring and erector spinae activation patterns in semi-professional rugby union players are reported. The results showed that most of the rugby players presented with an anterior tilted pelvis (83.1%), especially on the right side and most of the players were also right leg dominant (86.2%). In this study 68.4% rugby players also presented with a bad transverse abdominus activation (TrA), rather than good. EMG testing on the right and left side of the participants present a pattern of the following activation order: LES, GM, BF and ST. However, no practical significant differences

were found in the mean onset times of each muscle when the participants with normal and anterior pelvis tilt, as well as participants with bad and good TrA were compared.

In Chapter 4 the hamstring injury prevalence of rugby union players in the 2010 rugby season and its relationship to selected pelvic biomechanical parameters (transverse abdominus and gluteus maximus activation and pelvis tilt) were measured to determine retrospectively if hamstring injuries are related to the biomechanics of the pelvis and activation patterns of the hip muscles. A total of 24.6% of the rugby players previously suffered from hamstring injuries, 37.5% of those injured participants were suffering from re-injury. Of the 37.5% participants who suffered re-injury, 66.7% was identified with an anterior pelvis tilt on the left side and 83.3% was identified with and anterior pelvic tilt on the right side. Results at the start of the season showed that most of the injured players were identified with an anterior pelvic tilt especially on the right side (75.0 %). Most of the injured players were also identified with bad TrA (68.8%) before the season started. However, no practical significant between group differences were found between the injured and uninjured groups when participants with normal and anterior pelvis tilt left and right were compared. No practical significant between group differences were also found between the injured and uninjured groups when participants with bad and good TrA were compared. EMG results on the right and left side of the uninjured participants present a pattern of the following activation order: LES, GM, BF and ST. However, no practical significant between group differences were found in the onsets of the muscles relative to each other in the injured compared to the uninjured groups.

2. CONCLUSION

The conclusion of this study is derived from the stated hypotheses.

2.1 Hypothesis 1

Hypothesis 1 states that pelvis biomechanics (transverse abdominus activation and pelvis tilt) are positively related to gluteus maximus, hamstring and erector spinae activation patterns in semi-professional rugby union players.

An anterior pelvis tilt on the left side was observed in 64.6% of the participants and on the right side in 83.1% of the participants. TrA activation testing indicated that 68.4% of the participants were classified as presenting with bad and 31.6% with good activation. According to the results there was no practical significant difference in the mean onset times of each muscle when the participants with normal pelvis tilt was compared to the participants with an anterior pelvis tilt, as well as between the participants with bad transverse abdominus activation compared to participants with good transverse abdominus activation. Hypothesis 1 is, therefore, rejected.

2.2 Hypothesis 2

Hypothesis 2 states that a positive relationship exists between pelvic biomechanics (transverse abdominus activation and pelvis tilt) and gluteus maximus, hamstring and erector spinae activation patterns and hamstring injuries in semi-professional rugby union players.

The results of this study indicate no practical significant differences between the pelvic biomechanics (pelvic tilt) and activation patterns (ES, hamstring, gluteus maximus and TrA) of the injured and uninjured subjects. The results of this study found that no practical significant between group differences when the injured and uninjured participants were retrospectively compared with regard to normal and anterior pelvis tilt for left and right as well as for participants with bad and good TrA. No practical significant between group differences were found in the onset times of the muscles relative to each other retrospectively in the injured and uninjured participant groups. Hypothesis 2 is, therefore, rejected.

The conclusion that can be drawn from this study is that although differences were observed, the relationship between pelvis biomechanics (TrA and pelvis tilt) and GM, ES and hamstring activation patterns in semi-professional rugby union players is not practical significant. No practical significant differences in the mean onset times of each muscle in the participants with normal and anterior pelvis tilt, as well as between the participants with bad and good transverse abdominus activation were found.

There is a non practical significant relationship between pelvic biomechanics, transverse abdominus activation and muscle (ES, GM and hamstring) activation patterns and hamstring injuries in semi-professional rugby union players. No practical significant between group differences were found between the injured and uninjured groups when participants with normal and anterior pelvis tilt left and right and participants with bad and good TrA were compared. No practical significant between group differences were found in the onsets of the muscles relative to each other in the injured and uninjured groups. Further conclusions that can be drawn from this study are that semi-professional rugby union players (injured and uninjured) are prone to postural defects such as anterior tilt of the pelvis and bad TrA. Although no practical significant differences were observed in pelvic tilt, TrA and muscle activation patterns of the injured compared to the uninjured rugby players, earlier activation of the ES relative to the GM in the PHE were observed probably to stabilize the lumbar spine. Therefore, could we conclude that pelvic tilt and TrA may have some effect on the activation patterns of the ES, GM and hamstrings that may lead to hamstring injuries in semi-professional rugby union players, but in this study there was no clear evidence to support this finding.

3. LIMITATIONS AND RECOMMENDATIONS

No conclusive results were obtained with this study, but certain differences were observed in the injured and uninjured semi-professional rugby players. This study had some limitations that have influenced the results obtained. The following limitations were recognized and the recommendations that can improve future studies are presented in the following section:

- 3.1** Due to financial and logistical restrictions the pressure biofeedback device, also supported by previous research, was used to determine transverse abdominus activation. Transverse abdominus activation would have been more accurately determined by use of ultrasound imaging. Future research

should use ultrasound imaging if possible for TrA to determine TrA more accurately.

