PREVALENCE OF LUMBO-PELVIC PAIN AND FACTORS ASSOCIATED WITH IT IN CYCLISTS IN JOHANNESBURG

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DECLARATION

I, Merinda Rodseth, declare that this dissertation is my own work. It is being submitted for the degree of Master of Science in Physiotherapy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

M. Rodseth

On this _______day of _____________, 2014

DEDICATION

This work is dedicated to my wonderful husband, Christian,
and two beautiful boys, Roald and Jonathan.
Without your continual encouragement and support,
this would never have been possible.

ABSTRACT

Cycling has grown in popularity as a sport and is rated as one of the top 15 most popular sports in South Africa with more than 420 000 participants. Cyclists spend long continuous hours on the bicycle in an awkward position, which leads to unique overuse injuries. Overuse injuries in cyclists have been estimated to be as high as 85% with lower back and pelvis pain (LBPP) among the most common.

The lower back and pelvis is the foundation the cyclist use for powering and controlling the bicycle and optimal functioning thereof is essential for optimal comfort and performance in cycling. The prolonged forward flexed position of the cyclist on the bicycle is regarded as one of the main contributors to LBPP in cyclists. Cyclists with LBPP are known to assume a position of greater lumbar flexion compared to those without but the reason for this has not been extensively explored. The purpose of this study was therefore to not only establish the prevalence of LBPP in cyclists in South Africa, but also identify factors associated with it in cyclists. The factors were considered in three broad categories: (1) training methods used, (2) intrinsic functioning of the cyclist and (3) bicycle set-up. Intrinsic and bicycle set-up factors included were those proposed to influence the forward-backward and side-to-side position of the cyclist on the bicycle and thereby lead to the development of LBPP in cyclists.

The study had a cross-sectional descriptive design and comprised of two parts: a questionnaire (survey) investigating the prevalence of LBPP in cyclists together with the training methods used, and a physical assessment of the factors proposed to be associated with LBPP in cyclists. All cyclists belonging to cycling clubs registered with Cycling South Africa were invited to complete the online survey. From there, cyclists could indicate willingness to undergo a physical assessment which was done in the greater Gauteng area. The physical assessment included the following measurements: the lumbar curvature on the bicycle in all three handlebar positions, strength of gluteus maximus and gluteus medius, extensibility of the hamstring muscle group, control of lumbar movement in the direction of flexion, neurodynamics, active straight leg raise for load transfer, one leg stance test for lateral shift of the pelvis, leg-length discrepancy and bicycle set-up (saddle height, set-back and angle, handlebar height, forward reach, cleat position).

The study revealed a lifetime prevalence of 65% for LBPP among cyclists in South Africa. Of the factors assessed, only the lumbar curvature in the brake lever position i.e. flexion of the lumbar spine (p=0.03) and the weakness of gluteus medius (Gmed) (p=0.05) were significantly related to LBPP in cyclists.

This study was the first to assess the relationship between so many different factors and LBPP in cyclists, and the largest of its kind in cycling. Understanding the relationship between these factors and LBPP in cyclists can guide the development of preventative strategies and interventions with the aim of reducing the occurrence and recurrence of LBPP in cyclists and limiting the impact thereof.

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LIST OF ABBREVIATIONS

AHAbd	Active hip abduction
AKE	Active Knee Extension
AKEA	Active knee extension angle
ASIS	Anterior superior iliac spine
ASLR	Active straight leg raise
BDC	Bottom dead centre
BMI	Body mass index
CI	Confidence interval
CNSLBP	Chronic non-specific low back pain
CSA	Cycling South Africa
EMG	Electromyography
ES	Erector Spinae
FLLD	Functional leg-length discrepancy
FMU	Fast motor unit
FP	Flexion pattern
Gmed	Gluteus medius
Gmax	Gluteus maximus
ICC	Intraclass coefficient
ITB	Ilio-tibial band
κ	Kappa
KEA	Knee extension angle
Kg	kilograms
Kg/m^2	Kilogram per meter squared
L5	Fifth lumbar vertebra
LBP	Low back pain
LBPP	Low back and pelvis pain
LLD	Leg-length discrepancy
LM	Lateral malleolus
m	Metres
MCD	Movement control dysfunction
MM	Medial malleolus
MRI	Magenetic resonance imaging
MVC	Maximal voluntary contraction
n	Number of participants

NSLBP	Non-specific low back pain
PBU	Pressure biofeedback unit
PFPS	Patello-femoral pain syndrome
PGP	Pelvic girdle pain
PHE	Prone hip extension
PKE	Passive knee extension
PSLR	Passive straight leg raise
PRPP	Pregnancy related pelvic pain
PPPP	Posterior pelvic pain after pregnancy
QBPDS	Quebec back pain disability scale
r	Pearson product-moment correlation coefficient
ROM	Range of movement
S1	First sacral vertebra
SA	Sacral angle test
SASP	South African Society of Physiotherapy
SD	Standard deviation
SI	Sacro-iliac
SIJ	Sacro-iliac joint
SLLD	Structural leg-length discrepancy
SLR	Straight leg raise
SMU	Slow motor unit
SR	Sit and reach test
T12	Twelfth thoracic vertebra
TDC	Top dead centre
TFL	Tensor fascial lata
TrA	Transversus abdominus
TMM	Tape measure method
UCM	Uncontrolled movement

OPERATIONAL DEFINITIONS

Bottom dead centre: When the pedal is at the lowest position/bottom of the crank cycle/pedalling arch in the 6 o'clock position (Wanich et al 2007, De Vey Mestdagh 1998).

Crank cycle: the circle (360° arch) made by the crank during a revolution (Wanich et al 2007).

Flexion relaxation: myoelectric silence in the erector spinae muscles at mid to end range of trunk flexion (Shin and Mirka 2007, Olson et al 2004).

Intrinsic factor: An intrinsic factor is a factor that is attributable to athlete him/herself (person-related), coming from within the body, such as height, weight, flexibility and strength (Orchard et al 2001, Orchard 2001, Barker et al 1997, Meeuwisse 1994).

Leg-length discrepancy: a condition where paired lower limbs are noticeably unequal (Gurney 2002).

Lumbo-pelvic pain: Low back pain (LBP) is defined as "pain and discomfort localised below the costal margin and above the inferior gluteal folds, with or without referred leg pain" (Vleeming et al 2008, Koes et al 2006). Pelvic girdle pain (PGP) is defined as pain localised between the posterior iliac crest and the gluteal fold, especially in the area around the sacroiliac joints (SIJ) (Vleeming et al 2008). Vleeming and Stoeckart (2007) challenged the concept of categorising 'spine', 'pelvis' and 'legs' separately based on their anatomic location. Muscles of the 'spine' are strongly connected to the pelvis and to the ligaments around the SIJ. The pelvis (as the main bony platform) is connected to three levers (legs and spine) all of which have to be stabilised under continuously changing conditions. Viewing these areas separately impedes the understanding of the functional mechanisms at work in this complexly integrated area (Vleeming and Stoeckart 2007). These authors therefore proposed that PGP should rather be regarded as a specific form of LBP.

In the literature, the term LBP is often used quite loosely and the areas included are not always specified. Some view the lower back and pelvic areas as distinctly different while others combine them through the term 'lumbo-pelvic' pain (LBPP) (Vleeming et al 2008, O'Sullivan and Beales 2007b, Pool-Goudzwaard et al 1998). Based on concepts proposed by Vleeming and Stoeckart (2007) the author decided to use the term LBPP to describe the collection of patients with LBP and PGP.

For the operational purposes of this dissertation, the term LBPP will be used in this study. Therefore, when referring to the literature, it will imply LBP as used by most, whereas when referring to this study, it will include LBP and PGP as described above.

Relative stiffness-relative flexibility: When the range of movement at a joint is limited by stiffness (passive tension), the restriction will be compensated at the joint that is more flexible than the others (and supposed to remain stable) (Sahrmann 2012, Sahrmann 2002).

Top dead centre: When the pedal is at the top of the crank cycle in the 12 o'clock position (De Vey Mestdagh 1998).

Uncontrolled movement: inefficient active control of movement of a specific motion segment and in a specific direction (Comerford and Mottram 2012)

CHAPTER 1: INTRODUCTION

1.1 Background to the study

Cycling is one of the most popular sports in the world (So et al 2005). This popularity is also seen in South African cycling, where cycling has been rated as one of the top 15 most popular sports (Sidenberg 2009). It is further estimated that there are approximately 422 000 adult cyclists in South Africa of whom 78% participate actively at a social level (Sidenberg 2009). A number of cycling disciplines are available for cyclists to participate in, these include road racing, time trialling, mountain biking and track cycling (Hunter 2011).

Due to the nature of cycling, cyclists spend long continuous hours on the bicycle in training or in competition, which ultimately leads to the development of unique overuse injuries. These injuries are generally sustained in two different ways, through (1) direct injury with macro tissue trauma after a crash or fall from the bicycle or secondly, through (2) indirect overuse injury with micro-trauma to tissues (Callaghan 2005). Traumatic injuries sustained with cycling have been well documented in the literature whereas the body of evidence of non-traumatic or overuse injuries is still growing. The prevalence of non-traumatic cycling injuries has been estimated to be as high as 85% (Dettori and Norvell 2006, Wilber et al 1995). The most common areas for non-traumatic cycling injuries include the knees, hands, neck/shoulder, lower back, buttocks and perineum (Dettori and Norvell 2006). The world-wide prevalence of lumbo-pelvic pain (LBPP) in cyclists has been estimated to be between 2.7-58% (Clarsen et al 2010, Schultz and Gordon 2010, Marsden 2009, Dettori and Norvell 2006, Dannenberg et al 1996, Wilber et al 1995, Mellion 1991, Weiss 1985).

Three broad categories have to be considered when assessing overuse injuries in cyclists: (1) the intrinsic biomechanics of the cyclist, (2) training methods used and (3) bicycle set-up (Schultz and Gordon 2010, Marsden 2009, Wilber et al 1995). The sustained forward flexed position assumed by cyclists is regarded as one of the major contributing factors towards LBPP in cyclists (Van Hoof et al 2012, Muyor et al 2011a, Asplund and Ross 2010, Marsden and Schwellnus 2010, Srinivasan and Balasubramanian 2007, Dettori and Norvell 2006, Asplund et al 2005, Burnett et al 2004). Cyclists mostly adopt either a “round-back”/flexed or “flat-back” posture based on the extent to which the pelvis and spine has to flex to contribute towards the cyclist reaching the handlebars (Schulz and Gordon 2010, Burnett et al 2004). The seated position of the cyclist will increase the tendency towards a “round-back” or flexed lumbar spine position

(Burnett et al 2004) and cyclists will also often increase their forward-bent posture while pedalling to limit their aerodynamic drag (Srinivasan and Balasubramanian 2007, Burnett et al 2004).

The lower back and pelvis is the foundation the cyclist uses for powering and controlling the bicycle and optimal positioning and functioning of this foundation will determine the comfort and quality of a cyclist's ride (Asplund and Ross 2010, Abt et al 2007, Mellion 1994). The forwards-and-backwards and the side-to-side balance of this foundation plays an important role in proper transmission of forces to the pedals. Optimal control of the lumbar spine, including the neutral alignment thereof, is essential for optimal functioning of this foundation (Asplund and Ross 2010, Abt et al 2007, Mellion 1994). To limit pain and injury and maximise power output, the pelvis should be well aligned, not tilted too far forward, nor too far back or shift (rock) from side-to-side (Abt et al 2007, Mellion 1994). The proposed optimal cycling position is one of increased hip flexion, anterior pelvic tilt and flattening of the lumbar kyphosis (Marsden and Schwellnus 2010, Marsden 2009, McEvoy et al 2007, Salai et al 1999, Mellion 1994). The ability to maintain this more neutral position of the spine allows the cyclist to remain in a more aerodynamic position for longer periods of time without injury or discomfort (Asplund and Ross 2010).

The position of the spine and pelvis on the bicycle is mostly controlled by activity of the musculature surrounding it and therefore optimal functioning of the stabilizing muscles around the lumbo-pelvic area is essential (Abt et al 2007). In addition, optimal flexibility of the global musculature influencing the functioning of the global stabilisers and the neutral position of the spine and pelvis is just as important for efficient control of the lumbo-pelvic area (Mellion 1994). An inability to control the movement and position of the lower back and pelvis, especially an inability to control the lumbar flexion, could cause an increased tendency to ride in a sustained lumbar flexion posture, placing undue strain on the lower back and pelvis, leading to pain and pathology (Burnett et al 2004).

Various researchers have investigated the kinematics and curvature of the lumbar spine in an attempt to uncover the relationship between LBPP and cycling (Muyor et al 2013, Van Hoof et al 2012, Muyor et al 2011a, Chapman et al 2008b, Diefenthaeler et al 2008, Burnett et al 2004). Others have investigated the underlying electromyography (EMG) activity in various upper limb, trunk and lower limb muscles involved in cycling (Srinivasan and Balasubramanian 2007, Burnett et al 2004, Usabiaga et al 1997). Limited research focussed specifically on the intrinsic biomechanics of the cyclist and the efficient functioning of the stabilising and mobilising muscles for control of lumbo-pelvic movement.

Although is it hypothesised that control of forward-backward and side-to-side movement are essential in cyclists, no studies have comprehensively investigated the factors that could influence/cause movement in these directions.

Training methods and their possible association with LBPP have to some extent been investigated. Cyclists spend many hours in training while preparing for various races and the possible influence of their training methods cannot be disregarded. Wilber et al (1995), Marsden (2009) and Schultz & Gordon (2010) have investigated the relationship between various training factors and LBPP and found only the distance cycled per week to be related to LBPP. Further exploration of the influence of training factors is however necessary.

Besides the cyclist, the bicycle also plays an important role in the comfort of the cyclist while riding. A number of methods have been used to assess the multiple parameters of a bicycle set-up which can impact the comfort of the cyclist (Wanich et al 2007, Silberman et al 2005, De Vey Mestdagh 1998, Mellion 1994). The height of the saddle, distance from the saddle to the handlebars and height of the handlebars are often adjusted to alleviate LBPP in cyclists (Silberman et al 2005, Sanner and O'Halloran 2000, De Vey Mestdagh 1998, Mellion 1994). Very few studies have investigated the association between LBPP and the various parameters of a bicycle set up and most of the information available is anecdotal (Marsden 2009, Silberman et al 2005, Salai et al 1999, De Vey Mestdagh 1998, Mellion 1994).

1.2 Problem statement

Pain in the lumbo-pelvic area has been reported as one of the most common non-traumatic injuries in cycling (De Bernardo et al 2012, Clarsen et al 2010, Dettori and Norvell 2006, Wilber et al 1995, Mellion 1994, Weiss 1985). Previous studies on LBPP have investigated three aspects related to such injuries, which include the: (1) association between training factors and LBPP, (2) kinematics and position of the lower back on the bicycle and (3) surface EMG of the musculature of the hip, lumbar area, thoracic area and upper limbs (Muyor et al 2013, Van Hoof et al 2012, Muyor et al 2011a, Schultz and Gordon 2010, Schulz and Gordon 2010, Chapman et al 2008b, Diefenthaeler et al 2008, McEvoy et al 2007, Burnett et al 2004, Usabiaga et al 1997, Wilber et al 1995). Most of the studies have very small sample sizes and generally observed the population without testing for specific postural or movement dysfunctions. Only one Cape Town-based study has investigated the prevalence of LBPP in cyclists in South Africa and they only focused on the participants of one cycling race (Marsden 2009). No studies have collectively investigated the numerous intrinsic, training methods and bicycle set-up factors that could be associated with LBPP in cyclists. This lack of data results in the inability of health care practitioners, coaches or cyclists to optimally prevent or manage LBPP in cyclists.

1.3 Significance of the study

Due to the support cycling enjoys and the resultant high number of participants, it is important to understand the factors that cause LBPP in cyclists. It is critical to understand which of the many factors actually play a role in LBPP. Knowing this will allow health care practitioners to better manage LBPP in cyclists. Cyclists may be prone to LBPP due to factors such as prolonged lumbar flexion on the bicycle with subsequent dysfunction of the musculature that controls spinal movement/function, sub-optimal training or inefficient bicycle set-up. The prevalence of LBPP in cyclists has not been fully established. This dissertation reports on the lifetime, one-year and point prevalence of LBPP in cyclists in South Africa. Furthermore, by understanding the factors associated with LBPP in cyclists in South Africa, preventative strategies and interventions can be developed to minimise the occurrence and reoccurrence of LBPP in cyclists.

1.4 Research Question

What is the prevalence of LBPP in cyclists in South Africa, what factors are associated with LBPP in cyclists and is there an association between these factors?

1.5 Study Aim

The aim of this study is to establish the prevalence of LBPP in cyclists in South Africa and the factors associated with it in cyclists in Gauteng, as well as the relationship between these factors.

1.6 Objectives

a. To determine the prevalence of LBPP in cyclists in South Africa
b. To identify which factors are associated with LBPP in cyclists in the greater Gauteng area
c. To establish if there is a relationship between the above factors
d. To establish the intra-rater reliability of the measures assessed in the physical evaluation

1.7 Organisation of the dissertation

1.7.1 Chapter 1: Introduction

In this chapter an overview of the dissertation is given. Background information on the problem of lower back and pelvis pain in cyclists is presented and risk factors previously investigated in cyclists are discussed. The research question is formulated, the relevance and aim of the study is discussed.

1.7.2 Chapter 2: Literature review

This chapter contains a review of the literature concerning cycling and LBPP as an overuse injury in cycling is given. Included are: the prevalence of LBPP in cyclists, the risk factors associated with the development thereof and the mechanisms involved.

1.7.3 Chapter 3: Justification of measuring instruments

The measuring instruments and techniques used in this study are discussed and justified. The chapter is structured according to three sections a questionnaire, physical assessment of the various risk factors as well as an assessment of the bicycle set-up.

1.7.4 Chapter 4: Methodology

This chapter describes the study's methodology, addressing: the research design, study population, selection criteria, outcome measures, procedure and statistical analysis.

1.7.5 Chapter 5: Results

Following the study objectives, the results derived from the statistical analysis are presented and interpreted. They include the prevalence of LBPP in cyclists, the risk factors derived from the questionnaire as well as the physical and bicycle set-up assessment and a summary of the main findings.

1.7.6 Chapter 6: Discussion

In this chapter, the main findings are discussed according to the objectives of the study: prevalence of LBPP in cyclists, risk factors for LBPP and any relationships between these factors. Study limitations are also discussed and recommendations are made for future research.

1.7.7 Chapter 7: Conclusion

A summary of the findings and conclusions of the study is provided in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction to the Literature Review

This chapter will provide an overview of the literature on the prevalence of LBPP in cyclists and the factors proposed to be associated with the development thereof. An outline of the chapter can be seen in Figure 2.1.

Over the years cycling has grown in popularity as a sport and a means of transport (Van Hoof et al 2012, Asplund and Ross 2010, Srinivasan and Balasubramanian 2007, Dettori and Norvell 2006, Asplund et al 2005, Callaghan 2005, So et al 2005). The long continuous hours cyclists spend on the bicycle in training or in competition can ultimately lead to unique overuse injuries. These overuse injuries are often related to the prolonged periods spent in a flexed position on the bicycle, the riding technique used and the set-up of the bicycle (Van Hoof et al 2012, Dettori and Norvell 2006, Asplund et al 2005, Burnett et al 2004, Mellion 1994).

The literature search was conducted using the following databases: CINAHL, EBSCO host, Google Scholar, PEDro and Pubmed, starting from 1977 as to include as many of the studies on bicycling and the development of the assessment techniques as possible. English articles relevant to this study up to October 2013 were identified and analysed for quality and reliability. Keywords used in the literature search were: low back pain and cycling, cycling injuries, road cycling and overuse injuries, prevalence and low back pain and cycling, motor control, gluteus medius, gluteus maximus, hamstrings, combination of the previous terms with low back pain and with cycling, slump, neurodynamics, lumbar curvature, lumbar lordosis, leg length discrepancy, lateral sway, lateral shift, active straight leg raise, one leg stance, load transfer, lumbar stability, stability of the spine, low back pain, pelvic girdle pain, motor control tests, bicycle set-up, saddle angle, saddle height and a combination of the bicycle set-up factors and low back pain. The Scopus database was not used in the literature search of this study.

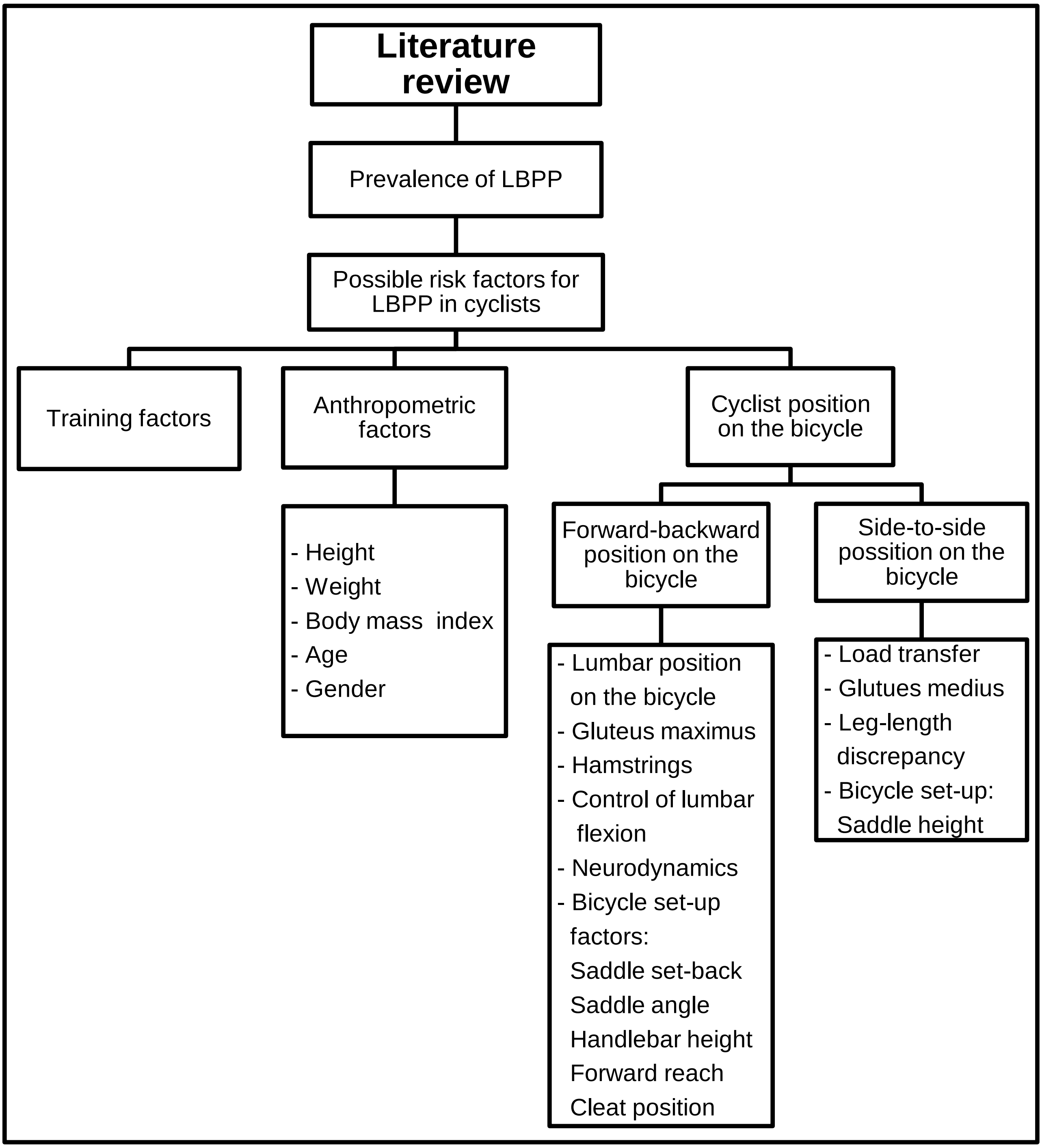

Figure 2.1 Illustration of the presentation of Chapter 2

2.2 Prevalence of lumbo-pelvic pain

2.2.1 Lumbo-pelvic pain in the general population

Lumbo-pelvic pain has become a major problem for many healthcare systems in developed countries in the western world (Balagué et al 2012, Louw et al 2007). The lifetime prevalence for LBPP in developed countries has been said to be as high as 84%

with a point prevalence ranging between 12-33% (Walker 2000). Statistics available from the African continent are very similar. In Africa the lifetime prevalence of LBPP ranges between 28-74%, with a point prevalence of 32% (range of 10-59%) (Louw et al 2007). Up to 85% of LBPP cases are classified as 'non-specific' as they have no definite diagnosis or specific anatomical problem/cause including negative X/rays and blood test results (Carlsson and Rasmussen-Barr 2013, O'Sullivan 2005, Waddell 2005). This has led to the classification of "non-specific low back pain" (NSLBP). NSLBP is related to "mechanical low back pain" and defined as LBPP without a known specific pathology or cause (Balagué et al 2012, McCarthy et al 2004). In recent years the international guidelines for acute LBPP have proposed a specific diagnostic triage for LBP, this includes (Waddell 2005):

- Nerve root/radicular pain (about 5% of cases, associated with disc prolapse or spinal stenosis)
- Serious spinal pathology (about 1-2%, vertebral fractures, infections, cauda equine syndrome, tumours, cancer)
- NSLBP (85-95% of cases)

2.2.2 Lumbo-pelvic pain in cyclists

Despite the non-weight bearing, low impact and smooth action of cycling, LBPP is still prevalent in cyclists. This may be because they spend considerably more time in training and racing compared to other sports which inevitably leads to the development of overuse injuries (Asplund and Ross 2010, So et al 2005). The prevalence of non-traumatic cycling injuries has been estimated to be as high as 85% (Wilber et al 1995). The most common areas for non-traumatic cycling injuries include the knees, hands, neck/shoulders, lower back, buttocks and perineum (De Bernardo et al 2012, Clarsen et al 2010, Marsden and Schwellnus 2010, Schultz and Gordon 2010, Marsden 2009, Dettori and Norvell 2006, Salai et al 1999, Callaghan and Jarvis 1996, Dannenberg et al 1996, Wilber et al 1995, Weiss 1985).

