

# **Pelvic biomechanics and muscle activation patterns during non-weighted squats in U/19 university-level rugby union players**

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Supervisor E.J. Bruwer

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It all starts here <sup>™</sup>



## Dedicated to my family



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**Miemie Greyling**

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## AUTHOR'S CONTRIBUTION

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The principal author of this dissertation is Miss M. Greyling. The contribution of the co-author is summarised below:

<b>Co-author</b>	<b>Contribution</b>
Ms E.J. Bruwer	Supervisor. Co-author - assistance in writing of manuscripts, study design, executing of testing, data extraction, technical editing, interpretation of results.

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

I hereby declare that my role in the preparation of the above mentioned manuscripts is as indicated above, and that I give my consent that it may be published as part of the M.Sc dissertation of Miemie Greyling.

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E.J. Bruwer

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# ABSTRACT

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## **Pelvic biomechanics and muscle activation patterns during non-weighted squats in U/19 university-level rugby union players**

Hyperlordosis or anterior pelvic tilt is a common non-neutral spinal posture associated with weak core stability, low back pain and altered lumbopelvic muscle activation patterns. Yet the effects of altered lumbopelvic posture and core stability on muscle activation patterns have not been evaluated during a functional movement. The main purpose of this study was to determine the relationship between pelvic tilt, core stability and muscle activation patterns during non-weighted squats in U/19 university-level rugby union players. A total of 49 rugby union players participated in this study. Pelvic tilt (dominant side) was measured from a digital photo with clear reflector markers on the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS) using the Kinovea video analysis software programme (version 0.8.15). Flexibility of the hamstrings, hip flexors and knee extensors was assessed with goniometry. Core stability was assessed using the pressure biofeedback unit and muscle onset times during the ascent phase of non-weighted squats. The onset times of the transverse abdominis (TrA), erector spinae (ES), gluteus maximus (GM) and biceps femoris (BF) muscles were measured using electromyography (EMG). Players were then grouped according to pelvic tilt (anterior and neutral) and by playing position (forwards and backs). The between group differences were evaluated for the abovementioned variables using p-value (statistical significance) and d-value (practical significance) measures. Muscle activation patterns and firing order were determined using descriptive statistics.

The mean pelvic tilt of all participants (N=49) was an anterior tilt of 15.35°. When grouped by pelvic tilt, the anterior tilt group showed a mean pelvic tilt of 17.83° (n=27) and the neutral pelvic tilt group showed a mean pelvic tilt of 11.75° (n=22). Despite the differences in pelvic tilt, there was no significant difference in flexibility between the groups. Another controversial result is that the anterior tilt group showed practical significantly better core stability (d=0.54) than the neutral tilt group (46.93° vs 56.3°).

During the double leg squat the muscle activation patterns were consistent between the groups. TrA activated first, followed by ES. Thereafter, the BF muscle activated, followed by the GM. The first place activation of TrA is consistent with the literature stating that the deep abdominal stabilisers of individuals with good core stability activate before the movement is initiated. The

early onset of muscle activity of ES points to a focus on back extension during the ascent of the squat. Because the pelvic tilt was measured during static standing only, it is unclear whether the players in the neutral tilt group were able to hold the neutral pelvic tilt posture throughout the movement. Research has shown that there is an increased focus on trunk extension during the ascent phase of the squat which is not present during the descent. Future research should focus on assessing the pelvic tilt at the beginning of the ascent phase of the squat to ensure accurate results.

The delay in GM activation during the ascent of the squat is concerning. GM acts as a lumbopelvic stabilizer, and its slow activation points to a decrease in lumbopelvic stability. This is very important in weight training, because weight training increases the strain on the lumbar spinal structures, which decreases performance and increases the risk of injury.

**Keywords:** Rugby union players, anterior pelvic tilt, electromyography, transverse abdominis activation, flexibility

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# OPSOMMING

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## **Pelvis biomeganika en spieraktiveringspatrone gedurende die squat beweging in O/19 rugby-unie spelers**

Hiperlordose of anterior pelvis tilt is 'n algemene nie-neutrale laerug postuur wat geassosieer word met swak abdominale stabilisering, laerug pyn en veranderde lumbo-pelvisiese spieraktiveringspatrone. Tog is die verband tussen hierdie nie-neutrale laerug postuur en abdominale stabilisering nog nie geëvalueer tydens 'n funksionele beweging nie. Daarom is die doel van hierdie studie om die verwantskap tussen pelvis tilt, abdominale stabiliseringskrag en spieraktiveringspatrone tydens die squat in O/19 rugby-unie spelers te evalueer. Nege en veertig rugby-unie spelers het deelgeneem aan die studie. Pelvis tilt (dominante kant) is gemeet vanaf 'n digitale foto met duidelike merkers op die anterior superior iliale spina (ASIS) en posterior superior iliale spina (PSIS) met behulp van die Kinovea analitiese sagteware program (weergawe 0.8.15). Soepelheid van die hampese groep, heup fleksore en knie ekstensore is gemeet met behulp van goniometrie. Abdominale stabiliseringskrag is bepaal met behulp van druksensitiewe bioterugvoer-eenheid, en spieraktiveringspatrone van die transverse abdominus (TrA), erector spinae (ES), gluteus maximus (GM) en biceps femoris (BF) spiere is met behulp van elektromiografie (EMG) gemeet tydens die opstaan-fase van die squat beweging. Tydens statistiese analise is die spelers gegroepeer volgens pelvis tilt (anterior of neutraal) en volgens speel-posisie (voorspelers of agterspelers). Die tussen-groep verskille is bereken vir die bogenoemde veranderlikes deur gebruik te maak van die p-waarde (statistiese betekenisvolheid) en die effekgrootte is ook bepaal om praktiese betekenisvolheid aan te dui (d-waarde). Spieraktiveringspatrone en die aktiveringsorde is bepaal deur gebruik te maak van beskrywende statistiek.

Die gemiddelde pelvis tilt van die proefpersone in totaal (N=49) is 'n anterior pelvis tilt van 15.35°. Die gemiddelde tilt van die anterior tilt geklassifiseerde groep is 17.83° (n=27) en 11.75° vir die neutrale tilt geklassifiseerde groep (n=22). Ten spyte van die verskil in pelvis tilt tussen die groepe is daar geen betekenisvolle verskil in soepelheid tussen die groepe nie. Die anterior pelvis tilt groep vertoon ook met prakties betekenisvol sterker abdominale stabiliseringskrag (d=0.54) as die neutrale tilt groep, wat in teenstelling is met onlangse literatuur (46.93° teenoor 56.3°).

Die spieraktiveringspatrone tydens die dubbel-been squat was dieselfde vir beide pelvis tilt groepe. Aktivering van TrA was die vinnigste, gevolg deur ES. Daarna het BF geaktiveer, met GM wat konstant laaste geaktiveer het. Die vroeë aktivering van TrA is in lyn met die literatuur wat voorstel dat in individue met goeie abdominale stabilisering die TrA spier sal aktiveer voor die aanvang van 'n beweging. Daar is wel ook 'n vroeë aktivering van ES waargeneem in hierdie studie, wat dui op 'n fokus op rug-ekstensie tydens die opstaan-fase van die squat. Omdat die pelvis tilt slegs tydens 'n stilstaande posisie gemeet was is dit onduidelik of die spelers in die neutrale pelvis tilt groep die neutral postuur kon behou regdeur die squat beweging. Literatuur beweer dat daar 'n verhoogde fokus op rug-ekstensie tydens die opstaan fase van die squat is, wat nie teenwoordig is tydens die afsak fase nie - dit lei tot die vroeë aktivering van ES. GM is verantwoordelik vir lumbo-pelviëse stabiliteit, en die vertraging in aktivering mag lei tot onstabiliteit rondom die pelvis. Dit is veral belangrik tydens krag-oefeninge, omdat hierdie tipe oefening spanning op die lumbale werwels verhoog. Toekomstige navorsing moet fokus op die evaluasie van die pelvis tilt tydens die beweging, om seker te maak dat die pelvis tilt nie oormatig verander tydens die beweging nie.

**Sleutelwoorde:** Rugby unie spelers, anterior pelvis tilt, elektromiografie, transverse abdominus aktivering, soepelheid

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<b>ACL:</b>	Anterior cruciate ligament
<b>ASIS:</b>	Anterior superior iliac spine
<b>ASLR:</b>	active straight leg raise
<b>BF:</b>	Biceps femoris
<b>cm:</b>	centimetre
<b>DLLT:</b>	double leg lowering test
<b>EMG:</b>	Electromyographic
<b>EO:</b>	External Obliques
<b>ES:</b>	Erector spinae
<b>GM:</b>	Gluteus maximus
<b>Hz:</b>	Hertz
<b>HF:</b>	Hip flexor
<b>HS:</b>	Hamstring
<b>KE:</b>	Knee extensor
<b>kg:</b>	kilogram
<b>L:</b>	Left
<b>L4:</b>	Fourth lumbar vertebrae
<b>L5:</b>	Fifth lumbar vertebrae
<b>LBP</b>	Low back pain
<b>mmHG</b>	MillimeterMillimetre of Mercury
<b>NWU:</b>	North-West University
<b>PHE:</b>	prone hip extension
<b>PSIS:</b>	Posterior superior iliac spine
<b>R:</b>	Right
<b>RA:</b>	Rectus abdominis
<b>RF:</b>	Rectus femoris
<b>SD:</b>	Standard deviation
<b>SIJ:</b>	Sacro-iliac joint
<b>SPSS:</b>	Statistical Package for the Social Sciences
<b>TrA:</b>	Transverse abdominis

**U/19:** Under nineteen  
**yrs:** years

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# CHAPTER 1

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## INTRODUCTION

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### 1.1 PROBLEM STATEMENT

Rugby is a high intensity and physically demanding contact sport that requires strength, endurance, speed and agility, combined with sport-specific skills (Gamble, 2004:10; Quarrie *et al.*, 2013:358). The all-round physically intense nature of the sport contributes to the rising number of players reporting lower back pain (LBP) (Iwamoto *et al.*, 2005:163). The game subjects the lumbar spine to compressive, shear and lateral bending forces due to scrum formation, tackling, mauling and rucking (Iwamoto *et al.*, 2005:166). These forces increase stress on the inter-vertebral discs, facet joints and pars inter-articularis in the lumbar spine, and can be exacerbated by an excessive lordotic lumbar curvature (Takasaki *et al.*, 2009:484). The squat is one of the foundational exercises used in functional strength training for the back and lower extremities, but is rarely performed correctly and can result in injury of multiple joints (Liebenson, 2003:230). The pelvis is the link between the torso and the lower extremities, and contributes towards the stability of the whole body (Kibler *et al.*, 2006:189).

Lubahn *et al.* (2011:101) suggests that sufficient activation of the muscles surrounding the pelvis may improve safety during functional and athletic movements. Pelvic or core stability is therefore considered to be crucial for performance enhancement and injury prevention in rugby union players (Butcher *et al.*, 2007:229; Leetun *et al.*, 2004:933).

LBP is a common problem among the general population, and it is no different with athletes. McManus *et al.* (2004:386) reported that 27% of amateur rugby players in Australian sports clubs suffer from chronic LBP, with a high recurrence rate. Further, there is evidence to suggest that LBP increases in concert with the physicality and competitiveness of play (Bathgate *et al.*, 2002:268). In an 8-year Australian study on high school rugby union players, 74% of players tested had radiographic lumbar abnormalities, including spondylolysis, disc space narrowing, spinal instability and disc herniation. Interestingly, only 41% of these children showed LBP (Iwamoto *et al.*, 2005:165). Of the players without lumbar abnormalities, 44% reported LBP. This concurs with Brooks *et al.* (2005:774) who stated that LBP may be caused by insufficient muscular stability of the lumbar spine, which may be aggravated by lumbar loading during play. The pelvis acts as the link between the upper and lower extremities and directly affects the biomechanics of the spine and lower extremities (Kibler *et al.*, 2006:189). This emphasises the need for proper lumbopelvic alignment and stability, as players in the front row can experience up to 1.5 tons of force exerted on the trunk with engagement of the scrum (Kaplan *et al.*, 2008:91). Altered lumbopelvic stability and related movement dysfunctions may also lead to hamstring injuries, and have been linked to the high recurrence rate of hamstring injuries in rugby union players (Devlin, 2000:277; Hoskins & Pollard, 2004:102).

Despite the load that the game of rugby puts on the lumbar spine, it is likely that LBP experienced by rugby players is also related to their strength training schedules (Fortin & Falco, 1997:698). The nature of elite sport requires constant mechanical tissue overload to improve performance and guard against injury, which puts emphasis on weight training to improve strength and power. Brooks *et al.* (2005:770) found that 55% of lumbar disc or nerve root injuries reported over a 98 week period by professional English rugby players were sustained during weight training, and these injuries were found to be more severe than injuries sustained during play. During a study conducted on 3 of the South African teams that competed in the 1999 Super 12 rugby competition, Holtzhauzen *et al.* (2006:1262) found that 34% of injuries occurred during training sessions, including the majority of back injuries reported during the season. Weighted squats are commonly used by rugby union players for strength training purposes, yet poor form and technique can decrease the efficiency of the exercises (Augustsson *et al.*, 1998:3), or even cause injury to multiple joints, especially the lumbar spine (Dolan & Adams, 1998:713; Fortin & Falco, 1997:706; Liebenson, 2003:230).

The squat is a closed-chain kinetic exercise with biomechanical and neurological similarities to several functional, multi-joint sporting movements (Augustsson *et al.*, 1998:7; Wilson *et al.*, 2005:98). For this reason, squats are advocated for the training of sportsmen, including rugby union players. Squats are also used in clinical settings to treat several hip, knee and ankle injuries (Bunton *et al.*, 1993:19; Dionisio *et al.*, 2008:134). The correct squatting technique requires practice, especially when progressing to weighted squats. If the squat is performed with an excessive lumbar lordosis or anterior pelvic tilt there is an increased reliance on ligamentous support (Norris, 1995:129), resulting in strain of the lumbar facet joints (Norris, 1994:12). Even with the correct posture, squatting can generate compressive, shear, tensile and torsional forces on the lumbar spine (Durall & Manske, 2005:64). Stability of the lumbar spine and pelvis is therefore strongly indicated during strength training regimes for safety and efficiency (Brooks *et al.*, 2005:774).

Stability of the lumbopelvic hip complex is maintained by a combination of bony structures, ligaments and muscle actions (Akuthota & Nadler, 2004:86; Muscolino & Cipriani, 2004:17). The transverse abdominus (TrA), rectus abdominus (RA), internal and external obliques (EO), quadratus lumborum (QL), multifidi and pelvic floor muscles form part of the core musculature that enables stability and support for all trunk and spinal movements (Akuthota & Nadler, 2004:87; Norris, 1995:129; Norris 1999:151; Queiroz *et al.*, 2010:87). The gluteal muscle group is responsible for hip stability, providing a stable base for movements of the lower extremities (Oliver & Keeley, 2010:3015). Malalignment of this pelvic region can be caused by muscle tightness or weakness, leading to LBP (Bendova *et al.*, 2007:980; Lehman *et al.*, 2004:4; Norris, 1994:12; Takasaki *et al.*, 2009:484; Wilson *et al.*, 2005:96). An anterior pelvic tilt is caused by tight hip flexor muscles (iliopsoas), putting the femur in flexion and shortening the hip flexor muscles even more (Deckert, 2007:110). The anterior tilt posture results in repetitive impingement of the lumbar vertebral facets during dynamic movements (Takasaki *et al.*, 2009:484; Trainor & Trainor, 2004:43), and more so during functional exercises such as the weighted squat (Fry *et al.*, 2003:631). The forward inclination of the pelvis results in a lordotic curvature in the lumbar spine, shortening the erector spinae muscles (ES), and lengthening the abdominal and gluteal muscle groups (Norris, 1999:154). Tightness of the ES and iliopsoas muscles causes these muscles functions in a restricted inner range of movement, and increases muscle tone. This muscular restriction results in inhibition of their antagonist muscles, the RA and the gluteal muscle group, due to their lengthened state (Norris, 1994:10; Queiroz *et al.*, 2010:90). If these muscles are lengthened over prolonged period, stretch

induced weakness will occur due to a reduced capacity of these muscles to activate in their outer range of movement (Muscolino & Cipriani, 2004:21; Norris, 1994:10). If the pelvis is tilted posteriorly to a neutral spinal position, the intra-umbilical portion of the RA, TrA and pelvic floor muscles can be activated more easily, contributing to pelvic stability (Norris, 1994:11; Queiroz *et al.*, 2010:90). Additionally, the reduction in anterior pelvic tilt may also increase gluteus maximus (GM) activation (Oh *et al.*, 2007:323), resulting in sacro-iliac joint (SIJ) compression and increased pelvic stability (Oliver & Keeley, 2010:3015). This combination of muscle actions results in optimal load transfer through the pelvis during functional movements (Hungerford *et al.*, 2003:1598) and are necessary for lumbar spine health during training and sporting activities.