- 3.2** The prone hip extension test is used in the EMG testing to determine the muscle firing order of the erector spinae, hamstrings and gluteus maximus. When the erector spinae and hamstrings are first to be activated and the activation of the gluteus maximus delayed, it is considered abnormal. Previous EMG studies using the prone hip extension test found that the gluteus maximus was usually activated last. The validity and reliability of the prone hip extension test is questioned. Studies using EMG to investigate the difference in activation patterns between prone hip extension and hip extension in standing are needed.
- 3.3** The prone hip extension is not a functional activity, but it is assumed to reflect muscle recruitment patterns during functional activities such as walking and running. However, the prone hip extension is an open kinetic non-weight bearing movement and muscle recruitment patterns may be different from those than in a weight-bearing position. Future research can investigate if the muscle firing patterns differ in prone hip extension from muscle firing patterns in hip extension in standing.
- 3.4** In this study timing of contraction is only one aspect of function which was evaluated. No data investigating force or torque of contraction were collected. Force and torque with which the gluteus maximus or hamstring contracts could have an influence on hip extension torque. According to researchers, the less forcefully the gluteus maximus contracts, the more forcefully the hamstrings must contract to produce the same amount of hip extension force. Thus, could a less forceful gluteus maximus contraction in hip extension also cause hamstring overloading and injury. Future research must also incorporate force and torque of the contraction when muscle activation in hip extension is tested.

- 3.5** In this study 65 participants were evaluated with only 13 participants injured during the season of 2010. A larger sample size will result in a larger sample of injured participants that will strengthen the power of the statistical analyses.
- 3.6** The total number of rugby union players detected with abnormal pelvic biomechanics (anterior pelvis tilt and bad TrA) and its relationship with hamstring injuries that was reported in this study, demonstrates the need for a biomechanical evaluation of the pelvis and lower back when hamstring injuries are assessed.
- 3.7** Coaches and sport scientists should be made more aware of pelvic biomechanics and its influence on injuries especially hamstring injuries. They should be educated in terms of identification of abnormal pelvic biomechanics in players during their gym programmes and while training on the field. By educating coaches and sport scientists who constantly work with the players, abnormal pelvic biomechanics can be identified early enough and be treated. In this way injuries and especially recurrent injuries, especially hamstring injuries, can be prevented.
- 3.8** Further studies should be conducted to evaluate the effect of transverse abdominus and gluteus maximus activation training on pelvic tilt angle and hamstring injuries.

Appendix A

Guidelines for Authors

Manual Therapy

Manual Therapy

Author Guidelines

The journal editors, Ann Moore and Gwen Jull, welcome the submission of papers for publication. Submission to this journal proceeds totally online at <http://ees.elsevier.com/math>. The system automatically converts source files to a single Adobe Acrobat PDF version of the article, which is used in the peer-review process. All correspondence, including notification of the Editor's decision and requests for revision, takes place by e-mail and via the Author's homepage, removing the need for a hard-copy paper trail.

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Technical and measurement notes 2000 words

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Letters to the Editors 500 words

These word counts do not include references or figures/tables

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The accuracy of references is the responsibility of the author.

Text: In the text your reference should state the author's surname and the year of publication (Smith 1989). If there are two authors you should give both surnames (Smith & Black 1989). When a source has more than two authors, give the name of the first author followed by 'et al'.

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Appendix B

Guidelines for authors

Journal of Biomechanics

JOURNAL OF BIOMECHANICS

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van Werff, K., 1977. Kinematic and dynamic analysis of mechanisms. A finite element approach. PhD. Thesis, Delft University Press, Delft.

D. Proceedings

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E. Footnotes

As distinct from literature references, should be avoided. Where they are essential, superscript Arabic numbers should be employed.

10. SI (Metric) Units must be used for all quantities in text, figures and tables. It is suggested that a complete list of symbols used and their explanation be included, in a notation section at the beginning of the manuscript.

11. Authors submitting manuscripts reporting data on cell responses to mechanical loads should report their study according to the standards suggested in the Editorial accompanying our special Issue on cell mechanics (Volume 33, Issue 1).

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Appendix C

Informed Consent letter

CONFIDENTIAL

Informed consent form
PART 1

1. School/Institute:
School for Biokinetics, Recreation and Sport Science.....
2. Title of project/trial: **The relationship between selected pelvic biomechanic parameters and hamstring injuries in semi-professional rugby players.**
.....
.....
3. Full names, surname and qualifications of project leader:
Sarah Johanna Moss (PhD).....
4. Rank/position of project leader:
Senior lecturer
5. Full names, surname and qualifications of supervisor of the project:
(Complete only if not the same person named in 4.)
Sarah Johanna Moss(PhD).....
.....
6. Name and address of supervising medical officer (if applicable):
Dr. Pierre Venter
7. Aim of this project.
To determine the role of pelvic biomechanics, transverse abdominus activation and gluteus maximus activation patterns in hamstring injuries.
8. Explanation of the nature of all procedures, including identification of new procedures: **No invasive measures will be taken. During the EMG analysis, subjects will be asked to perform prone hip extension while all the movements will be recorded by video camera. Surface electrodes will be placed strategically to accurately determine the EMG patterns During biofeedback, subjects will extend their legs while in supine position, while they attempt to keep the pressure on the biofeedback apparatus at 40 mmHg. For the pelvic**

tilt assessment, subjects will be photographed in the lateral and posterior views with minimal clothing.