A number of studies have investigated the incidence/prevalence of overuse injuries in elite and recreational cyclists (De Bernardo et al 2012, Clarsen et al 2010, Schultz and Gordon 2010, Marsden 2009, Salai et al 1999, Callaghan and Jarvis 1996, Wilber et al 1995, Weiss 1985). The incidence of LBPP in recreational multiday long-distance tour cyclists varied from 1.6 – 16% (Townes et al 2005, Dannenberg et al 1996, Weiss 1985, Kulund and Brubaker 1978) and Callaghan & Jarvis (1996) reported a LBPP incidence of 28-32% for a mixed group of track and road cyclists. Wilber et al (1995) proposed that the injuries sustained during multi-day long-distance recreational tours are mostly acute overuse injuries and could not be compared to those reported in non-tour cyclists. Overuse injuries in long-distance tours are thought to be mostly due to poor rider condition and poor pre-tour preparation (Dannenberg et al 1996).

The prevalence of LBPP varied from 15.7 – 58% in elite/professional cyclists (De Bernardo et al 2012, Clarsen et al 2010, Callaghan and Jarvis 1996) and 30.3 – 50% for non-competitive/recreational cyclists (Schultz and Gordon 2010, Salai et al 1999, Wilber et al 1995). Marsden (2009) investigated the prevalence of LBPP in a group of mixed recreational and competitive cyclists in South Africa and found a one-year prevalence of 42.9% and a lifetime prevalence of 50.7%. Details of the different populations can be found in Table 2.1 and Table 2.2.

Table 2.1 Summary of the incidence of LBPP in cyclists in previous studies

Population	Study	Details of study	Participants	Incidence of LBPP
Multi-day long-distance cyclists	Kulund & Brubaker (1978)	4500 miles over 80 days	-	15%
	Weiss (1985)	496 miles over 8 days	132	2.7%
	Dannenberg et al (1996)	339 miles	1140	16%
	Townes et al (2005)	520 miles	244	1.6%
Elite/ professional cyclists	Callaghan & Jarvis (1996)	Mixed discipline (track, road and combination) elite British squad	71	28-32%

Table 2.2 Summary of the prevalence of LBPP in cyclists in previous studies

Population	Study	Details of study	Participants	Prevalence of LBPP
Elite/ professional cyclists	Clarsen et al (2010)	7 professional European teams	116	58% (1-year prevalence)
	De Bernardo et al (2012)	Top level road cyclists	51	15.7% (prevalence over 4 years)
Recreational cyclists	Wilber et al (1995)	Non-competitive cyclists	518	30.3% (possibly point prevalence)
	Salai et al (1999)	Road bicycles/mountain bicycles/city bicycles	80	50% (point prevalence)
	Marsden (2009)	Mixed recreational and non-elite competitive cyclists	468	42.9% (1-year prevalence) 50.7% (lifetime prevalence)
	Schultz & Gordon (2010)	Road cyclists from local clubs	66	50% (prevalence over last 6 months)

The studies on the incidence and prevalence of LBPP were cross-sectional in design and had relatively large sample sizes as can be seen in Table 2.1 and Table 2.2.

2.3 Factors proposed to be associated with lumbo-pelvic pain in cyclists

2.3.1 Introduction

The lower back and pelvis is at the centre of the functioning of the cyclist on the bicycle. It has to absorb and distribute loads from the upper limbs and lower limbs, yet in itself provide a stable base for the control and powering of the bicycle (Asplund and Ross 2010, Abt et al 2007, Mellion 1994). Optimal control of the lumbo-pelvic area will limit excessive movement in a forward-backward and side-to-side direction, increase power output and enable the cyclist to maintain a more aerodynamic position for longer periods of time, while limiting discomfort and injury (Asplund and Ross 2010, Abt et al 2007, Mellion 1994).

There are three main aspects around cycling that could influence the development of LBPP in cyclists: (1) training factors, (2) intrinsic physical factors of the cyclist and (3) bicycle set-up factors. The association between training factors and LBPP in cyclists have been investigated to some extent, but the influence of both intrinsic factors and bicycle set-up factors have barely been assessed (Schultz and Gordon 2010, Marsden 2009, Wilber et al 1995). Poor positioning of the cyclist of the bicycle, sub-optimal bicycle set-up and the cyclist's training method, intensity and frequency will all superimpose on any pre-existing positional or control faults. These might over time overload the spinal structures and result in pain and pathology. The theoretical framework underlying these aspects as well as the possible influence of anthropometric factors will be discussed in the following sections.

2.3.2 Training factors

Mellion (1994) identified the necessity of including training factors as a possible reason for the development of back pain. Training factors and their influence in the development of LBPP were assessed by Weiss et al (1985), Wilber et al (1995), Marsden (2009) and Schultz and Gordon (2010). These factors include:

- Intensity of training (average speed/pace during training)
- Frequency of training (number of days cycled per week)
- Duration of training (number of hours spent on the bicycle in training, number of kilometres per week and number of years cycled)
- Cycling event participation
- Cycling terrain
- Cycle equipment

When considering all these factors, distance cycled per week was the only factor consistently associated with LBPP (Schultz and Gordon 2010, Marsden 2009, Wilber et al 1995). This was quantified by Schultz and Gordon (2010) who indicated that cyclists who ride more than 160 kilometres (km) per week were more likely to experience LBPP.

2.3.3 Anthropometric and demographic factors

2.3.3.1 Height, weight and body mass index

A large number of studies have been reported on the association between body weight and LBPP with outcomes that were often contradicting. Body weight is considered by some to be a strong contributing factor for the development of LBPP while others don't regard it as a risk factor (Manchikanti 2000). The consensus from earlier studies, which includes a large population study by Leboeuf-Yde (2000), was to regard body weight as a risk factor for LBPP until better evidence is available (Leboeuf-Yde 2000, Deyo and Bass 1989). More recently a very large population-based study on 63 968 people done by Heuch et al (2010) concluded that obesity was associated with a high prevalence of LBPP. What is clear from the literature reviewed is that there is no evidence to conclude that weight is associated with the development of LBPP in cyclists.

Walsh et al (1991) indicated an increase in risk with increased height in men in general, but not among women. This is supported by Manchikanti (2000) who also reported a positive relationship between height and LBPP. In direct contrast to this, Han et al (1997) in a large 1993-1995 Dutch cohort study (n=5887 males and n=7018 females), found no relationship between height and LBPP. Again the evidence is inconclusive with regards to height playing a role in the development of LBPP in cyclists.

The association between height, weight and body mass index (BMI) and LBPP in cyclists was assessed in only one case controlled study by Marsden (2009) (n=40). This author compared height, weight and BMI in cyclists with and without back pain and concluded that cyclists with LBPP weighed significantly more and were significantly taller than those without. No relationship was however found between BMI and LBPP. This study will attempt to uncover if any of the above literature can be supported or refuted.

2.3.3.2 Gender and age

Studies on LBPP in cyclists mostly report only on the collective demographics of the population (age, height, weight, BMI) and not on the differences between males and females nor the association between various factors and LBPP (Van Hoof et al 2012, Muyor et al 2011b, Muyor et al 2011a, Clarsen et al 2010, Chapman et al 2008b, Diefenthaeler et al 2008, Abt et al 2007, McEvoy et al 2007, Srinivasan and Balasubramanian 2007, Burnett et al 2004, Bressel and Larson 2003, Salai et al 1999, Dannenberg et al 1996, Wilber et al 1995, Weiss 1985). Many of the studies that analysed association of clinical factors and LBPP only included male cyclists. This does not allow for comparisons to be made between male and female cyclists (Van Hoof et al 2012, Muyor et al 2011b, Chapman et al 2008b, Diefenthaeler et al 2008, McEvoy et al 2007, Srinivasan and Balasubramanian 2007). More information on the demographic characteristics of cyclists in the studies reviewed can be found in Appendix 1.

Of the studies reviewed for this literature review, only three studies reported on the influence of gender and age in cyclists (Dannenberg et al 1996, Wilber et al 1995, Weiss 1985). Weiss (1985) reported on gender differences in knee injuries, but did not investigate LBPP. In a study conducted by Dannenberg et al (1996) it was noted that the prevalence of back complaints were three times higher in cyclists aged 10-19 years compared to those older than 40. Even though they did not investigate the reason for this, it can be hypothesised that older cyclists might be doing less mileage at a lower intensity or might have better cycling equipment and bicycle set-up because of better financial resources compared to the younger population, and hence the decrease in back and knee complaints.

Wilber et al (1995) reported significant differences between male and female cyclists for height, weight, miles cycled per week, days cycled per week, average cycling pace, intensity of riding, the use of interval training and participation in other sports. They also reported that females are 1.5 times more likely to sustain an overuse injury of the neck compared to males, and 2.12 times more likely to sustain an overuse injury of the shoulder. In their study they found a statistically significant relationship between male cyclists who reported both more miles cycled per week and a fewer mean number of gears used, and back pain. From the literature reviewed, it would appear that clear evidence is not available to support the theory that gender plays a role in cyclists developing LBPP.

2.3.4 Position of the cyclist on the bicycle

The position of the cyclist on the bicycle is influenced by movement in two main directions – the forwards-and-backwards movement between the saddle and the handlebars and secondly the side-to-side movement between the saddle and the pedals (Mellion 1994). Previous studies that investigated LBPP in cyclists are sparse and generally conducted on small study populations, reducing the merit of such findings. These studies have mostly focussed on the forward-and-backward positioning of the cyclist on the bicycle through investigation of lumbar kinematics and positioning on the bicycle and the EMG activity of various trunk and limb muscles (Van Hoof et al 2012, Muyor et al 2011a, Srinivasan and Balasubramanian 2007, Burnett et al 2004).

When cycling, cyclists will assume either a “round-back”/flexed or “flat-back” posture based on the extent to which the pelvis and spine have to flex to contribute towards the cyclist reaching the handlebars (Schulz and Gordon 2010, Burnett et al 2004). The seated position of the cyclist leads to a natural increased tendency towards a “round-back”/flexed posture which is emphasised by the increased forward bent position often assumed by cyclists in an attempt to reduce their aerodynamic drag (Srinivasan and Balasubramanian 2007, Burnett et al 2004).

What further complicates this concept of posture is that no “ideal” sitting posture on a bicycle has been established for cyclists. Various authors have attempted to do this but consensus has not been reached. Most authors suggest that the lower back should be in a neutral position, that the pelvis should be positioned in an anterior tilt and that the forward flexion should be generated through hip flexion in order to flatten the kyphotic lumbar curve (Marsden and Schwellnus 2010, Marsden 2009, Abt et al 2007, McEvoy et al 2007, Salai et al 1999, Mellion 1994). Consensus on a neutral sitting posture for normal upright sitting on a chair/solid surface has not even been established which illustrates the complexity of quantifying what an ideal sitting posture should be (O'Sullivan et al 2010a).

The literature indicates that there seems to be general consensus that sustained end-range forward flexion of the lumbar spine during cycling could be pivotal to the development of LBPP in cyclists (Van Hoof et al 2012, Muyor et al 2011a, Schulz and Gordon 2010, Burnett et al 2004). Van Hoof et al (2012) and Burnett et al (2004) observed that, although all cyclists adopt a position of lumbar flexion, cyclists with LBPP assume a position of greater lumbar flexion on the bicycle compared to asymptomatic cyclists, which agrees with the hypothesis that LBPP is due to the flexed position on the bicycle.

Muyor et al (2011a) assessed lumbar angles of 120 asymptomatic male master (n=60) and elite (n=60) cyclists while positioned on the bicycle in different handlebar positions. Both groups presented with variable degrees of lumbar flexion on the bicycle in all three handlebar positions (brake levers, drop position and seated upright position). Their findings indicate that elite cyclists assume a position of greater lumbar flexion and greater posterior pelvic tilt compared to master cyclists. This is in contrast with the proposed “neutral spine” which other authors proposed for the prevention of LBPP (Mellion 1994). It is therefore clear that all cyclists, including asymptomatic cyclists, assume a flexed lumbar posture on the bicycle (Van Hoof et al 2012, Muyor et al 2011a, Usabiaga et al 1997) and whether this will predispose them to injury is yet to be established.

A combination of studies with small sample sizes (n=13-34) (Van Hoof et al 2012, Schulz and Gordon 2010, McEvoy et al 2007, Srinivasan and Balasubramanian 2007, Burnett et al 2004) to larger sample sizes (n=40-120) (De Bernardo et al 2012, Muyor et al 2011a, Marsden 2009, Salai et al 1999) were included in the literature review on the lumbar positioning. Although the majority of studies were cross-sectional studies (which have their own limitations), some of the smaller studies were case controlled studies of participants with LBPP and those without (Van Hoof et al 2012, Marsden 2009, Srinivasan and Balasubramanian 2007, Burnett et al 2004). No studies with a higher level of evidence could be located on this topic.

Several biomechanical and physiological responses have been described for the lumbar spine in response to prolonged flexion (Shin and Mirka 2007, Olson et al 2004, Solomonow et al 2000) (Figure 2.2):

- With sustained flexion the passive spinal tissues deform at a slow rate. The increase in laxity in the passive tissues leads to a decrease in resistance to the forward flexion movement and is known as mechanical creep deformation of the visco-elastic tissues. Creep has been related to spinal instability under load and the development of LBPP.
- Ligament inflammation and muscle spasms also follow the prolonged spinal flexion.
- An increased demand is placed on the lumbar extensors to generate additional forces in compensation for the lack of resistance in the visco-elastic tissues resulting in muscle fatigue and an inability to maintain lumbar stability.
- Flexion relaxation (myoelectric silence in the erector spinae muscles at mid to end range trunk flexion) occur, and with this reduced activity in the muscle, the passive structures (i.e. ligaments, intervertebral discs) are placed at higher risk.

Constant increased loading of the passive posterior spinal structures and sustained increased pressure in the intervertebral discs can result in accumulated micro-damage as evident in the posterior annulus of the intervertebral discs (Burnett et al 2004, Solomonow et al 2003b, Callaghan and McGill 2001). The prolonged forward flexed position assumed on the bicycle could thereby potentially influence the development of LBPP in cyclists (Muyor et al 2011a, Smith et al 2008, Harrison et al 2005, Burnett et al 2004).

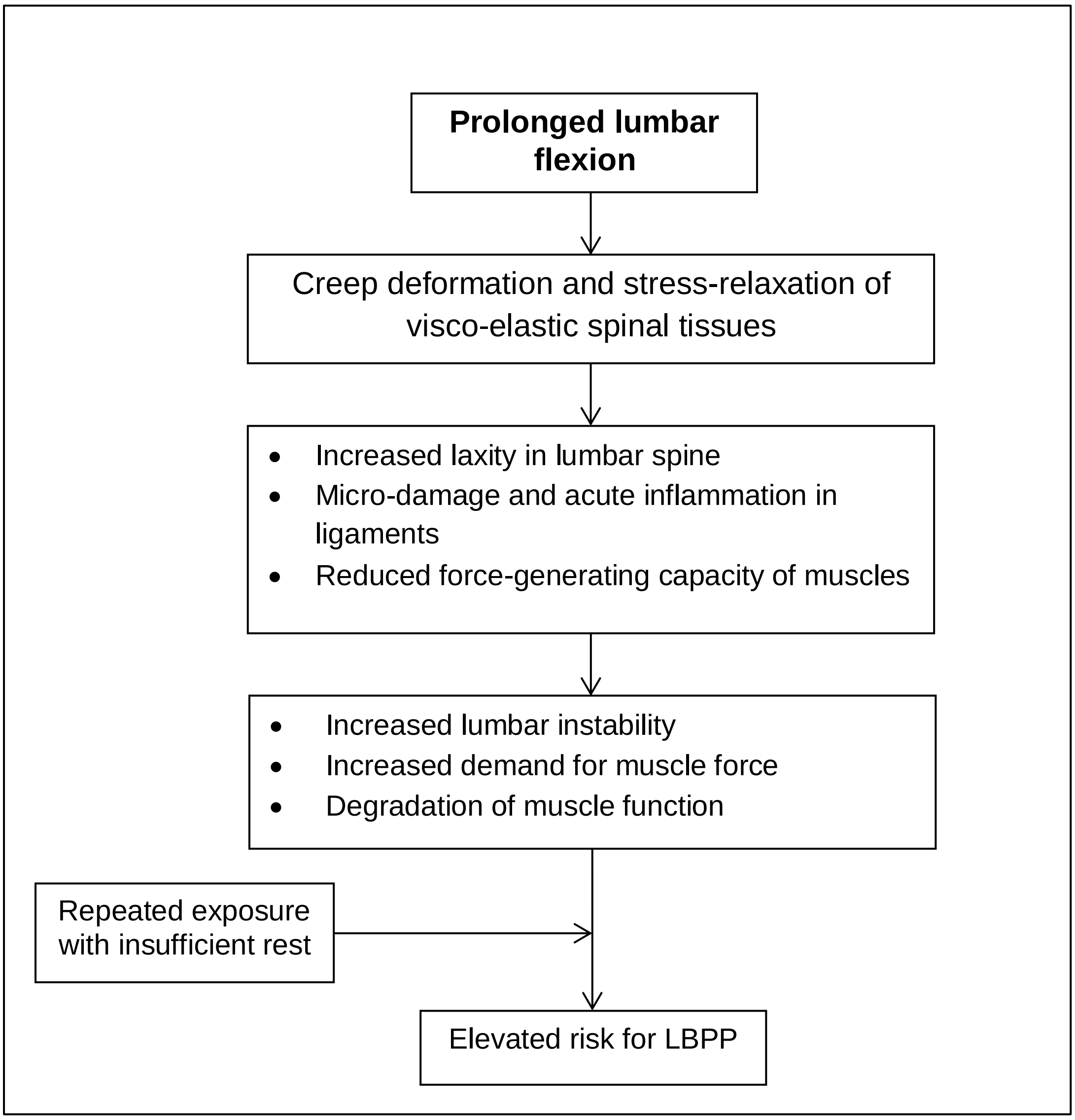

Figure 2.2 Conceptual model for risk factors with prolonged lumbar flexion (reproduced from Shin and Mirka (2007).

Several patho-mechanical mechanisms have been proposed for the development of LBPP in cyclists following sustained forward flexion (Van Hoof et al 2012, Burnett et al 2004). These are:

- Mechanical creep

Burnett et al (2004) expressed that this might be unlikely in cyclists as part of the cyclist's mass is also supported by the upper limbs on the handlebars and they are therefore not positioned in an open-ended position typically found in occupational settings. Two studies have assessed the possible development of creep in cyclists and one reported an increase in lumbar flexion (possible creep) in recreational cyclists (n=13) over a 10 minute static cycling period (Schulz and Gordon 2010) whereas the other reported no change in the magnitude of lumbar flexion over a two hour outdoor training ride (n=17) (Van Hoof et al 2012). Both of these studies had a case-controlled, cross-sectional design but with relatively small sample sizes (n=13 and n=17).

- Flexion relaxation phenomenon

Juker et al (1998) proposed that flexion-relaxation might occur in certain cycling postures. An EMG study by Srinivasan and Balasubramanian (2007) illustrated fatigue in the right erector spinae muscle in cyclists with LBPP which could be indicative of asymmetrical loading of the spine. This is proposed to be reflective of the flexion relaxation phenomenon in the Erector Spinae muscles proposed as a mechanism for the increase in lumbar flexion in cyclists. Even though the study by Srinivasan and Balasubramania (2007) was a case-controlled (LBPP vs. no LBPP) cross-sectional study, the sample size was small (n=14) and the results have to be interpreted with caution.

- Transfer of mechanical loads generated by the lower extremities through a flexed and/or rotated lumbar spine.

Limited anterior pelvic tilt due to shortening of the hamstring muscle group was in theory proposed as a reason for LBPP in cyclists by Mellion (1994). Muyor et al (2011b) investigated the association between hamstring extensibility and lumbar curvature on the bicycle based on the proposition that a decrease in extensibility will limit the anterior tilt of the pelvis and thereby demand an increase in lumbar flexion, yet they found no relationship. The study by Muyor et al (2011b) had a large sample size (n=96 cyclists) and only included highly trained cyclists (daily training of 2-4 hours, 3-6 days per week, minimum five years cycling experience) without hamstring or spinal pain in the last three months without comparing the findings of the asymptomatic cyclists to those of cyclists with LBPP.

Though identified, none of these factors have been extensively investigated and many other factors that could influence the position assumed and sustained on the bicycle were not considered or investigated. Control of the side-to-side position on the bicycle is also considered important, yet no studies could be located where it was investigated (Mellion 1994). In lieu of the limited research available on factors associated with LBPP in cyclists it was hypothesised that factors that could influence the forward-and-backward and side-to-side position of the cyclist on the bicycle as illustrated in Figure 2.2, could be contributing to the development of LBPP in cyclists.