Many studies have described muscle activation patterns during the squat movement, focusing on squat depth (Caterisano *et al.*, 2002:428; Robertson *et al.*, 2008:333), stance width (Anderson *et al.*, 1998:236), supported wall squat technique (Blanpied, 1999:123), unstable base (Anderson & Behm, 2005:33; McBride *et al.*, 2006:915), warm-up (Sotiropoulos *et al.*, 2010:326) and the single-leg squat (McCurdy *et al.*, 2010:57). Studies evaluating muscle activation patterns during the prone hip extension (PHE) have also been widely published (Lehman *et al.*, 2004:5; Lewis & Sahrman, 2009:239; Oh *et al.*, 2007:321; Sakamoto *et al.*, 2009:106), and is considered as a screening test for altered muscle activation patterns when assessing for lumbopelvic dysfunction. Even though these authors discuss activation patterns of GM and ES, among others, the PHE is completed on the prone lying position and is therefore not functional. It cannot be assumed that muscle activation patterns observed during prone lying will be the same during functional, athletic movements. This prone position also gives rise to a common procedure error, in which the subject initiates lifting of the thigh by going into an anterior pelvic tilt, which compromises the normal activation patterns (Liebenson, 2004:112). Yet no recent studies evaluate the effects of pelvic stability and biomechanics on muscle activation patterns during the squat movement.

Therefore, the research questions to be answered by this study are firstly, what are the lumbopelvic biomechanical characteristics of U/19 rugby union players at the North-West University (NWU), Potchefstroom Campus? Secondly, does core stability and selected lumbopelvic flexibility measures differ according to pelvic tilt in U/19 rugby union players at the NWU (Potchefstroom Campus)? Thirdly, do selected lumbopelvic muscle activation patterns differ according to pelvic tilt during the non-weighted squat in U/19 rugby union players at the NWU (Potchefstroom Campus)?

Considering the application of the squat in strength training for rugby union, the results of this study will provide information on muscle activation patterns in relation to core stability and pelvic function during execution of this functional exercise.

## 1.2 OBJECTIVES

The objectives of this study are to:

- Evaluate selected pelvic biomechanical characteristics in U/19 university-level rugby union players (NWU, Potchefstroom Campus).
- Determine whether core stability and selected lumbopelvic flexibility measures differ according to pelvic tilt in U/19 university-level rugby union players at the NWU (Potchefstroom Campus).
- Determine whether selected lumbopelvic muscle activation patterns of U/19 university-level rugby union players differed according to pelvic tilt during the non-weighted squat.

## 1.3 HYPOTHESES

The study is based on the following hypotheses:

- The majority of U/19 university-level rugby union players will not present with a neutral pelvic position and will also have insufficient lumbopelvic stability.
- U/19 university-level rugby union players with a neutral pelvic tilt will have significantly better core stability and lumbopelvic flexibility than players with an anterior pelvic tilt.
- U/19 university-level rugby union players with a neutral pelvic tilt will show significantly more correct muscle activation patterns than players with an anterior pelvic tilt.

## 1.4 STRUCTURE OF DISSERTATION

- Chapter 1: Introduction
- Chapter 2: Pelvic biomechanics and injury: a literature review
- Chapter 3: Pelvic biomechanics in university level rugby players (This article will be presented to: *South African journal of sports medicine*)
- Chapter 4: Pelvic biomechanics and muscle activation patterns during non-weighted squats (This article will be presented to: *Preventive medicine*)
- Chapter 5: Summary, conclusion and recommendations

Each chapter in the dissertation will be followed by references, with Chapter 1 and Chapter 2 written according to Harvard style. Chapter 3 and Chapter 4 was written in accordance with the reference style required by the peer-reviewed journal it will be submitted to. These requirements are listed in Appendix A and Appendix B.

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## CHAPTER 2

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### **PELVIC BIOMECHANICS AND INJURY: A LITERATURE REVIEW**

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#### **2.1 INTRODUCTION**

Injuries around the pelvic region are very common among the sporting elite, with the majority of these injuries being related to increased strain, micro-trauma and excessive loading of the surrounding joints (Fredericson & Moore, 2005:669; Geraci & Brown, 2005:711). Dysfunction of the lumbopelvic girdle causes inefficient and compensatory movement patterns (Fredericson & Moore, 2005:669) that are implicated in hip, buttock and groin pain (Geraci & Brown, 2005:713). The pelvis acts as a link between the spine and the lower extremities, and a detailed biomechanical approach is necessary to determine the cause of dysfunction, which may be related to functional deficits in the lumbar spine, pelvis, hip or thigh (Geraci & Brown, 2005:711). Lumbopelvic stability is an important component optimal athletic function,

as it mediates movements through the kinetic chain in all planes of movement (Kibler *et al.*, 2006:190).

This chapter will cover the biomechanics and anatomy of the pelvis, the effects of dysfunction on the surrounding musculoskeletal structures and its relation to rugby union injuries.

## 2.2 NEUTRAL SPINE AND CORE STABILITY

Neutral spine is defined as the ability to hold a lumbopelvic position in space during which load transfer is optimised through the weight-bearing structures, and where the length-tension relationships of the motion segments are balanced (Akuthota & Nadler, 2004:88; Geraci & Brown, 2005:713; Scannell & McGill, 2003:908; Wallden 2009:351). Neutral spine differs for every person, and depends on the individual's natural, anatomical spinal structure (Deckert, 2007:117); it does not mean a posterior pelvic tilt, as is commonly believed. A degree of lordosis is necessary to protect the spine against the compressive forces of gravity, and assists in absorbing impact forces during high-impact activities (Fredericson & Moore, 2005:670); a lordosis further provides biomechanical stability and strength (Morningstar, 2003:137). Neutral spine refers to the lumbopelvic posture in which the least amount of strain is put on any of the adjacent structures, and force can be generated without excessive movement (Nesser *et al.*, 2008:1750), and is associated with an increased automatic activation of the deep spinal stabilisers (Pinto *et al.*, 2011:582; Wallden 2009:356). This posture is generally achieved via an anterior pelvic tilt, within the range of 7 - 15° (Magee, 2002:623).

This neutral spine position requires the synergistic muscle activity of all the lumbopelvic stabilising muscles, or “core muscles”, namely transversus abdominis (TrA), the pelvic floor muscles, multifidus, quadratus lumborum (QL), the diaphragm, internal and external obliques (EO), paraspinals and the gluteus group (Faries & Greenwood, 2007:12; Norris, 1999:151; Willardson, 2007:979). These “core muscles” are stabilisers i.e. they do not only generate movement, but act to stabilise and support the lumbar spine (Faries & Greenwood, 2007:12; Norris, 1999:155) by working synergistically through antagonistic muscle activity to maintain neutral spinal posture and stability (Akuthota & Nadler, 2004:86; Stokes *et al.*, 2011:797). The core muscles prevent movement instead of initiating it (McGill, 2010:34). The other muscles surrounding the pelvis are mobilisers (such as rectus abdominis and rectus femoris), and are better adapted to generate movements (Comerford & Mottram, 2001:16; Norris, 1999:151).

Some of these mobilising muscles can however have a secondary stabilising role, such as rectus abdominis (RA) (Faries & Greenwood, 2007:12; Norris 1999:151). If working correctly, the stabilising muscles control the inter-segmental motion and stiffness of the spine, while the mobilising muscles transfer loads through the pelvis (Comerford & Mottram, 2001:16). This stability provides support during axial rotation (Wallden 2009:351) and explosive movements (Fredericson & Moore, 2005:669). With muscle imbalances, the mobilisers tend to shorten, while the stabilizers are lengthened (Wallden, 2009:351). These changes alter the muscle activity around the joint and can cause malalignment and pain (Norris 1999:153).

**Table 1: Functional classification of lumbopelvic muscles**

<b>Primary local stabilisers</b>	<b>Secondary local stabilisers</b>	<b>Global mobilisers</b>	<b>Both a stabilizer and mobiliser</b>
<ul style="list-style-type: none"> <li>• Maintains mechanical spinal stiffness</li> <li>• Controls intersegmental movement</li> <li>• Maintains neutral spinal posture</li> </ul>	<ul style="list-style-type: none"> <li>• Maintains mechanical spinal stiffness</li> <li>• Controls intersegmental movement</li> <li>• Maintains neutral spinal posture</li> </ul>	<ul style="list-style-type: none"> <li>• Load transfer through thoracic spine or pelvis</li> <li>• Controls larger movement (power and speed; limb movements)</li> </ul>	<ul style="list-style-type: none"> <li>• Generates larger movements</li> <li>• Assists in lumbopelvic stability</li> </ul>
Transverse abdominis Multifidi	Internal oblique Medial fibers of external oblique Quadratus Lumborum Diaphragm Pelvic floor muscles Iliocostalis (lumbar) Longissimus	Erector spinae Iliocostalis (thoracic) Latissimus dorsi Rectus abdominis Lateral fibers of external obliques Psoas major	Gluteus medius Gluteus maximus Rectus abdominis Lateral hamstring
Compiled from: Comerford & Mottram, 2001:16; Faries & Greenwood, 2007:12; Norris, 1999:151			

Recent studies have provided evidence to support the theory that impaired function of the stabilising muscles of the pelvis contributes to low back pain (Stokes *et al.*, 2011:798; Takasaki *et al.*, 2009:484) and discomfort in the hips, gluteal group and groin (Dawson-Cook, 2011:27). The pelvic girdle plays a significant role in the kinetic chain, acting as a link between the lower extremities and the spine (Akuthota & Nadler, 2004:88). Weak lumbopelvic stability has also been shown to increase the risk of injury due to the altered transfer of energy through the muscles (Nesser *et al.*, 2008:1750) and compensatory movement patterns (Fredericson &

Moore, 2005:669). This suggests that core stability is necessary for pain-free function and performance.

Core stability is a “moving target”, which will change through different planes of movement and with varying loads (McGill *et al.*, 2003:358; Reed *et al.*, 2012:698). Core exercises need to be task specific, to train the muscles for the function required, such as during functional sporting movements (McGill, 2010:33). The goal of such a training program should be to optimise the efficiency and fluency of movement (Lynn & Noffal, 2012:2417) to improve performance and decrease the strain on the musculoskeletal components (Robertson *et al.*, 2008:333).

Activities such as pushing, pulling, lifting, carrying and torsional exertion can be completed without activation of the core muscles, but energy output is compromised if the spine bends or buckles (McGill, 2010:34). The control of these “energy leaks” may account for increased lifting strength in research subjects undertaking core training programmes (Myers *et al.*, 2008:619; Szymanski *et al.*, 2007:1124) even though the effects of improved core stability on power is indirect (Hibbs *et al.*, 2008:1006; Willardson, 2007:983). The core musculature stabilises the lumbopelvic girdle, allowing the proximal and distal segments to generate or resist forces to optimise athletic function (Kibler *et al.*, 2006:193; Willardson *et al.*, 2007:984). This function implies that core stability will enhance athletic performance (Akuthota & Nadler, 2004:86).

Core training should focus on the role it will play in upper and lower extremity function and sport specific requirements (Kibler *et al.*, 2006:195). It should not focus on isolating a few muscles, but should train a simultaneous co-activation of all core and movement producing muscles governing the action required (Vera-Garcia *et al.*, 2007:557). This suggests that after achieving activation of the deep stabilising muscles such as TrA, the program should change to include functional resistance exercises of the global mobilising muscles (McGill, 2010:41; Willardson, 2007:980)

### **2.3 NON-NEUTRAL SPINE**

If the spine is in a non-neutral position, one or more skeletal components will bear greater loads than they are able to, resulting in cumulative micro-stress (Bendova *et al.*, 2007:980), intervertebral joint strains (Han *et al.*, 2011:477) and subsequent potentially degenerative

changes (Wallden, 2009:352). The result of a non-neutral posture on muscle tissue is that the muscles on one side of the joint will be in a relatively shortened or compressed position, while those on the other side of the joint will lengthen and become distractively loaded (Fredericson & Moore, 2005:676; Wallden 2009:351). This is communicated to the inner muscle unit musculature, which goes into a tonic state to try to restore neutral spinal position (Wallden 2009:351). Over time, this impairs the ability of surrounding the joint to passively restrict excessive joint movement (Wallden 2009:351). This change in muscle activation patterns decreases pelvic stability and mechanical efficiency of the body during movement (Takasaki *et al.*, 2009:484).

The most common non-neutral spinal position described in recent literature is the anterior pelvic tilt (Lim *et al.*, 2013:66). This causes shortening of the muscles anterior to the hip (psoas major) and lumbar paraspinals (erector spinae (ES)) and stretch weakness of the abdominal muscles (TrA), hamstrings and gluteals due to their anatomical insertion on the pelvis (Yerys



*et al.*, 2002:222). The tension these muscles exert on the pelvis becomes asymmetrical, which results in pelvic malalignment (Bendova *et al.*, 2007:986). The resulting lordosis causes the centre of gravity to align with the spinous processes, and not the body, of the vertebrae (Jensen, 1980:767), potentially causing facet joint strain, nerve impingement and increased pressure on the intervertebral discs (Han *et al.*, 2011:477). It has been proven that a structured core strengthening program (3 sessions per week of 50 minute duration for 7 weeks) can reduce the degree of lumbar hyperlordosis significantly (Carpes *et al.*, 2008:27).

**Figure 1: Anterior pelvic tilt**



**Figure 2: Posterior pelvic tilt** structures.

A decreased lordotic curve can also be harmful to the spine. Hypolordosis of the lumbar spine, which is often caused by hip extensor weakness or hip flexor contractures (Potter & Lenke, 2004:1794) can cause paraspinal muscle spasms (Gilbert *et al.*, 2009:96). Additionally, increased flexion of the lumbar spine is thought to increase pressure on the posterior aspects of the lumbar discs (due to loading on anterior aspect) (Wallden, 2009:354) and can cause inflammation due to increased tissue stress (Scannell & McGill, 2003:908). A reduction in lumbar lordosis also alters the biomechanics of the spine during weight-bearing by increasing pressure in the lumbar intervertebral discs (Legaye & Duval-Beaupere, 2005:219). This may cause degenerative lesions to the lumbar spinal

Because the nervous system always attempts to restore the body to its natural position of strength, it is important to obtain strength in the neutral spinal position (Wallden 2009:352). If strength is present in the neutral spine position, the length-tension relationship of the muscles surrounding the trunk will be optimised, because muscles become strongest in their mid-range of movement (Wallden 2009:356). This gives the spine a greater capacity to generate force, reduces shear forces, optimises load transfer at the proximal joints and decreases risk of low back pain (Carpes *et al.*, 2008:23; Wallden, 2009:356).

## 2.4 PELVIC BIOMECHANICS AND MUSCLE ACTIVATION PATTERNS

Few studies have described muscle activation patterns around the pelvis during functional movements. There is an abundance of research regarding muscle activation patterns during the prone hip extension (PHE), which is considered a valid test to identify individuals with lumbar deviation (Murphy *et al.*, 2006:377) and low back pain due to altered muscle activity (Arab *et al.*, 2011:23). The generally accepted sequence in muscle activation during the PHE is that HS

activates first, followed by ES and GM (Bruno & Bagust, 2007:75; Guimaraes *et al.*, 2010:355). However, Oh *et al.* (2007:323) observed a decrease in ES muscle activity with a reduction in the degree of anterior pelvic tilt. Also, the muscle activation of GM was significantly greater when the movement was initiated while the subject performed the abdominal drawing-in maneuver (Oh *et al.*, 2007:320) or when the pelvis was stabilised (Lewis & Sahrman, 2009:247). The PHE is performed in the prone lying position, and more research into the effect of anterior pelvic tilt and core muscle activation on more functional movements is required.

The importance of muscle activation patterns lies in the fact that if one muscle fatigues or is unable to activate correctly, the task is transferred partially or totally to another muscle, resulting in reduced performance and stability (Bradl *et al.*, 2005:275). This resulting compensatory mechanism has been widely researched, proving that decreased activation of the GM muscle results in increased workload on the biceps femoris (BF) muscle with resulting recurring muscle strains (Hoskins & Pollard, 2005:100; Vogt *et al.*, 2003:24). Fatigue of the GM has been found to increase the anterior tilt of the pelvis (Alvim *et al.*, 2010:211), and unilateral weakness of the GM may create an ipsilateral disruption of the pelvic position or angle (Alvim *et al.*, 2010:211). Studies have also suggested that early activation of the BF may cause delayed activation of the deep abdominal stabilisers such as TrA (Hungerford *et al.*, 2003:1596). It can thus be proposed that efficient core stability will support normal muscle activation patterns during functional movements (Devlin, 2000:281).

## **2.5 MUSCLE ACTIVATION PATTERNS DURING THE SQUAT**

Athletes employ the weighted squat as a strength training exercise for the hip, thigh and back (Dionisio *et al.*, 2008:134; Escamilla, Fleisig, Lowry *et al.*, 2001:984; Lynn & Noffal, 2012:2418). Researchers have been trying to establish the best squatting posture for decades, due to the apparent correlation between the squat and low back pain (Delitto *et al.*, 1987:1329). The single leg squat is often used in the rehabilitation of several back, hip, knee and ankle injuries (Richards *et al.*, 2008:482). Efficient execution of the squat requires mobility of the ankle, hip and thoracic spine, and sufficient stability of the foot, knee and lumbar spine (Kritz *et al.*, 2009:83).

### 2.5.1 NORMAL SQUAT

The ascent phase of the squat has been widely accepted as the most important and difficult part of the movement, and shows greater muscle activity than the descent phase (Escamilla, Fleisig, Zheng *et al.*, 2001:1557). During the descent phase, the body falls freely due to gravitational forces, resulting in small activation of the quadriceps and hamstring muscle groups (Dionisio *et al.*, 2008:141). Muscle activity during the ascent phase increases by 25-50% for the quadriceps group and 100-180% for the hamstrings group (Escamilla, Fleisig, Zheng *et al.*, 2001:1560).