9. Description of the nature of discomfort or hazards of probable permanent consequences for the subjects which may be associated with the project:
(Including possible side-effects of and interactions between drugs or radio-active isotopes which may be used.)

No discomfort will be experienced by subjects.....

.....

10. Precautions taken to protect the subjects:

The project supervisor as well as the student is a registered Biokineticists and the procedures of this project are within the scope of practice of Biokineticists registered with the HPCSA.

11. Description of the benefits which may be experienced from this project:
A better understanding of selected pelvic biomechanics that may predispose rugby players to future hamstring injuries. These data can be used to improve the stability programs of rugby players to improve their pelvic biomechanics to prevent future hamstring injuries.

12. Alternative procedures which may be beneficial to the subjects:
(Complete only if applicable).

.....

.....

.....

Signature: Date: **13 January 2008**.....

Project leader

PART 3

Consent

Title of the project:

The relationship between selected pelvic biomechanical parameters and hamstring injuries in semi-professional rugby players.

.....
I, the undersigned.....(full names)
read/listened to the information on the project in PART 1 and PART 2 of this document and I declare that I understand the information. I had the opportunity to discuss aspects of the project with the project leader and I declare that I participate in the project as a volunteer. I hereby give my consent to be a subject in this project.

I indemnify the University, also any employee or student of the University, of any liability against myself, which may arise during the course of the project.

I will not submit any claims against the University regarding personal detrimental effects due to the project, due to negligence by the University, its employees or students, or any other subjects.

(Signature of subject)

Signed at on.....

Witnesses

1.

2.

Signed at.....on.....

For non-therapeutic experiencing with subjects under the age of 21 years the written approval of a parent or guardian is required.

I, ...(full names),
parent or guardian of the subject named above, hereby give my permission that he/she may participate in this project and I also indemnify the University and any employee or student of the University, against any liability which may arise during the course of the project.

Signature:

Date:.....

Relationship:

Appendix D

Data Sheet

Demographic information:

Name:	No:	
Celnr:		
Team:	Position of play:	
Date of Birth:		
Age:	Mass:	Stature:
Dominant leg:		
Medication(Chronic, acute, supplementation):		

Prior hamstring injuries: ☐ Yes ☐ No
(last 3, 6, 12 months)

If Yes:

Date of injury: _____

Playing position at the time of injury: _____

Side of body injured: ☐ Left ☐ Right ☐ Bilateral

Diagnosed by (Doctor, physio, other): _____

Treatment (Physio, rehab, other): _____

Severity of injury: ☐ Minor (if able to return to game/training immediately)

☐ Mild (if missed one week)

☐ Moderate (if missed two weeks)

☐ Severe (if missed more than 2 weeks)

Do you suffer from recurrent hamstring injuries (same type at same site).

☐ Yes ☐ No

Was the injury caused by: ☐ overuse ☐ trauma

Did the injury occur during: ☐ training ☐ match

During what action did injury occur: running/sprinting

(Encircle the right one)

Increasing speed

Decreasing speed

Changing direction

Picking up the ball

Kicking

Tackling

Maul

Ruck

Scrum

Transverse abdominus activation:.....

0 = 90° - 75° ☐

1 = 74° – 60° ☐

2 = 59° – 45° ☐

3 = 44° – 30° ☐

4 = 29° – 15° ☐

5 = 14° - 0° ☐

0 = Very bad
 1 = Bad
 2 = Average
 3 = Good
 4 = Very Good
 5 = Excellent

Bulging tummy: ☐ yes ☐ no

Breath-holding: ☐ yes ☐ no

Descending of anterior rib cage: ☐ yes ☐ no

Posterior pelvic tilting: ☐ yes ☐ no
 (Rectus abdominus activation)

EMG Testing:

Muscle	MVC L	Left mean value	Left peak value	MVC R	Right mean value	Right peak value
Gluteus max						
Biceps femoris						
Semitendinosus						
Lumbar ES						

Muscle	Left time of onset	Left time of offset	Left firing order	Right time of onset	Right time of offset	Right firing order
Gluteus max						
Biceps femoris						
Semitendinosus						
Lumbar ES						

Pelvic tilt assessment**Right:**

- ☐ Normal (7 – 15 degrees)
- ☐ Anterior pelvic tilt (> 15 degrees)
- ☐ Posterior pelvic tilt (< 7 degrees)

Left:

- ☐ Normal (7 – 15 degrees)
- ☐ Anterior pelvic tilt (> 15 degrees)
- ☐ Posterior pelvic tilt (< 7 degrees)