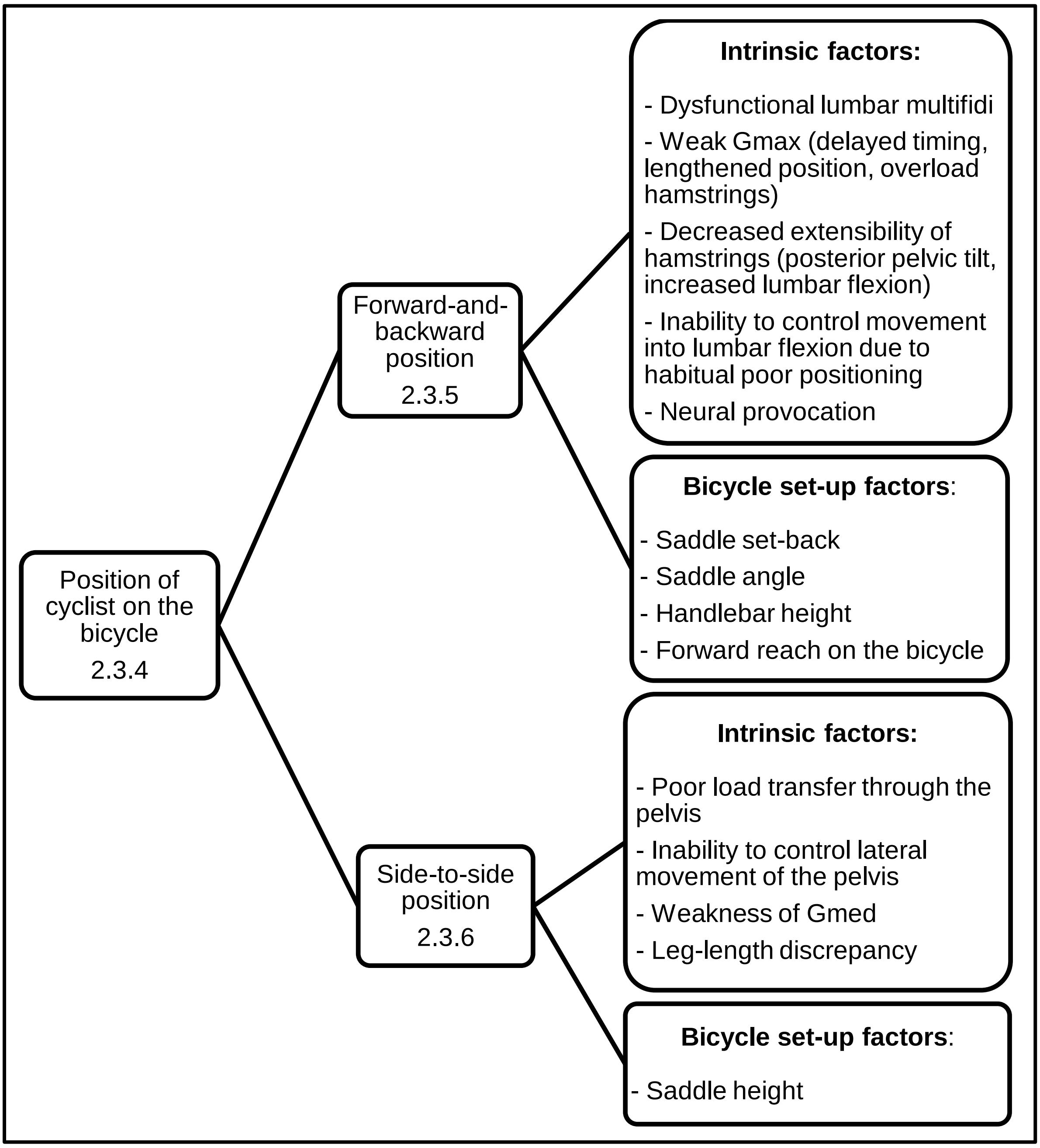

Figure 2.3 Factors influencing forward-and-backward and side-to-side position on the bicycle

Control of the position on the bicycle is enhanced by efficient lumbo-pelvic stability. The theoretical framework underlying this stability will be briefly discussed in the next section followed by the discussion of the combined intrinsic and bicycle set-up factors that could influence the position of the cyclist on the bicycle, as illustrated in Figure 2.2.

2.3.4.1 Lumbo-pelvic stability

Lumbo-pelvic stability is defined as "the ability to control movement of the lumbar spine and pelvis relative to an arbitrarily defined neutral position" (Mills et al 2005). Panjabi (1992) proposed in a theoretical model that stability of the spine is mediated through three systems: the active, passive and neuromuscular control systems. The discs, spinal joint surfaces, spinal ligaments and joint capsules make up the passive control system and are responsible for passive restriction of movement. The active control system is made up of muscles and their tendons which actively cause movement and the neural control system is responsible for the control and coordination of the movement (Panjabi 1992). A similar model was proposed by Sahrmann (2002), which included the following elements: (1) base (muscular and skeletal systems), (2) modular (nervous system regulating and controlling movement), (3) biomechanical (statics and dynamics) and (4) support (cardiac, pulmonary and metabolic systems maintain the livelihood of the other systems).

Dysfunction in any of these systems could lead to the development of pathology and pain. Disc degeneration, herniation, annular tears, continuous strain and overstretching of ligaments and degeneration of joint surfaces with subsequent osteophyte formation will all lead to the development of pain (Panjabi 1992). In sustained positions, as seen in cyclists, the active and passive control systems are under prolonged stress. With continuous stress the collagenous fibres elongate (creep) and strain develops. With continuously sustained strain in an incorrect posture/position, discs are subject to shear forces which eventually lead to damage of the annular fibres. When collagenous fibres are continuously exposed to strain, the tissues will slowly adapt to the forces and lengthen. Over time the tissue structures will habituate to the new elongated position and the collagenous fibres will remain lengthened, weakening the functioning of the system (Luomajoki 2010, Bogduk 2005).

In the active control system, prolonged flexion will lead to changes in the length-tension relationships of muscles and to laxity of the visco-elastic structures. With prolonged flexion, the multifidus muscle first reacts with tension, which decreases after 2-3 hours of loading, rendering the spine to the risk of instability (Comerford and Mottram 2012, Luomajoki 2010). Jackson (2001) reported a sharp decrease in feline multifidus muscle (n=7) activity after static flexion loading for 20 minutes, which did not recover in the following seven hours. Dysfunction of the active control system will be explored in more detail in the next section.

Dysfunction can also occur in the neural control system. Activity of the neural control system is mediated through learning. Learning consists of conditioning and repetition which will lead to habit-forming behaviour. Specific activities with their respective neural pathways that are frequently used will strengthen the used pathways and through repetition automatize the activity. This process is entirely mediated through the neural control system and causes habituation. This explains why people persistently use incorrect and pain-provoking movements as they have become habituated to it and hence they are no longer aware of what is happening to their bodies (Luomajoki 2010, Moseley 2008).

Stability of the lumbo-pelvic spine through control of movement lies somewhere in the integration of the different control systems discussed above. Luomajoki (2010) proposed that neuromuscular control deficits may have the biggest impact on the development of uncontrolled movement resulting in LBPP. Discussions about the control of movement and the development of uncontrolled movement will be partly based on the theoretic model for control of movement developed by Sahrmann (2002) and Comerford & Mottram (2012, 2001b) which, although it has not been extensively tested, is the best available explanation of the topic.

2.3.4.2 Muscular contributions to lumbo-pelvic stability

Integrated functioning of the muscle system is essential for optimal movement and stability. The muscle system has been classified in various ways. Muscles were initially classified according to their function as mobilisers or stabilisers. The primary function of mobiliser muscles is to produce movement through concentric acceleration and the production of high forces. Mobiliser muscles extend over two or more joints and tend to become overactive and lose their extensibility. Stabiliser muscles, such as the Gmed and Gmax, are important for postural holding tasks, anti-gravity function and control. These stabilisers generally extend over one joint and have a tendency towards weakness and inhibition (Sahrmann 2002, Comerford and Mottram 2001b, Norris 1999).

Bergmark (1989) classified muscles according to the local or global function they displayed when controlling load transfer across the lumbar spine and pelvis. Local muscles control inter-segmental movement of the spine by increasing and maintaining the mechanical stiffness across joints. Local muscle function is biased towards low-load activities, but they also maintain control over inter-segmental translation during high load activities. Global muscles produce and control the range and the direction of movement during load-transfer between the trunk and the pelvis (Bergmark 1989). Comerford and Mottram (2012, 2001b) further categorised global muscles as having a stabilising or mobilising role and integrated the two concepts into a model for muscle classification (Table A2.1, Appendix 2, p.165).

According to Comerford and Mottram (2012, 2001b), the global stabilising muscles have four main functions:

- to concentrically shorten to produce movement ("mobility function")
- to isometrically hold the position ("postural control function")
- to eccentrically lengthen to return to the resting position ("stability function")
- to provide proprioceptive feedback to the central nervous system.

Normal function with efficient stability can only be mediated through integrated action from the local and global muscle systems (Comerford and Mottram 2012). Dysfunction in the local stability system primarily presents as (1) abnormal segmental control and (2) deficits in motor recruitment. There is wide-spread consensus that the local stability muscles are inhibited by pain and pathology and dysfunction therefore mostly appears after the development of pain and pathology (Hides et al 2008a, 1996, 1994). Dysfunction in the global muscle system predominantly surfaces in three different ways: (i) length associated changes, (ii) altered recruitment patterns and (iii) direction specific hypermobility/uncontrolled movement (Comerford and Mottram 2012, Sahrmann 2002).

i. **Length associated changes**

The effective functioning of a muscle is directly related to its ability to produce tension which is again related to the number of linked actin-myosin cross-bridges (Kendall et al 1993, Gossman et al 1982, Williams and Goldspink 1978). The efficacy and force production of muscles are optimised in their mid-range position (close to their resting length) of functioning. Muscles that are elongated or shortened appear functionally weak and less efficient during contraction (physiological of mechanical insufficiency) (Sahrmann 2002, Williams and Goldspink 1978). Physiological insufficiency occurs when a muscle shortens into its inner range where the actin-myosin filaments are maximally overlapped and fewer cross-bridges can be linked. The shortened muscle loses sarcomeres and increases in connective tissue resulting in a reduction in force production. Mechanical insufficiency is the direct opposite of this phenomenon. When a muscle contracts in its lengthened position there is inadequate overlapping of the actin-myosin filaments, fewer cross-bridges can be linked and again the muscle cannot produce adequate force. The lengthened muscle gains sarcomeres in series and is able to generate higher peak forces, but only in the outer ranges of movement. The muscle will test weak in its mid- and inner-range and fatigue more readily in postural control tasks. A muscle will change its functional resting length to adapt to the length that it is habitually used in, whether elongated or shortened (Lieber and Ward 2011, Sahrmann 2002, Kendall et al 1993, Gossman et al 1982, Williams and Goldspink 1978).

ii. Altered muscle recruitment patterns

Two different types of motor units have been predominantly identified in muscles: slow low threshold motor units (SMU) and fast high threshold motor units (FMU) (Levangie and Norkin 2011, Lieber 2009, Enoka and Fuglevand 2001, Belanger and McComas 1981). SMU are resistant to fatigue and are mostly recruited in low-load activities and postural control tasks. FMU fatigue quickly when recruited, have a higher activation threshold and are mostly used as load increases. SMU are recruited in one-joint stability muscles during low-load antigravity or postural control functions. They have a low threshold for activation and should react easily to low-force loading. Mobiliser muscles recruit their high threshold FMU for higher load, fast actions and should not be sensitive to low load SMU activation. In a dysfunctional situation the one-joint stabiliser muscles increase their threshold for activation and become less responsive to low load stimulation, only responding to greater loads. As a result, multi-joint mobiliser muscles reduce their threshold to take over the stability role and become more reactive to low load stimulation like postural sway and postural control. This inevitably leads to inappropriate recruitment of the mobiliser muscles for a stability task (Belanger and McComas 1981).

This concept is clearly illustrated in the changes in recruitment and sequencing between stabiliser and mobiliser muscles as reported by Janda (1985) and Sahrmann (2002). Sahrmann (2002) reported consistent imbalances in recruitment patterns between different muscle groups. These included imbalances between contralateral hamstrings and abdominal muscles during active straight leg raise in supine (ASLR); hamstrings and back extensors in forward bending; TFL, iliotibial band (ITB) and posterior

Gmed in hip abduction and hamstrings and gluteal muscles during prone hip extension.

The consistent pattern that emerges is that one-joint stabiliser muscles should activate before multi-joint mobiliser muscles in normal/no pain situations. Dysfunctional sequences and patterns of recruitment become evident in the presence of pain and pathology. Multi-joint mobiliser muscles are recruited earlier and often lack extensibility while one-joint stabiliser muscle recruitment is delayed and the muscles are inefficient in controlling an inner range contraction.

iii. Direction specific increased movement

Sahrmann (2002) developed the concept of "relative stiffness-relative flexibility". She proposed that one-joint muscles, if lengthened and unable to adequately shorten into inner range, will become more flexible and inadequate in preventing uncontrolled movement at that joint. Multi-joint muscles, if they lack extensibility and become stiffer, will limit normal range of motion (ROM) at that joint. When the range of movement at a joint is limited by stiffness, the restriction will be compensated for elsewhere in order to maintain function. If this occurs in muscles performing the same movement then excessive direction-specific uncontrolled movement will develop at the joint inadequately controlled by the one-joint stabiliser muscle.

Luomajoki et al (2007) reiterated this concept of movement occurring through the pathway of least resistance (relative flexibility theory). He indicated that more flexible structures will compensate for less flexible/stiffer ones during function which will create stress and strain in a specific direction. With repetitive loading, this direction-specific hypermobility will be reinforced resulting in tissue damage, pain and uncontrolled movement (Sahrmann 2002).

The clinical implication is that in 'ideal' functioning systems, relative stiffness and flexibility are well regulated by motor control processes. The body will however adapt in the presence of significant restrictions and compensate for these restrictions by increasing mobility elsewhere in the system in order to maintain function at all costs. This excessive increase in mobility often results in uncontrolled movement and may result in the development of pain and pathology. There is a complex interaction between muscles to provide stability and control of the spinal joints during movement. Loss of this stability can also lead to LBPP.

2.3.5 Factors influencing the forward flexed position on the bicycle

2.3.5.1 Lumbar multifidi

The lumbar multifidi are classified as local stabilisers of the spine and ideally situated to control segmental translation and create extension in the lumbar spine. Several studies have indicated localised atrophy of the lumbar multifidi in the presence of acute and chronic LBPP which does not recover spontaneously (Hides et al 2008a, Hides et al 2008b). Therefore, in the presence of pain and pathology, local stability muscle dysfunction is expected and its influence on poor motor control and recurrence of symptoms is undeniable. In the pursuit of the factors that could contribute to the development of LBPP, it is difficult to establish if the local stability dysfunction causes the LBPP, was as a result of the LBPP or a combination of both. Dysfunction of the local stability system is therefore beyond the scope of this study and even though its contribution to LBPP is undeniable, its influence will not be further explored here.

2.3.5.2 Gluteus Maximus

Gmax is a primary extensor of the hip and although most studies on the anatomy of Gmax refer to the muscle as a whole (Barker et al 2013, Neumann 2010, Ward et al 2010), Grimaldi et al (2009) proposed that Gmax should be considered as having two functionally separate entities based on their position relative to the centre of rotation of the hip. The upper Gmax arises from the posterior iliac crest, acts above the centre of rotation of the hip and is active in hip abduction. Lower Gmax acts below the centre of rotation of the hip, is responsible for hip extension and originates from the inferior sacrum and upper lateral coccyx. Gmax is also strongly connected to the ITB with 80% of it inserting into the ITB (Antonio et al 2013, Reiman et al 2012, Conneely et al 2006). There seems to be some consensus that Gmax has a global stability role around the pelvis and that it plays a major role in postural holding/anti-gravity stability including stability of the SIJ, and in transferring forces from the lower extremities to the trunk (which would be more the function of the lower Gmax) (Antonio et al 2013, Kang et al 2013, Ward et al 2010, Gibbons 2007, Conneely et al 2006, Willson et al 2005). The evidence on the anatomy and function of Gmax ranges from literature reviews/clinical commentaries (Neumann 2010, Ward et al 2010) and cross-sectional and case-controlled cross-sectional studies

(Antonio et al 2013, Kang et al 2013, Grimaldi et al 2009, Conneely et al 2006) to systematic reviews (Reiman et al 2012).

Gmax has been described to be to the SIJ what the quadriceps is to the knee (Lee 1996). Through its extensive connections to the thoracodorsal fascia and to the sacrotuberous ligament, it aids in increasing force closure around the pelvis, thereby contributing to stability of the sacro-iliac joints (SIJ) and pelvis (Forst et al 2006, Cohen 2005, Hossain and Nokes 2005, Pool-Goudzwaard et al 1998, Lee 1996, Vleeming et al 1996). Barker et al (2013) reported that 70% of Gmax crossed the SIJ, indicating the ability of Gmax to increase the compressive forces across the SIJ and its role in assisting with load transfer between the lower extremities and the trunk.

Reduced activity and poor endurance of the Gmax muscle has been observed in patients with chronic LBPP as described in several case controlled cross-sectional (Hungerford et al 2003, Leinonen et al 2000, Kankaanpää et al 1998), experimental (Sharma et al 2012) and prospective repeated-measures studies (Ekstrom et al 2007). Most muscles with an antigravity stability function use their middle and inner ranges for that stability role (like the Gmax) and when muscles are habitually used or positioned in a lengthened position, they will become elongated and will lack force efficiency in their shortened/inner range positions ("stretch weakness") (Grimaldi 2011, Levangie and Norkin 2011, Ward et al 2010, Sahrmann 2002, Norris 1999, Sims 1999, Norris 1995, Kendall et al 1993, Richardson and Sims 1991, Williams and Goldspink 1978).

Gmax is susceptible to length-tension changes following its habitual use in an elongated position as with prolonged sitting. This is evident in cyclists who sustain a position of forward flexion for prolonged periods of time. Richardson and Sims (1991) investigated the length-tension relationship of Gmax in cyclists in a case-controlled cross-sectional study (n=29), and found that competitive road cyclists who habitually use their Gmax muscles in a lengthened position were unable to control/hold an inner range contraction of Gmax. In their study the mean inner range holding time in the normal population was 37.06 seconds compared to the 5.08 seconds mean holding time in competitive road cyclists.

An elongated, weak Gmax will generate insufficient tension in the lumbo-pelvic ligamentous system, which could lead to decreased force closure, excessive movement and therefore poor control around the pelvis, SIJ and hip joints (Takasaki et al 2009, Hossain and Nokes 2005, Hungerford et al 2003, Sahrmann 2002, Pool-Goudzwaard et al

1998). Frequent, excessive movement (such as increased lumbo-pelvic rotation) induced by a weak Gmax may result in hypermobility of the joints in the lumbo-pelvic region following the imbalance in the passive tension of the muscles affecting the area and result in micro-trauma and eventual macro-trauma of the spinal structures (Sahrmann 2012).

The gluteal muscles are prone to changes in recruitment sequence and several studies have consistently reported delayed activation of the gluteal muscles in individuals with LBPP (Sharma et al 2012, Takasaki et al 2009, Hungerford et al 2003, Comerford and Mottram 2001b, Nadler et al 2000). Delayed recruitment of Gmax is associated with an increase in the activation threshold of its SMU which in turn results in a decrease in the activation threshold of the FMU of the hamstring muscle group and earlier activation of the hamstrings (Jung et al 2013, Hungerford et al 2003) . Following on this, earlier activation of the hamstring muscle group to supplement decreased activity of Gmax, will lead to dominant use of the hamstrings which again could limit the opportunity to activate Gmax and consequently further weaken it (Jung et al 2013). Recruitment and sequencing of Gmax plays an important role in the functioning of the muscle, but is beyond the scope of this study. Both the Jung et al (2013) and the Hungerford et al (2003) were case-controlled cross-sectional studies with relative small sample sizes (n=31 and n=28 respectively).

Lower Gmax is a primary extensor of the hip (Neumann 2010) and weakness of this muscle will place an increased compensatory demand on the hamstrings, leading to overuse of the hamstring muscles (Chance-Larsen et al 2010, Sahrmann 2002, Lee 1996). As cyclists habitually use their Gmax in an elongated position, resulting in "stretch-weakness" of the muscle, it could be expected that they will place an increased demand on their hamstring muscles to compensate for the change in its length-tension relationship.

2.3.5.3 Hamstring muscle group

The hamstring muscle group is another group of muscles that are often subject to length-associated changes. The hamstrings have a global mobiliser function (active in knee flexion and hip extension) and are prone to shortening and over activity (Sahrmann 2002, Kendall et al 1993). The cycling action involves alternating flexion-extension movements of the hip and knee with the hip extension action mediated through the Gmax, hamstring muscle group, adductor magnus and adductor group as a whole at ranges of increased flexion (Neumann 2010). With the feet cleated into the pedals, cyclists use knee flexion more powerfully to increase power output and speed, thereby further increasing the demand on the hamstring muscle group (Silberman et al 2005, De Vey Mestdagh 1998).

The increased demand placed on the hamstring muscle group through the combined effects of a weak, elongated Gmax and the increased knee flexion moment created by the use of cleated pedals on the bicycle, will result in hypertrophy of the hamstring muscle group (Sahrmann 2012). Hypertrophy of muscle is associated with an increase in myosin. With the increase in myosin there is a six fold increase in titin/contractin which will lead to increased passive stiffness of the muscle. The imbalance in the relative passive stiffness of the hamstrings and that of the lumbo-pelvic musculature will induce an increase in movement in the lumbo-pelvic area and over time result in joint hypermobility. The frequent use of this increased joint range will over time lead to micro-trauma and eventual macro-trauma in the spinal structures (Sahrmann 2012). The evidence presented by Sahrmann (2012) is based on previous studies done by them and was presented at the 2012 International Federation of Physical Therapy conference in Quebec.

In the forward flexed position adopted by cyclists on the bicycle, a decrease in the extensibility of the hamstrings could prevent the anterior tilt needed for optimal positioning of the spine during cycling (Mellion 1994). Biceps femoris is connected to the ischial tuberosity and a lack of extensibility will restrict the anterior motion of the pelvis, leading to the maintenance of a more posteriorly tilted position and restriction of hip flexion range during forward bending which is typical of a cyclist's posture (Mellion 1994). To compensate for this and to maintain function, the lumbar spine will flex excessively, overstraining the extensor muscles of the spine (Sahrmann 2002). This in conjunction with poor control and stability from an elongated Gmax could result in uncontrolled movement of the lumbar spine in the direction of flexion. This direction specific hypermobility is reinforced during functional movements and will ultimately result in tissue pathology and pain if loaded repetitively (Sahrmann 2012, Sahrmann 2002, Hamilton and Richardson 1998).

Numerous studies have concluded that patients with a history of LBPP will have increased lumbar flexion during forward bending and stiffer hamstrings than those without LBPP (Sahrmann 2002, Hamilton and Richardson 1998). Muyor et al (2011b) investigated the influence of hamstring extensibility on spinal curvatures in 98 asymptomatic cyclists. They found that hamstring extensibility influence thoracic angle and pelvic position when performing maximal trunk flexion with the knees in extension (as for the sit-and-reach test). Hamstring extensibility did however not influence the spinal curvature in standing or on the bicycle with the hands in the drop position. The difference in hamstring length between cyclists with and without LBPP was investigated by Marsden (2009) and they observed a significantly impairment in the hamstring length of cyclists with LBPP compared to those without. An important exclusion in the Marsden's study is that the relationship between hamstring length and lumbar curvature was not investigated. The study by Marsden (2009) is a case-controlled cross-sectional study with a relatively small sample size (n=40) compared to the one by Muyor et al (2011b) where 98 asymptomatic cyclists participated, but the latter was not case-controlled (no symptomatic cyclists and hence no comparison between groups). No higher level evidence such as randomised controlled trials or systematic reviews on the relationship between hamsting length and LBPP and especially this relationship in cyclists could be found.

2.3.5.4 Control of movement into lumbar flexion

There are numerous ways to perform any specific task, which complicates defining normal/optimal movement. Comerford and Mottram (2012) defined optimal movement as the efficient execution of postural control tasks and functional activities in a way that creates the least amount of physiological stress. The coordinated interaction between the active, passive and neural control systems is essential for the controlled, optimal execution of movement.

Uncontrolled movement (UCM) is defined as inefficient active control of movement at a specific motion segment and in a specific direction (Comerford and Mottram 2012). Many researchers have shown that in clinical tests, people with LBPP have earlier movement of their lumbo-pelvic spine during active leg movement (Sahrmann 2012, Scholtes and Van Dillen 2007). With early lumbo-pelvic movement comes an increased frequency of movement at a specific region which places increased stress and strain on tissues resulting in pain (Scholtes et al 2009, Van Dillen et al 2005, Sahrmann 2002). This concept of uncontrolled movement creating cumulative micro-trauma through increased loading and resulting in neuromusculoskeletal pain, is becoming increasingly popular (Sahrmann 2012, Van Dillen et al 2005, Sahrmann 2002).