**Table 2: Muscle contraction during different phases of the squat**

Phases	Concentric lumbopelvic contraction	Eccentric lumbopelvic contraction	Isometric lumbopelvic contraction	Gravitational influences
Descent	Hamstrings	Quadriceps Erector spinae Gluteus maximus Hamstrings	Transverse abdominis Multifidus	Causes free fall of body with small levels of muscle activity to control descent
Ascent	Erector spinae Quadriceps Hamstrings Gluteus maximus	Hamstrings	Transverse abdominis Multifidus	Causes increase in the level of muscular activity during first part of movement to overcome gravity and initiate ascent
Compiled from: Anderson & Behm, 2005:43; Dionisio <i>et al.</i> , 2008:141; Escamilla, Fleisig, Zheng <i>et al.</i> , 2001:1560; Schoenfeld, 2010:3500				

The ascent phase is initiated by strong activation of the quadriceps to extend the knees (Escamilla, Fleisig, Zheng *et al.*, 2001:1560), and has been shown to be the muscle group that activates most strongly during the ascent phase of the squat (Caterisano *et al.*, 2002:431). Many studies evaluate the effect of stance width, foot position, bar load and squat depth has on muscle activity (Caterisano *et al.*, 2002:429; Dionisio *et al.*, 2008:135; Distefano *et al.*, 2009:533; Gullett *et al.*, 2009:286; Wallace *et al.*, 2002:142).

The squat, irrespective of the technique or posture with which it is performed, is a favoured quadriceps exercise. The rectus femoris (RF) muscle has its origin on the anterior superior iliac spinae (ASIS), and will produce an increased anterior pelvic tilt if it dominates the squat movement (Lynn & Noffal, 2012:2423). Thus, it is important to spread the load to include the

other muscles surrounding the pelvis to control excessive RF activation during the squat, which can lead to knee injuries (John & Liebenson, 2013:137; Kulas *et al.*, 2012:19).

During the ascent phase of the squat, hamstring muscle activity increases to stabilise the pelvis and extend the hips (Dionisio *et al.*, 2008:141). The activity levels of the hamstring group are lower than those of the quadriceps, most likely because of their shared muscular function with the GM (Caterisano *et al.*, 2002:431; Escamilla, Fleisig, Zheng *et al.*, 2001:1556). The maximum activity levels of the hamstrings occur during the first third of the ascent phase (Escamilla, Fleisig, Zheng *et al.*, 2001:1560). This may imply that during this phase the GM muscle has not activated yet, due to the postural anatomy changes in the muscle (Escamilla, Fleisig, Zheng *et al.*, 2001:1560). This is in agreement with Schoenfeld (2010:3500) who stated that the biomechanical position of the GM at 90° of hip flexion has the lowest capacity to produce torque. Also, because the hamstring group acts as both a hip extensor and a knee flexor, its length stays fairly consistent, and may contribute to the consistent production of force throughout the squat (Schoenfeld, 2010:3501).

The abdominal stabilisers play a role in stabilising the spine and pelvis, and should activate strongly during the first half of the ascent phase (Anderson & Behm, 2005:43). Continued activity levels at a lower intensity are expected throughout the movement to maintain intra-abdominal pressure and lumbar stabilisation (Willardson, 2007:984). Recent research has concluded that the lumbopelvic stabilizer, TrA and multifidus, activate before any movement starts, which increases intra-abdominal pressure and tightens the thoracolumbar fascia, assisting in stability of the spine (Kibler *et al.*, 2006:190). This serves to alleviate vertebral loading (Schoenfeld, 2010:3501). The muscle activation of the abdominal muscle group has also been shown to increase with increased resistance and unstable surfaces (Clark *et al.*, 2012:1176/7).

The ES muscle has also been shown to activate significantly more during the ascent phase than the descent phase of the squat (Anderson & Behm, 2005:42). However, at the start of the ascent phase a significant drop in lumbo-sacral ES muscle activity occurs, due to the lumbar spine going into flexion (Anderson & Behm, 2005:43). After the start of the ascent, the ES muscle activity seems to vary with individual back postures during squatting. Squatting with the lumbar spine in flexion puts the muscle in a lengthened position, and decreases the amount of muscle activity (Schoenfeld, 2010:3501). This places more strain on the intervertebral discs and vertebral bodies, increasing the risk of injury (Legaye & Duval-Beaupere, 2005:219).

Conversely, lumbar extension increases ES activity and consequently spinal compressive forces (Schoenfeld, 2010:3501). ES activity has also been shown to decrease when ES co-contracts with the abdominal stabilisers, diminishing the spinal tension that would have been created by the ES muscle action alone (Schoenfeld, 2010:3501).

The GM muscle produces the most varied recorded activation levels in the squat movement (Caterisano *et al.*, 2002:430). The muscle is believed to act eccentrically to control the descent phase, and will contract powerfully to initiate ascent (Schoenfeld, 2010:3500). However, as mentioned earlier, GM produces less force at 90° of hip flexion as the muscle is in a lengthened position (Schoenfeld, 2010:3500). It has the function of assisting hip extension, assists in control of knee abduction and adduction and stabilises the pelvis (Lieberman *et al.*, 2006:2144). The GM muscle also serves to avoid any lateral pelvic rotation and compresses the sacro-iliac joint to maintain pelvic stability (Alvim *et al.*, 2010:211). Therefore, the GM muscle has great importance during the squat, as it serves to both stabilise the pelvis and extend the hips during the ascent phase of the squat.

Errors in squatting technique include back hyperlordosis and excessive anterior knee displacement (John & Liebenson, 2013:137); non-neutral postures that lead to an increase in ES muscle activity during the ascent phase of the squat (Sorensen *et al.*, 2011:150). To perform the squat safely requires rigidity of the spine with minimal planar motion (Schoenfeld, 2010:3501). It has also been shown that an excessive anterior pelvic tilt can decrease GM muscle activity (Alvim *et al.*, 2010:211), reducing both strength and stability. These factors combine to result in impingement of the lumbar facet joints (Han *et al.*, 2011:477) and low back pain.

### 2.5.2 SINGLE LEG SQUAT

The single limb squat has been widely used in rehabilitation as a screening tool (Livengood *et al.*, 2004:24), a post-rehabilitation clearance test (DiMattia *et al.*, 2005:109) and a strengthening exercise (Boudreau *et al.*, 2009:92). This particular exercise has been favoured for strengthening due to the marked increase in muscle activity when compared to other single limb exercises (Boudreau *et al.*, 2009:98). This exercise incorporates a dynamic version of the Trendelenburg test to identify gluteus medius weakness (Livengood *et al.*, 2004:24), and challenges the neuromuscular control of the trunk, hip, knee and ankle (DiMattia *et al.*, 2005:109). Correct technique for the single leg squat requires hip flexion < 65°, hip abduction

or adduction of  $<10^\circ$  and knee valgus or varus of  $<10^\circ$  at the maximum descent phase (Livengood *et al.*, 2004:25).

The single limb squat has been proven to strongly activate the gluteus muscles, mostly the gluteus medius of the weight-bearing leg (Boudreau *et al.*, 2009:99; Distefano *et al.*, 2009:537). The gluteus medius muscle of the non-weight bearing leg is also activated (Boudreau *et al.*, 2009:99), most possible due to the gluteal group resisting the gravitational force towards hip adduction of the raised leg whilst standing unilaterally (Distefano *et al.*, 2009:538). The single limb squat also strongly activates the GM, possibly due to its role in lumbo-pelvic stability, eccentric control of hip flexion and concentric hip extension (Distefano *et al.*, 2009:538). But more than any other muscle, the RF shows the highest level of muscle activity during the single leg squat (Boudreau *et al.*, 2009:98).

The single leg squat has been widely incorporated into sport specific training programs due to its neuromuscular similarities to unilateral, weight-bearing activities (McCurdy *et al.*, 2010:57). Research suggests that it is a better strengthening exercise than the double leg squat due to the increased demand of the neuromuscular system to support the body in the frontal plane of movement (McCurdy *et al.*, 2010:58). Additionally, the smaller support base of a single leg may mimic more accurately the strength and proprioception requirements of functional, athletic movements (McCurdy *et al.*, 2010:58). However, the unstable posture of the single leg squat makes it risky to incorporate weighted resistance, as the exercise requires synergistic activation of the knee, hip and trunk stabilisers to be completed safely (DiMattia *et al.*, 2005:119). Risks during this exercise include excessive knee valgus/varus movement (McCurdy *et al.*, 2010:65), lateral pelvic drop (McCurdy *et al.*, 2010:66) and increased lumbar extension loading (DiNaso *et al.*, 2012:55). Therefore, a modified version of this exercise has been promoted, with the trail leg providing support and balance (placed on a stable structure) without being fully weight-bearing (McCurdy *et al.*, 2010:58). This still provides increased muscle activity when compared to the normal squat (McCurdy *et al.*, 2010:64), but adds the necessary stability to enable progression to moderately loaded strength training.

### 2.5.3 KNEE-DOMINANT SQUAT VS HIP-DOMINANT SQUAT

The knee-dominant squat, as the name implies, has an increased knee flexion-based movement pattern, while the hip-dominant squat is characterised by an increase in hip flexion, causing a

forward trunk lean and a decreased knee flexion angle (McCurdy *et al.*, 2010:64). It has been proposed that a hip-dominant squat produces a more efficient movement pattern than a knee-dominant squat (Lynn & Noffal, 2012:2418) because of the decreased load it places on the lumbar spine and knee joints (John & Liebenson, 2013:137).

The squat is a closed-chain kinetic movement with biomechanical and neurological similarities to several functional, multi-joint movements performed daily (Augustsson *et al.*, 1998:7; Wilson *et al.*, 2005:98). Decreasing the load this movement places on the joints is therefore of great importance. The knee-dominant squat increases loading of the knee joint (John & Liebenson, 2013:137) and the anterior cruciate ligament (ACL) (Kulas *et al.*, 2012:19). An earlier study has shown that preventing the knees moving over the toes during the squat exercise decreased knee torque from  $150.1 \pm 50.8$  Nm to  $117.3 \pm 34.2$  Nm (Comfort & Kasim, 2007:11). It has also been demonstrated that a moderate forward trunk lean during the squat decreased the amount of strain and force placed on the ACL (Kulas *et al.*, 2012:20). An increased knee flexion angle has been shown to have an effect on the lumbar angle during squat lifting (Hwang *et al.*, 2009:19), and should be corrected for safe squatting.

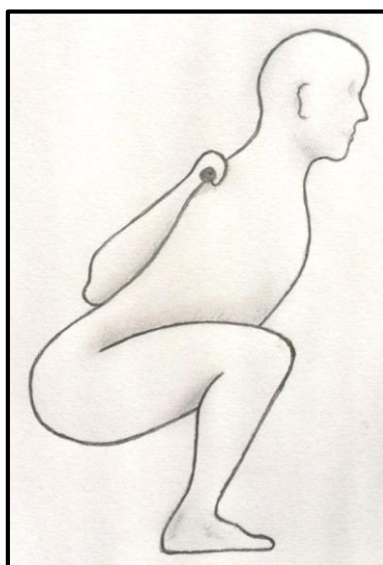
The biomechanical change from knee to hip dominance during the functional squat movement has been proven to change muscle activation patterns significantly (Anderson & Behm, 2005:41). Forward trunk lean has been associated with increased activation of the hip extensor (GM and the hamstring group) and abdominal stabiliser muscles (DiNaso *et al.*, 2012:55; McCurdy *et al.*, 2010:64), and decreased activation of the hip flexors (RF) (Kulas *et al.*, 2012:19). The forward trunk lean associated with the hip dominant squat will cause a mechanical shortening of the RF muscle and decreased knee joint torque (Kulas *et al.*, 2012:19). The RF muscle has its origin on the anterior inferior iliac spinae (ASIS), and will produce an increased anterior pelvic tilt if it dominates the squat movement, increasing the load on the lumbar facet joints (Lynn & Noffal, 2012:2423). Therefore, the hip-dominant squatting pattern does not only decrease muscle activity that increases pelvic inclination (RF), but also provides a more favourable posture for muscle activity that provides lumbopelvic stability (Anderson & Behm, 2005:43).

The hip-dominant squat will also increase the torque going through the hip joint rather than the knees (Comfort & Kasim, 2007:11), possibly because of the increased GM activity it produces during the ascent phase of the squat (Lynn & Noffal, 2010:2422). Strengthening of the extensor portion of the GM is also important, as this muscle exerts force on the pelvis in the sagittal

plane and can assist in pelvic stability and effective load transfer through the trunk to the lower extremities (Barker *et al.*, 2013:6). Finally, the GM has a larger cross sectional area than the entire quadriceps group combined (4842 mm<sup>2</sup> versus 4317.5 mm<sup>2</sup>) (Ito *et al.*, 2003:49), and is supported by the hamstrings group (Ward *et al.*, 2010:99), thus indicating the benefits of hip extension during the ascent. This technique of squatting has also been proven to increase hamstring muscle activity, especially when the knee is flexed more than 65°, placing focus on its importance during the ascent phase of the squat (Kulas *et al.*, 2012:19).

Correcting muscle activation deficiencies during the squat can delay or even prevent the occurrence of musculoskeletal injuries (Lynn & Noffal, 2012:2417). Instructions on how to activate the core muscles during the execution of the squat movement can lead to an immediate increase in EMG activity of RA, EO and TrA, with improved recruitment patterns in a short period of time (Bressel *et al.*, 2009:503). Researchers agree that the best way to avoid injury during weight training is to maintain a neutral spinal position at all times (Colado & Garcia-Masso, 2009:106; Durall & Manske, 2005:70; Han *et al.*, 2011:477; McGill *et al.*, 2003:356), yet no studies have evaluated the effects of core stability on lumbopelvic posture and muscle activation patterns during strength training.

The correct posture for the squat exercise has been widely debated. For the squat to be performed safely and efficiently, the mitigation of impact across all joints needs to be optimised (Fry *et al.*, 2003:632). After a review of the literature regarding squatting technique, Kritz *et al.* (2009:83) concluded that for execution of a safe squat a person requires mobility of the ankle and hip joints, and stability of the feet, knees and trunk.



**Figure 3: Optimal squatting technique**

**Table 3: Correct squatting alignment and posture**

Body area	Proposed alignment	Reason for proposed alignment
Head	Head held straight or looking slightly up, head in line with shoulders	Prevents excessive lumbar and thoracic flexion
Thoracic spine	Slight extension of spine, scapulae in neutral position and held stable	Avoids excessive loading on lumbar spine
Lumbar spine	No extension or flexion at any time during movement, held stable in neutral	Avoids excessive loading on lumbar spine
Hip joints	Hips aligned with knees, stable, no medial or lateral rotation.	Optimises load transfer through the pelvis
Knee joints	Aligned with hips and feet, no excessive medial or lateral rotation, no excessive movement forward (over toes) or backwards	Avoids excessive knee torque, and excessive trunk flexion during ascent phase of squat
Feet/ankle joints	Feet stable, heels on the ground throughout movement	Maintains balance and control of squat movement
Compiled from: Fry <i>et al.</i> , 2003:632; Kritz <i>et al.</i> , 2009:78		

## 2.6 LUMBOPELVIC INJURIES IN RUGBY UNION

Rugby union is a high intensity contact sport with varying phases of play, exposing participants to axial loading (line out), rotational forces (scrum, ruck and maul), impact collisions (tackle) and running/sprinting (Castinel *et al.*, 2007:337). The strain the game places on the body has been widely documented, and several aspects of rugby union can lead to injury (Brown *et al.*, 2012:53; Gianotti *et al.*, 2009:372; Hermanus *et al.*, 2010:231; Murray *et al.*, 2012:1). Most injuries reported result from contact with another player, such as tackles, rucks, mauls and scrums (Brooks *et al.*, 2005a:292; Brooks *et al.*, 2005b:760; Hermanus *et al.*, 2010:232; King *et al.*, 2011:127; Sinibaldi & Smith, 2007:18). The number of tackles, rucks and mauls during rugby union matches has steadily increased in recent years (Quarrie & Hopkins, 2007:900), increasing the risk of injury to players.

Researchers have evaluated the forces generated during scrumming (Du Toit *et al.*, 2004:33; Sinibaldi & Smith, 2007:18) indicating high levels of force. Even at junior level, forwards can generate 1400N on average during sustained scrumming (Du Toit *et al.*, 2004:46). The scrum is a contact manoeuvre involving 16 players that can injure the cervical spine (Du Toit *et al.*, 2004:34; Hermanus *et al.*, 2010:232; Kuster *et al.*, 2012:550; MacLean & Hutchison,

2012:592; Sinibaldi & Smith, 2007:18), thoracic spine (Boran *et al.*, 2011:862) lumbar spine (Davis *et al.*, 2009:796; Sakai *et al.*, 2010:284) and shoulder (Crichton *et al.*, 2011:539; Sundaram *et al.*, 2011:112). The impact of scrumming on the spine can cause long-term damage, compromising the integrity of the intervertebral discs, joints and ligaments (Sinibaldi & Smith, 2007:19). Players in the front row of the scrum are at increased risk of injury due to the biomechanical loading of the spine, especially if they scrum in a hyperlordotic posture (Castinel *et al.*, 2006:337).

Of further is the high number of injuries induced by weight training (Brooks *et al.*, 2005b:770). Weight training can result in chronic low back pain that manifests over time due to repetitive damage to the vertebral bodies, growth plates and intervertebral discs (Colado & Garcia-Masso, 2009:104; Durall & Manske, 2005:67; Walsh *et al.*, 2007:928). This risk of injury is increased if the proper technique is not applied. If the squat is performed with the back in hyperlordosis, the lumbar spine's ability to distribute the compressive force evenly is reduced and reaction forces increase (Adams *et al.*, 2000:1632; Durall & Manske, 2005:66; Han *et al.*, 2011:477; Walsh *et al.*, 2007:928;). Adams *et al.* (2000:1629) found that the stress peak in the posterior annulus of the lumbar spine increased by 114% if the spine is extended only 2° away from neutral. Awareness of lumbar extension is of particular concern in players who have not reached skeletal maturity yet (Walsh *et al.*, 2007:931).

## 2.7 SUMMARY

It is well established that both training for and playing rugby carry a risk of injury. The lumbar spine in particular is vulnerable to injury if the player presents with an anterior pelvic tilt. Increased core muscle strength is commonly believed to reduce the degree of anterior pelvic tilt (McGregor & Hukins, 2009:220), and used in clinical settings as treatment for low back pain. Even though core training has been included in the training regimes of sporting professionals in recent years, little is known about the effects of core stability on posture and muscle activity during sport.

No previous research has evaluated the effects of core stability and lumbopelvic biomechanics on muscle activation during functional movement. Lumbopelvic stability has been proven to play an integral part in optimal muscle functioning (Fredericson & Moore, 2005:676), and we need to better understand the role it plays during functional, closed-chain, sporting movements.

This knowledge may help to prevent injuries during training and game play by individualising each player's conditioning program to promote optimal functioning.

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## CHAPTER 3

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# CORE STABILITY, MUSCLE FLEXIBILITY AND PELVIC TILT IN RUGBY UNION PLAYERS

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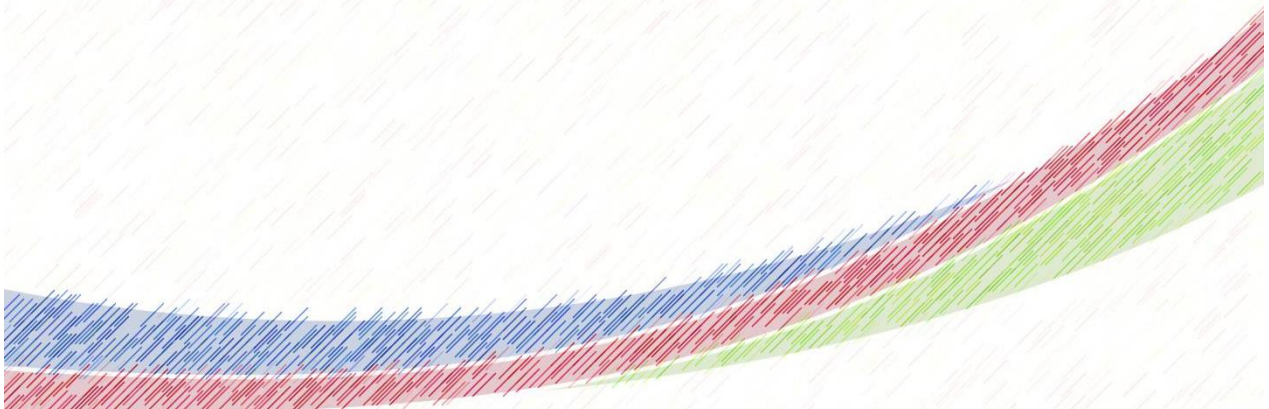
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## ABSTRACT

**Background:** The anterior pelvic tilt posture causes altered muscle activation in the trunk and hip area, resulting in decreased core muscle activation and lumbopelvic instability.

**Objectives:** To determine whether core stability and selected lumbopelvic flexibility measures in U/19 university-level rugby union players with an anterior pelvic tilt differs significantly from those with a neutral pelvic tilt, grouped by playing position.

**Methods:** This once-off cross sectional study was performed on the male U/19 rugby union training group of the North-West University for the 2013 season (N=49). Pelvic tilt was measured from a digital photo with clear reflector markers on the ASIS and PSIS using a video analysis software programme. Flexibility of the hamstrings, hip flexors and knee extensors was assessed with goniometry measurements. Core stability was assessed with the double leg lowering test.

**Results:** There was a significant difference ( $p=0.000$ ) in the mean degree of pelvic inclination between the group classified as having a neutral pelvic tilt ( $11.75^{\circ}$ ,  $n=20$ ) and the anterior pelvic tilt group ( $17.83^{\circ}$ ,  $n=29$ ). There was however no statistical significant ( $p\leq 0.05$ ) or practical significant ( $d\geq 0.8$ ) difference in core stability or flexibility measures between the anterior and neutral pelvic tilt groups. The mean core stability of the entire group was classified as being good ( $50.76^{\circ}$ ), with the anterior pelvic tilt group showing slightly better core stability than the neutral tilt group.

**Conclusion:** Pelvic tilt does not influence core stability and flexibility in selected pelvic muscles in rugby union players during the midseason. Future research should be conducted at the beginning of the year to eliminate the possible effect of core training regimes on the results observed.

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### 3.1 INTRODUCTION

As attested to in recent literature, the anterior pelvic tilt posture seems to be the most common non-neutral spinal position.<sup>[1]</sup> This position causes altered muscle activation patterns around the trunk and hips<sup>[2]</sup>, resulting in decreased lumbopelvic stability.<sup>[3]</sup> It has been theorised that the anterior pelvic tilt posture places the abdominal and gluteal muscles in a lengthened position, causing stretch weakness and hindering normal muscle activity.<sup>[4]</sup> A reduction in anterior pelvic tilt will increase gluteus maximus (GM) activation,<sup>[5]</sup> resulting in sacro-iliac joint (SIJ) compression and increased pelvic stability.<sup>[6]</sup> It is also believed that a neutral lumbopelvic posture can increase the degree of transverse abdominis (TrA) muscle activation.<sup>[7]</sup> Overall, it seems that a reduction in the degree of anterior pelvic tilt can support lumbopelvic stability.

Core stability, defined as the ability to hold a neutral lumbopelvic position while load transfer is optimised through the weight-bearing structures<sup>[7]</sup> has been suggested to contribute to a reduction in low back pain.<sup>[4]</sup> An increase in core stability has also been proven to optimize athletic function.<sup>[8]</sup> By stabilising the central body segments, a stable core allows for optimal forces to be transferred through the pelvis, as well as through the upper and lower extremities.<sup>[8,9]</sup> This is of particular importance in participants of a high intensity contact sport, as the core muscles also assist in absorbing shocks during high-impact activities.<sup>[2]</sup> As a result, core muscle training has been included in the conditioning programs of most individuals who participate in sport.<sup>[9]</sup>

It is commonly believed that anterior pelvic tilt is one of the leading causes of low back pain.<sup>[10]</sup> Not only does this posture cause repetitive impingement of the lumbar facet joints,<sup>[11]</sup> but has also been identified as a possible contributing factor in the development of spondylololsthesis.<sup>[10]</sup> If untreated, this posture may cause pain and degenerative change to the lumbar spinal structures.<sup>[7]</sup> This has led to the that sportsmen/women can improve performance and reduce the likelihood of injury by improving their core stability and back posture.<sup>[12]</sup> This is relevant to a high intensity contact sport such as rugby union, in which the spine is subjected to compressive, shear and lateral bending forces due to scrumming, tackling, mauling and rucking.<sup>[13]</sup> In addition to the high risk of injury in rugby union, recent studies have documented a high incidence of weight training-related injuries to the lumbar spine.<sup>[12,14]</sup> Given the emphasis on weight training in rugby, the avoidance of such injuries is arguably of high priority, indicating the need for core strengthening and the use of proper posture and technique when performing exercises with weights.

Therefore, the aim of this study is to determine whether core stability, as well as selected lumbopelvic flexibility measures of U/19 rugby union players differ according to pelvic tilt and playing position.

### 3.2 METHODS

#### 3.2.1 Locality

The study was conducted by a Biokineticist at the High Performance Institute of the North-West University's Potchefstroom campus during a week-long testing period in April 2013.

### 3.2.2 Population

The subjects for this once-off cross sectional study was the male U/19 rugby union training group (N=49; average age 18.51 years) for the 2013 season at the North-West University (NWU), Potchefstroom campus. This particular age group was chosen because of the increased training intensity rugby union players experience in the first year of participation in semi-professional rugby union. Ethical approval was obtained from the Ethics Committee of the NWU (NWU-00048-11-A1). Prior to the study an educational session on pelvic stability was presented to the players and coaches of the U/19 squad. Players who agreed to participate signed informed consent prior to testing. Players who were injured, or recovering from back or knee surgery, or any other unresolved orthopaedic conditions, and players who underwent physical rehabilitation in the previous season were excluded from the study.

### 3.2.3 Measurements

The test protocol comprised a demographic and injury history questionnaire (used for the exclusion criteria, see Appendix C), anthropometric assessment, selected pelvic flexibility measures and assessment of core stability.

#### Anthropometric measurement

Stature was measured with a stadiometer to the nearest 0.1 cm, with shoes removed and head held in the Frankfort plane. Weight was determined using an electronic scale (Beurer 3V Lithium electronic scale, CR2032) to the nearest 0.1 kg, with minimal clothing.<sup>[15]</sup>

#### Pelvic tilt measurement

Reflective markers were placed on the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS). The participant was then asked to turn sideways with the dominant side facing towards a camera placed on a stationary tripod (Manfrotto) two meters away. A digital photo was taken with the arms crossed over the chest, ensuring the reflecting markers were clearly visible. The pelvic tilt (the angle between the horizontal line of the PSIS and the line connecting the reflecting markers of the ASIS and PSIS) was measured to the nearest degree using the Kinovea video analysis software programme (version 0.8.15).

#### Flexibility measurements

Bilateral flexibility was assessed using a goniometer, recorded as a mean of two measurements to the nearest degree. A third measurement was taken if the initial two measurements differed by more than 5°. Landmarks were placed on the greater trochanter of the femur, and the head and lateral malleolus of the fibula.

Hamstring flexibility was assessed with the active straight leg raise (ASLR) performed from the supine position. A goniometer was used to measure the angle from the horizontal to the highest level of straight leg hip flexion before any knee flexion occurred (the line connecting the greater trochanter of the femur and the head of the fibula).<sup>[16]</sup>

Hip flexor and knee extensor flexibility was assessed using the modified Thomas and Kendall method.<sup>[17]</sup> The hip flexor angle was measured with the stable arm of the goniometer horizontal from the greater trochanter, and the moving arm aligned with the landmark on the fibula head.<sup>[17]</sup>

Knee extensor flexibility was measured as the angle between the horizontal line created by connecting the greater trochanter of the femur and the fibula head, and the line created by connecting the fibula head and the lateral malleolus.<sup>[17]</sup>

### Core stability measurement

Each participant's core stability was determined using the double leg lowering test (DLLT).<sup>[18]</sup> In the supine position with a pressure biofeedback unit under the lumbar spine, the participant was asked to lift both legs to 90° of hip flexion and 90° of knee flexion. The biofeedback unit was then inflated by one researcher to 40 mmHg, with the participant activating their core muscles. The participant was then instructed to lower and extend both legs down towards the plinth, trying to keep the lumbar spine in a neutral position. The first researcher stopped the participant as soon as the biofeedback unit moved more than 10 mmHg up or down, with a second researcher measuring the degree of descent. Measurement started with the goniometer at a 90° angle, placed on the greater trochanter of the femur. The stable arm is placed on the horizontal line of the plinth, and the angle of descent is measured on the line connecting the greater trochanter and the head of the fibula. The test was completed twice; the best measurement being recorded to the nearest degree (better core stability was indicated by a smaller value).

### 3.2.4 Statistical analysis

The statistical analyses were performed with the Statistica 10 software package (StatSoft, Inc., 2011) by the Statistical Consultation Services of the North-West University, Potchefstroom campus. Independent t-tests ( $p \leq 0.05$ ) were used to determine the differences in measured parameters between forward and backline players, and to determine differences according to pelvic tilt (neutral- and anterior pelvic tilt). Effect sizes were calculated to indicate practical significant differences for measured parameters according to pelvic tilt. A small effect size is indicated by  $d \geq 0.2$ , a medium effect size by  $d \geq 0.5$  and a large effect size by  $d \geq 0.8$ <sup>19</sup>.

## 3.3 RESULTS

The basic characteristics of the participants (N=49) are presented in Table 1. The forwards (n=27) were significantly taller and heavier than the backline players (n=22).

**Table 1: Descriptive statistics of rugby union players**

Variables	Total group (N=49)	Forwards (n=27)	Backs (n=22)	p-value
<u>Basic characteristics (Mean ± SD)</u>				
Age (yrs)	18.51 ± 0.51	18.48 ± 0.51	18.55 ± 0.51	0.66
Stature (cm)	182.58 ± 5.80	184.96 ± 5.54	179.67 ± 4.77	0.00*
Weight (kg)	92.90 ± 12.26	101.11 ± 8.58	82.82 ± 7.69	0.00*
SD = standard deviation; * = statistically significant p-value ( $p \leq 0.05$ )				

**Table 2: Pelvic biomechanics characteristics of rugby union players**

Variables	Total group (n=49)	Forwards (n=27)	Backs (n=22)	p-value	d-value
<u>Flexibility</u>					
<u>(mean ° ± SD)</u>					
HS dominant	71.31 ± 8.57	70.37 ± 9.37	72.46 ± 7.53	0.40	0.22
HS non-dominant	73.10 ± 7.55	72.70 ± 8.40	73.59 ± 6.50	0.69	0.11
HF dominant	3.90 ± 7.64	3.19 ± 7.95	4.77 ± 7.34	0.48	0.2
HF non-dominant	4.69 ± 5.79	4.37 ± 6.02	5.09 ± 5.61	0.67	0.12
KE dominant	134.29 ± 7.78	132.56 ± 7.90	136.41 ± 7.26	0.09	0.49
KE non-dominant	133.27 ± 7.50	132.22 ± 8.14	134.55 ± 6.59	0.29	0.29
<u>Core stability</u>					
<u>(mean ° ± SD)</u>					
Double leg lowering test	50.76 ± 17.76	52.15 ± 17.16	49.05 ± 18.73	0.55	0.17
<u>Pelvic tilt</u>					
<u>(mean ° ± SD)</u>					
Anterior pelvic tilt	15.35 ± 3.92	14.96 ± 4.79	15.82 ± 2.52	0.454	0.18
HS = hamstrings; HF = hip flexors; KE = knee extensors; ° = degrees; ±SD = standard deviation; p-value* = p ≤ 0.05; d ≥ 0.2 = small practical significance; d ≥ 0.5 = medium practical significance; d ≥ 0.8 = large practical significance					

Table 2 presents the pelvic biomechanical characteristics of the group. Flexibility measures did not differ significantly between the two groups. Both groups presented with tightness in their hamstrings (norm is 90°) and quadriceps muscle groups (norm is 125°), with the hip flexor muscle group presenting within the normal recommended range (norm is 5°). The dominant leg showed decreased flexibility in all muscle groups tested when compared to the non-dominant side.

The mean anterior pelvic tilt for the group is 15.35°, which is higher than the normal recommended levels. There was no significant difference in pelvic inclination between the forwards (14.96°) and backs (15.82°).

The mean core stability for the group was 50.76±17.76°, which is classified as good core stability. There was no significant difference in core stability between the forwards and backs.

**Table 3: Differences in core stability and degree of pelvic tilt**

	Pelvic position	Degree of tilt (mean° ± SD)	p-value	d-value
<b>Total group</b>	Neutral pelvic tilt (n=20)	56.3 ± 17.35	0.07	0.54 <sup>ψ</sup>
	Anterior pelvic tilt (n=29)	46.93 ± 17.31		
<b>Forwards</b>	Neutral pelvic tilt (n=11)	57.91 ± 18.61	0.15	0.52 <sup>ψ</sup>
	Anterior pelvic tilt (n=16)	48.19 ± 15.43		
<b>Backs</b>	Neutral pelvic tilt (n=9)	54.33 ± 16.54	0.28	0.45 <sup>ψ</sup>
	Anterior pelvic tilt (n=13)	45.39 ± 19.91		
SD = standard deviation; <sup>ψ</sup> = practical significant d-value; d ≥ 0.2 = small practical significance; d ≥ 0.5 = medium practical significance; d ≥ 0.8 = large practical significance				

Table 3 presents the differences in core stability between players according to the pelvic tilt. The average pelvic tilt of players classified as having an anterior pelvic tilt was 17.83°, while those with a neutral tilt had a statistically significantly ( $p=0.000$ ) decreased anterior pelvic tilt of 11.75°. Although not statistically significant, players with an anterior pelvic tilt seem to have a slightly better core stability than those with a neutral tilt, with a smaller value indicating better core stability (medium practical significance observed;  $d=0.54$ ).

**Table 4: Dominant side flexibility measures and pelvic tilt**

	<b>Total group</b>			
	<b>Neutral</b> (n=20)	<b>Anterior</b> (n=29)	<b>p-value</b>	<b>d-value</b>
<b>Flexibility (mean ° ± SD)</b>				
Hamstrings	72.55±8.19	70.45±8.87	0.405	0.24
Hip flexors	3.05±8.68	4.49±6.94	0.525	0.17
Knee extensors	134.25±5.77	134.31±9.02	0.979	0.01
	<b>Forwards</b>			
	<b>Neutral</b> (n=11)	<b>Anterior</b> (n=16)	<b>p-value</b>	<b>d-value</b>
<b>Flexibility (mean ° ± SD)</b>				
Hamstrings	72.73±9.10	68.75±9.49	0.287	0.42 <sup>ψ</sup>
Hip flexors	2.09±7.31	3.94±8.50	0.563	0.22
Knee extensors	132.55±6.22	132.56±6.22	0.996	0.00
	<b>Backs</b>			
	<b>Neutral</b> (n=9)	<b>Anterior</b> (n=13)	<b>p-value</b>	<b>d-value</b>
<b>Flexibility (mean ° ± SD)</b>				
Hamstrings	72.33±7.45	72.54±7.89	0.952	0.03
Hip flexors	4.22±10.45	5.15±4.58	0.777	0.09
Knee extensors	136.33±4.66	136.46±8.82	0.969	0.01

SD = standard deviation; <sup>ψ</sup> = practical significant d-value;  $d \geq 0.2$  = small practical significance;  $d \geq 0.5$  = medium practical significance;  $d \geq 0.8$  = large practical significance

Table 4 presents the flexibility measures classified by pelvic tilt. No statistical or large practical significant differences were indicated in flexibility measures between players with an anterior pelvic tilt and those with a neutral tilt.