The very broad "diagnosis" of NSLBP has necessitated the development of a classification system for sub-groups of patients with NSLBP to enhance the effective management of this vast group (Dankaerts et al 2006, O'Sullivan 2005, Waddell 2005, McCarthy et al 2004, Petersen et al 2004, O'Sullivan 2000, Petersen et al 1999). Impaired control of movement is regarded as one of the main reasons for NSLBP (Reeves et al

2007, Moseley and Hodges 2006, Hodges and Moseley 2003). Based on this concept, O'Sullivan (2005) developed a mechanisms-based classification system for patients with NSLBP. With his classification system, patients present with either a movement impairment or a control impairment, with the latter more commonly observed in clinical practice (O'Sullivan 2005). Following this, O'Sullivan (2005) described the presentation of a control impairment as direction-dependant and sub-grouped them as:

- Flexion pattern
- Extension pattern (passive/active)
- Lateral shift control impairment
- Multi-directional control impairment

Of these groups, the flexion pattern group and active extension group seem most common in patients with NSLBP (Dankaerts et al 2009). The "flexion pattern" pain disorder is related to a flexion strain on the lower back and is characterised by LBPP which is reproduced by sustained or repeated lumbar flexion and eased by extension of the lumbar spine. It is further associated with a loss of lower lumbar lordosis and dysfunction of the spinal multifidus even though there is no loss of spinal mobility (Burnett et al 2004, O'Sullivan 2000). The "flexion pattern" is hypothesised to result from a loss of control of the neutral zone of the spinal motion segment followed by a repetitive strain of that spinal segment and tissues (i.e. ligaments, intervertebral discs, zygapophyseal joints and capsular structures) at the end of the lumbar flexion range (Van Hoof et al 2012, Burnett et al 2004, O'Sullivan et al 2003).

Control of lumbar movement in the direction of flexion is of particular interest in this study because of the biomechanics of cycling, the sustained forward flexed position of the cyclist on the bicycle and the nature of the sport. Observing cyclists in the prolonged forward flexion position on their bicycles almost immediately raises the question of their ability to control the lumbar flexion they sustain for long periods of time. Cyclists change their lumbar curve from a lordosis to a kyphosis when seated on the bicycle (Muyor et al 2011a, Usabiaga et al 1997). It is this sustained positioning in flexion which seems to contribute to the development of their LBPP (Burnett et al 2004).

Burnett et al (2004) propose that cyclists with LBPP commonly present with a lumbar flexion strain pain disorder resulting in a pattern of uncontrolled lumbar flexion. They reported that cyclists with LBPP have a tendency towards increased spinal flexion and rotation when compared to asymptomatic cyclists. This was confirmed by Van Hoof et al (2012) who found that cyclists with LBPP assume and sustain a position of greater lower lumber flexion compared to asymptomatic cyclists and that maintaining this increased flexion, significantly increased the LBPP during a two hour cycling field test. Cyclists also present with greater mean trunk flexion values during fast cycling compared to slower intensity cycling (Chapman et al 2008b).

With uncontrolled lumbar flexion there is inefficient active recruitment of the lumbar spinal muscles to prevent flexion of the lumbar spine (Comerford and Mottram 2012). Several factors may be contributing to the development of UCM (Comerford and Mottram 2012, Sahrmann 2002):

- Compensation for a restriction
- Direct overfacilitation
- Sustained passive postural holding
- Trauma

Of the various factors related to the development of uncontrolled movement only two are proposed to be applicable to the development of overuse injuries in cyclists:

- Compensation for a restriction

  UCM develops over time in compensation for a myofascial, neurodynamic or articular restriction with the aim of maintaining normal function. Restriction in movement develops gradually in response to various factors of which habitual positioning in a shortened position, overuse and protective responses are just some of them. This restriction in movement has to be compensated for in order to maintain function. The body compensates for the restriction by increasing movement elsewhere in the system. Compensation can be a normal adaptive process if there is still efficient active control. In the presence of inefficient active control, various structures will be subjected to cumulative micro-trauma and if this exceeds the tissue tolerance will result in the development of pain and pathology (stability dysfunction) (Sahrmann 2012, Sahrmann 2002). An example of this is the compensation by the inefficient back extensor muscles for a shortened hamstring restricting hip flexion in forward bending resulting in uncontrolled lumbar movement in the direction of flexion.

  Cyclists continuously sit with their hips in excessive flexion which ultimately leads to elongation of Gmax (one-joint stabiliser). A lengthened Gmax will have a reduced ability to shorten into a full inner range position and maintain that position for any length of time (Richardson and Sims 1991). Dysfunction in this one-joint stabiliser might lead to an increased threshold of the SMU to low load stimuli and cause a decrease in stimulation threshold in the two-joint hamstrings. In compensating for the elongated Gmax, hamstrings might become overloaded and possibly shorten (Sahrmann 2012). The shortened hamstrings may in turn restrict the range of hip flexion necessary for forward reach to the handlebars. This restriction might be compensated for by the relatively less stiff back extensors creating hyper-flexion of the spine, eventually resulting in uncontrolled movement in the direction of flexion (Comerford and Mottram 2012, Sahrmann 2002).

- Sustained passive postural holding

  Sahrmann (2002) propose that faulty/incorrect movement is not only the result of pain and pathology but can also create pain and pathology. Dysfunction in movement often develops as a result of sustained postures and habitual movements (Sahrmann 2002). Static loading/holding pain, overuse pathologies (which includes low load repetitive strain or high load/impact repetitive strain) and postural pain all have a component of movement dysfunction which contributes to pain.

  The passive process of habitually positioning and sustaining a joint or region in an end of range position can result in UCM. Over time a lengthening strain of the stabiliser muscles and passive positional shortening of the mobiliser muscles will develop. Adding gravity and body weight will result in a sustained, direction-specific loading mechanism. This is generally a passive insiduous process. Habitually sitting in a passive sustained slumped/flexed position will eventually result in uncontrolled lumbar flexion (Sahrmann 2002). This theory has been illustrated in the cycling population who assume and sustain a forward flexed position for hours when training or competing. Van Hoof et al (2012) found that cyclists with LBPP spend more than 38.5% of their total cycling time in an end of range position exceeding 80% of their total lumbo-pelvic flexion compared to the 4% found in asymptomatic cyclists. Cyclists will often also further reduce their frontal cross-sectional area by adopting an even more flexed posture in order to reduce their aerodynamic drag, which could further contribute to the development of UCM (Burnett et al 2004).

Control of movement is to some extent still a theoretical concept and poorly researched, hence the limited experimental evidence available. The majority of evidence is from text books (Comerford and Mottram 2012, Sahrmann 2002) with a small number of case reports (Van Dillen et al 2005), cross-sectional studies (Muyor et al 2011a, Scholtes and

Van Dillen 2007, O'Sullivan et al 2003) and case-controlled studies (Van Hoof et al 2012, Scholtes et al 2009, Burnett et al 2004, Richardson and Sims 1991) starting to build the evidence. No systematic reviews or randomised controlled trials exist for the assessment of the control of lumbar flexion.

2.3.5.5 Neural tissue provocation

During normal movement nerves move in relation to the tissues that surround them and undergo mechanical deformation (Kuilart et al 2005). Normal movement of the neural tissue depends on three main functions: (1) the ability to withstand tension, (2) be compressible and (3) slide in its container/sleeve (Ellis and Hing 2008, Shacklock 2005). Nerves were made to move, but the extent of their movement is directly related to the movement of the tissues which surround them. This is an important factor, especially in less mobile people where tight musculature and old scarring might impede the movement of the neural structures (Butler 2000). Nerves are very dependent on an uninterrupted blood supply which emphasises the importance of preventing ischaemia. This is however not done easily as ischaemia in neural tissue occurs in response to tension and compression. Elongation of 8% results in a reduction of blood flow through the peripheral nerve. All circulation in and around the nerve is obstructed at 15% elongation.

Intraneural tension is also closely related to time duration, with a longer duration of tension creating greater ischaemia and a longer recovery time (Shacklock 2005). When neural strain of 6% is maintained for an hour, a 70% reduction in nerve conduction occurs. This clearly portrays the increased likelihood of intra- and extraneural adverse events when the neural tissues are sustained in an elongated position (Davis et al 2008a, Kuilart et al 2005, Shacklock 2005). Elongation (tensioning) of the spinal neural structures (nerve roots and dural sleeve) also occurs with flexion of the spine (Cleland et al 2006). Considering the slumped position assumed and sustained by cyclists for the duration of their ride raises the question of possible adverse events occurring because of tension in the neural structures. Abnormal neural mechanosensitivity can also lead to a loss of extensibility in the mobility muscles which might in turn be implicated in the development of LBPP (Comerford and Mottram 2012). Tension of the nerve and nerve sleeve can therefore also produce symptoms and it is important to take these into account when considering the factors associated with LBPP in cyclists.

Limited data exists on the presence and implication of neural dynamics and hence most of the literature available is still from textbooks (Shacklock 2005, Butler 2000), which is generally regarded as having a lower level of evidence. Of the studies that have been done on the topic of neural dynamics, the majority were cross-sectional observational studies (Davis et al 2008b, Kuilart et al 2005). One pilot randomised controlled intervention study (Cleland et al 2006) was also located. Sample sizes varied from n=30 for the intervention study to n=42 (Kuilart et al 2005) and n=84 (Davis et al 2008b). No studies have been done on adverse neural mechanics in cyclists.

2.3.5.6 Bicycle set-up factors

Proper bicycle set-up is essential for injury prevention, safety, comfort and peak performance (Silberman et al 2005). Bicycle set-up plays an important role in the development and treatment of LBPP in cyclists (Mellion 1994). Some might argue that bicycle set-up is the most important factor involved in the development of pain and pathology. With cycling, the asymmetrical variables of the body have to adapt to the symmetrical design of the bicycle to function as one unit (Holmes et al 1994). Often abnormal stress loads are placed on tendons and muscles because of the conflict between a symmetric bicycle and an asymmetric human body. Optimal fitting of the bicycle to the rider's body geometry should result in less stress and strain on the body and decrease the incidence of injury (Wanich et al 2007, De Vey Mestdagh 1998, Holmes et al 1994).

Optimal cycling posture is dependent on two main variables: (1) posture height (saddle height, crank length, position of the cleats on the shoe, saddle setback) and (2) posture length (reach, handlebar level and handlebar width) (De Vey Mestdagh 1998). The cyclist has three contact points with the bicycle (saddle, handlebars and pedals), all of which play an important role in efficient alignment of the cyclist on the bicycle (Silberman et al 2005). Contact with these three points will determine the forward-backward and side-to-side position of the cyclist. The balance of the forward-backward and side-to-side position of the cyclist on the bicycle is critical for effective transmission of force to the pedals and optimal performance of the rider (Mellion 1994).

Bicycle set-up varies substantially according to the goal of the cyclist, whether it is to increase performance or to attain a more comfortable ride. In setting up the bicycle, there is therefore a continuous play-off between performance and comfort. The ultimate goal should however be the prevention of injury, above enhancement of performance (De Vey Mestdagh 1998). The individual aspects of bicycle set-up will be reviewed to understand the role each plays in the development of LBPP.

- **Saddle set-back**

Saddle set-back influences the cyclist's reach distance towards the handlebars and hence the position of the lower back and pelvis. A saddle positioned further back will position the cyclist in a more extended posture but will also elevate the saddle. Moving the saddle forward will not only shorten the reach to the handlebars but also lower the saddle height (Silberman et al 2005, De Vey Mestdagh 1998, Mellion 1994). Saddle set-back is measured by dropping a plumb line from the posterior aspect of the patella with the pedal positioned forward and parallel to the floor (3-o'clock position). The plumbline should fall directly through the pedal axle (Wanich et al 2007, Silberman et al 2005, De Vey Mestdagh 1998). This position will enable efficient functioning of the hip and knee flexors and extensors in a balanced relationship. A saddle positioned too far forward will increase the force needed by the quadriceps to extend the knee and lead to patellofemoral disorders while a saddle positioned too far backwards will reduce efficient functioning of the hamstrings, Gmax and gastrocnemius (De Vey Mestdagh 1998).

- **Saddle angle**

Saddle angle directly influences the angulation of the pelvis on the bicycle (Marsden and Schwellnus 2010, Salai et al 1999). Most of the studies on bicycle set-up recommend that the saddle should be level/parallel to the floor (Wanich et al 2007, Silberman et al 2005). Salai et al (1999) decreased the occurrence of back pain in a group of cyclists by tilting the saddle anteriorly by 10-15°. Following this, an anteriorly tilted saddle has been related to an increased anterior pelvic tilt and a decrease in tension on the ligaments of the lumbar spine (Marsden and Schwellnus 2010, Salai et al 1999).

- **Handlebar height**

Handlebar height is directly associated with upper body posture, which again influences the aerodynamics of the cycling position (De Vey Mestdagh 1998). This is influenced by the goal of the ride, either performance or recreation. Handle bars are generally set lower in competitive cyclists for a more aggressive aerodynamic position compared to a more relaxed upright position with increased comfort observed in recreational riders (Wanich et al 2007, Silberman et al 2005, De Vey Mestdagh 1998).

- **Reach**

Many problems experienced by cyclists are due to an incorrect posture length, mostly because of an incorrect reach distance (distance between the rear of the saddle and the transverse part of the handlebars) (De Vey Mestdagh 1998, Mellion 1994). Many studies have postulated that the reach distance should be shortened in cyclists presenting with LBPP so that the pelvis will go into a posterior tilt (Silberman et al 2005, Mellion 1994). De Vey Mestdagh (1998) disagreed with this and reasoned that lower back pain arises because of an insufficient reach distance.

He proposed that a short reach distance will cause the cyclist to be too bunched up in a position of thoracic and lumbar flexion with posterior pelvic tilt. In the bunched up position too much stress will be placed on the natural form of the lumbar and cervical spine, strain is placed on the surrounding tissues all which will lead to the development of lower back or neck pain. When the posture is too short, the arms will move into a more vertical position which will lead to "locking" of the upper limb making them absorb most of the shock, instead of providing supple support. The pelvis will be tilted backwards, the neutral curvature of the lumbar spine flattened (increased flexion) and more pressure will be placed on the intervertebral discs and posterior structures of the spine (De Vey Mestdagh 1998).

By increasing the reach distance, the pelvis will be positioned in a more anteriorly rotated position and the cyclist will be able to better maintain the neutral alignment of the spine (Sanner and O'Halloran 2000, De Vey Mestdagh 1998). A more extended cycling posture is therefore recommended as extension, rather than flexion, produces less of a strain on the lower back and enlarges the thorax for more efficient respiration (De Vey Mestdagh 1998).

- **Cleat position**

The shoe-cleat-pedal interface is the last point of contact of the cyclist's body with the bicycle and therefore important in the consideration of bicycle setup. The position of the cleats mostly influences the development of knee problems, but because of its direct impact on the set-back position of the saddle, it was included in this study (Silberman et al 2005). There is general consensus among bicycle fitters that the cleat should be positioned in line with the first metatarsal head (Silberman et al 2005, De Vey Mestdagh 1998) This optimises the use of the lever formed by the hind-foot and the mid-foot. If this preferred cleat position causes symptoms of compression of the digital nerves between the metatarsals, the cleats can be moved slightly backwards. The cleats should not be moved further forward as this could lead to the overstressing of the Achilles tendon and the gastrocnemius (De Vey Mestdagh 1998).

Many studies comment on the impact of “incorrect bicycle set-up” but only one study measured the association between bicycle set-up factors and the development of LBPP in cyclists. Marsden (2009) assessed various bicycle set-up factors which included saddle height, saddle angle, saddle set-back, forward reach and reach ratio. Of the factors assessed only reach ratio, which is the ratio between total reach (torso length plus arm length) divided by the reach distance from the saddle to the handlebars, was significantly related to LBPP. The implication and importance of reach ratio was not discussed in their study and hence the impact thereof cannot be established.

The evidence available on bicycle set-up is mostly descriptive in nature (Wanich et al 2007, Silberman et al 2005, Sanner and O'Halloran 2000, De Vey Mestdagh 1998, Mellion 1994) without any experimental support, except for the study done by Marsden (2009) which was a case-controlled cross-sectional study (n=40) and the study on seat angles and LBPP done by Salai et al (1999) which was an intervention study (n=80). The available evidence is general of a low standard and many of the statements on bicycle set-up have got no research supporting it.

2.3.6 Factors possibly influencing side-to-side shift on the bicycle

Side-to-side rocking (lateral pelvic tilt) occurs naturally during cycling, and is exaggerated at higher speeds (Farrell et al 2003). Chapman et al (2008a) reported that lateral tilt of the pelvis is the greatest movement that occurs during cycling. During slow intensity cycling lateral pelvic movement occurs towards the leg at its bottom dead centre (BDC) (when the pedal is in the 6 o’clock position at the bottom of the crank cycle), which increase with fast trials (Chapman et al 2008a). Increased lateral shift of the pelvis during the weight-shifting action of pedalling combined with an impairment of the lumbo-pelvic musculature in transferring loads between the trunk and the legs, could ultimately lead to the development of LBPP in cyclists. Both of these studies are observational cross-sectional studies with small sample sizes (n=9 and n=10 for Chapman et al (2008b) and Farrell et al (2003) respectively) which lowers the level of evidence, but was used as they were the only studies available that reflect on the side-to-side movement on the bicycle.

2.3.6.1 Control of load transfer across the lumbar spine and pelvis

One of the main functions of the lumbar spine and pelvis is to effectively transfer the loads generated by body weight and gravity during sitting, standing and walking (Snijders et al 1993). The efficacy of this load-transferral determines the effectiveness of function (Hungerford et al 2004). Load transfer between the trunk and the legs is mediated through the pelvic girdle (Lee 2005, Mens et al 1999). Effective load-transfer between the trunk and the legs and efficient control of movement are essential for the prevention of injury (Mottram and Comerford 2008, Mens et al 2001).

During weight bearing some movement also occurs at the sacroiliac joints (SIJ) and the pubic symphysis and therefore control of intrapelvic movement is also essential for effective load-transfer (Hungerford et al 2004). Load transfer through an unstable SI joint will cause excessive loading and strain on the surrounding tissues and eventually result in pain and pathology (Pool-Goudzwaard et al 1998).

Effective load transfer and stability of the pelvis is a dynamic process and depends on three main factors (Arumugam et al 2012, Roussel et al 2007, Hungerford et al 2004, Panjabi 1992):

- Optimal functioning of the ligaments, joints and bones (Passive system - form closure)
- Optimal functioning of muscles and fascia (Active system - force closure)
- Appropriate neuromuscular control

Following this model, form closure refers to the contribution of the bony anatomy of the sacro-iliac joints (SIJ) to resist shear forces whereas force closure refers to the dynamic contribution of the muscular system, augmented by ligaments and fascia. Neuromuscular control involves the involuntary activation of dynamic constraints to prepare for (feedforward) and/or respond to (feedback) loading or movement of joints. Through this system, joint stability is maintained and restored when under load (Arumugam et al 2012). Impairment in any of the three systems can be associated with pain dysfunctions in the lumbo-pelvic area (Arumugam et al 2012, O'Sullivan et al 2002).

Active stability through force closure is of particular interest for physiotherapists as it is, when needed, the most important point of intervention. Many muscles and ligaments play a role in force closure of the pelvis and SIJ. Three muscle slings have been proposed for increased force closure (Pool-Goudzwaard et al 1998). These consist of the:

- Longitudinal sling (multifidus – sacrum – deep thoracolumbar fascia – sacrotuberous ligament – long head of biceps) through (1) nutation of the sacrum increasing tension in the interosseus and short dorsal SI ligaments (sacral multifidus), (2) inflation of the thoracolumbar fascia through muscles and (3) increased tension in the sacrotuberous ligament (erector spinae and biceps femoris contractions).
- Posterior oblique sling (1) directly through contraction of latissimus dorsi and Gmax and (2) indirectly through tension in the sacrotuberous ligament (connections with latissimus dorsi, Gmax and thoracolumbar fascia)
- Anterior sling (external and internal obliques abdominal muscles and transversus abdominus) through connections to the rectus sheath.

Delays in onset of EMG activity has been observed in the Gmax, multifidus and internal oblique abdominus muscles for participants with SIJ pain during single leg stance (Jung et al 2013, Hungerford et al 2003). EMG activity in biceps femoris also occurred significantly earlier in those with SIJ pain compared to asymptomatic participants (Hungerford et al 2003). This reiterates the phenomenon observed in LBPP where with dysfunction there is a delay in activation of the stabilising muscles (local and global as with Gmax) with multi-joint mobiliser muscles (hamstrings) being activated earlier.

Childs et al (2003) hypothesised that a soft tissue or biomechanical dysfunction in the lumbo-pelvic area could manifest itself as a difference in side-to-side weight shift between the lower extremities, indicating inefficient load transfer. In their study, patients with LBPP presented with an increased side-to-side weight shift as compared to asymptomatic patients. Dysfunction in lumbo-pelvic motor control has also been proposed to result in impaired load transfer through the pelvis contributing to pain (O'Sullivan and Beales 2007b).

Load transfer and the ASLR test has been investigated relatively extensively with the majority of studies being case-controlled observational studies with small to acceptable sample sizes (n=21-200) (Jung et al 2013, Hungerford et al 2004, Childs et al 2003, Hungerford et al 2003, O'Sullivan et al 2002, Mens et al 2001). One systemtematic review (high level of eveidence) was also included in this section (Arumugam et al 2012).

2.3.6.2 Control of Gluteus Medius

Optimal load transfer is also dependant on efficient functioning of the lateral stabilising mechanism of the hip and pelvis (Grimaldi 2011). The lateral stabilising mechanism is made up of three different layers:

- Gluteus minimus (deepest layer)
- Gmed and piriformis (intermediate layer)
- Muscles influencing tension in the ilio-tibial band (ITB) – Gmax, TFL and vastus lateralis (superficial layer)

The gluteal muscles contributes to 70% of the abduction forces required to maintain the pelvis in a level position during single leg weight-bearing compared to the 30% provided by the muscles that increase tension in the ITB (Grimaldi 2011, Kummer 1993). The hip abductor muscles are primarily responsible for medio-lateral (frontal plane) stability in standing to maintain a level pelvis (Flack et al 2013, Semciw et al 2013, Osborne et al 2012, Reiman et al 2012, Grimaldi 2011, O'Dwyer et al 2011, O'Sullivan et al 2010b, Ward et al 2010, Willson et al 2005, Mascal et al 2003). Gmed structurally comprises of three different parts: anterior, middle and posterior Gmed. While anterior and middle Gmed is proposed to be mainly responsible for abduction of the hip, with the anterior Gmed also doing internal rotation of the hip, the posterior Gmed actively abducts, extends and laterally rotates the hip, thereby stabilising the head of the femur in the acetabulum and initiating load transfer (Flack et al 2013, Semciw et al 2013, Hoffmann and Pfirrmann 2012, Reiman et al 2012, O'Sullivan et al 2010b).

The external rotators of the hip (piriformis, posterior Gmed, anterior fibres of Gmax) reverse their horizontal plane actions with greater hip flexion and become internal rotators of the hip, especially at angles greater than 60° (Neumann 2010). Hip flexion is one of the strongest actions during cycling and as the hip approaches the top dead centre (TDC) (12 o'clock position during the pedalling action while cycling), the hip flexion angle also greatly increases. This increase in hip flexion is associated with a strong increase in the hip internal rotation moment (Neumann 2010). Hoffman et al (2011) investigated the effect of hip internal rotation on lumbo-pelvic rotation and observed that women moved through 16° of hip internal rotation before the onset of lumbo-pelvic rotation, compared to 5.4° used by men. With the early onset of lumbo-pelvic rotation with hip internal rotation and the increase in hip internal rotation with greater ranges of hip flexion, the resultant increased lumbo-pelvic rotation during cycling, combined with the frequent use of this movement, will eventually lead to micro- and macro-damage of the lumbo-pelvic structures (Sahrmann 2012). Weakness of Gmed has also been associated with increased hip adduction (Osborne et al 2012, Bolgla et al 2008, Piva et al 2005, Mascal et al 2003) which will further contribute to the increased lumbo-pelvic rotation and subsequent pathology.

Weakness of Gmed has been noted in individuals with low back pain (Reiman et al 2012, Ekstrom et al 2007, Nadler et al 2002). This weakness could lead to an increased side-to-side/lateral shift of the pelvis in cyclists with a subsequent loss of pelvic control (Preininger et al 2011). Poor endurance of the muscle could also result in early onset pelvic rotation as compensation (Lee and Powers 2013) and, combined with frequent movement in the increased range, result in joint hypermobility leading to micro-damage and eventual macro-damage of the lumbo-pelvic structures (Sahrmann 2012). Weakness in Gmed could also (i) place an increased load on the lateral structures in the lumbo-pelvic area (including the lumbar facet joints, the SI-joints and soft tissues situated laterally in the area) (ii) demand increased activity from the lateral trunk stabilisers (like Quadratus Lumborum) to stabilise the pelvis and thereby possibly contribute to LBPP (Nadler et al 2002).
“Stretch weakness” can occur in the hip abductors due to poor postural habits. This includes habitual standing postures in which the hip is positioned in hip adduction (“hanging on one hip”), sitting cross-legged with the hips in adduction and sleeping in side-lying with the hip positioned in flexion and adduction (Grimaldi 2011, Presswood et al 2008). Habitual adduction of the hip with the pedalling action in cycling could therefore also lead to elongation and weakness in Gmed. Weakness in Gmed could therefore be the result of habitual unwanted hip adduction or lateral pelvic movement but if weak could also induce the increase in hip adduction or lateral shift of the pelvis. Delayed recruitment of the Gmed has also been demonstrated widely (Hungerford et al 2003, Nadler et al 2000), but is beyond the scope of this study.

The literature available on the function of Gmed ranges from low (case report by Mascal et al (2003)) to very good (systematic review by Reiman et al (2012)). The majority of studies were cross-sectional observation studies with sample sizes ranging from 2-102 (Flack et al 2013, Lee and Powers 2013, Semciw et al 2013, O'Dwyer et al 2011, Preininger et al 2011, O'Sullivan et al 2010b). One intervention study (Osborne et al 2012) and one case-controlled study (Bolgla et al 2008) were included as well as numerous descriptive studies (Hoffmann and Pfirrmann 2012, Grimaldi 2011, Neumann 2010, Ward et al 2010, Presswood et al 2008).

In the cyclist, effective load transfer also involves optimal leg-length and correct bicycle set-up. Asymmetry in the lengths of the legs might affect efficient load transfer and could result in a lateral shift on the bicycle with subsequent weakness of Gmed and poor control of movement.

2.3.6.3 Leg length discrepancy

Leg length discrepancy (LLD) is defined as a condition where paired lower extremities are noticeably unequal (Gurney 2002). A big variance in prevalence (4-95%) has been reported because of poor agreement on what constitutes significant LLD (Brady et al 2003). The 3-12.5mm discrepancy in leg-lengths in the normal population, observed in the studies reviewed by Brady et al (2003), resulted in them proposing that a big part of the population is intuitively likely to have a minor difference in leg-length while only a small part of the population is likely to have a big LLD.

Leg-length discrepancy can be subdivided into two different groups: a structural or anatomic LLD (SLLD) and a functional or apparent LLD (FLLD). SLLD is defined as a shortening of the bony structures whereas with a FLLD there is no shortening of bone. FLLD is reported to be a result of asymmetric neurophysiological changes along the kinetic chain, like faulty foot mechanics (ankle pronation), pelvic rotation, muscle tightness (or weakness) or joint tightness in any joint in the lower extremity or spine (Woodfield et al 2011, Brady et al 2003, Gurney 2002, McCaw and Bates 1991).

Brady et al (2003) discussed a measuring classification system developed by Reid and Smith (1984) for categorizing LLD in which 0-30mm discrepancy is considered mild, a 30-60mm discrepancy is considered moderate and a discrepancy of more than 60mm is considered severe. There seems to be a general consensus that a LLD of more than 20 mm will have a significant impact on the development of various musculoskeletal pathologies like gait anomalies and spinal deformities (Woodfield et al 2011, Brêtas et al 2009, Defrin et al 2005, Gurney 2002).

Leg-length discrepancy has been implicated in various disorders including LBPP, pelvic and sacral mal-alignment, scoliosis, osteoarthritis and many other lower extremity disorders (Defrin et al 2005, Brady et al 2003, Krawiec et al 2003, Gurney 2002, McCaw and Bates 1991). Controversy still exists around the impact of LLD. Many authors have investigated the relationship between LLD and LBPP but no association has been unequivocally established (Brady et al 2003). Defrin et al (2005) hypothesised that LLD resulted in a derangement of the normal biomechanical function of the spine and pelvis because of increased stress and strain caused by asymmetries in the lower limbs, spine and pelvis. Pelvic asymmetry has also been associated with LLD because of innominate rotation in adaptation for the LLD (Krawiec et al 2003). LLD correlated well with pelvic tilt which could lead to scoliosis, but could also result in SI-malalignment and innominate rotation, thereby negatively affecting the SIJ. Innominate rotation can also lead to asymmetrical loading of the SIJ and hence poor movement strategies and poor load transfer through the pelvis (Defrin et al 2005, Gurney 2002).

Even though controversy exists around the impact of LLD, individuals who are involved in sport seem consistently more affected by LLD than others (Gurney 2002). LLD that could be tolerable during normal daily activities, including gait, can become problematic with cycling because of the fixed position the cyclist assumes as well as the high number of repetitive crank cycles the cyclist performs per minute whilst cycling (Burke and Pruitt 2003). Silberman et al (2005) proposed that a LLD of more than 6 mm is of significance in cyclists with a detrimental effect on comfort, power output and prevention of overuse injuries while riding.

Leg-length discrepancy has also been associated with an increased side-to-side shift of the pelvis during the cycling action (Mellion 1994). It is proposed that the increased side-to-side shift will adversely affect optimal load transfer through the pelvis which could further lead to the development of lower back or pelvic pain (Childs et al 2003). This asymmetry in movement could increase the stress and strain in the pelvis and back, thereby increasing the workload exerted on various structures in the back region (muscles, ligaments, joint capsules) as well as the joints and discs. These changes could eventually lead to changes in the lumbar spine which includes facet joint degeneration, asymmetric facet joint angles, disc compression, traction spurs etc. (Defrin et al 2005). Leg-length discrepancy has also been identified as a risk factor for the development of sacroiliac joint pain as described by Cohen (2005) and Gurney (2002). The mechanism could be increased innominate rotation and asymmetrical loading of the SIJ combined with numerous repetitions of this action during the cycling mechanism (Gurney 2002).

The literature available on LLD varies from literature review studies (Brady et al 2003, Gurney 2002), observational studies (Krawiec et al 2003) and reliability studies (Woodfield et al 2011, Brêtas et al 2009) to randomised controlled intervention studies (Defrin et al 2005) with a higher level of evidence. Sample sizes varied from 35-50. No systematic reviews or randomised controlled trials with larger sample sizes could be located.

2.3.6.4 Bicycle set-up factors

Wanich et al (2007) and De Vey Mestdagh (1998) proposed that proper seat height and position may be the most important factors in bicycle set-up and in the prevention of LBPP in cyclists.

- **Saddle height**

The height of the saddle has a profound effect on the length-strength relationship of muscles. If the saddle is too high and the knee extends fully when the pedal is at the BDC position, the knee flexors (hamstrings and gastrocnemius) will not function to their full capacity and locking of the knee joint might occur. Rocking of the pelvis over the saddle (lateral shift) will also occur which could lead to the development of lower back pain. If the saddle is too low, the knee and hip extenders will be disadvantaged (quadriceps and Gmax) and the increased force needed from the quadriceps might lead to the development of patella-femoral problems (Wanich et al 2007, De Vey Mestdagh 1998). Even though a saddle positioned higher will result in better power output, a lower positioned saddle is generally recommended for power output over a longer period (De Vey Mestdagh 1998). A knee flexion angle of 25° to 30 ° with the leg in the bottom dead position (BDP) (6-o'clock position) is widely recommended for optimal performance and injury prevention (Silberman et al 2005, De Vey Mestdagh 1998). Peveler et al (2005) recommended relaxing that range to 25-35° for greater prevention of overuse injuries.

2.4 Conclusion

The available evidence for the prevalence and development of LBPP in cyclists has been discussed in this chapter. It must be noted that the evidence is limited and does not provide any conclusive evidence to support a link between LBPP and many of the aspects reviewed. The findings in this study may support or refute some of the claims made while seeking to understand the origins of LBPP in cyclists. The measuring instruments used in this study will be discussed and justified in Chapter 3.

CHAPTER 3: JUSTIFICATION OF MEASURING INSTRUMENTS

3.1 Introduction

The aim of this chapter is to describe the validity and reliability of the various measuring instruments used in this study. The measuring instruments/techniques will be reviewed and discussed as follows: Prevalence and training factors, intrinsic physical factors and bicycle set-up factors.

3.2 Prevalence and training factors

A questionnaire (see Appendix 6) was developed to obtain information on demographics, training characteristics as well as the prevalence and characteristics of LBPP. The questionnaire was based on validated questionnaires developed by Wilber et al (1995), Schultz and Gordon (2010) and Burger (2012). Wilber et al (1995) and Schultz and Gordon (2010) investigated the demographics, training characteristics and prevalence of LBPP in cyclists. Schulz and Gordon (2010) added some aspects of the behaviour of low back pain to the questionnaire initially developed by Wilber et al (1995). The study done by Burger (2012) was on a work-related low back pain population and some of the low back pain behavioural questions used in this questionnaire were adapted from there. The questionnaires developed by Wilber et al (1995), Schulz and Gordon (2010) and Burger (2012) included the following:

- Demographics: such as age, gender and smoking history
- Cycling history: which included the following aspects:
    - Number of years cycled
    - Number of hours cycled per week
    - How many days cycled per week
    - Average cycling pace
    - Type of terrain cycled
    - Number of cycling events participated in per year
    - Estimate of the percentage time spent cycling in different riding positions such as in an upright position, in the drops position, on the brake levers or on the aero bars
- Presence of LBPP generally
- Presence of LBPP during or after cycling

- Behaviour of the pain: the timing, number of incidences in the last five years, location of the pain, investigations (X-rays, magnetic resonance imaging (MRI), ultrasound scans etc.), referral of the pain, riding position that elicited the pain and the impact of the pain on cycling (training/competing)
- Female participants were asked to report on the relationship between LBPP and their menstrual cycle, the number of children they have and when they had their last pregnancy.

The following questions were added to those used from the questionnaires developed by Wilber et al (1995), Schultz and Gordon (2010) and Burger (2012):

- In order to ensure that only cyclists eligible for participation in this study completed the questionnaire, which was made available online, a question stating the criteria of the study was added which included:
    - Cyclists must be 18 years or older
    - Cycling more than 3 hours but less than 12 hours per week
    - Previous participation in at least one race of more than 90km
    - Cycling with cleats
    - Participation in less than 20 races per year
    - Use of a road/racing bicycle when training or competing in races
    - Had been cycling for more than one year
    - No history of traumatic injury to the spine in the past two years
    - No low back pain with a specific or known structural pathology (e.g. spondylolisthesis)
    - No previous spinal surgery

  These conditions were excluded because any trauma or serious pathology involving the spine could cause LBPP. Surgery may also change the normal biomechanics of the spine or result in scarring that may lead to the development of pain and dysfunction.
- A question on work-related activities and positions was included in an attempt to identify if any cyclists spent the majority of their working day in a flexed position which might predispose them for the development of LBPP
- The pedalling technique used (high cadence, low cadence, big gears, small gears) as it changes the amount of effort needed to propel the bicycle which increases the demand on the stabilising muscles to stabilise the lower back and pelvis on the bicycle.

The study was aimed at the competitive cyclist with some experience and all novice and elite cyclists were excluded, based on the time spent cycling per week as well as the number of races done per year. Novice cyclists were excluded on the basis that the pain and discomfort experienced by them might be due to under training or poor conditioning prior to racing. All previous studies have focused on professional/elite cyclists and as these are a small percentage of the cycling population in South Africa, it was decided to focus on the competitive cyclists.

The questionnaire used in this study was piloted on 12 cyclists (three of whom were experienced physiotherapists and biokineticists) for clarity and appropriateness of the individual questions to establish the validity of the questionnaire. They were asked to comment on the questionnaire and complete a feedback form depicting their suggestions. Small changes were made such as adding pictures illustrating the handlebar positions and the locations of the pain, but the overall content was satisfactory and acceptable (see Appendix 6).

3.3 Intrinsic physical factors

3.3.1 Height, weight and Body Mass Index

In this study body weight was measured with a digital electronic scale in kilograms (kg) (Carmen Care) and standing height was measured with a portable stadiometer (HS, Scales 2000) in meters (m).

Body Mass Index is an expression of the proportion of body weight-to-height and is supposed to reflect excess adiposity in individuals (Romero-Corral et al 2008, WHO 2006). Body mass index was calculated according to the standard formula of body weight in kg divided by the square of the height in m^2 (kg/m^2) (Romero-Corral et al 2008). Although BMI is fairly accurate, its greatest shortcoming is the inability to distinguish between lean mass and fat mass, especially at a BMI of less than 30 kg/m^2 (Okorodudu et al 2010, Mei et al 2002, Gallagher et al 2000). Body mass index scores are also influenced by sex, age and ethnicity. Gallager et al (2000) observed that older men had higher fat percentages influencing their BMI and that the Asian population had a greater body fat percentage for any given BMI compared to African Americans and Whites.

Romero-Corral et al (2008) reported a sensitivity of 83% and specificity of 76% for BMI to detect body fat percentage at a BMI cut-off of 25.5 kg/m^2 (men: sensitivity 78%, specificity 70%; women: sensitivity 85%, specificity 88%). A lower sensitivity (0.50) but higher specificity (0.90) was reported by Okorodudu et al (2010). The classification of BMI is illustrated in Table 3.1 (WHO 2006, Gallagher et al 2000).

Table 3.1 BMI classification

BMI classification	Status
Underweight	Under 18.5 kg/m^2
Normal	18.5-24.9 kg/m^2
Overweight	25.0-29.9 kg/m^2
Obese	Over 30 kg/m^2

3.3.2 Lumbar position on the bicycle

Various methods are used to measure lumbar movement and posture (Tyson 2003) and X-rays are still seen as the “gold standard” assessment tool. They are however relatively expensive, pose a low risk for radiation and are not readily available to clinicians during a routine clinical assessment of patients (De Carvalho et al 2010, Littlewood and May 2007, Norton et al 2004, Tyson 2003, Ng et al 2001). External measurements of spinal posture and ROM are frequently used in clinical practice because they are inexpensive and easy to apply and provide valuable information relating to lumbar posture and movement. External methods include observation, the fingertips-to-floor method (tape measurement), the Schöber, modified Schöber and modified-modified Schöber method (skin distraction method), flexible curve lineals, goniometry (electrical, electromagnetic, mechanical), the inclinometer (electrical and mechanical) and various computerised and photographic measurement systems (Muyor et al 2011a, Littlewood and May 2007, Norton et al 2004, Tyson 2003, Lee et al 2002, Ng et al 2001, Burdett et al 1986).

Studies on lumbar curvature and kinematics in cyclists have mostly employed photographic measuring systems which involved reflective markers with anything from 2-12 cameras or two-dimensional video analysis systems (Chapman et al 2008a, Diefenthaeler et al 2008, Sauer et al 2007) or computerised measurement systems such as the “spinal mouse system” (Muyor et al 2011a), the 3-space Fastrack electromagnetic tracking device (Burnett et al 2004) or the “Body Guard” spinal position monitoring system (Van Hoof et al 2012). Changes in lumbar spine position have also been evaluated during different cycling positions in three professional cyclists with X-rays, using the upper level of S1 and the upper level of L1 as reference points (Usabiaga et al 1997). Schulz and Gordon (2010) assessed the lumbar spine angle in 13 recreational cyclists and three different riding positions (upright, on-the-brakes and on-the-drops positions) with the use of a single digital inclinometer (recordings at S2 and T12/L1). They reported excellent intra-rater reliability for lumbar spine angle measurement with an inclinometer (ICC of 0.97).

A single digital inclinometer was used in this study to measure lumbar curvature, as it:

- measures regional movement of the spine without including movement of the hip, whole spine or pelvis as seen with the various Schöber methods and the fingertip-to-floor method (Lee 2002, Ng et al 2001)
- is less affected by movement of the skin compared to the various Schöber techniques (Lee 2002, Ng et al 2001)
- is more accessible, simpler to use and less expensive than computerised or photographic measuring systems (Norton et al 2004, Lee 2002, Ng et al 2001)
- is not influenced by the presence of metal as with the electro-magnetic methods, which was important as the measurements were taken with the cyclist on the bicycle (Lee 2002)

Various studies have reported the non-invasive inclinometer technique to be both reliable and valid (MacIntyre et al 2013, MacIntyre et al 2011, Norton et al 2004, Lee 2002, Ng et al 2001, Saur et al 1996, Mellin 1986). These studies reported intrarater correlation coefficients (ICC) and Pearson's (r) correlation coefficients ranging from 0.73 -0.99. The ICC and reliability coefficients for the measurement of static lumbar position and lumbo-sacral angle with a single digital inclinometer have been reported to range from 0.91 to 0.97 for intra-rater reliability (MacIntyre et al 2013, MacIntyre et al 2011, Schulz and Gordon 2010) and 063-0.75 for inter-rater reliability (MacIntyre et al 2011, Sullivan et al 2000). Criterion validity of pendulum inclinometer measurements for lumber ROM were demonstrated by comparison with X-ray measurements and showed a high correlation (r=0.73-0.98) (Tyson 2003, Lee et al 2002, Saur et al 1996, Burdett et al 1986, Mayer et al 1984). No studies could be located which investigated the correlation between digital inclinometry and X-ray measurements.

Different types of inclinometers (digital inclinometers, gravity inclinometers, bubble inclinometers) and methods of measurement (double and single inclinometer methods) are used to assess lumbar curvature (MacIntyre et al 2013, MacIntyre et al 2011, Schulz and Gordon 2010, Tyson 2003, Ng et al 2001, Saur et al 1996, Keeley et al 1986).

Measurements with an inclinometer involve making skin markings at the T12/L1 and L5/S1 interspinous spaces. With the single inclinometer method, the inclinometer is placed on the T12/L1 and L5/S1 interspinous spaces respectively with a reading taken at each of these positions. The lumbo-sacral measurement (L5/S1) is then deducted from the thoraco-lumbar measurement (T12/L1) to determine the lumbar position (MacIntyre et al 2011, Tyson 2003, Ng et al 2002, Ng et al 2001, Saur et al 1996, Portek et al 1983). A single digital Saunders inclinometer (Saunders Group) was used in this study to measure lumbar curvature according to the technique described in the preceding section.

3.3.3 Muscular control of lumbo-pelvic stability

Optimal functioning of lower extremity muscles, such as Gmax, Gmed and the hamstring muscle group, is important for optimal lumbo-pelvic stabililty as they play an important role in the transferral of forces from the lower extremities to the spine and could have an influence on the development of low back or pelvic pain (Antonio et al 2013, Barker et al 2013, Kang et al 2013, Reiman et al 2012, Sharma et al 2012, Nadler et al 2002, Nadler et al 2001, Nadler et al 2000).

3.3.3.1 Inner range control of Gluteus Maximus

Various methods have been described in the literature to assess the functioning of Gmax. These include:

- EMG to assess the activity of Gmax during functional activities, like walking, as well as the pattern of activation of Gmax as a measure of its function (Chance-Larsen et al 2010, Takasaki et al 2009, Hungerford et al 2003, Bullock-Saxton et al 1993)
- the prone hip extension (PHE) test to assess:
    i. muscle recruitment patterns for activation of the Gmax (Kang et al 2013, Chance-Larsen et al 2010, Lewis and Sahrmann 2009, Sakamoto et al 2009, Bruno et al 2008, Bruno and Bagust 2007, Lehman et al 2004, Hungerford et al 2003, Vogt and Banzer 1997)
    ii. the holding capacity of Gmax in its inner range (Norris 1999, Sims 1999, Richardson and Sims 1991). Richardson and Sims (1991) assessed the inner range holding capacity of Gmax in cyclists during hip extension (from relative flexion into inner range extension) in the prone, trunk support only, position, keeping the knee in flexion.
    iii. maximal voluntary contraction (MVC) using dynamometry (Thorborg et al 2010, Takasaki et al 2009, Pua et al 2008, Piva et al 2005)

iv. motor control of the lumbar spine (Murphy et al 2006) while mostly keeping the knee in extension.

- magnetic resonance imaging (MRI) to assess the cross sectional area of Gmed in relation to hip joint pathologies (Grimaldi et al 2009)
- a MCD test in the prone trunk support only position assessing concentric shortening of the muscle, isometric inner range holding and eccentric lowering while controlling movement of the lumbar spine and pelvis (Comerford et al 2007).

In this study a combination of the test procedures of the hip extension with knee flexion test in prone, trunk support only, as described by Richardson and Sims (1991) and Comerford and Mottram (2007) was used to measure the function of Gmax. Richardson and Sims (1991) used various instruments, like a rod positioned to mark the inner range hip extension position and two pressure biofeedback units (PBU) to control for lumbo-pelvic movement, in order to improve the objective measurement of the inner range holding capacity of Gmax. In their study they measured maximal holding time in cyclists and non-cyclists to illustrate the relative inner range weakness of a muscle mostly used in its elongated position. Comerford et al (2007) proposed two repetitions of 15 second holds to assess for normal Gmax inner range holding while visually assessing for control of the lumbar spine throughout the movement. A combination of these tests was included in order to:

- include objective measures to control for compensatory movements of the lumbar spine and pelvis as well as the inner range holding position for Gmax (positioning of a rod at the back of the thigh and of the pressure biofeedback units for lower back/pelvis movement) (Richardson and Sims 1991),
- assess all three aspects of the muscle's functioning (concentric shortening, isometric holding in inner range and eccentric lowering) (Comerford et al 2007) and
- assess the stabilising role of Gmax compared to (1) a pure strength test as done with the use of a dynamometer or (2) test for recruitment as done with EMG studies (Kang et al 2013, Chance-Larsen et al 2010, Lewis and Sahrmann 2009, Sakamoto et al 2009, Takasaki et al 2009, Bruno et al 2008, Bruno and Bagust 2007, Bullock-Saxton et al 1993).

Reliability studies have been done on the use of a dynamometer in determining the strength of Gmax during prone hip extension (Stark et al 2011, Thorborg et al 2010, Pua et al 2008, Scott et al 2004, Bohannon 1986) and on the muscle recruitment patterns with

PHE (Azevedo et al 2013, Murphy et al 2006). Reliability of κ=0.72-0.76 and ICC of 0.69-0.85 has been described for assessing lumbar movement during the PHE test (Azevedo et al 2013, Murphy et al 2006), but no studies commented on repeatability of the inner range holding capacity for hip extension. As far as could be determined, no reliability or validity studies are available for assessing both control through range and inner range strength of Gmax with the prone, trunk support only, hip extension test while keeping the knee in flexion.

3.3.3.2 Hamstrings extensibility

Four common methods of measuring hamstring muscle extensibility have been described in the literature and these are the passive straight leg raise (PSLR), knee extension angle (KEA), sit-and-reach (SR) and the sacral angle (SA) tests (Davis et al 2008b, Gajdosik et al 1993).

The KEA test has been proposed as the gold standard for measuring hamstring muscle extensibility (Davis et al 2008b) and was used in this study as it:

- has been shown to have significantly less pelvic rotation when compared to the SLR test (Davis et al 2008b, Bohannon et al 1985, Bohannon 1982)
- does not involve any anthropometric factors (length of arms, trunk, legs) which can influence the measured ROM as in the SR and SA tests (Davis et al 2008b)
- excludes the influence of neural tension compared to the SLR, SA and SR tests where resistance to elongation of the nerve/mechanosensitivity might influence the measurement (Davis et al 2008b, Gajdosik et al 1993, Gajdosik and Lusin 1983)
- does not stretch the hip joint capsule and is not influenced by contralateral hip flexor tightness as evident in the PSLR test (Davis et al 2008b, Gajdosik et al 1993)
- limits the contribution of lumbar spine range of motion as the pelvis is stabilised on the plinth in the dissociated position and no lumbar flexion occurs as in the forward reach during the SR and SA tests (Davis et al 2008b).
- has a more objectively repeatable point of hamstring length measurement (maximal knee extension) compared to the AKEA test and measures maximal elongation of the hamstring muscle (Gajdosik et al 1993).