### 3.4 DISCUSSION

This study aimed to determine whether flexibility and core stability parameters differed according to pelvic tilt in U/19 rugby union players. The average tilt of the group was in an anterior inclination. Although backline players had a slightly higher degree of anterior pelvic tilt when compared to the forwards, they presented with slightly better core stability (although not statistically significant). This is consistent with the results of Nourbakhsh,<sup>[4]</sup> who found no relationship between lumbar lordosis and decreased lumbopelvic stability.

Injuries and pain surrounding the lumbar spine have commonly been reported in rugby union,<sup>[20]</sup> but are not specific to specific playing positions. Even though lumbar disc and nerve

root injuries have been correlated with scrumming and forward play, backline players also incur frequent injuries to the lumbar spine, as well as lumbar muscle strains.<sup>[21]</sup> This highlights the need for lumbopelvic stability in all rugby union players, and the need to achieve a neutral spinal posture in order to reduce lumbar spinal strain. This study found no significant difference between forwards and backs, and the entire group presented with good core stability.

Tables 3 and 4 presented core stability measures in relation to pelvic tilt. No statistically significant differences in these parameters were observed between players with anterior and neutral pelvic tilts. Interestingly, those with an anterior pelvic tilt showed slightly better core stability, although only of medium practical significance. This is in contrast with the literature, which states that an anterior pelvic tilt is associated with a decrease in muscle activity of the lumbopelvic stabilising muscles.<sup>[2]</sup> The literature also reports that an increase in core stability will decrease the degree of anterior pelvic tilt,<sup>[22]</sup> supporting injury prevention to the lumbar spine<sup>[7]</sup> and reducing muscular imbalances.<sup>[2]</sup> It is common for core training regimes to be completed in the supine position, which is how core stability was assessed in this study. There is, however, a need for more functional movement-based core stability exercises. These are needed to specifically strengthen the core and improve lumbopelvic posture for the functional movements performed in the high intensity/impact situations encountered in rugby union.

No significant differences in flexibility measures were indicated between the pelvic positions. However, both groups of players in an anterior and neutral pelvic tilt were tested to have limited knee extensor flexibility. As mentioned earlier, the average pelvic tilt for the group in total was 15.35° in the anterior position. One would therefore expect the hip flexor muscles and the knee extensor muscles to test as being tight<sup>[4]</sup> and the hamstrings to test as being tight as they are in a lengthened position.<sup>[23]</sup> An anterior pelvic tilt posture has also been linked to the occurrence of recurrent hamstring strain,<sup>[23]</sup> because of the muscle's insertion on the ischial tuberosity on the posterior aspect of the pelvis.<sup>[24]</sup> This is especially important for rugby union players, because of the abrupt direction changes and sprints that occur during play.<sup>[20]</sup> If left untreated, this posture can result in chronic pain or injury. Another common injury in which anterior pelvic tilt may be implicated is the Gilmore's groin (herniation of the oblique aponeurosis).<sup>[25]</sup> This is especially common in sport with quick accelerations and sudden directional changes, and this condition can be aggravated by muscular imbalance around the pelvis.<sup>[25]</sup>

Despite the difference in pelvic tilt between the anterior and neutral pelvic tilt groups, no difference in the flexibility between these groups was measured. This is consistent with the results of Nourbakhsh,<sup>[4]</sup> who found no correlation between hip flexor tightness and anterior pelvic tilt. An increased anterior pelvic tilt could contribute to the development of spondylolisthesis,<sup>[10]</sup> and result in intervertebral joint strain<sup>[11]</sup> and degenerative changes to the lumbar spine.<sup>[7]</sup> The RF muscle is both a hip flexor and a knee extensor, and originates from the anterior inferior iliac spine of the os coxa.<sup>[26]</sup> It is possible that tightness or dominance of RF could affect the lumbar spinal position, especially during functional movements in a standing position. However, in the current study the knee extensors were also not flexible in the players with a neutral pelvic position.

The findings of the current study did not show core stability and flexibility to be influenced by pelvic position. When grouped according to pelvic tilt and playing position, the number of participants in each group decreased significantly, and might have influenced the statistical significance of the tests. Testing was completed in April, 4 months after the players started their preseason training. The coaches of the U/19-squad told the researchers that core stability training had been an integral part of the training programme since January 2013. For a more

adequate data set, testing should be done during the pre-season and followed up regularly during the season.

### **3.5 CONCLUSION**

In conclusion, the study showed that core stability and flexibility of rugby union players with an anterior pelvic tilt did not differ significantly from players with a neutral pelvic tilt. Therefore, core stability and flexibility is not dependant on pelvic tilt in selected pelvic muscles in rugby union players during the midseason.

#### **Study Limitations**

There are several limitations to this study. Firstly, the measurements took place during April, which is the start of the midseason for this rugby union squad. This implied that the players have been exposed to core training regimes for almost 4 months before testing commenced - this might have influenced our results. Ideally, testing should be completed before the start of the season and follow-up testing should take place at regular intervals during the season, and at its end. This would provide a baseline against which changes in core stability could be recorder. The most important limitation of this study is the number of participants. After grouping the players according to playing position and pelvic biomechanics, the number of participants per group was too small for meaningful comparison.

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## CHAPTER 4

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# PELVIC TILT AND MUSCLE ACTIVATION PATTERNS DURING NON-WEIGHTED SQUATS

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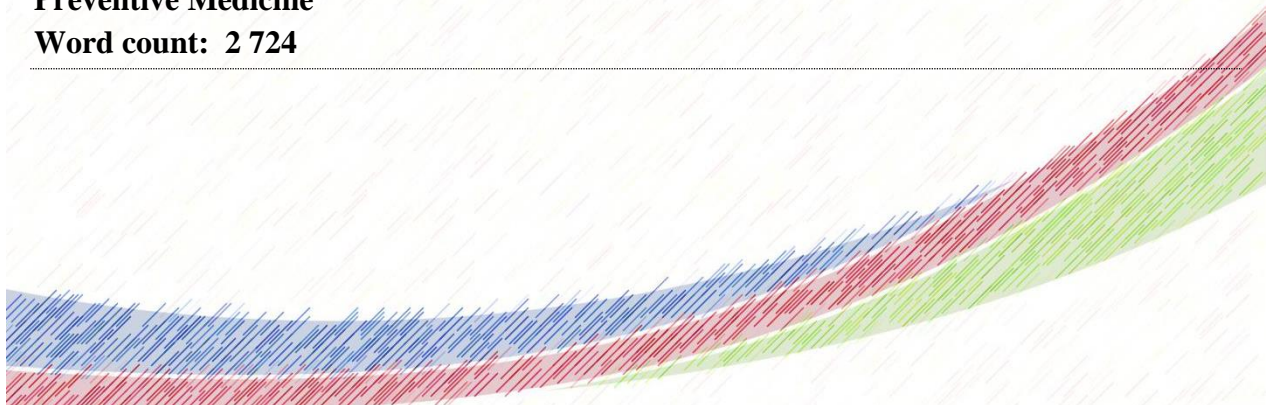
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## ABSTRACT

**Objectives:** To determine whether selected lumbopelvic muscle activation patterns of university-level rugby union players differ according to pelvic tilt during the non-weighted squat.

**Method:** U/19 rugby union players (N=49) of the North-West University in Potchefstroom, South Africa were tested during a week in April 2013. Pelvic tilt angle was measured from a digital photo with clear reflector markers on the ASIS and PSIS using the Kinovea computer programme and core stability was assessed with a pressure biofeedback unit. EMG activity was assessed bilaterally during the non-weighted double leg squat of Transverse abdominis (TrA), Erector spinae (ES), Biceps femoris (BF) and Gluteus Maximus (GM).

**Result:** The mean core stability of the group can be classified as good ( $50.76^\circ$ ), with the anterior tilt group showing better core stability ( $46.93^\circ$ ) than the neutral tilt group ( $56.3^\circ$ ). No statistical- ( $p \leq 0.05$ ) or practical significant ( $d \geq 0.8$ ) differences in muscle activation patterns were observed between players in an anterior and neutral pelvic tilt. The activation sequence during ascent of the squat was consistent in both the anterior and neutral tilt groups, with TrA first, ES second, BF third and GM fourth.

**Conclusion:** The lumbopelvic muscle activation patterns of the university-level rugby union players tested in this study did not show significant differences according to pelvic tilt during the ascending phase of the non-weighted squat. This finding may be attributed to the good core stability observed in both the neutral and anterior pelvic tilt groups. GM activation was however delayed in both groups, which could reduce lumbopelvic stability during a functional movement.

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## 4.1 INTRODUCTION

A neutral lumbar spine has been shown to be important in the activation of the abdominal stabilising muscles (Pinto et al. 2011). Muscle activation of the deep abdominal stabilisers has been documented before the onset of lower limb movements, most probably to stabilise the lumbopelvic complex before force is generated for the task at hand (Pinto et al. 2011). A stable lumbopelvic girdle during functional movements is extremely important for optimal performance and injury prevention in sport (Akuthota & Nadler, 2004:86), especially in a high intensity, high impact sport such as rugby union.

Anterior pelvic tilt or lumbar lordotic posture is commonly believed to cause chronic low back pain (Lim et al. 2013; Evcik and Yucel, 2003). Numerous studies have also identified an altered muscle activation pattern around the lumbopelvic girdle in subjects with low back pain when compared to pain free subjects (Dankaerts et al. 2006; Rasouli et al. 2011; Van der Hulst et al. 2010). This altered muscle activation pattern results in insufficient hip stability, delayed or decreased core muscle activation (Pinto et al. 2011), decreased stability around the trunk (Tateuchi et al. 2012) and excessive loading of the surrounding muscle groups (such as the hamstring muscle group) (Chance-Larsen et al. 2009).

A high number of lumbar spinal injuries in rugby union players occur during training (Brooks et al. 2005). Weight training has been shown to cause strain on the vertebral bodies and intervertebral discs (Walsh et al. 2007). The squat, which is frequently used during strength training for the lower limbs, is a closed chain kinetic exercise with biomechanical and neuromuscular similarities to several functional, multi-joint sporting movements (Wilson *et al.*, 2005), and is therefore a popular exercise for rugby union players. However, if the squat is performed in the anterior tilt posture the strain on the lumbar spine is increased (Han et al. 2011), lumbopelvic stability is decreased, increasing risk of serious back injury.

Therefore, the aim of the study is to determine whether selected lumbopelvic muscle activation patterns differ according to pelvic tilt in U/19 university-level rugby union players during the non-weighted squat.

## 4.2 METHODS

### 4.2.1 PARTICIPANTS

The target population of this once-off cross sectional study was the male U/19 rugby union training group (N=49; average age 18.51 years) for the 2013 season at the North-West University (NWU), Potchefstroom campus. This particular group was chosen due to the increased training intensity rugby union players experience in the first year of participation in semi-professional rugby union. Ethical approval was obtained from the Ethics Committee of the NWU (NWU-00048-11-A1). Prior to the study an educational session on pelvic stability was presented to the players and coaches of the u/19 squad. Players whom agreed voluntarily to participate signed informed consent prior to testing. Players suffering from any injury, recovering from back or knee surgery or any other unresolved orthopaedic condition, as well as players who underwent physical rehabilitation in the previous season were excluded from the study.

### 4.2.2 ANTHROPOMETRIC MEASUREMENTS

Stature was measured with a stadiometer to the nearest 0.1 cm, with shoes removed and head held in the Frankfort plane. Weight was determined using an electronic scale (Beurer 3V Lithium electronic scale, CR2032) to the nearest 0.1 kg, with minimal clothing (Marfell-Jones et al. 2006)

### 4.2.3 PELVIC TILT MEASUREMENT

Reflective markers were placed on the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS). The participant was then asked to turn sideways with the dominant side facing towards a camera placed on a stationary tripod (Manfrotto) two meters away. A digital photo was taken with the arms crossed over the chest, ensuring the reflecting markers were clearly visible. The pelvic tilt (the angle between the horizontal line of the PSIS and the line connecting the reflecting markers of the ASIS and PSIS) was measured to the nearest degree using the Kinovea video analysis software programme (version 0.8.15).

### 4.2.4 CORE STABILITY

Each participant's core stability was determined using the double leg lowering test (DLLT) (Ashmen et al. 1996). In the supine position with a pressure biofeedback unit under the lumbar

spine, the participant was asked to lift both legs to 90° of hip flexion and 90° of knee flexion. The biofeedback unit was then inflated by one researcher to 40 mmHg, with the participant activating their core muscles. The participant was then instructed to lower and extend both legs down towards the plinth, trying to keep the lumbar spine in a neutral position. The first researcher stopped the participant as soon as the biofeedback unit moved more than 10 mmHg up or down, with a second researcher measured the degree of descent. Measurement started with the goniometer at a 90° angle, placed on the greater trochanter of the femur. The stable arm is placed on the horizontal line of the plinth, and the angle of descent is measured on the line connecting the greater trochanter and the head of the fibula. The test was completed twice; the best measurement being recorded to the nearest degree (better core stability was indicated by a smaller value).

#### 4.2.5 EMG MUSCLE ACTIVITY

Muscle activation times were recorded using surface electromyography (EMG) (MyoTrace 400, Noraxon USA, Inc., Scottsdale, Arizona) during the execution of non-weighted squats. The onset of muscular activity was considered to occur when the activity of each of the muscles exceeded two standard deviations from the mean value. The EMG signals were full wave rectified and low and high pass filtered, with cut-off frequency set between 500 and 10 Hertz (Hz). Latency was measured in milliseconds with the EMG-onset time set at 0.001 sec. After cleaning the skin thoroughly with isopropyl alcohol, EMG electrodes were placed bilaterally, parallel to the muscle fibers on the following muscles: gluteus maximus (GM), biceps femoris (BF), erector spinae (ES) and transverse abdominis (TrA). The GM electrodes were placed midway between the last sacral vertebrae and greater trochanter (Sakamoto et al. 2009). BF electrodes were placed midway between the greater trochanter and lateral condyle (Sakamoto et al. 2009). ES electrode placement was parallel to the lumbar spine at the level of the third lumbar vertebra, 2cm lateral to the spinal process (Sakamoto et al. 2009). TrA measuring electrodes were placed on the mid-axillary line, 2cm inferior to the twelfth rib (Crommert et al. 2011).

#### Squatting procedure

Subjects completed three repetitions of a normal non-weighted squat, descending to 90° of knee flexion. The last trial repetition for each squat test was analyzed, to check that the subject was comfortable with the movement. During the descent phase the body falls freely due to

gravitational forces, resulting in small levels of muscle activity, mainly to decelerate the descent (Dionisio et al. 2008). Therefore, only the ascent phase of the squat was analyzed for the purpose of this study.

#### 4.2.6 STATISTICAL ANALYSIS

The statistical analyses were performed with the Statistica 10 software package (StatSoft, Inc., 2011) by the Statistical Consultation Services of the North-West University, Potchefstroom campus. Independent t-tests ( $p \leq 0.05$ ) were used to determine the differences in measured parameters for players with anterior and neutral pelvic tilts. Effect sizes were calculated to indicate practical significant difference for measured parameters according to pelvic tilt. A small effect size is indicated by  $d \geq 0.2$ , a medium effect size by  $d \geq 0.5$  and a large effect size by  $d \geq 0.8$  (Ellis and Steyn, 2003). The differences in placement frequency (how many times a muscle is activated in a certain place in the firing order) were determined using the chi-square test ( $p \leq 0.05$ ).

### 4.3 RESULTS

**Table 1: Basic characteristics of rugby union players**

Variables	Total group (n=49)	Forwards (n=27)	Backs (n=22)	p-value
<b>Basic characteristics (Mean <math>\pm</math> SD)</b>				
Age (yrs)	18.51 $\pm$ 0.51	18.48 $\pm$ 0.51	18.55 $\pm$ 0.51	0.66
Stature (cm)	182.58 $\pm$ 5.80	184.96 $\pm$ 5.54	179.67 $\pm$ 4.77	0.00*
Weight (kg)	92.90 $\pm$ 12.26	101.11 $\pm$ 8.58	82.82 $\pm$ 7.69	0.00*
Core stability (°)	50.76 $\pm$ 17.76	52.15 $\pm$ 17.16	49.05 $\pm$ 18.73	0.55
Pelvic tilt (°)	15.35 $\pm$ 3.92	14.96 $\pm$ 4.79	15.82 $\pm$ 2.52	0.45
° = degrees; SD = standard deviation; * = statistically significant p-value ( $p \leq 0.05$ )				

The basic characteristics of the participants (N=49) are presented in Table 1. The forwards (n=27) were significantly taller and heavier than the backs (n=22). The mean degree of anterior pelvic tilt for the group in total was 15.35°, which is higher than the normal recommended levels. Twenty players (forwards=11 and backs=9) were categorized in the neutral pelvic tilt group with the mean of this group being 11.75°. The mean degrees of tilt for the players categorized in the anterior pelvic tilt group were 17.83° (n=29; forwards=16 and backs =13). There was no statistical significant difference ( $p \leq 0.05$ ) in pelvic inclination between the

forwards and backs. The mean degree representing core stability for the entire group was 50.76°, which is classified as good and there was no significant difference in core stability was observed between the forwards (52.15°) and backs (49.05°).

**Table 2: Differences in core stability and degree of pelvic tilt**

	Pelvic position	Core stability (mean° ± SD)	p-value	d-value
<b>Total group</b>	Neutral pelvic tilt (n=20)	56.3 ± 17.35	0.07	0.54 <sup>ψ</sup>
	Anterior pelvic tilt (n=29)	46.93 ± 17.31		
<b>Forwards</b>	Neutral pelvic tilt (n=11)	57.91 ± 18.61	0.15	0.52 <sup>ψ</sup>
	Anterior pelvic tilt (n=16)	48.19 ± 15.43		
<b>Backs</b>	Neutral pelvic tilt (n=9)	54.33 ± 16.54	0.28	0.45 <sup>ψ</sup>
	Anterior pelvic tilt (n=13)	45.39 ± 19.91		

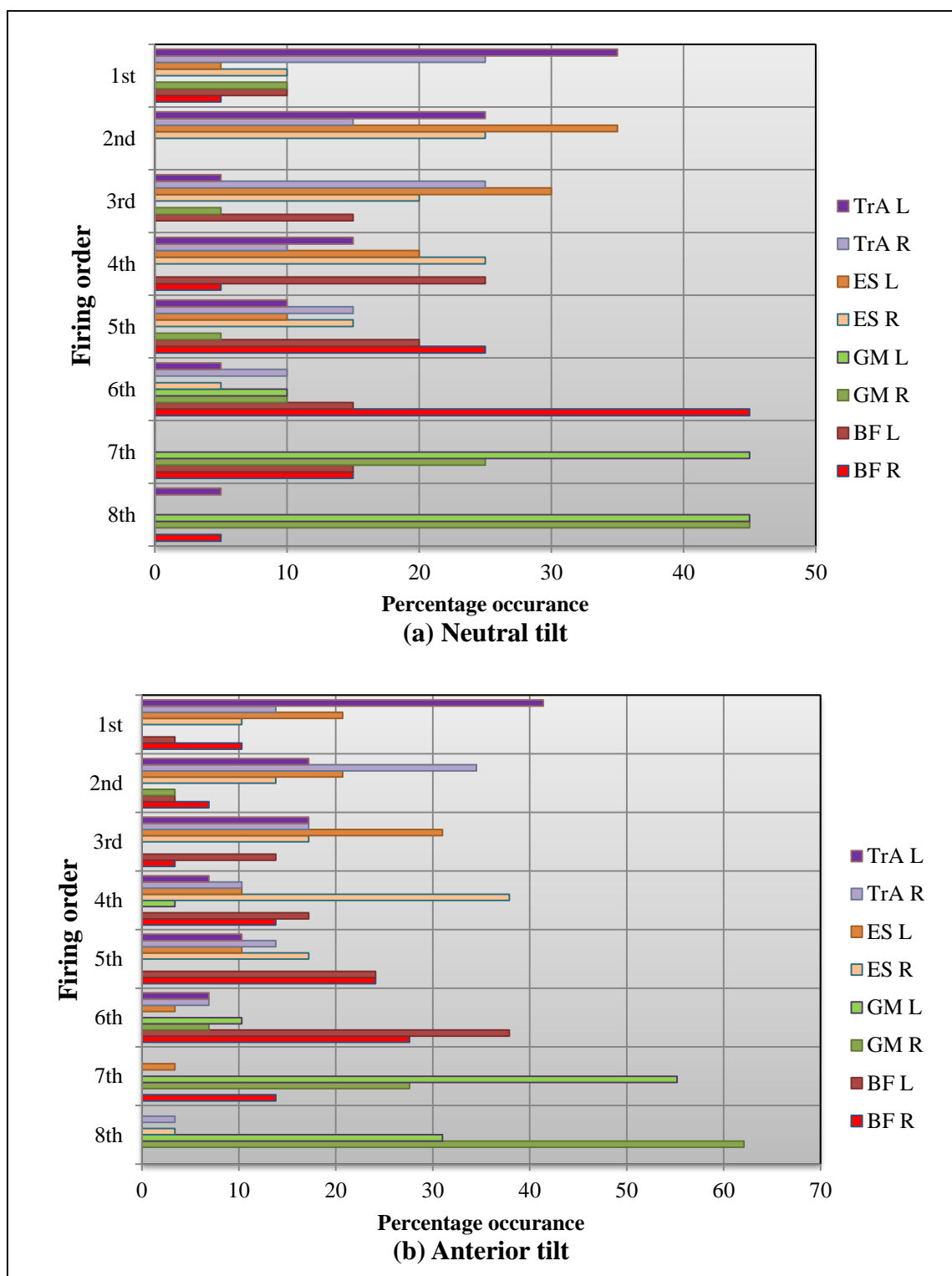
SD = standard deviation; <sup>ψ</sup> = practical significant d-value; d ≥ 0.2 = small practical significance; d ≥ 0.5 = medium practical significance; d ≥ 0.8 = large practical significance

**Table 3: Differences in activation time according to pelvic position in the non-weighted double leg squat**

Muscles	Neutral (n=20)	Anterior (n=29)	p-value	d-value
<b>Mean onset time (sec±SD)</b>				
TrA L	0.136±0.28	0.123±0.19	0.86	0.05
TrA R	0.119±0.16	0.183±0.27	0.31	0.23
ES L	0.124±0.13	0.142±0.19	0.69	0.10
ES R	0.143±0.12	0.212±0.27	0.24	0.25
GM L	1.183±0.30	1.081±0.42	0.33	0.24
GM R	0.984±0.56	1.146±0.37	0.26	0.29
BF L	0.300±0.27	0.361±0.22	0.40	0.23
BF R	0.485±0.38	0.381±0.32	0.32	0.27

TrA = Transverse abdominis; ES= erector spinae; GM= gluteus maximus; BF= bicep femoris; SD= Standard deviation; ; d ≥ 0.2 = small practical significance; d ≥ 0.5 = medium practical significance; d ≥ 0.8 = large practical significance

The mean muscle onset times of the ascent phase of the double leg squat are presented in Table 3. There was no statistically significant difference in onset times between the anterior tilt and neutral tilt groups. In both groups the TrA and ES muscles showed the fastest muscle activation times, with the GM indicating the slowest onset times.



**Figure 1: Firing order according to pelvic tilt in the non-weighted double leg squat**

There were no statistical significant differences ( $p \leq 0.05$ ) in the placement frequency for the tested muscles between the pelvic tilt groups. Fig. 1(a) indicates that in the neutral pelvic tilt group. TrA on both the left and right sides showed the highest percentages of first activations, with the ES group showing the highest percentages of activating second. The GM muscles had the highest percentages for activating last in both neutral and anterior pelvic tilt groups (fig.

1(b)). The percentages of first activations for the TrA muscles were not as high in the anterior pelvic tilt group (fig. 1(b)) as in the neutral pelvic tilt group.

#### 4.4 DISCUSSION

This study aimed to determine whether selected muscle activation patterns differed according to pelvic tilt during the non-weighted squat in U/19 rugby union players. The average tilt of the group was anterior, and no statistically significant differences emerged for muscle activation patterns between the anterior and neutral pelvic tilt groups during the double leg squat. A possible reason for this is that the core stability of subjects with both anterior and neutral tilts was good, a finding unsupported by the available literature which suggests a correlation between anterior tilt and poor core stability (Takasaki et al. 2009).

Although not statistically significant, TrA consistently fired first in both the neutral and anterior tilt groups. This is supported by literature, which states that the deep abdominal stabilisers fire before the start of a movement in individuals with good core stability (Kibler et al. 2006). In the current study, the core stability of both pelvic tilt groups was classified as good. However, these findings are in contrast to recent biomechanical literature, which states that there is a decrease in deep abdominal stabiliser's muscle activity in subjects with a non-neutral or anterior pelvic tilt (Fredericson and Moore 2005). Despite the ability of the subjects in this study's ability to activate their abdominal stabilisers efficiently, there is still an inherent risk for injury to the lumbar spine with an anterior pelvic tilt or hyperlordotic posture, such as lumbar nerve root impingement, increased pressure on the intervertebral discs and lumbar facet joint strain (Han et al. 2011). This is especially important for rugby union players, due to the high number of injuries to the lumbar spine which occurs during weight training (Brooks et al. 2005).

After TrA, the sequence of activation was ES, BF and finally GM. Because of ES being in a mechanically shortened position in the anterior tilt posture (Yerys et al. 2002), it would be expected that ES would fire sooner than was observed in this study. On the contrary, ES activated second more frequently in the neutral tilt group. A possible explanation for this result is that the ES might be in a better length-tension relationship in neutral pelvic tilt, and can act more effectively in its role as trunk extensor. Similar results were found by Tateuchi et al.

(2012), who observed delayed firing of the contra-lateral ES muscle in subjects with an increase in anterior pelvic tilt (Tateuchi et al. 2012).

GM was consistently last to activate in both pelvic tilt groups. GM produces less force at 90° of hip flexion as the muscle is in a lengthened position (Schoenfeld, 2010), which could explain a slight delay in muscle activity. Also, during the ascent phase of the squat there is an increase in the curvature of the lumbar spine which is not present during the descent phase (List *et al.*, 2013), possibly to counter act the trunk flexion seen during the descent of the squat with increased lumbar extension (Hartmann *et al.*, 2013). This could result in an increase in anterior tilt angle not seen during the static posture analysis, resulting in delay in GM activation due to the biomechanical disadvantage. The GM plays a stabilising role around the pelvis (Lieberman et al. 2006) and this delay in activation could result in decreased stability and increased injury risk during the squat movement.

A high number of lumbar spinal injuries observed in rugby union players occur during weight training. Even though the TrA (deep abdominal stabiliser) activated first in both anterior and neutral pelvic tilt groups, increased extension loading on the lumbar spine was observed in this study with the consistent early activation of ES (even in the neutral tilt group). This supports the proposed increase in extension loading of the lumbar spine and musculature during the ascent of the squat.

## 4.5 CONCLUSION

No statistical or practical significant differences in muscle activation patterns were indicated for university-level rugby union players between anterior and neutral tilts, a finding that may be attributed to the good core stability observed in both pelvic tilt groups. To clarify the relationship between core stability, pelvic tilt and susceptibility to lumbar spinal injury, it is advocated that future research initiate testing prior to the onset of the rugby season in order to establish a baseline predating the assumption of core stability training exercises. Mid and end-of-season measurements could then be evaluated relative to pre-season fitness to describe the relation between core conditioning, pelvic orientation, muscle activation and injury.

Future research should also include analysis of the pelvic inclination throughout the squat movement. There is a strong possibility that the subjects in the neutral tilt group were not able

to maintain neutral tilt throughout the ascent of the squat movement, resulting in similar results to the subjects in anterior pelvic tilt. To ensure an accurate depiction of the effect anterior pelvic tilt has on muscle activation patterns, digital photos taken during the ascent of the squat should be used to describe pelvic tilt during this functional movement. For future studies, the use of intramuscular EMG testing should be considered, to eliminate interference on the EMG from other muscles.

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## CHAPTER 5

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### SUMMARY, CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

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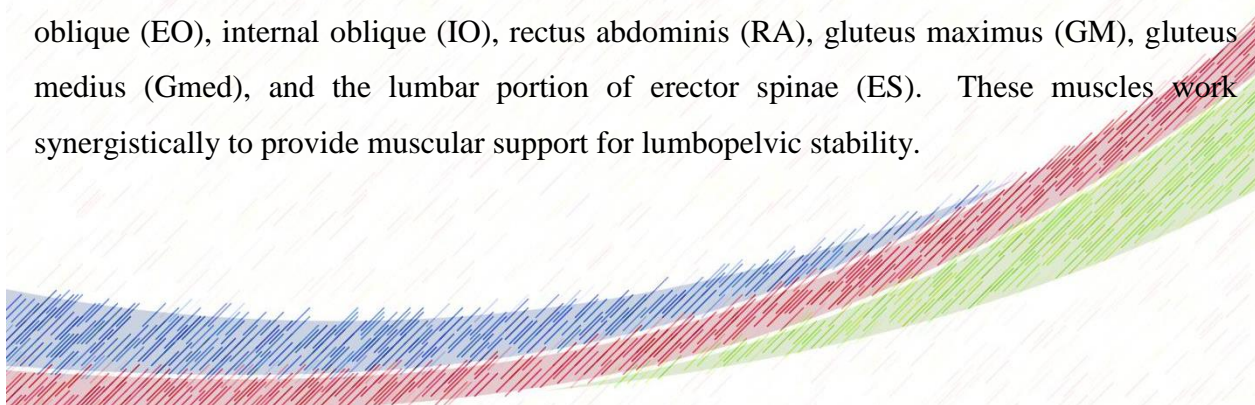
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#### 5.1 SUMMARY

The main aim of this study was to determine whether core stability, lumbopelvic flexibility measures and muscle activation patterns differ according to the pelvic tilt in U/19 university-level rugby union players during the non-weighted squat.

In Chapter 1 the problem statement, aim of the study and hypotheses were explained, and the structure of the dissertation laid out. Chapter 2 provided a literature review which discussed the lumbopelvic core musculature and its role in functional stability. The lumbopelvic stabilising muscles were identified as: transverse abdominis (TrA), multifidus, external oblique (EO), internal oblique (IO), rectus abdominis (RA), gluteus maximus (GM), gluteus medius (Gmed), and the lumbar portion of erector spinae (ES). These muscles work synergistically to provide muscular support for lumbopelvic stability.



Core stability is a “moving target” which is task specific and continually changing according to the demands placed on the body by the specific situation. Core exercises for sportsmen/women also need to be sport-specific, and aimed at training the muscles in a functional manner. The goal of such a training program should be to optimise the efficiency and fluency of required movement to improve performance and decrease the strain on the musculoskeletal components around the lumbopelvic girdle.

When the lumbar spinal posture is altered, core muscles cannot function optimally. The required posture for optimal muscular function around the pelvis is the neutral spinal position, which minimises the strain being placed on muscular or spinal structures around the lumbar spine. This posture also promotes increased automated activation of the deep abdominal stabilisers before initiation of movement, providing an optimal lumbopelvic condition for performance.

Hyperlordosis or anterior pelvic tilt is a common non-neutral spinal posture, commonly believed to contribute to low back pain (LBP). This posture intensifies the gravitational forces on the spinous processes of the spine, creating strain on the lumbar facet joint and the lumbar intervertebral discs; it is also associated with weak abdominal and GM activation, and tightness in the ES and hip flexor muscles.

A decreased lordotic curve can also be harmful to the spine. Hypolordosis of the lumbar spine is thought to increase pressure in the posterior aspects of the lumbar discs (due to loading on anterior aspect), causing inflammation due to increased tissue stress. It also alters the biomechanics of the spine during weight-bearing, increasing pressure in the lumbar intervertebral discs, and may cause degenerative lesions to the lumbar spinal structures.

Because the body always attempts to re-establish its position of strength, it is important to build strength in the neutral spinal position. If strength is built in the neutral spine position, the length-tension relationship of the muscles surrounding the trunk will be optimised. This confers on the spine a greater capacity to generate force, lower levels of shear forces, optimisation of load transfer at the proximal joints and decreased risk of low back pain.

While there is an abundance of research on muscle activation patterns during the prone hip extension (PHE), studies testing the effect of lumbar posture on muscle activation during a functional movement are limited. According to research during the PHE, the muscle activation of GM was significantly greater during the abdominal drawing-in manoeuvre, or when the

pelvis was stabilised. It is unclear whether this response will translate into the same results during a functional movement. This information is important in clinical settings, because inefficient performance in a muscle group causes the task to be transferred partially or totally to another muscle group, resulting in sub-optimal performance and stability.

The squat is a multi-joint, closed chain exercise used by athletes to target the hip, thigh and back. The squat requires mobility of the ankle, hip and thoracic spine, and sufficient stability of the foot, knee and lumbar spine. Correcting muscle activation deficiencies during the squat can delay or even prevent the occurrence of musculoskeletal injuries. There is much research on muscle activity during the squat, little on the effects of core stability and lumbar posture on muscle activity. During the prone hip extension, research has showed a delay in ES activation and improved GM activation associated with a neutral spinal posture and pelvic stability. However, it is not known whether these results will translate to the squat. Thus more research is needed to determine the effects of anterior pelvic tilt and core stability on muscle activation patterns for functional movements.

From the gathered literature, the following research question was formulated: Do core stability and lumbopelvic posture affect muscle activation patterns around the pelvis during the squat movement?

Chapter 3 presented the results, following an assessment of core stability and pelvic flexibility as attributes of pelvic tilt. Research subjects had a mean pelvic tilt with an anterior inclination ( $15.35^\circ$ ), and subjects with an anterior pelvic tilt showed slightly better core stability than those with a neutral pelvic tilt. This contrasts with the literature, which states that an anterior pelvic tilt is associated with a decrease in muscle activity of the lumbopelvic stabilising muscles. As mentioned earlier, the average pelvic tilt for the group was in the anterior position. One would therefore expect the hip flexor and knee extensor muscles to test as being tight, and the hamstrings to test as being tight as they are in a lengthened position. However, this study found no correlation between pelvic position and core stability or flexibility, possibly because the average group pelvic tilt was anterior and the core stability of the group in total was classified as good.