The KEA is measured using either an universal goniometer or an inclinometer. Both the inclinometer and the universal goniometer have been found to be reliable in measuring knee flexion and extension with the inclinometer showing better reliability (goniometer:

intrarater reliability ICC=0.91-0.97, interrater ICC=0.63-0.96; inclinometer: intrarater ICC=0.95-0.98, interrater ICC=0.98) (Dos Santos et al 2012, Borman et al 2011, Mayer et al 1997, Rothstein et al 1983). This is believed to be due to the ease of use of the inclinometer and that there is no need to align anatomic references to specific segments (Dos Santos et al 2012). A KEA of more than 20° is regarded a positive test for decreased hamstring muscle extensibility (Davis et al 2008b). Two methods are used in identifying the KEA, the active knee extension (AKE) test and the passive knee extension (PKE) test. Both tests have demonstrated good reliability in the literature. Ford et al (2005) and Davis et al (2008b) reported excellent intrarater reliability for the PKE test (ICC of 0.98, n=12 and 0.94 respectively, n=10) using a universal goniometer and inclinometer. Kuszewski et al (2009) and Youdas et al (2005) also demonstrated excellent reliability (ICC >0.90, n=30 and ICC of 0.97 for the right leg and 0.98 for the left leg respectively, n=43) while using an inclinometer. Gajdosik et al (1993) reported an ICC of 0.86 for the AKE test and 0.90 for the PKE test. Gabbe et al (2004) reported excellent inter-rater reliability for the AKE test (ICC =0.93, n=15) (bubble inclinometer), confirmed by Kuilart et al (2005) (ICC 0.99, n=42, goniometer and digital photography), Gajdosik and Lusin (1983) (r=0.99) and Sullivan et al (1992). The latter demonstrated an ICC of 0.99 (n=12) for the AKE test using a digital inclinometer. An interrater reliability of ICC=0.93 was reported by Gnat et al (2010) for the PKE test using a goniometer (n=30).

Davis et al (2008b) reported poor to fair concurrent validity for the KEA, PSLR, SA and SR tests with correlations with the KEA test as follows: PSLR (κ=0.36, r=0.63, R^2=0.40), SR (κ=0.42, r=0.57, R^2=0.33) and SA (r=0.45, R^2=0.20). They hypothesised that the differences in testing positions (supine vs. sitting), neural tension and pelvic and lumbar movement might be the reason for this.

Most of the studies using the PKE test measured terminal (maximal) knee extension where the patient reported a strong but tolerable stretch sensation (Gnat et al 2010, Kuszewski et al 2009, Davis et al 2008b, Youdas et al 2005, Gajdosik et al 1993) compared to the point of onset of tension generally used in the AKE test (Kuilart et al 2005, Norris and Matthews 2005). For the PKE test, the examiner moved the lower leg into knee extension until a firm end point was identified and it was thought that the PKE test was therefore more objective and repeatable (Gajdosik et al 1993).

The PKE test was used in this study because of the reasons mentioned above and as it has been reported to have a more objectively repeatable point of hamstring length measurement (maximal knee extension), measuring maximal elongation of the hamstring muscle (Gajdosik et al 1993).

3.3.3.3 Through range control of gluteus medius

Gmed function has mostly been investigated through:

i. EMG studies assessing its activation and recruitment (Semciw et al 2013, Reiman et al 2012, O'Dwyer et al 2011, O'Sullivan et al 2010b, Distefano et al 2009, Marshall et al 2009, Nelson-Wong et al 2009, Souza and Powers 2009, Nelson-Wong et al 2008) and
ii. muscle strength testing (Lee and Powers 2013, Rabin et al 2013, Osborne et al 2012, Davis et al 2011, McMoreland et al 2011, O'Dwyer et al 2011, Marshall et al 2009, Nelson-Wong et al 2009, Bolgla et al 2008, Presswood et al 2008, Laheru et al 2007, Niemuth 2007, Piva et al 2005, Scott et al 2004, Ireland et al 2003, Nadler et al 2002, Nadler et al 2000, Norris 1999, Sims 1999).

The strength of Gmed has been tested in a variety of different ways, each inherently addressing a different aspect of the muscle’s function. The majority of studies measured the strength of Gmed by resisting hip abduction in supine or side lying either with manual muscle testing (Semciw et al 2013, Marshall et al 2009, Ekstrom et al 2007, Niemuth 2007) or with the use of a dynamometer (Lee and Powers 2013, Osborne et al 2012, Grimaldi 2011, McMoreland et al 2011, O'Dwyer et al 2011, O'Sullivan et al 2010b, Thorborg et al 2010, Souza and Powers 2009, Bolgla et al 2008, Pua et al 2008, Youdas et al 2008, Laheru et al 2007, Robinson and Nee 2007, DiMattia et al 2005, Piva et al 2005, Ireland et al 2003, Mascal et al 2003, Nadler et al 2002, Nadler et al 2000). This gives an indication of the MVC of the muscle, but does not reflect anything about the ability of Gmed to control the movement (Grimaldi 2011). MVC also does not reflect on the ability of a muscle to:

- Concentrically shorten to produce the range of motion (‘mobility function’)
- Eccentrically hold the position (‘postural control function’)
- Eccentrically lengthen to lower the leg, resisting the pull of gravity (“stability function’) (Comerford and Mottram 2001a).

Different variations of the side lying active hip abduction (AHAbd) test have been described for assessing the through range stabilising and inner range holding capacity of

Gmed through observation of the compensatory movements of the tested leg, lumbar spine and pelvis in the frontal plane (no associated loss into hip flexion or pelvic rotation) (Rabin et al 2013, Comerford and Mottram 2012, Davis et al 2011, Nelson-Wong et al 2009, Comerford et al 2007, Sahrmann 2002, Norris 1999, Sims 1999, Norris 1995). Several other studies reported observing for pelvic movement in assessing strength of Gmed, but did not judge the test according to the observed pelvic control (Semciw et al 2013, Preininger et al 2011, Piva et al 2005, Mascal et al 2003).

The AHAbd test described by Rabin et al (2013), Davis et al (2011) and Nelson-Wong et al (2009) was developed to assess the individual's ability to control the trunk and pelvis while raising the leg, thus focusing on the strength of Gmed as reflected by its stabilising capacity. They used a 4 point (0-3) rating scale, with "0" depicting smooth performance of the test and "3" major difficulty to control the movement with an inability to correct the movement, to rate the frontal plane control of the pelvis during active hip abduction. An interrater ICC of -0.09 (Rabin et al 2013) to 0.70 (Davis et al 2011) and an intrarater ICC of 0.74 (Davis et al 2011) was reported by them for the AHAbd test rating system. Rabin et al (2013) expressed the need for clearer guidelines for distinguishing deviations of the pelvis during AHAbd.

Sims (1999) and Norris (1999) recommend using an inner range holding test in side lying hip abduction to assess for possible length-associated changes as well as the endurance of the Gmed muscle, with immediate loss of the position indicating elongation of the muscle and an inner range holding capacity of less than 10 seconds reflecting poor endurance of Gmed. Norris (1999) proposed that optimal endurance would be reflected by a full inner range holding capacity of 10-20 seconds. No indication was given as to the reliability of this method. Comerford et al (2007) and Sahrmann (2002) observed for control of (1) concentric shortening, (2) isometric holding in full inner range and (3) eccentric lowering during the AHAbd test in side lying. They propose that both a loss of control of the pelvis, hip or lumbar spine (thereby movement occurring) as well as a decrease in inner range holding capacity is indicative of weakness in Gmed. Full inner range for Gmed was proposed by some to be at 45° of hip abduction (Rabin et al 2013, Nelson-Wong et al 2009, Comerford et al 2007) and Comerford et al (2012, 2007) recommended that two repetitions of 15 second inner range holds would indicate acceptable endurance of the muscle. This test was chosen for use in this study as it assessed the primary stabilising role of Gmed necessary to control lateral movement of the pelvis on the bicycle vs. only the MVC.

As far as could be determined, no studies have assessed the reliability or validity of side lying AHAbd test used to investigate the control function of Gmed as was described by Comerford et al (2007), Sahrmann (2002), Sims (1999) and Norris (1999, 1995).

3.3.4 Control of lumbar flexion

Following the high prevalence of NSLBP, O'Sullivan (2005) developed a mechanism based classification system where poor control of movement is proposed as one of the major reasons for NSLBP. Various studies indicate substantial to excellent agreement (κ=0.65-0.96) between clinicians in classifying patients into the various motor control impairment groups as proposed by O'Sullivan (2005) or Sahrmann (2002) (Harris-Hayes and Van Dillen 2009, Vibe Fersum et al 2009, Dankaerts et al 2006, Van Dillen et al 1998). The Flexion Pattern (FP) is described as one of the most common LBPP patterns and has been implicated in LBPP in cyclists (Carlsson and Rasmussen-Barr 2013, Lehtola et al 2012, Van Hoof et al 2012, Dankaerts et al 2009, Burnett et al 2004). It is hypothesised that cyclists will present with a flexion pattern of dysfunction of the lumbar spine because of the position they assume and sustain on the bicycle while riding (Van Hoof et al 2012, Schulz and Gordon 2010, Burnett et al 2004) and therefore lumbar flexion dysfunction/control of the lumbar spine was assessed in this study.

Movement control tests are based on the concept of "dissociation", where some muscles are isometrically contracted to retain control of one segment while movement is produced in a different segment/area (Carlsson and Rasmussen-Barr 2013). Control of movement is most commonly assessed through visual estimation using various visual rating systems (Comerford and Mottram 2012, Luomajoki et al 2008, Luomajoki et al 2007).

Many tests have been described to assess control of lumbar flexion, which include the standing trunk lean/waiters bow, sitting knee extension, backward push in four-point-kneeling/rocking backwards, double bent leg lift in crook lying, sitting forward lean, chest drop in sitting, double knee extension in sitting and ischial weight bearing measured from standing to sitting tests (Comerford and Mottram 2012, Enoch et al 2011, Roussel et al 2009, Luomajoki et al 2008, Luomajoki et al 2007, Sahrmann 2002, Van Dillen et al 1998).

The sitting forward lean test as described by Enoch et al (2011) was considered to best represent/reflect the forward bending motion performed by the cyclist on the bicycle and was therefore chosen to assess control of lumbar flexion in this study. With the sitting forward lean test the participant should be able to dissociate the lumbar spine from the hip flexion and reach 30° of forward lean without movement of the lumbar spine.

The accuracy of the visual estimate of lumbar movement during motor control tests has come under scrutiny (Enoch et al 2011). Enoch et al (2011) expressed the need for more precise test descriptions as well as methods that are more quantitative and better reproducible in the assessment of motor control dysfunction. He subsequently described objectively measurable guidelines for the same test with the aim of increasing objective reproducibility and reported excellent interrater reliability (ICC of 0.96, n=40) for the test. No normative values for lumbar flexion control was provided in the article by Enoch et al (2011) but in personal correspondence with the author he recommended using a shift of less than one centimetre as the normative value for control of lumbar flexion.

As far as could be determined, no studies have investigated the validity of the sitting forward lean test. It is however expected to have the same face validity as the "waiter's bow", "sitting knee extension" and "rocking on all fours" tests, where hip flexion is expected to occur while the lumbar spine is stabilised and flexion of the lumbar spine subsequently regarded as a positive test (Luomajoki et al 2008).

Although test-retest reliability has to some extent been investigated for a few of these movement control tests, as far as can be determined, no studies have investigated the sensitivity or specificity of any of the motor control tests, (Luomajoki et al 2008). Luomajoki (2010) proposes the lack of a "gold standard" for measuring dysfunction of movement control as a reason for the inability to determine sensitivity and specificity of the movement control tests. He further proposes that kinematic analysis or functional MRI might become the "gold standard" against which to measure the validity, sensitivity and specificity of movement control tests.

3.3.5 Neural tissue provocation

The slump and straight-leg-raise (SLR) tests are the two most commonly used tests to assess the mechanosensitivity of the neural tissues in the lumbar spine and its involvement in lower back related leg pain (Walsh and Hall 2009, Walsh et al 2007, Shacklock 2005). The slump test is regarded as functionally more relevant than the SLR and occasionally more sensitive than other neurodynamic tests (Majlesi et al 2008, Butler 2000). Reproduction of the patient's symptoms during any neurodynamic test, with a subsequent change in the symptoms with the addition of structural differentiation is generally considered to be a positive sign for impaired neural dynamics (Schmid et al 2009, Walsh and Hall 2009, Walsh et al 2007, Coppieters et al 2005, Kuilart et al 2005, Shacklock 2005, Butler 2000, Turl and George 1998, Philip et al 1989).

Neurodynamic testing does not only influence the nervous system, but also non-neural structures like muscles and fascia. Structural differentiating movements are hypothesised to selectively influence mechanical loading of the nervous tissues (Herrington 2006, Coppieters et al 2005). In support of this, Coppieters et al (2005) illustrated that the addition of sensitizing (structural differentiation) movements to the SLR and slump tests did not change the participants' perception of experimentally induced tibial or calf pain respectively. Lew and Briggs (1997) further illustrated that no association existed between the increase in posterior thigh pain with the addition of cervical flexion to the slump test in asymptomatic individuals and a simultaneous increase in EMG activity in the hamstring muscle, adding to the validity of structural differentiating movements in neurodynamic testing.

Shacklock (2005) indicated that the classification of neurodynamic tests as "positive" or "negative" in isolation will only help determine if a response is musculoskeletal or neurodynamic and that patients might present with a "covertly abnormal neurodynamic response", where the neurodynamic test is positive and structural differentiation is positive, yet the patient's symptoms were not elicited and the response therefore circumstantial and possibly irrelevant for the patient's main complaint. He stressed the importance of the reproduction of the patient's symptoms with the neurodynamic testing which would indicate an "overtly abnormal response" which could be regarded as a "true abnormal neurodynamic response", which was reiterated by Walsh et al (2007).

Considering the similarities in the slumped position assumed by cyclists when riding and the slump test, it was decided to use the slump test as described by Shacklock (2005) and Butler (2000) to assess the dynamics of the neural structures in this study. Philip et al (1989) reported excellent inter-rater reliability for the slump test k=0.83 while Gabbe et al (2004) reported excellent intra-rater (ICC=0.95 and 0.80) and inter-rater reliability (ICC=0.92). Substantial to excellent inter-rater reliability of 0.89 and 0.70 (ICC) (κ=0.71) was reported by Walsh and Hall (2009) for the slump test and Herrington et al (2008) reported an excellent intra-rater reliability of r=0.88.

Walsh and Hall (2009) indicated substantial agreement (κ=0.69) between the SLR and slump tests. They also reported a strong correlation (r=0.64) between ROM of SLR and slump on the symptomatic side in 45 patients with LBPP and unilateral leg pain, indicating substantial construct validity. They found that ICCs were higher on the symptomatic limb for both tests and proposed that pain as reported by the patient was more reliable than tester-interpreted resistance in determining the end position for the test. Opposing this, Davis et al (2008a) observed a high false positive rate of 33.3% for the slump test in 84 asymptomatic people. They regarded the slump test positive if the participant reported a decrease in peripheral symptoms in the slumped position with the release of cervical flexion (structural differentiation) with no regard for the reproduction of the patient's symptoms (as this was an asymptomatic population), which, together with the difference in test sequence, might explain the opposing findings. Majlesi et al (2008) reported a sensitivity of 0.84 and specificity of 0.83 for the slump test in patients with lumbar disc herniation when compared to MRI findings which supports the validity of the slump test.

3.3.6 Load transfer through the pelvis

The active straight leg raise test (ASLR) and one leg stance/standing hip flexion (Trendelenburg) test are both used clinically to evaluate the ability of the lumbo-pelvic area to transfer loads between the trunk and the legs (Roussel et al 2007).

3.3.6.1 Active straight leg raise

The ASLR is a valid and reliable technique for the assessment of load transfer between the spine and the legs through the pelvis, as will be illustrated in this section (Kwong et al 2013, Beales et al 2010a, Mens et al 2010, Roussel et al 2007, O'Sullivan et al 2002, Damen et al 2001, Mens et al 2001, Mens et al 1999). A positive relationship has been observed radiographically between impairment in the ASLR and an unilateral increase in mobility of the pelvis at the symphysis pubis, but no reference was made as to the statistical magnitude of this relationship (Mens et al 1999). Many studies have observed a reduction in impairment in the ALSR with addition of pelvic compression, either manually or through a pelvic belt, simulating the action of the lumbo-pelvic stability muscles in providing force closure around the pelvis in order to restrict movement of the pelvic joints (Arumugam et al 2012, Hu et al 2012, Beales et al 2010a, Mens et al 2006, Lee and Lee 2004, Damen et al 2002, O'Sullivan et al 2002, Mens et al 2001). This supports the hypothesis of impaired motor control and stability around the pelvis being the main cause of PGP (Damen et al 2002, O'Sullivan et al 2002).

The ASLR was validated as a diagnostic tool for patients with posterior pelvic pain after pregnancy (PPPP) (Mens et al 2001, Mens et al 1999) but has since been accepted as an important component in the assessment of LBPP (Hu et al 2012, Beales et al 2009, Vleeming et al 2008, Roussel et al 2007, O'Sullivan et al 2002). Excellent test-retest reliability has been reported for the ASLR in women with PPPP (Pearson's r=0.87, ICC = 0,83; n=50) (Mens et al 2001) whereas Roussel et al (2007) and Kwong et al (2013) reported substantial to excellent interobserver reliability (κ=0.70 for the left ASLR and κ=0.71 for the right legs in patients with chronic NSLBP,n=36 and κ=0.87 in 31 non-pregnant women respectively).

The test is scored by the participant on a six point scale for perceived effort (Table 3.2).

Table 3.2 ASLR score based on participant perceived effort

Not difficult at all	0
Minimally difficult	1
Somewhat difficult	2
Fairly difficult	3
Very difficult	4
Unable to do	5

The score of both the left and right sides are added, resulting in a score ranging from 0-10. In a study done by Mens et al (2001), a cut-off between 0 and 1 for the sum of the scores of the left and right ASLR tests resulted in high sensitivity (κ=0.87 or 54%, n=200) and specificity (κ=0,94 or 88%, n=50) for the ASLR test, indicating excellent discriminative validity (Mens and Pool-Goudzwaard 2012, Mens et al 2010, Mens et al 2001). Similar findings were reported by Kwong et al (2013) with a sensitivity and specificity of 71% and 91% respectively for detecting LBPP. Damen et al (2001) reported a sensitivity of 0.58 and specificity of 0.97 for the ALSR test in women with pregnancy related pelvic pain (PRPP).

The score of the ASLR was compared to the posterior pelvic pain provocation test and a Pearson's coefficient of r=0.27 observed (Mens et al 2001). They reasoned that the ASLR test must test aspects of PGP different to that of the posterior pelvic pain provocation test. Mens et al (2002) further explored the construct validity of the ASLR by comparing it to the Québec Back Pain Disability Scale (QBPDS) and observed a high correlation (r=0.70), indicating that the ASLR effectively measures disease severity in patients with PPPP. The outcome of the ASLR was also compared to the Functional Pelvic Pain Scale and the Roland-Morris Disability Questionnaire and showed a substantial correlation (Spearman's Rho of 0.77 and 0.70 respectively) (Kwong et al 2013).

The ASLR test with a cut-off between 0 and 1 for the sum of the scores of the left and right ASLR tests was used in this study to assess for the control of load transfer through the pelvis and the presence of PGP.

3.3.6.2 One leg stance test/standing hip flexion test

The one leg stance test (Gillet's test, standing hip flexion test, Trendelenburg test) is described as one of the tests that is used clinically to assess load transfer through the pelvis (Roussel et al 2007, Childs et al 2003). The basic test has been described in various ways, all assessing different aspects of pelvic stability. The Gillet/standing hip flexion test is used to assess the movement of the innominates, where posterior rotation of both the weight-bearing and the hip flexion leg indicates acceptable inherent stability of the pelvic girdle (Lee 2007, Hungerford et al 2004). In this way, it is by palpation that the assessor decides whether the pelvic girdle is inherently stable or not. Hungerford et al (2004) confirms that the reliability and predictive ability of the standing hip flexion test is still uncertain. Roussel et al (2007) describes this load transfer test as the "Trendelenburg"/standing hip flexion test and evaluated fatigue of maintaining the non-weight bearing pelvis lifted above the trans-iliac line (in part assessing strength of Gmed). They observed that patients with LBPP fatigued faster than healthy participants and reported a substantial test-retest reliability of the Trendelenburg test, with a weighted κ value of 0.79 (0.83 for the left side and 0.75 for the right side).

The one leg stance test is also described as a movement control dysfunction (MCD) test that reflects control of lateral flexion and rotation of the lumbar spine (Luomajoki et al 2008, 2007). MCD is characterised by a reduced control of active movement with the underlying hypothesis that people injure themselves by subconsciously moving in a way that aggravates their pain, due to a decreased ability to control the active movement of their backs (Luomajoki et al 2007). Following this theory, the expectation is that hip joint ab- and adduction should occur during the lateral weight shift, while the lumbar spine stays in a neutral position (Luomajoki et al 2008). They reported a high effect size for the ability to control movement between groups with and without low back pain (d=1.18) (Luomajoki et al 2008). With extension rotational dysfunction there will be a marked difference in the lateral shift of the pelvis (Luomajoki et al 2007). Luomajoki et al (2007) reported significant to excellent intra-rater reliability (κ=0.84 and κ=0.67 for the left leg and right leg respectively) and moderate to substantial inter-rater reliability (κ=0.65 for left leg and κ=0.43 for right leg) for the one leg stance test.

Childs et al (2003) assessed for differences in side-to-side weight shift between the lower extremities with two independent electronic scales and observed significant differences in side-to-side weight shift in participants with LBPP compared to a healthy control group. Mascal et al (2003) used movement from double leg stance to single leg stance to assess pelvic drop as well as lateral excursion of the pelvis in an intervention study in patients with patellofemoral pain syndrome (PFPS) but did not report on the reliability of the test.

Optimal cycling performance and comfort is dependent on a minimal side-to-side shift on the bicycle. Poor control of side-to-side movement could result in an increased strain through the lumbo-pelvic region, resulting in pain and pathology (Chapman et al 2008a, Childs et al 2003, Mellion 1994). No test could be found that either assessed the magnitude of the lateral movement during weight shift or specified what a normal shift should be. The one leg stance MCD test as described by Luomajoki et al (2008, 2007) appeared to best assess the magnitude of lateral movement during weight shift and was therefore used in this study. Besides measuring the extension/rotation control of the lumbar spine, it seemed to be the most objective way of measuring a) the load transfer capacity of the pelvis and b) the ability of participants to actively control their lateral movement during one leg stance, as well as c) the magnitude of the lateral movement. Following their guidelines the test was deemed incorrect/abnormal if (1) lateral transfer of the umbilicus exceeded 10cm to either side or (2) if the difference in weight shift between the left and the right sides was more than two centimetres (Luomajoki et al 2008, 2007).

3.3.7 Leg length discrepancy

X-rays are seen as the gold standard in measuring LLD but even though X-rays and other imaging techniques (MRI, computer tomography) are more accurate, they are expensive, not readily available in clinical practice and contain some form of radiation risk (Brêtas et al 2009, Brady et al 2003, Petrone et al 2003, Gurney 2002, McCaw and Bates 1991). Subsequently, alternative clinical methods have been developed to measure LLD. The two main clinical methods that have emerged includes an “indirect” and a “direct” method. The indirect method uses visual estimates of the pelvic level and lift blocks under the short leg in standing to assess the presence and extent of a LLD whereas the direct method uses a tape measure to measure the distance between fixed bony landmarks in the supine position (Brady et al 2003, Gurney 2002). Both methods serve well as a screening tool for patients with LLD who could then be further referred for radiological studies when appropriate (Gurney 2002).

Two methods are used to determine LLD with a tape measure: measurement of the distance between the anterior superior iliac spine (ASIS) and the medial malleolus (MM) and the ASIS and the lateral malleolus (LM). ASIS to MM has been reported to have substantial to excellent intra- and intertester reliability (ICC=0.68-0.99) (Brêtas et al 2009, Terry et al 2005, Krawiec et al 2003, Hoyle et al 1991, Beattie et al 1990, Gogia and Braatz 1986) and correlated well with X-rays (r=0.98), a mini scanogram (ICC=0.79) and computed tomography scanogram (ICC=0.85) as a measure of criterion validity (Jamaluddin et al 2011, Beattie et al 1990, Gogia and Braatz 1986).

Krawiec et al (2003) assessed the reliability of the ASIS to MM and the ASIS to LM and reported an ICC of 0.99 without specifying which test it was for. They observed a Pearson's product correlation of r=0.75 between the measurements of ASIS to MM and ASIS to LM and recommended the ASIS to LM to the ASIS to MM measurement because of its proposed greater precision of measurement. An excellent intra- and interrater reliability was observed by Terry et al (2005) for both the ASIS to LM (ICC=0.88 and 0.83 respectively) and ASIS to MM (ICC= 0.78 and 0.8 respectively) measurements. Using the average of two measurements between the ASIS and medial malleolus in screening for LLD has been found to increase the validity and reliability of the measurements (Jamaluddin et al 2011, Beattie et al 1990). Beattie et al (1990) observed an increase in reliability (ICC of 0.668 to 0.910) and criterion validity (ICC of 0.683 to 0.793) of the ASIS to MM measurement when the mean of two paired measurements were used. Similar findings were reported by Jamaluddin et al (2011) who also observed an increase in criterion validity with using the mean of two measurements of the ASIS to MM when compared to computed tomography scanogram (ICC of 0.81 to 0.85).

The direct tape measure method measuring LLD from the ASIS to the LM was chosen for use in this study as it:

- eliminates the contour of the thigh as a possible source of measurement error as reported with the ASIS to medial malleolus technique and has a more direct line of measurement (Sabharwal and Kumar 2008, Krawiec et al 2003, Woerman and Binder-Macleod 1984). Woerman and Binder-Macleod (1984) observed a smaller mean difference (0.025cm) with ASIS to LM measurement compared to ASIS to

MM (1.17cm) in participants with known LLD but made no reference as to the statistical analysis of this relationship.

- eliminates the need for multiple blocks of known-height, a calliper spirit level to compare iliac crest heights as well as accurate location of the height of the iliac crests necessary for the indirect pelvic level method (Sabharwal and Kumar 2008, Brady et al 2003, Gurney 2002, Mann et al 1984, Woerman and Binder-Macleod 1984)
- is used more commonly in clinical practice, is inexpensive and reported to have acceptable reliability as a screening tool (Jamaluddin et al 2011, Brêtas et al 2009, Sabharwal and Kumar 2008, Brady et al 2003, Gurney 2002, McCaw and Bates 1991, Beattie et al 1990)

3.4 Bicycle set-up factors

Bicycle set-up and the measurement thereof is a very controversial issue. Literature pertaining to bicycle set-up is sparse, often contradictory and is mostly concerned with improving the performance and efficiency of cycling rather than preventing overuse injuries (Marsden and Schwellnus 2010). Bicycle set-up will vary substantially according to the goal of the cyclist, whether it is to increase performance or to attain a more comfortable ride. A number of schools of thought seem to exist, some purely measuring the set-up of the bicycle in static conditions, but most taking some anthropometric measurements and relating them to some extent to the set-up of the bicycle. In the literature reviewed, most set-ups are described in static conditions and very few dynamic bicycle set-up assessments are described (Marsden 2009, Silberman et al 2005, De Vey Mestdagh 1998). A number of different anthropometric measuring systems with their corresponding computer programs and measuring instruments have been developed and are used by most bicycle shops offering bicycle set-ups. The “Cyclefit” protocol developed by De Vey Mestdagh (1998) is but one of them, and measurements of the set-up of the bicycle in this study were mostly based on the method he described as it best described the execution of the various measurements in what seemed to be the most objectively measurable way. He also included anthropometric measurements of the cyclist in his set-up which contributes to the best fit of the bicycle to the cyclist and not just the cyclist to the bicycle.

Optimal cycling posture is dependent on two main variables: posture height (saddle height, crank length, position of the cleats on the shoe, saddle setback) and posture length (reach, handlebar level and handlebar width) (De Vey Mestdagh 1998). A limited number of studies provide guidelines of how these different variables should be assessed and very few have related the measurements to LBPP in cyclists (Schulz and Gordon 2010, Marsden 2009, De Vey Mestdagh 1998). Only one study has reported on the reliability or validity of some of the bicycle set-up measurements (Schulz and Gordon 2010). These will be discussed individually in the section below.

3.4.1 Saddle height

Various methods have been proposed for the measurement of saddle height, most of which have focussed on power output (Ferrer-Roca et al 2012, Wanich et al 2007, Peveler et al 2005, Silberman et al 2005, Farrell et al 2003, De Vey Mestdagh 1998, Holmes et al 1994, Nordeen-Snyder 1977, Hamley and Thomas 1967). Various formulae involving inside leg length (inseam length, symphysis pubis length) have been used to determine seat height for optimal power output. Inside leg length was measured from the floor to the height of the symphysis pubis (Hamley and Thomas 1967). Hamley and Thomas (1967) recommended that a 109% of the inside leg length will produce maximum power over a short period (Hamley technique). Subsequently angles of between 101.7-112.1% of the inside leg length has been recommended (Ferrer-Roca et al 2012, Silberman et al 2005, De Vey Mestdagh 1998, Nordeen-Snyder 1977).

An alternative method of measuring saddle height was developed by Holmes et al (1994). They recommended using a knee angle of 25-35° in the BDC to reduce the risk of overuse injuries in cyclists. This has been confirmed by other researchers (Peveler et al 2005). Knee angles of 25-30° have also been proposed (Wanich et al 2007, Silberman et al 2005, Farrell et al 2003, Burke 2002, De Vey Mestdagh 1998). Peveler et al (2007) reported significantly higher mean power output (increased performance) when the knee was at a 25° angle compared with 109% inside leg length. They recommended using a 25-35° knee angle for injury prevention as well as more efficient performance (Peveler et al 2007) with the 25° knee angle for more power while still preventing injury (Peveler and Green 2011). The knee angle was consistently measured with a goniometer (Peveler and Green 2011, Peveler et al 2007).

In this study a knee angle of 25-35° as measured with a goniometer with the pedal at the BDC was regarded as indicative of a normal saddle height. As far as could be determined, no studies have assessed the reliability or validity of measuring saddle height in cyclists.

3.4.2 Saddle set-back

Saddle setback is measured uniformly in the literature. With the pedal positioned in the most forward position (pedals in the 3 o'clock and 9 o'clock positions), a plumb line is dropped from the posterior aspect of the patella (some describe it as the level of the tibial tuberosity) to the floor. The plumb line should dissect the axle of the most forward pedal when the saddle setback is optimal for the cyclist (Wanich et al 2007, Silberman et al 2005, De Vey Mestdagh 1998). Again no studies could be located that assessed the reliability or validity of measuring saddle set-back in cyclists.

3.4.3 Saddle angle

Saddle angle has a profound effect on the position of the pelvis on the bicycle (Marsden and Schwellnus 2010, Salai et al 1999). It has been widely accepted that the saddle should be level/parallel to the floor (Wanich et al 2007, Silberman et al 2005) but following a decrease in the occurrence of LBPP in a group of cyclists with tilting the saddle anteriorly by 10-15° as observed by Salai et al (1999) an anteriorly tilted saddle has been related to a decrease in tension on the ligaments of the lumbar spine (Marsden and Schwellnus 2010, Salai et al 1999). In the studies reviewed, saddle angle was measured with a standard carpenter's level (Wanich et al 2007) or with a goniometer (Van Hoof et al 2012, Salai et al 1999) with no reference made to the reliability or validity of measuring saddle angle in cyclists. In this study a saddle angle which was level or tilted anteriorly was considered as acceptable for proper bicycle set-up.

3.4.4 Handlebar height

Handlebar height is often influenced by the goal of the ride, i.e. performance or recreation (De Vey Mestdagh 1998). Handle bars are generally set lower for more competitive cyclists to obtain a more aggressive aerodynamic position compared to a more relaxed upright position for recreational riders (De Vey Mestdagh 1998). Silberman et al (2005) recommend a 5-8 cm difference in height between the saddle and the handlebars, with the handlebars being lower than the saddle (dependant on the flexibility of the cyclist). Wanich et al (2007) recommend that the handlebars be set 3-10 cm below the saddle for road bicycling with the lower level being more aerodynamic. Asplund et al (2005) again recommend that the handlebars should ideally be even with the seat or between even and 4cm below the seat in recreational riders and up to 5 to 9 cm below the seat in extremely fit and flexible cyclists.

As far as could be determined, no studies have assessed the influence of different handlebar heights on cycling performance, comfort or injury prevention and no reference has been made to the reliability or validity the measurements. Schulz and Gordon (2010) report excellent intrarater reliability for measuring the distance from the handlebars to the floor (ICC=0.98) and the seat to the floor (ICC=0.98) (n=13). As far as could be determined, no other studies reported on the validity and reliability of measuring handlebar height. A handlebar height of between 5 and 8 cm below the seat was taken as indicative of proper bicycle set-up in this study.

3.4.5 Reach

Reach distance is defined as the distance between the saddle and the handlebars (measured from the rear of the saddle to the transverse part of the handlebars) while considering contributions from the length of the arm and the upper body (Asplund et al 2005, De Vey Mestdagh 1998, Mellion 1994). The position of the lumbar spine and pelvis is directly influenced by the reach distance (Sanner and O'Halloran 2000, De Vey Mestdagh 1998).

De Vey Mestdagh (1998) calculated the correct reach distance based on the length of the arm and the upper body and Marsden (2009) used this method in assessing the association between reach distance and LBPP in cyclists. Aplund et al (2005) and Silberman (2005) recommend using the distance between the bent elbows and the knees in the TDC, dropping a plumb line from the nose in the handlebar position or the cyclist's view of the front hub as measures of determining correct reach based on the work of Burke (1994) and LeMond and Gordis (1990). None of the studies available have commented on the reliability and validity of any of the measuring techniques available.

In this study an assessment of the reach distance was made, based on the sum of the full arm and upper body measurements according to measures suggested by De Vey Mestdagh (1998) as it included the influence of the length of the arms and upper body and appeared to be more objective in the absence of any reliability studies:

- De Vey Mestdagh (1998) measured the length of the arm in upright standing from the superior aspect of the acromion to the distal aspect of the most distal metacarpal joint head. He proposed the use of sliding callipers to make this measurement. Marsden (2009) used a rigid tape measure to measure arm length in cyclists. Neither of the studies reviewed mentioned the reliability of the measuring method used to measure arm length.

- Upper body length is measured from a flat stool to the incisura jugularis of the manubrium sterni in the upright seated position (De Vey Mestdagh 1998). De Vey Mestdagh (1998) again used sliding callipers to measure the distance while Marsden (2009) used a rigid tape measure. No indication was given of the reliability of either of these measuring techniques.

3.4.6 Cleat position

The position of the cleats mostly influences the development of knee problems, but because of its direct impact on the fore-aft position of the cyclist and hence the set-back position of the saddle, it was included in this study (Silberman et al 2005). Aligning the cleat on the shoe with the head of the first metatarsal bone positions the foot directly in line with the pedal spindle and is the most common technique used for setting the cleat position (Wanich et al 2007, Callaghan 2005, Silberman et al 2005, De Vey Mestdagh 1998). As far as could be determined, no studies have investigated the reliability or validity of this technique.

3.5 Conclusion

The literature on the available and most suitable measuring instruments for the various factors observed in this study was reviewed in this chapter. Where available, the validity and reliability of the measuring instruments were reported, the instruments chosen for this study were justified and the measuring techniques used in this study were briefly discussed. The research methodology, including research design, sample selection, procedures and the statistical analysis for this study will be discussed in detail in Chapter four.

CHAPTER 4: METHODOLOGY

4.1 Introduction

This chapter describes the research design, study population, selection criteria, materials and apparatus, the procedure and the statistical analysis used in this study. The research method of this study is represented in Figure 4.1.

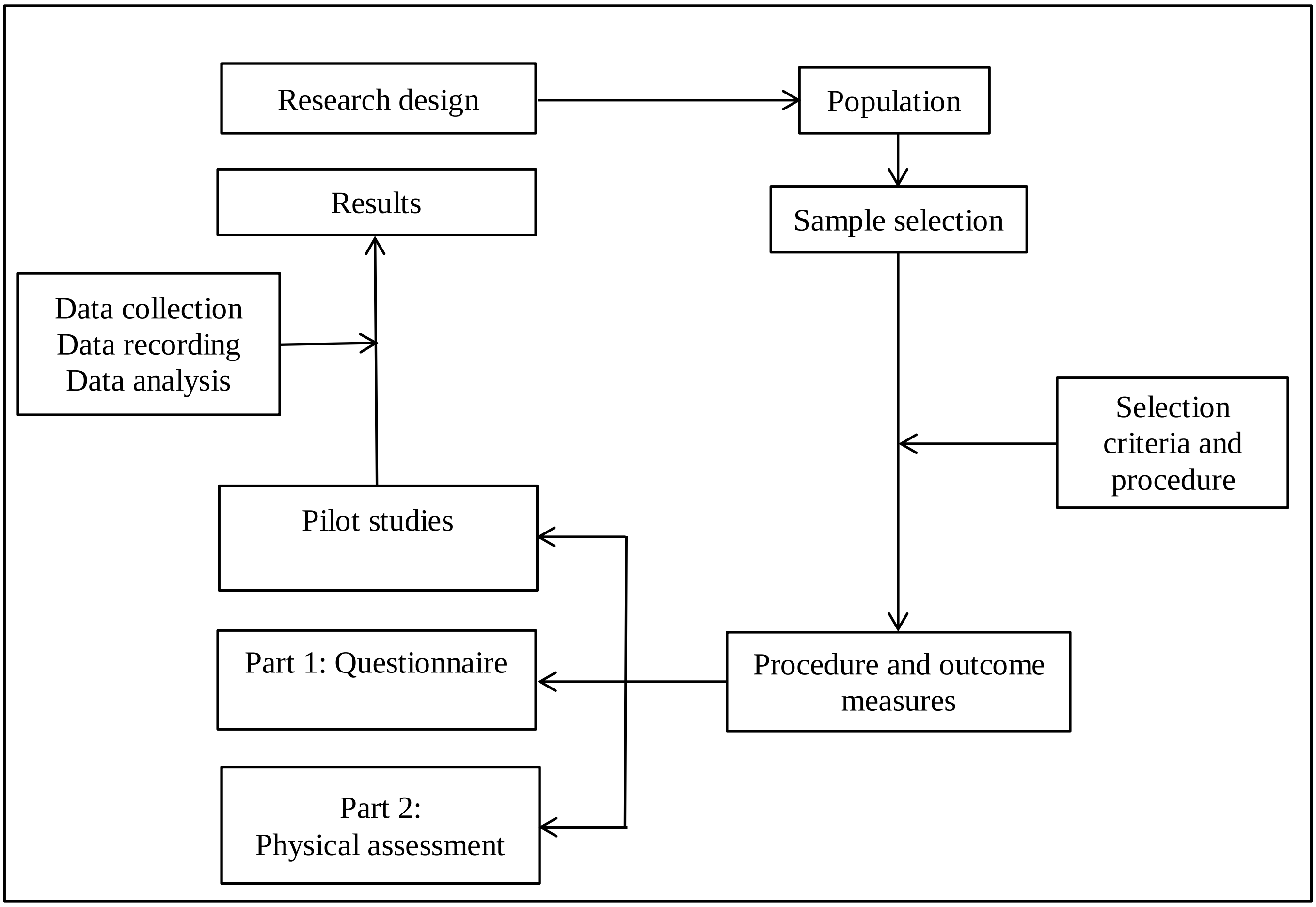

Figure 4.1 Diagrammatic presentation of the research method used in this study

4.2 Research Design

A cross-sectional descriptive study design was used for this study.

4.3 Sample selection

4.3.1 Study population

All cyclists who are members of Cycle Lab in Fourways, Johannesburg were contacted through an advertisement in their weekly electronic newsletter which included the link to the online questionnaire on the Qualtrics website. After only 34 responses were obtained, Club 100 Cycling club in Sandton was also contacted. Their cyclists were also reached through an advertisement in their electronic newsletter with the link to the online questionnaire embedded in the advertisement. A poor response rate from both clubs resulted in a more generalised approach being taken.

An article was written for the Ride Magazine, which was placed in the February 2012 issue, explaining the extent of the study and providing the contact details of the researcher as well as the web address to access the online questionnaire. An advertisement was also placed on thehub.co.za cycling chat room with a link to the online questionnaire. In addition, the researcher contacted Cycling South Africa (CSA) who provided the contact details of all the cycling clubs registered with them for the whole of South Africa. These clubs were then contacted via e-mail. The e-mail explained the extent of the study and included the link to the online questionnaire on the Qualtrics website. A request was made to all the club chairpersons to forward this e-mail to their members and for the members to follow the link to the online questionnaire. A few questionnaires were also handed out at the 94.7 cycling race in Johannesburg and after a talk at a breakfast ride for the Cradle Crawlers cycling club.

A sample of convenience was used for the second part of the study from all the cyclists who completed the questionnaire and then volunteered to be tested in the second part. It was stated in the questionnaire that all assessments would be done in the greater Gauteng area and that they should be available in this area for the physical assessment.

4.3.2 Sample selection

4.3.2.1 Inclusion criteria:

- Aged 18 years and older
- Cycling more than three hours per week on a road bicycle
- Cycling history of more than one year
- Previous participation in at least one race of more than 90 km

- Cycling with cleats
- History of either no low back pain or previous non-specific mechanical low back pain

4.3.2.2 Exclusion criteria

- Cycling more than 12 hours per week
- Participation in more than 20 races per year
- Use of a mountain bicycle or hybrid when cycling
- History of traumatic injury to the spine in the past two years
- Low back pain that has a specific/known structural pathology (e.g. spondylolisthesis)
- Any spinal surgery

4.3.3 Sample size

From a cross-sectional study it is expected that following univariate analysis no more than 10-12 factors would be associated with low back pain when testing at the liberal 0.15 level of significance (Nunnally 1978). These factors were then analysed using a logistic regression and by convention 10-15 subjects need to be included for each factor. Hence at least 120 volunteers were included. Furthermore, this sample size would estimate the expected prevalence of 35% to an accuracy well below 10% (nQuery Version 7).

4.3.4 Ethical considerations

Ethical approval was obtained from the Human Research Ethics Committee at the University of the Witwatersrand (Appendix 3). Participants were invited to participate in the study. They were informed that completion of the questionnaire in Part 1 of the study was considered as consent to participate in the first section of the study.

The participants of Part 1 had the opportunity to volunteer again to participate in Part 2 of the study. Participants received an information sheet (Appendix 4) explaining the study before commencement of Part 2 of the study, and signed informed consent to participate in Part 2 of the study (Appendix 5). All data were coded and personal information kept separately and securely in order to guarantee confidentiality of the information received. Detailed written feedback was given to each participant after completion of the study and recommendations were made according to the findings. The results of the study were made known to all the participants of the study.

4.4 Procedure and measuring instruments

All measuring instruments used in this study were discussed and justified in Chapter 3. The study consisted of two parts:

- Part 1 included the completion of an online questionnaire depicting the demographics of the cyclists, training history and the behaviour of LBPP where applicable (see Appendix 6).
- Part 2 consisted of a physical assessment of the factors hypothesised to contribute to the development of LBPP in cyclists (see Appendix 7).

An expert group of physiotherapists experienced in the treatment of cyclists and/or motor control dysfunction were contacted prior to the commencement of the study. They provided input into the questionnaire and advised on the potential factors that could be associated with LBPP in cyclists. Their recommendations were included in the questionnaire as well as in the physical assessment.

4.4.1 Pilot study

4.4.1.1 Questionnaire

A pilot study was done to assess the ease of following and completing the questionnaire. Twelve cyclists completed a trial version of the questionnaire on the Qualtrics website. They were asked to report on ease of understanding of the questions, time taken to complete the questionnaire and if they thought anything of importance was left out. Changes were made according to their suggestions (see section 3.2, Chapter 3).

4.4.1.2 Physical assessment

A pilot study was conducted to practice the flow of the physical assessment, the handling of the measuring instruments, use of the data collection sheet and to resolve some of the challenges that could arise from the execution of the actual physical assessment. Five volunteers participated in the pilot study of the physical assessment. The order of the physical assessment and the data collection sheet was adapted to match and improve the flow of the physical assessment and the time used to execute it. The execution of some of the tests, posterior Gmed through range control, Gmax inner range control, lateral shift with the one leg stance test, ASLR, hamstring extensibility test and aspects of the bicycle set-up, was adapted to be more precise during collection of data. The equipment used to test the above factors was also adapted in order to increase the accuracy of the measurements.

Following this, thirteen cyclists were included in a reliability study to assess the repeatability of the measurements of the physical factors taken by the researcher. During the reliability study all participants were assessed on two occasions, one week apart. The results of the factors assessed were compared and the repeatability of each factor was calculated. The intrarater reliability of each factor assessed can be found in Chapter 5.

4.4.2 Questionnaire

An online questionnaire was created on the Qualtrics website (2012) using a combination of the three previously validated questionnaires as discussed in Chapter 3. As mentioned previously, a description of the study with a link to this questionnaire was sent to all the cycling clubs country wide registered with CSA. The respective chair persons of the clubs were asked to forward the information to the cyclists belonging to their clubs. Cyclists followed the link to the questionnaire and were included or excluded from the study depending on their responses on the study requirements page of the questionnaire. A few printed questionnaires were also handed out by committee members of the South Gauteng South African Society of Physiotherapists (SASP) at the 94.7 cycling race expo as well as after a talk done by the author at a cycling breakfast of the Cradle Crawlers cycling club. The printed questionnaires were entered on the Qualtrics website by the author. The questionnaire was closed for responses after being available for eight months.

4.4.3 Anthropometric measurements

4.4.3.1 Body weight

Body weight was measured with an electronic digital bathroom scale (Carmen Care) in kilograms (kg). The participants were dressed in cycling gear (cycling shorts and tops) without shoes and socks for the assessment of body weight.

4.4.3.2 Standing Height

The height of the participants was measured with a portable stadiometer (HS, Scales2000) in centimetres (cm). The participants had to stand upright and barefoot with their backs to the upright part of the stadiometer. The arm of the stadiometer was pulled down to make contact with the top of the participant's head and the height was read from the stadiometer.

4.4.3.3 Body mass index

The body mass index was calculated with the standard formula: body weight in kg divided by height in m^2 and classified according to the groups specified in Table 3.1 (Chapter 3).

4.4.4 Lumbar spine angle on the bicycle

A Saunders digital inclinometer (Saunders Group) was used to measure the lumbar angles and curvature in this study. The inclinometer is a hand-held device and designed to measure spinal posture and mobility. Before measurement of the spinal posture, the following anatomical reference points were marked in the unsupported upright seated position on the bicycle (no hand contact was made with the handle bars):

- The lumbo-sacral joint (L5/S1) – reference point A. The sacral midpoint was found midway on a line connecting the inferior aspects of the posterior superior iliac spine. The lumbo-sacral joint lies approximately 3 cm above this point.
- The thoracolumbar joint (T12/L1) – reference point B. Starting from the L5/S1 joint as number one, six interspinous spaces were counted upwards to locate the T12/L1 joint.

To measure lumbar spine posture, the participants were positioned in three different positions on the bicycle (Figure 4.2):

- The "seated upright" position, with hands on the transverse part of the handlebar
- The "brake lever" position, with hands placed on the brake hoods, and
- The "drops" position, with hands placed on the drops (rounded bottom part of the handlebar).

Key: Front left to right: Upright seated position, Brake lever position, Drops position

Figure 4.2 Illustration of handlebar positions

Participants were instructed to perform a few peddling cycles on the bicycle per riding position and then instructed to stop peddling, keeping both feet in a position parallel to the floor (pedals at 3 and 9 o'clock positions) with the right foot always forward (Muyor et al 2011a, Schulz and Gordon 2010). A measurement was then taken by placing the inclinometer with the short base on the L5/S1 joint (Position A). The inclinometer was then moved to the T12/L1 joint (Position B) where a second measurement was taken. The lumbar flexion curvature was calculated by subtracting the measurement at L5/S1 from the T12/L1 measurement (B-A). This process was repeated three times in all three riding positions and the mean of the measurements per riding position was used as the lumbar flexion angle for each riding position.