In chapter 4 the difference in core stability and muscle activation patterns according to pelvic tilt was assessed during a double leg squat. No significant differences in muscle activation patterns were found between the anterior and neutral tilt groups. The activation sequence was as follows: TrA first, ES second, BF third and GM fourth. The activation of TrA first is

consistent with recent research, which holds that the deep abdominal stabilisers will activate first in individuals with good core stability, as was the case in this study. The activation of ES second shows that there is a focus on trunk extension early in the squat movement. BF's third position indicates possible delayed muscle activation due to the lengthened position of the muscle in the anterior tilt posture. Even subjects with neutral pelvic tilt showed this delay, possibly due to a squatting technique that emphasises trunk extension before hip extension. GM was consistently last to activate. Even though the muscle is at a biomechanical disadvantage at the beginning of the ascent phase, GM has a stabilising role around the pelvis and assists BF in hip extension. This muscle activation sequence indicates a focus on trunk extension early in the squat movement, increasing the lumbar extension angle. This posture can increase the risk of lumbar spinal injury, which has been shown to be common among rugby union players during weight training.

## 5.2 CONCLUSION

The conclusions of the study are derived from the stated hypothesis.

### 5.2.1 Hypothesis 1

**The majority of U/19 university-level rugby union players will not indicate a neutral pelvic position and will also have insufficient lumbopelvic stability.**

An anterior pelvic tilt was observed in 59% of the players, with a mean pelvic tilt across the entire group of  $15.35^{\circ}$  in an anterior orientation. The entire group showed good core stability, with 73% being categorised as either good or excellent. Interestingly, the anterior pelvic tilt group showed better core stability than the neutral pelvic tilt group, but this difference was not statistically significant. While 59% of the research subjects displayed an anterior pelvic orientation, this condition did not result in poor core stability, as it is commonly believed to.

The first part of Hypothesis 1 is partially accepted, and the second part being rejected.

### 5.2.2 Hypothesis 2

**U/19 university-level rugby union players with a neutral pelvic tilt will have significantly better core stability and lumbopelvic flexibility than players with an anterior pelvic tilt.**

The results of this study showed a non-significant difference in core stability between the anterior and neutral pelvic tilt groups ( $p=0.07$ ), with the anterior pelvic tilt group showing better core stability than the neutral tilt group. This is in contrast with recent literature, which states that an anterior pelvic tilt is related to a decrease in core stability. Also, the findings of the current study did not show pelvic position to influence core flexibility.

Hypothesis 2 is therefore rejected.

### 5.2.3 Hypothesis 3

**U/19 university-level rugby union players with a neutral pelvic tilt will show significantly more optimal muscle activation patterns than players with an anterior pelvic tilt.**

In the majority of cases TrA activated first, which, according to the literature, is the expected activation sequence in individuals with good core stability. ES activated second, which points to a focus on lumbar extension early in the squat movement. Third was BF and finally GM, pointing to a delay in hip extension during the ascent of the squat movement. There was however no significant difference in muscle activation patterns between the anterior and neutral pelvic tilt groups.

Hypothesis 3 is therefore rejected.

The conclusion of this study - that an anterior pelvic tilt posture does not correlate to weak core stability - is in contrast with the expected results. While the anterior tilt group showed better core stability than the neutral tilt group, the entire group could be classified as having good core stability. Therefore, the results were very similar for the anterior and neutral tilt groups. Flexibility measures also bore no relationship to pelvic tilt measurements, and pelvic tilt did not appear to affect muscle activation patterns during the ascent phase of the non-weighted squat. Even though pelvic tilt was assessed during static standing, there was a consistent focus on lumbar extension seen in the entire group. This could have affected the results, because

pelvic inclination was not assessed on different angles of the squat movement and the posture of players could have deviated from the static pelvic tilt measured.

The muscle activation pattern recorded showed that TrA activated first, as is expected in individuals with good core stability. ES followed, indicating a focus on trunk extension during the ascent phase of the squat in most subjects. BF and GM, the muscles responsible for hip extension, were last to activate, with GM showing delayed activation. Even though the deep abdominal stabilisers were quick to activate, the delay in GM activation could result in lumbopelvic instability during the functional squat movement. This could further result in an increased risk of injury and decreased efficiency of the squat movement. Further research needs to be done to clarify the effect of squatting posture on muscle activity.

### **5.3 LIMITATIONS AND RECOMMENDATIONS**

No conclusive results were obtained from this study, with no significant differences seen between the anterior and neutral pelvic tilt groups. This study had several limitations which may have affected the results. The following limitations were identified with recommendations on how to improve future research:

- The study was completed in April 2013 and not at the beginning of the season in January. At the time of testing the players had already been exposed to core strengthening regimes which could have affected the results that were obtained. Future research needs to be initiated at the beginning of the pre-season preparation period and repeated throughout the season. This could result in cleared differences being seen between the groups and could also provide useful information to the coaches with regard to the effect of core strengthening regimes used.
- The sample size was too small for the purpose of this study, especially after players were grouped according to pelvic tilt, the amount of participants in each group resulted in the lowering of statistical power during data analysis.

After conclusion of this study, the following statements were identified as recommendations for future research:

- The quality of the movement should be assessed. Rather than using a digital photo of the upright static posture to measure the pelvic inclination, a video recording of the entire squat movement should be taken. This will ensure the possibility to measure the pelvic inclination at different angles during the movement to assess whether there is a change in the pelvic tilt angle from the previously measured static posture.
- The maximum voluntary contraction of the muscles was not tested during electromyographic testing. These data would have indicated the contribution of tested muscles to the ascent phase of the squat, perhaps clarifying further the effects of anterior pelvic tilt on strength and efficiency in performing this exercise.

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APPENDIX A

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**AUTHOR'S GUIDELINES:  
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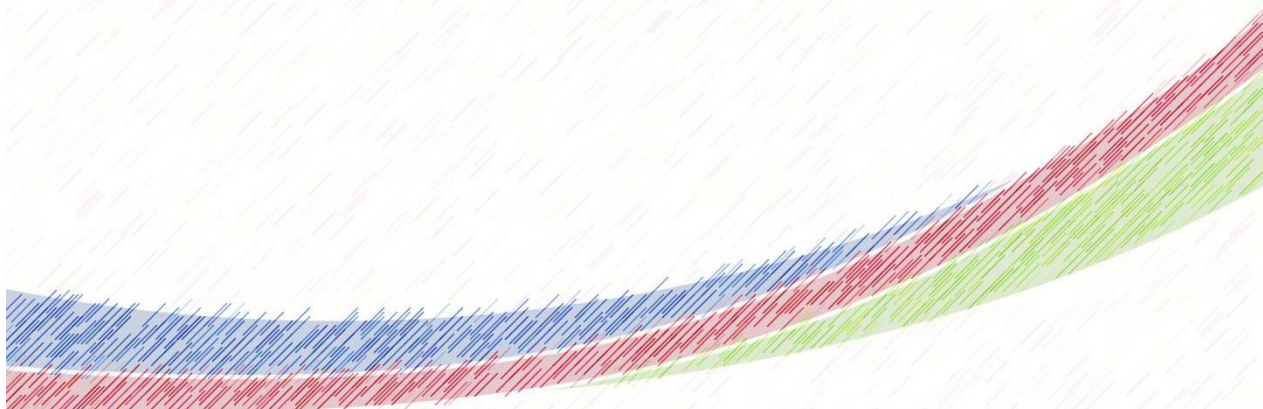
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When you submit your article for the first time, please make sure that it has a structured abstract,

Methods, Results and Discussion sections, and that the references are formatted and cited according to the Harvard (alphabetical, non-numbered) style. Please ensure that your paper

conforms to the following word counts: 600 words for a Letter to the Editor, 1200 words for a Brief Original Report, 2500 words for a full Original Research Paper, 3500 words for a full Original Research Paper reporting the results of a randomized controlled trial, or 4500 words for a Review Article. Your paper WILL THEN HAVE TO also conform to the more detailed author guidelines listed below.

### *Use of wordprocessing software*

Regardless of the file format of the original submission, at revision you must provide us with an editable file of the entire article. Keep the layout of the text as simple as possible. Most formatting codes will be removed and replaced on processing the article. The electronic text should be prepared in a way very similar to that of conventional manuscripts (see also the Guide to Publishing with Elsevier: <http://www.elsevier.com/guidepublication> ). See also the section on Electronic artwork.

To avoid unnecessary errors you are strongly advised to use the 'spell-check' and 'grammar-check' functions of your wordprocessor.

### *Article structure*

Please include appropriate Cover Letter (with CONSORT checklist is appropriate). The Title Page should include the usual - title, authors' names and affiliations, the corresponding author's name and email address - as well as the word counts of the main text and abstract (word count excludes in-text citations and references). Text should be 1.5 line-spaced. Do not use footnotes in the text.

### *Subdivision - numbered sections*

*Main headings* are Introduction, Methods, Results, Discussion, and Conclusion.

### *Introduction*

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

### *Materials and methods*

Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described. The Methods section should include a separate, second-level subsection, Statistical analyses (if applicable), which concisely describes the statistical methodology.

### *Experimental*

Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described.

*Theory/calculation*

A Theory section should extend, not repeat, the background to the article already dealt with in the

Introduction and lay the foundation for further work. In contrast, a Calculation section represents a practical development from a theoretical basis.

*Results*

Results should be clear and concise.

*Discussion*

This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Avoid extensive citations and discussion of published literature. In this section, a second-level subsection entitled Study limitations and strengths is strongly encouraged.

*Conclusions*

The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section.

*Appendices*

If there is more than one appendix, they should be identified as A, B, etc. Formulae and equations in appendices should be given separate numbering: Eq. (A.1), Eq. (A.2), etc.; in a subsequent appendix, Eq. (B.1) and so on. Similarly for tables and figures: Table A.1; Fig. A.1, etc.

*Essential title page information*

- **Title.** Concise and informative. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible.
- **Author names and affiliations.** Where the family name may be ambiguous (e.g., a double name), please indicate this clearly. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript letter immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name and, if available, the e-mail address of each author.
- **Corresponding author.** Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. **Ensure that phone numbers (with country and area code) are provided in addition to the e-mail address and the complete postal address.**

**Contact details must be kept up to date by the corresponding author.**

• ***Present/permanent address.*** If an author has moved since the work described in the article was done, or was visiting at the time, a 'Present address' (or 'Permanent address') may be indicated as a footnote to that author's name. The address at which the author actually did the work must be retained as the main, affiliation address. Superscript Arabic numerals are used for such footnotes.

### ***Abstract***

A structured abstract, 200 words or less, comprising of: Objective, Method, Results, Conclusion. Abstracts should include sample sizes and the location and date of the study.

### ***Graphical abstract***

A Graphical abstract is optional and should summarize the contents of the article in a concise, pictorial form designed to capture the attention of a wide readership online. Authors must provide images that clearly represent the work described in the article. Graphical abstracts should be submitted as a separate file in the online submission system. Image size: Please provide an image with a minimum of  $531 \times 1328$  pixels (h  $\times$  w) or proportionally more. The image should be readable at a size of  $5 \times 13$  cm using a regular screen resolution of 96 dpi. Preferred file types: TIFF, EPS, PDF or MS Office files. See <http://www.elsevier.com/graphicalabstracts> for examples.

Authors can make use of Elsevier's Illustration and Enhancement service to ensure the best presentation of their images also in accordance with all technical requirements: Illustration Service.

### ***Highlights***

Highlights are mandatory for this journal. They consist of a short collection of bullet points that convey the core findings of the article and should be submitted in a separate file in the online submission system. Please use 'Highlights' in the file name and include 3 to 5 bullet points (maximum 85 characters, including spaces, per bullet point). See <http://www.elsevier.com/highlights> for examples.

### ***Abbreviations***

Define abbreviations that are not standard in this field in a footnote to be placed on the first page of the article. Such abbreviations that are unavoidable in the abstract must be defined at their first mention there, as well as in the footnote. Ensure consistency of abbreviations throughout the article.

### ***Acknowledgements***

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

***Database linking***

Elsevier encourages authors to connect articles with external databases, giving their readers one click access to relevant databases that help to build a better understanding of the described research. Please refer to relevant database identifiers using the following format in your article:  
Database: xxxx

(e.g., TAIR: AT1G01020; CCDC: 734053; PDB: 1XFN).

See <http://www.elsevier.com/databaselinking> for more information and a full list of supported databases.

***Math formulae***

Present simple formulae in the line of normal text where possible and use the solidus (/) instead of a horizontal line for small fractional terms, e.g., X/Y. In principle, variables are to be presented in italics. Powers of e are often more conveniently denoted by exp. Number consecutively any equations that have to be displayed separately from the text (if referred to explicitly in the text).

***Footnotes***

Footnotes should be used sparingly. Number them consecutively throughout the article. Many Word processors build footnotes into the text, and this feature may be used. Should this not be the case, indicate the position of footnotes in the text and present the footnotes themselves separately at the end of the article. Do not include footnotes in the Reference list.

***Table footnotes***

Indicate each footnote in a table with a superscript lowercase letter.

***Electronic artwork******General points***

- Make sure you use uniform lettering and sizing of your original artwork.
- Preferred fonts: Arial (or Helvetica), Times New Roman (or Times), Symbol, Courier.
- Number the illustrations according to their sequence in the text.
- Use a logical naming convention for your artwork files.
- Indicate per figure if it is a single, 1.5 or 2-column fitting image.
- For Word submissions only, you may still provide figures and their captions, and tables within a single file at the revision stage.
- Please note that individual figure files larger than 10 MB must be provided in separate source files.

A detailed guide on electronic artwork is available on our website:

<http://www.elsevier.com/artworkinstructions>.

**You are urged to visit this site; some excerpts from the detailed information are given here.**

### *Formats*

Regardless of the application used, when your electronic artwork is finalized, please 'save as' or convert the images to one of the following formats (note the resolution requirements for line drawings, halftones, and line/halftone combinations given below):

EPS (or PDF): Vector drawings. Embed the font or save the text as 'graphics'.

TIFF (or JPG): Color or grayscale photographs (halftones): always use a minimum of 300 dpi.

TIFF (or JPG): Bitmapped line drawings: use a minimum of 1000 dpi.

TIFF (or JPG): Combinations bitmapped line/half-tone (color or grayscale): a minimum of 500 dpi is required.

### **Please do not:**

- Supply files that are optimized for screen use (e.g., GIF, BMP, PICT, WPG); the resolution is too low.
- Supply files that are too low in resolution.
- Submit graphics that are disproportionately large for the content.

### *Color artwork*

Please make sure that artwork files are in an acceptable format (TIFF (or JPEG), EPS (or PDF), or MS Office files) and with the correct resolution. If, together with your accepted article, you submit usable color figures then Elsevier will ensure, at no additional charge, that these figures will appear in color on the Web (e.g., ScienceDirect and other sites) regardless of whether or not these illustrations are reproduced in color in the printed version. **For color reproduction in print, you will receive information regarding the costs from Elsevier after receipt of your accepted article.** Please indicate your preference for color: in print or on the Web only. For further information on the preparation of electronic artwork, please see <http://www.elsevier.com/artworkinstructions>.

Please note: Because of technical complications which can arise by converting color figures to 'gray scale' (for the printed version should you not opt for color in print) please submit in addition usable black and white versions of all the color illustrations.

*Figure captions*

Ensure that each illustration has a caption. A caption should comprise a brief title (**not** on the figure itself) and a description of the illustration. Keep text in the illustrations themselves to a minimum but explain all symbols and abbreviations used.

*Text graphics*

Text graphics may be embedded in the text at the appropriate position. If you are working with LaTeX and have such features embedded in the text, these can be left.

**Tables**

Number tables consecutively in accordance with their appearance in the text. Place footnotes to tables below the table body and indicate them with superscript lowercase letters. Avoid vertical rules. Be sparing in the use of tables and ensure that the data presented in tables do not duplicate results described elsewhere in the article.

Tables should be short, single-spaced and begin on a separate page. Table legends should provide details on the location and date of the study, and the study population (if applicable). The aim of

presenting tables results is not only to show adjusted effects but also to enable readers to understand the methods used, evaluate the results, and potentially integrate them into meta-analyses. Thus, presentation of sufficient detail in tables to permit readers to compute crude (unadjusted) effects is strongly encouraged. (For example, adjusted odds ratios should also be accompanied by subgroup sample sizes or percentages for each variable included in the model.)

**References****Reference List Style**

References should be arranged first alphabetically and then further sorted chronologically if necessary.

More than one reference from the same author(s) in the same year must be identified by the letters “a”, “b”, “c”, etc., placed after the year of publication.

**Author names** {last name & initial(s) - without period(s) or comma between} in the reference list should appear as follows:

1. Single author: the author's name and the year of publication;
2. Two authors: both authors' names and the year of publication;
3. Three or more authors: first nine (maximum) author's names followed by “et al.” and the year of publication.

**Examples:****References to journal publications (list volume, but not issue, number):**

Milikan R, 2002. The changing face of epidemiology in the genomics era. *Epidemiology* 13:472-480.

Altman DG, Royston P, 2000. What do we mean by validating a prognostic model? *Stat Med* 19:453-73.

Blair A, Saracci R, Vineis P, Cocco P, Forastiere F, Grandjean P, Kogevinas M, Kriebel D, McMichael A,

et al., 2009. Epidemiology, public health and the rhetoric of false positives. *Environ Health Perspect*

117:1809-1813.

**Reference to a book:**

Strunk Jr W, White, EB, 1979. *The Elements of Style*, 3rd ed., Macmillan, New York.

**Reference to a chapter in an edited book:**

Mettam GR, Adams LB, 1999. How to prepare an electronic version of your article, in: Jones, BS,

Smith RZ (Eds.), *Introduction to the Electronic Age*. E-Publishing Inc., New York: 281-304.

**Citations in the text**

Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Any references cited in the abstract must be given in full. Unpublished results and personal communications are not recommended in the reference list, but may be mentioned in the text. If these references are included in the reference list they should follow the standard reference style of the journal and should include a substitution of the publication date with either 'Unpublished results' or 'Personal communication'. Citation of a reference as 'in press' implies that the item has been accepted for publication.

**All citations in the text should refer to:**

1. Single author: the author's name (without initials, unless there is ambiguity) and the year of publication;
2. Two authors: both authors' names and the year of publication;
3. Three or more authors: first author's name followed by "et al." and the year of publication.

Citations may be made directly (or parenthetically). Groups of references should be listed first alphabetically, then chronologically.

Examples: “as demonstrated (Allan, 1996a, 1996b, 1999; Allan and Jones, 1995). Kramer et al.

(2000) have recently shown ....”

### *Reference links*

Increased discoverability of research and high quality peer review are ensured by online links to the sources cited. In order to allow us to create links to abstracting and indexing services, such as

Scopus, CrossRef and PubMed, please ensure that data provided in the references are correct. Please note that incorrect surnames, journal/book titles, publication year and pagination may prevent link creation. When copying references, please be careful as they may already contain errors. Use of the DOI is encouraged.

### *Web references*

As a minimum, the full URL should be given and the date when the reference was last accessed. Any further information, if known (DOI, author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list.

### *Reference management software*

This journal has standard templates available in key reference management packages EndNote (<http://www.endnote.com/support/enstyles.asp>) and Reference Manager

(<http://refman.com/support/rmstyles.asp>). Using plug-ins to word processing packages, authors only need to select the appropriate journal template when preparing their article and the list of references and citations to these will be formatted according to the journal style which is described above.

### *Free Reference Style*

There are no strict requirements on reference formatting at submission. References can be in any style or format as long as the style is consistent. Where applicable, author(s) name(s), journal title/book title, chapter title/article title, year of publication, volume and issue/book chapter and the pagination must be present. Use of DOI is highly encouraged. The reference style used by the journal will be applied to the accepted article by Elsevier at the proof stage. Note that missing data will be highlighted at proof stage for the author to correct. If you do wish to format the references yourself they should be arranged according to the following examples:

### *Journal abbreviations source*

Journal names should be abbreviated according to the

List of title word abbreviations: <http://www.issn.org/2-22661-LTWA-online.php>.

### ***Video data***

Elsevier accepts video material and animation sequences to support and enhance your scientific research. Authors who have video or animation files that they wish to submit with their article are strongly encouraged to include links to these within the body of the article. This can be done in the same way as a figure or table by referring to the video or animation content and noting in the body text where it should be placed. All submitted files should be properly labeled so that they directly relate to the video file's content. In order to ensure that your video or animation material is directly usable, please provide the files in one of our recommended file formats with a preferred maximum size of 50 MB. Video and animation files supplied will be published online in the electronic version of your article in Elsevier Web products, including ScienceDirect: <http://www.sciencedirect.com>.

Please supply 'stills' with your files: you can choose any frame from the video or animation or make a separate image. These will be used instead of standard icons and will personalize the link to your video data. For more detailed instructions please visit our video instruction pages at

<http://www.elsevier.com/artworkinstructions>. Note: since video and animation cannot be embedded in the print version of the journal, please provide text for both the electronic and the print version for the portions of the article that refer to this content.

### ***Supplementary data***

Elsevier accepts electronic supplementary material to support and enhance your scientific research.

Supplementary files offer the author additional possibilities to publish supporting applications, high resolution images, background datasets, sound clips and more. Supplementary files supplied will be published online alongside the electronic version of your article in Elsevier Web products, including

ScienceDirect: <http://www.sciencedirect.com>. In order to ensure that your submitted material is directly usable, please provide the data in one of our recommended file formats. Authors should submit the material in electronic format together with the article and supply a concise and descriptive caption for each file. For more detailed instructions please visit our artwork instruction pages at

<http://www.elsevier.com/artworkinstructions>.

### ***Submission checklist***

The following list will be useful during the final checking of an article prior to sending it to the journal for review. Please consult this Guide for Authors for further details of any item.

**Ensure that the following items are present:**

One author has been designated as the corresponding author with contact details:

- E-mail address
- Full postal address
- Telephone

All necessary files have been uploaded, and contain:

- Keywords
- All figure captions
- All tables (including title, description, footnotes)

**Further considerations**

- Manuscript has been 'spell-checked' and 'grammar-checked'
- All references mentioned in the Reference list are cited in the text, and vice versa
- Permission has been obtained for use of copyrighted material from other sources (including the Web)
- Color figures are clearly marked as being intended for color reproduction on the Web (free of charge) and in print, or to be reproduced in color on the Web (free of charge) and in black-and-white in print
- If only color on the Web is required, black-and-white versions of the figures are also supplied for printing purposes

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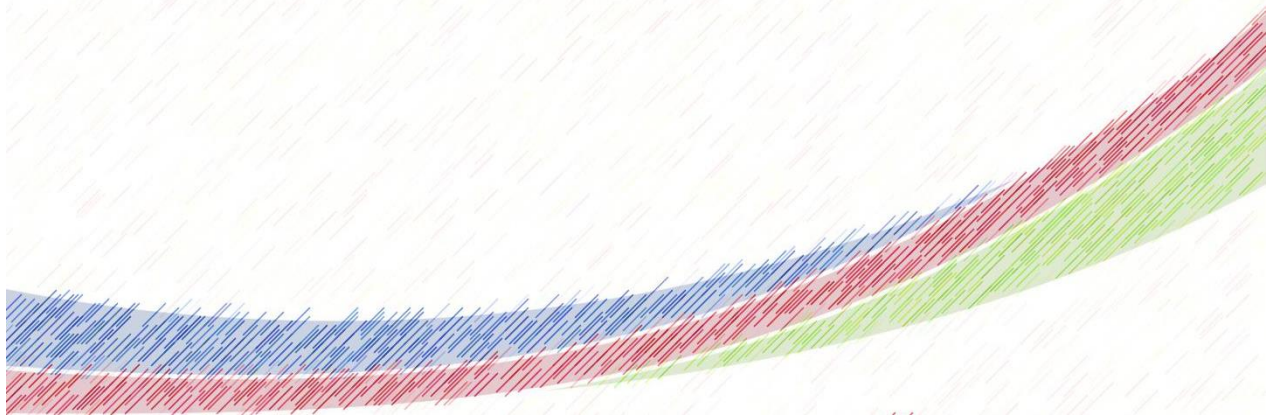
<http://support.elsevier.com>

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APPENDIX C

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**DEMOGRAPHIC INFORMATION  
&  
INFORMED CONSENT**



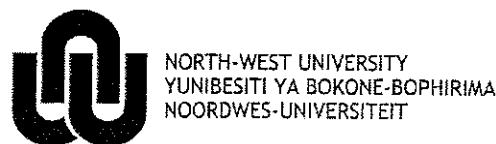
**Demographic information**

Name \_\_\_\_\_  
Date of birth \_\_\_\_\_  
Gender \_\_\_\_\_  
Ethnicity \_\_\_\_\_  
Playing position \_\_\_\_\_  
Cell number \_\_\_\_\_  
Email address \_\_\_\_\_  
Physical address \_\_\_\_\_  
Emergency contact person \_\_\_\_\_

**Injury history**

Site of Injury \_\_\_\_\_  
Acute/Chronic \_\_\_\_\_  
During game/training \_\_\_\_\_  
Diagnosed by \_\_\_\_\_

Severity  Minor (returned to game/session)  
 Mild (missed one week)  
 Moderate (missed two weeks)  
 Severe (missed more than two weeks)

**CONFIDENTIAL****Informed consent form****PART 1****1. School / Institute:**

School for Biokinetics, Recreation and Sport Science

**2. Title of the project/trail:**

Pelvic biomechanics and muscle activation patterns during non-weighted squats in university level rugby union players

**3. Full names, surname and contact details of project leader:**

Erna Jana Bruwer, (018) 299-2034, Erna.Bruwer@nwu.ac.za

**4. Rank/position of project leader:**

Lecturer of anatomy and orthopedic rehabilitation in the School for Biokinetics, Recreation and Sport Science

**5. Full names, surname and qualifications of supervisor of the project:**

Not applicable

**6. Name and address of supervising medical officer:**

Not applicable

**7. Aims of this project:**

- To evaluate selected pelvic biomechanical parameters in u/19 university level rugby union players
- To determine muscle activation patterns during the non-weighted squats (double and single legged) in u/19 university level rugby union players
- To determine the relationship between selected pelvic biomechanical parameters and the muscle activation patterns during non-weighted squats

**8. Explanation of the nature of all procedures, including identification of new procedures:*****Demographic and general information***

The subject's demographic and personal information (age, gender, race, etc.) will be collected by means of a general information questionnaire. The subject's exercising habits, injury history and competing level will also be determined by means of this questionnaire. Data will be collected via a test battery which will include the following measurements.

**Anthropometric measurements**

Anthropometric measurements such as body mass (electronic scale, to the nearest 1kg) and stature (stadiometer, to the nearest 1cm) will be measured for each player.

**Pelvic biomechanics**

The level of pelvic tilt will be measured by placing bright markers on the ASIS and PSIS and taking a digital photograph. The tilt will be analyzed by using the computer program Dartfish version 4.06.0 (Dartfish, Switzerland).

**Core stability**

The double leg lowering test will be used to analyze the subject's core stability, using the Biofeedback unit (Chattanooga Group limited, Bicester, UK) to assess the ability to keep neutral spine. In the supine position, the subject will aim to keep the Biofeedback unit at 40mmHg while lowering and extending the legs down.

**Flexibility**

Flexibility measures will be taken by a registered Biokineticist, using a goniometer. Measurements will be taken twice, and recorded to the nearest degree. The following muscle groups will be evaluated:

- Hamstrings
- Hip flexors
- Quadriceps

**EMG during squats**

For the EMG testing, the skin will be cleaned with an alcohol swab and two pre-gelled self-adhesive active Ag/AgCl surface electrodes will be attached to each muscle. Muscle activity will be measured with an electromyograph (MyoTrace 400, Noraxon USA, Inc., Scottsdale, Arizona). The subject will start by completing a double leg squat, with corrective feedback where necessary. The test will be completed for 3 repetitions, after which the single leg squat will be completed for 3 repetitions on each leg. After completing all repetitions, the subject will be quered into a neutral spinal posture, and the tests will be repeated. EMG activity of the following muscles will be recorded bilaterally:

- Erector Spinae
- Transverse Abdominus
- Gluteus Maximus
- Biceps Femoris

**9. Description of the nature of discomfort or hazards of probable permanent consequences for the subjects which may be associated with the project:**

The participant may experience slight discomfort during the flexibility assessment.

**10. Precautions taken to protect the subjects:**

Only subjects that do not suffer from injuries at the time of testing will participate in the project. A familiarization period will precede each of the testing sessions. Qualified Biokineticists will perform all test procedures and the intervention sessions will also be guided by these Biokineticists.

**11. Description of the benefits which may be expected from this project:**

Athletes will gain a better understanding of their pelvic biomechanics and core stability, and will gain information with regards to better posture and exercise techniques to prevent injury.

**12. Alternative procedures which may be beneficial to the subjects:**

Baseline testing will equip athletes with knowledge of weak links in their postural, range of motion and strength characteristics.

**PART 2****To the subject signing the consent as in part 3 of this document:**

You are invited to participate in a research project as described in part 1 of this document. It is important that you read the following general principles, which apply to all participants in our research project:

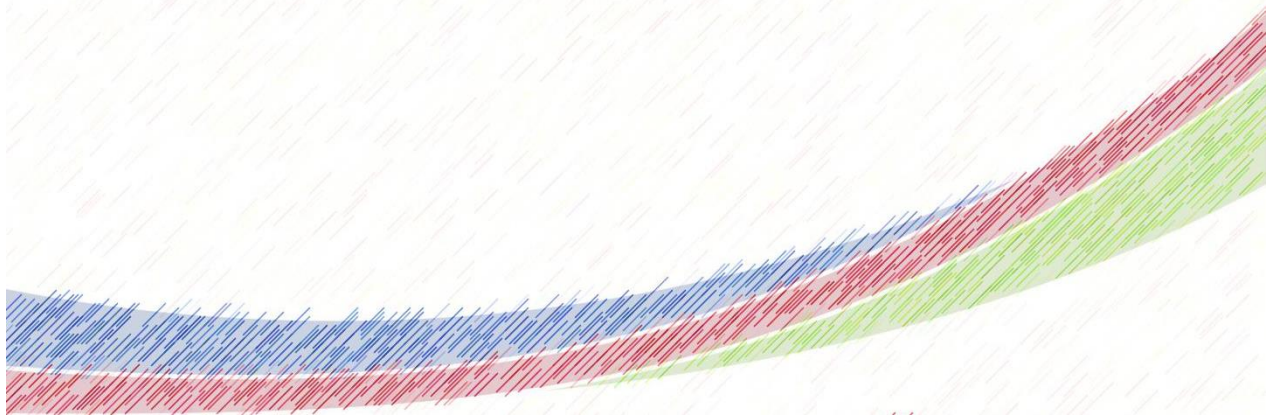
1. Participation in this project is voluntary.
2. You will be free to withdraw from the project at any stage without having to explain the reasons for your withdrawal. However, we would like to request that you would rather not withdraw without a thorough consideration of your decision, since it may have an effect on the statistical reliability of the results of the project.
3. We encourage you to ask questions at any stage about the project and procedures to the project leader or personnel, who will readily give more information.
4. If you are a minor, we need written approval of your parent or guardian before you may participate.
5. We require that you indemnify the University from any liability due to detrimental effects of treatment to yourself or another person due to participation in this project, as explained in Part 1.
6. If you are married, it is required that your spouse abandon any claims that he/she could have against the University regarding treatment or death of yourself due to the project explained in Part 1.

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## APPENDIX D

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# TESTING PROTOCOL



## PELVIC BIOMECHANICS AND MUSCLE ACTIVATION PATTERNS: TESTING PROTOCOL 2013

Name: \_\_\_\_\_ ID: \_\_\_\_\_

Contact nr: \_\_\_\_\_ Age: \_\_\_\_\_ Dominant side: \_\_\_\_\_

Playing position: \_\_\_\_\_

### HISTORY/PREVIOUS INJURY

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### 1. Anthropometric assessment

Stature: \_\_\_\_\_ cm

Body mass: \_\_\_\_\_ kg

### 2. Pelvic biomechanics

Pelvic tilt: \_\_\_\_\_ ° (Normal 7° - 15°)

Core stability: \_\_\_\_\_ ° (Poor 90°-75°, Fair 75°-60°, Good 60°-30°, Excellent 30°-0°)

### 3. Flexibility

	Test 1		Test 2		Test 3	
	Left	Right	Left	Right	Left	Right
Active straight leg raise						
Thomas/Kendall hip flexion						
Thomas/Kendall knee extension						

### 4. Muscle activation patterns

Gluteus maximus

- Midway between last sacral vertebrae and greater trochanter

Erector spinae

- Parallel to lumbar spine at level of L3, 1cm lateral to spinal process

Transverse abdominal

- Mid-axillary line, 2cm posterior to the 12th rib

Biceps femoris

- Midway between greater trochanter and lateral condyle

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APPENDIX E

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**LETTER FOR ETHICAL APPROVAL**

Privaat sak X6001, Potchefstroom  
Suid-Afrika, 2520

Tel: 018 299-1111/2222  
Web: <http://www.nwu.ac.za>

Aan wie dit mag aangaan

**Etiëk Sub-komitee Fakulteit  
Gesondheidswetenskappe**  
Tel: 018 2992095  
Faks: 018 2992088  
E-pos: [Annamarie.Kruger@nwu.ac.za](mailto:Annamarie.Kruger@nwu.ac.za)

Geagte Prof. Moss

### **Etiëkaansoek: NWU-00048-11-A1 Addisionele Versoek**

U versoek om addisionele metings in die Rugbybeserings projek in te sluit is deur die etiëkkomitee paneel geëvalueer en goedgekeur, die navorsers kan dus voortgaan.

Vriendelike groete



Prof. Annamarie Kruger  
Voorsitster

Oorspronklike gegewens: Prof. Annamarie Kruger(10062416) C:\Users\13210572\Documents\ETIEK\2011 ETHICS\NWU-00048-11-A1 Addisionele Versoek.docm  
21 Februarie 2013

Verwysingsnommer: NWU-00048-11-A1 Ad.versoek

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APPENDIX F

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**LETTER FROM LANGUAGE EDITOR**



Date: 19/11/2013

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**CONFIRMATION OF EDITING**

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**CLIENT:** Miemie Greyling

**Dissertation Title**

*Pelvic biomechanics and muscle activation patterns during non-weighted squats in U/19 university-level rugby union players*

Light editing services were rendered for the above MSc dissertation, in November 2013, for: *Ms Miemie Greyling*

In addition to the editing, numerous recommendations for the finalisation and improvement of the document were made. The implementation of these changes remains the sole responsibility of the author.

Sincerely,

Dr D.A. Barraclough

---

Professional Writing, Editing,  
Proofreading and Research Solutions



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PO Box 348, Kloof 3640; [cell: 083-2330578](tel:083-2330578); [fax: 086-2186461](tel:086-2186461); [info@copywriting.co.za](mailto:info@copywriting.co.za); [www.copy-writing.co.za](http://www.copy-writing.co.za)  
Acceptance of the quote confirms compliance with our [Terms of Use and Privacy Policy](#) (see company website)

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