4.4.5 Musculature involved in lumbo-pelvic stability:

4.4.5.1 Inner range holding capacity of Gluteus maximus

Inner range holding capacity of Gmax was tested according to the test described by Richardson and Sims (1991). After consultation with Dr C. Richardson (2012) it was decided to combine their test procedure with that of Comerford and Mottram (2012).

The participant was positioned in prone with trunk support only over the treatment plinth. Both feet were supported on the floor with the knees slightly flexed. Two PBU (Stabilizer Pressure Bio-feedback by Chattanooga) were positioned under the ASIS on the left and the right side and inflated to 20mmHg (as recommended by Dr Richardson). The participant's lower back was positioned in the neutral lumbar position (long shallow lordosis).

The examiner assessed the available passive range of hip extension, with the knee in 90° flexion while passively stabilising the lumbo-pelvic area in neutral. A rod was positioned to touch the posterior aspect of the thigh when the hip was in the neutral extension (0°)/horizontal position to serve as an objective benchmark of where neutral hip extension was. The participant was instructed to keep one leg on the floor and to lift the other into hip extension with the knee kept in 90° of flexion (to disadvantage the hamstrings). The participant was instructed to keep lifting until the back of the thigh touched the pre-positioned rod and to maintain contact with the rod for 15 seconds before lowering it again. The neutral position of the lumbo-pelvic area had to be maintained throughout the lifting, holding and lowering of the leg and their ability do so was measured with the two PBF meters (20 mmHg). If the participant was able to concentrically shorten to full passive inner range, maintain that position for 15 seconds and eccentrically lower the leg again with good, smooth control and no movement or substitution in the lumbo-pelvic area, a second repetition was done with the same leg.

This test procedure was then repeated with the other leg. Successful completion of two repetitions of this procedure indicated normal inner range control of Gmax. The test was considered positive for insufficient inner range control of Gmax when the participant was unable to concentrically shorten into full passive inner range (0°) hip extension, smoothly maintain that position for 15 seconds and eccentrically lower again with good control and without shaking or substitution in the lumbo-pelvic area for two repetitions.

The participant performed three practise sessions with feedback from the examiner as to movement occurring in the lumbar spine. The practise sessions did not involve holding the position for the required time, but to provide feedback to the participants on their ability to control the lumbar neutral position and reach the benchmark for testing (0° hip extension).

4.4.5.2 Hamstring muscle extendibility

Extendibility of the hamstring muscle was measured in supine on a treatment plinth. The leg to be tested was placed in 90° of hip flexion (measured with an inclinometer), with the thigh supported against a frame in that position. The participant was instructed to hold onto the frame to ensure good contact of the posterior thigh with the frame. The foot was supported on the frame with the knee relaxed in flexion. The opposite non-test leg was placed in a neutral hip position on the plinth under the frame. The knee of the tested leg was passively extended by the examiner until firm resistance was felt or the participant reported a strong stretch sensation (Gnat et al 2010, Kuszewski et al 2009, Davis et al 2008b, Sauer et al 2007). The knee extension angle was then measured with a digital inclinometer placed midway between the patella and a line joining the two malleoli (Kuszewski et al 2009). The test was repeated three times on each leg to increase the accuracy of the measurement. No warm-up was done prior to testing.

4.4.5.3 Through range control of Gluteus Medius

The through range control and inner range holding capacity of Gmed was measured according to a combination of the tests described by Davis et al (2011), Comerford and Mottram (2012, 2007), Nelson-Wong et al (2009) and Sahrmann (2002), assessing for both inner range control and control of lumbo-pelvic movement. The participants were positioned in side lying with the lower back and pelvis in neutral alignment. Full passive range of motion was assessed by the examiner lifting the top leg into hip extension, external rotation and abduction while stabilising the lumbo-pelvic area in the neutral position. A rod was positioned to touch the lateral aspect of the leg when the hip reached the benchmark of 45° abduction. The participant was positioned so that the spine and pelvis were in neutral alignment and the bottom leg in a slightly flexed position.

The instruction was given to lift the uppermost extended leg up and backwards towards the ceiling while keeping the leg in an externally rotated position until contact was made with the rod. The participant then had to maintain controlled contact with the rod for 15 seconds before smoothly lowering the leg again. Neutral alignment of the lower back and pelvis had to be maintained throughout this procedure and an inability to do so resulted in failure of the test. This procedure was repeated once more if the participant successfully completed the first movement. The test procedure was also repeated for the other leg. The ability to perform two smoothly controlled repetitions of this procedure without substituting with movement of the hip, lower back or pelvis was deemed as sufficient through range control of deep posterior Gmed. Three practise runs of the procedure were allowed with corrective verbal and tactile input from the examiner before commencement of the test procedure.

4.4.6 Control of lumbar flexion

The participant's ability to control flexion of the lumbar spine was assessed with the sitting-forward-lean test as described by Enoch et al (2011). The test was performed in the sitting position with the knees and hips at 90° flexion with the hands relaxed on the thighs and the feet supported. The examiner positioned the participant's lower back in a visually estimated neutral position (slight lumbar lordosis and a relaxed throrax) (O'Sullivan et al 2010a) and made a mark at the S1 vertebra and at a point 10cm above that, with a non-permanent whiteboard marker using a flexible tape measure. The participant was instructed to keep the lower back in its neutral position with the two points 10cm apart while leaning forwards to 120° of hip flexion as measured with a goniometer.

Five practice runs of the test were allowed with verbal and tactile input from the examiner on the participant's ability to maintain the neutral lumbar curvature. The test was then performed five times without any feedback from the examiner. The participant was instructed to lean forward to 120° hip flexion while keeping the back still (the two points 10cm apart) and to sustain the forward lean position for a few seconds while the examiner measured the distance between the two marks with a flexible tape measure to the nearest mm. The mean value of the five repetitions was calculated. If the patient was able to maintain a distance of 10cm between the two marks, or if there was a change of less than 1cm, the test result was deemed negative, indicating adequate control of lumbar flexion (Enoch 2013).

4.4.7 Neural tissue dynamics

The mobility of the pain-sensitive neuromeningeal structures were assessed with the slump test. The slump test was performed following the six stage sequence as described by Butler (2000) and Shacklock (2005) (also described in Cleland et al (2006) and Kuilart et al (2005)):

(1) The participant was positioned in sitting with the feet unsupported, knee creases at the edge of the treatment plinth and thighs lying parallel to each other. The participants were instructed to place their hands behind their back and to link their fingers.

(2) The participant was instructed to flex the thoracic and lumbar spine while maintaining the neck in neutral and without rocking the pelvis backwards. The examiner applied overpressure through the C7 spinous process, directed towards the hips in the direction of flexion

(3) While maintaining the thoracic and lumbar flexion, the participant was instructed to bend his neck down by pulling his chin to his chest (cervical flexion). Overpressure to cervical flexion was added (while maintaining overpressure of thoracic and lumbar flexion).

(4) While maintaining overpressure of the cervical, thoracic and lumbar flexion, the participant was instructed to extend or straighten one knee

(5) Dorsiflexion of the ankle was then added as the final component of the movement by asking the participant to pull their toes up towards them.

(6) The neural tissue was then structurally differentiated from the musculo-skeletal tissues, by releasing the overpressure of the cervical spine and instructing the participants to extend their neck by looking up while maintaining the position of the thoracic spine, lumbar spine, knee and ankle.

The participant was asked about the presence or absence of symptoms throughout the testing sequence and the location of any reported symptoms were noted on the data collection sheet. The test was considered positive if the participant's symptoms were reproduced at any point of the testing sequence and alleviated with the release of neck flexion indicating an overtly abnormal neurodynamic response (Schmid et al 2009, Davis et al 2008a, Cleland et al 2006, Coppieters et al 2005, Kuilart et al 2005, Shacklock 2005). Including the reproduction of the patient's symptoms as a diagnostic criterion for a positive slump test has been proposed to decrease the false positive rate for the slump test (Davis et al 2008a).

4.4.8 Load transfer through the pelvis

4.4.8.1 Active Straight leg raise test

The ASLR test was performed in the supine position with the feet 20cm apart. The participant was asked to raise a straight leg, one after the other, 20cm off the bed and rate the perceived effort on a 6 point scale (Table 3.2, Chapter 3).

The test was repeated twice to increase the precision and the mean of the values was used to calculate the sum of the two legs (Hu et al 2012). The scores of both sides were added, resulting in a score ranging from 0-10. The test was deemed positive if the mean of the scores was greater than 1 and negative if it was less than 1. A severe load transfer dysfunction was defined as a sum score of more than 4 (Mens and Pool-Goudzwaard 2012).

The ASLR was then repeated with the addition of manual pelvic compression through the ilia. An improvement in the ability to raise the leg (reduction in ASLR score) was also deemed a positive test (Hu et al 2012, Beales et al 2010a, O'Sullivan and Beales 2007a, Mens et al 2006, O'Sullivan et al 2002).

4.4.8.2 One leg stance test

Lateral shift of the pelvis was measured using the one-leg-stance movement control test as described by Luomajoki et al (2008, 2007). Besides measuring the extension/rotation control of the lumbar spine, it seemed to be the most objective way of measuring a) the load transfer capacity of the pelvis and b) the ability of participants to actively control lateral movement during one leg stance.

Participants were positioned in the normal upright standing position with their feet one third of their trochanteric distance apart and the umbilicus aligned with an upright pole. They were instructed to shift their weight from the normal standing position onto the left and the right leg respectively (standing on one leg). The lateral movement of the umbilicus from the midline (fixed pole) was measured with a spirit-level ruler at the completion of this weight transfer. The test was repeated three times to each side and the mean value of the weight shift to the left and the right was calculated.

Symmetrical transfer of the umbilicus to the left and the right sides was considered a normal test, with the difference between sides being less than two centimetres. The test was deemed incorrect/abnormal if lateral transfer of the umbilicus exceeded 10cm or if the difference between the left and the right sides was more than two centimetres (Luomajoki et al 2008, 2007).

4.4.9 Leg-length discrepancy

The direct tape measure method, measuring the distance between the ASIS and the LM, was used to measure leg-length discrepancy (Terry et al 2005, Krawiec et al 2003, Beattie et al 1990, Woerman and Binder-Macleod 1984). Participants were positioned in supine on the treatment plinth and instructed to draw their legs up, perform a "bridge" and straighten the legs again before commencement of the measurement. The examiner palpated the ASIS and positioned the top edge of a flexible tape measure at that point. The most distal and lateral part of the LM was then palpated and a measurement taken with the tape measure. This measurement was taken for the left leg first and then for the right and repeated to increase the reliability of the measurement. The average of the two measurements was used as the value for the LLD.

4.4.10 Bicycle set-up

Inadequate bicycle set-up is regarded as one of the most important contributors to the development of LBPP in cyclists (Marsden and Schwellnus 2010, Asplund et al 2005, Silberman et al 2005, De Vey Mestdagh 1998). The three points of contact the rider has with the bicycle are regarded as the key to proper bicycle set-up. These include:

(1) Contact of the shoe-cleat with the pedal

(2) Contact of the pelvis with the saddle

(3) Contact of the hands with the handlebars (Silberman et al 2005).

De Vey Mestdagh (1998) regards posture height (which includes saddle height, crank length, shoe cleat position and saddle set-back) and posture length (reach, handlebar level and handlebar width) as crucial for a correct cycling position/posture.

Incorrect saddle position (height and setback) and reach distance (which incorporates handlebar height) are generally described in the literature as the most problematic aspects of bicycle set-up in the development of lower back pain.

4.4.10.1 Saddle height

Saddle height was measured on the bicycle by assessing the angle of the knee with the pedal in the BDC. The participant was instructed to pedal and to stop with the right foot in the BDC position. The angle of knee flexion in the BDC position was measured with a universal goniometer. This procedure was repeated three times to increase the accuracy with the participant pedalling in between each measurement. This procedure was also repeated on the left leg, again measuring knee flexion angle with the pedal in the BDC position. The height of the saddle was considered acceptable if the knee flexion angle was between 25-35°(Peveler et al 2007, Peveler et al 2005).

4.4.10.2 Saddle set-back

Saddle set-back was measured with the participant on the bicycle and the crank arm of the tested leg in the horizontal forward position (3 o'clock). A plumb line was dropped from the posterior aspect of the patella. With proper saddle set-back the plumb line intersected the pedal axle and the posterior aspect of the patella was therefore directly above the pedal axle (Silberman et al 2005, De Vey Mestdagh 1998).

4.4.10.3 Saddle angle

The angle of the saddle has a direct influence on the position of the pelvis on the bicycle. Silberman et al (2005) recommended that the saddle should be close to level, thus parallel to the ground. Salai et al (1999) illustrated that 70% of cyclists with low back pain experienced relief from pain when the saddle was tilted forward (anteriorly) by 10-15°.

In this study the angle of the saddle was measured with a digital spirit level and recorded as level, anteriorly tilted or posteriorly tilted while noting the magnitude of inclination. A level or anteriorly tilted saddle was regarded as acceptable for optimal saddle angulation.

4.4.10.4 Cleat position

Cleat position was measured by palpating the first metatarsal head with the participant in the standing position. The position of the first metatarsal head was marked with a pencil on the shoe. The participants were asked to remove their cycling shoes and the line drawn was followed through to determine if the cleat was aligned with this line. The line bisecting the first metatarsal head should lie directly over the pedal axle for proper shoe-cleat to pedal contact and should therefore be in line with the position of the cleat (Silberman et al 2005, De Vey Mestdagh 1998).

4.4.10.5 Posture length/reach

Reach distance is at the centre of the debate on lower back problems and cycling (De Vey Mestdagh 1998). Reach distance is defined as the distance from the rear of the saddle to the transverse bar of the handlebars. The most accurate reach distance was calculated by considering the three factors involved in reaching forwards: the distance between the back of the saddle and the transverse bar of the handlebars, full arm length and the length of the upper body (De Vey Mestdagh 1998). The distance between the handlebars and the back of the saddle was measured with a tape measure in centimetres.

Arm length is defined as the distance between the superior part of the acromion and the metacarpal heads. This was measured with the participant standing with the arms next to the side and hands relaxed in a fist. The distance between the acromion and the metacarpal heads was measured with a tape measure, the level of the acromion/starting position of measurement confirmed with a rigid spirit-level ruler. Upper body length is indicated by a measurement of the distance between the flat seat of a chair and the incisura jugularis of the manubrium sterni. The participant was placed in sitting position on the treatment plinth with the thighs and feet well supported. The distance between the flat surface of the plinth and the incisura jugularis of the manubrium sterni was measured with a rigid 1,5 meter metal ruler and a mathematical triangle with a sharp edge, levelled with a spirit level. The sharp point of the mathematical triangle was positioned at the incisura jugularis of the manubrium sterni and matched at right angles with the rigid metal ruler resting on the treatment plinth. A reading of the upper body length was taken from the rigid metal ruler. All measurements were repeated thrice and the mean of the three measurements was used as the reach distance, arm length and upper body length, respectively.

The three measurements were matched on a table of recommended reach distances developed by De Vey Mestdagh (1998), with the combined arm and upper body length determining what the reach should be (Appendix 7).

4.4.10.6 Handlebar height

Handlebar height is defined as the vertical distance between the handlebar stem and the top of the saddle (De Vey Mestdagh 1998). Silberman et al (2005) recommended that the vertical distance between the top of the saddle and the top of the handlebar stem should be 5-8 cm with the handlebar stem 5-8 cm below the top of the saddle.

The height of the stem of the handlebars and the top of the saddle was measured with a tape measure with the bicycle mounted on an A-frame resistance trainer and the distance between the floor and the lifted wheels subtracted from the measurement. A handlebar height that fell within the 5-8cm difference parameter set by Silberman (2005) was considered as adequate.

4.4.11 Data recording

The data from the questionnaires were directly exported from Qualtrics into a Microsoft Excel spreadsheet with the participants' reference numbers and the contact details of those who volunteered to participate in Part 2 of the study. The contact details and names of participants were placed in separate spread sheets to keep all personal information separate. The data were cleaned, column names adapted for ease of use in the statistical programme and the data checked for any inconsistencies. One participant was removed from the data sheet as he had completed the questionnaire twice. The data of another 14 participants were removed as they did not meet the selection criteria for hours spent on the bicycle. The printed questionnaires received were manually entered into the Qualtrics website database by the researcher.

The data obtained from the physical assessments were entered onto a standard data capturing form (Appendix 7) with each participant's reference number as received from the Qualtrics website. This information was subsequently transferred into a Microsoft Excel spreadsheet.

4.5 Statistical analysis

Intraclass correlations and Kappa values with their 95% confidence intervals were used to indicate the intrarater reliability of the tests expressed as poor (values less than 0.4), moderate (0.40-0.60), substantial (values greater than 0.60 but less than 0.75) and excellent (values higher than 0.75) (Portney and Watkins 2009).

Prevalence was expressed as a percentage along with a 95% confidence interval. In univariate analyses subjects with and without low back pain were compared using Students' two sample t-test and Mann-Whitney ranksum while for discrete variables Pearson's Chi-square test or Fisher's exact test was employed. The factors that were significant at the 0.20 level of significance were included into the multivariate analysis as to acquire a more generous look at the data and the influence of the factors on each other when put together in a logistic regression. From the multivariate analysis, i.e. logistic regression, the statistics of interest were odds ratios and their 95% confidence intervals for the exposure factors included in the regression. Testing was done at the 0.05 level of significance. Data analysis employed Stata Release 12.0 statistical software (StataCorp 2011).

For the purpose of the data analysis, categorisation of the data obtained in the physical assessment occurred as follows:

- **Body mass index**

Body mass index was divided into four sub-categories: underweight (if the BMI was less than 18.5), normal (BMI from 18.5 to less than 25), overweight (BMI from 25 to less than 30) and obese (BMI more than 30) (WHO 2006, Gallagher et al 2000). Body mass index was further categorised into "BMI in normal limit" for those with a normal BMI and "BMI out of limit" for the overweight and obese participants.

- **Lateral shift**

Lateral shift was defined as within normal limits if the shift during one leg stance was less than 10cm for each leg and the difference in shift between the two legs was less than 2cm (Luomajoki et al 2008, Luomajoki et al 2007).

- **Sitting forward lean**

The sitting-forward-lean test, as an indication of lumbar flexion control, was classified as within normal limits if the change in lumbar curvature, as measured with a tape measure between two pre-marked points, was less than one centimetre. The average of five measurements was used for the data analysis (Enoch et al 2011).

- **Slump**

The slump test, as a measure of the integrity of the neural dynamics, was divided into three groups. The slump test was defined as normal, if there were no abnormal symptoms indicating neural tension and if there was no limitation in range of motion for knee extension and dorsiflexion of the ankle. A covertly positive slump/neural dynamic test was defined as a positive neurodynamic test if there was a change in symptoms with structural differentiation (release of cervical flexion), but with no reproduction of the participant's LBPP symptoms. With an overtly positive slump test, there was a change in symptoms with structural differentiation as well as reproduction of the LBPP symptoms. The results were further classified as "normal" if the test was normal or covertly positive and "positive" if the participant reported a change in symptoms with the release of cervical flexion as well as the reproduction of the LBPP (overtly positive neurodynamic response) (Shacklock 2005).

- **Gluteus Maximus inner range holding capacity**

A normal inner range Gmax test encompassed all factors below (Richardson and Sims 1991):

  - ➢ equal active and passive ROM to neutral hip extension in the prone upper body support position
  - ➢ ability to maintain the position for two repetitions of 15 seconds each for each leg
  - ➢ efficient control of the lumbo-pelvic region (less than 10 mmHg change in pressure measured with the PBF units) throughout the concentric shortening, isometric holding and eccentric lowering

- **Leg-length discrepancy**

The measured difference in lengths between the left and the right leg was divided into three categories: Discrepancy less than 6mm, discrepancy less than 10mm and discrepancy less than 20mm (Brêtas et al 2009, Defrin et al 2005, Silberman et al 2005, Gurney 2002).

- **Active straight leg raise**

The scores reported for the ASLR of the left and the right leg were added. If the mean of the sum of the scores added up to more than one out of ten, the ASLR test was regarded as positive, indicating an impaired load transfer through the pelvis (Mens and Pool-Goudzwaard 2012, Mens et al 2001).

- **Hamstring length**

Hamstring length was defined as normal if the KEA for both legs was less than 20 degrees, as measured with a digital inclinometer (Davis et al 2008b).

- **Gluteus medius inner range holding capacity**

The inner range holding capacity of Gmed, as a measure of lumbo-pelvic stability, was regarded as within limit if the following conditions were met (Rabin et al 2013, Nelson-Wong et al 2009, Comerford et al 2007):

- Equal active and passive range of hip abduction to the benchmark of 45° hip abduction in the side lying position without substitution
- Ability to maintain this position for two repetitions of 15 second holds without substitution

- **Lumbar spine curvature on the bicycle**

The position/curvature of the lumbar spine on the bicycle was measured in three different positions: brake lever position (hands on the brake hoods), seated upright position (hands on the transverse bar of the handlebars) and drops position (hands on the drops) (Muyor et al 2011a).

- **Saddle height**

The height of the saddle was defined by the KEA on the bicycle with the tested leg in the BDC position. The saddle height was considered to be in limit if the KEA for both legs were between 25-35 degrees (Peveler et al 2007, Peveler et al 2005).

- **Saddle set-back**

Saddle set-back was defined as within normal limits if a plumb line dropped from the posterior aspect of the patella of the knee was in line with the pedal spindle with the pedal in the forward horizontal position (3 o'clock) parallel to the floor (Silberman et al 2005, De Vey Mestdagh 1998).

- **Saddle angle**

The angle of the saddle was classified as within normal limits if it was level or tilted anteriorly (Silberman et al 2005, Salai et al 1999).

- **Handlebar height**

Handlebar height was calculated by subtracting the actual height of the handlebars as measured from the floor from the height of the saddle (measured from the floor to the top of the saddle). It was defined as within normal limits if the handlebars were 5-8cm saddle below the saddle (Silberman et al 2005).

- **Reach**

Reach was calculated by adding the average arm length and upper body length, combining it with the reach distance from the rear of the saddle to the handlebars and comparing it to values set out by De Vey Mestdagh (1998). No literature could be found on whether the average length of the two arms, the shorter arm or the longer arm should be used in this calculation. For the purpose of this study, the average length of the two arms was used for the calculation of the reach distance (Marsden 2009).

- **Cleat position**

The position of the cleat on the shoe was deemed as within limits if the cleat was in line with the first metatarsal head and out of limit if it was either too far forwards or too far back (Wanich et al 2007, Silberman et al 2005, De Vey Mestdagh 1998).

4.6 Summary

The research design, sample selection, measuring instruments and procedure around these were described in this chapter. The procedures used in collecting and recording the data (and the statistical analysis) were also described and the results of the statistical analysis will be presented and described in Chapter 5.

CHAPTER 5: RESULTS

5.1 Introduction

The aim of this study was to determine the prevalence of LBPP in cyclists, the possible risk factors for LBPP in these cyclists and the association between these risk factors. Data were collected by means of a questionnaire and a physical assessment (as described in Chapter 4). This chapter is structured according to the objectives of the study as set out in Chapter 1. A summary of the presentation of the results is provided in Figure 5.1.

Due to the tremendous number of results obtained from this study, only the main findings are presented in this chapter in order to ensure clarity of the findings. All data is available in Appendix 8-10 and will, as far as possible, be referred to in the text. Additional data was organised as follows:

- Appendix 8 – Additional data on the reliability study
- Appendix 9 – Additional data on the factors assessed in the physical examination (anthropometric, intrinsic and bicycle set-up factors)
- Appendix 10 – Additional data on the interrelationships between factors

Summaries of the main findings for the different sub-sections of the results are given in Table 5.10, Table 5.12, Table 5.13, Table 5.14, Figure 5.2, Figure 5.3 and Figure 5.4.

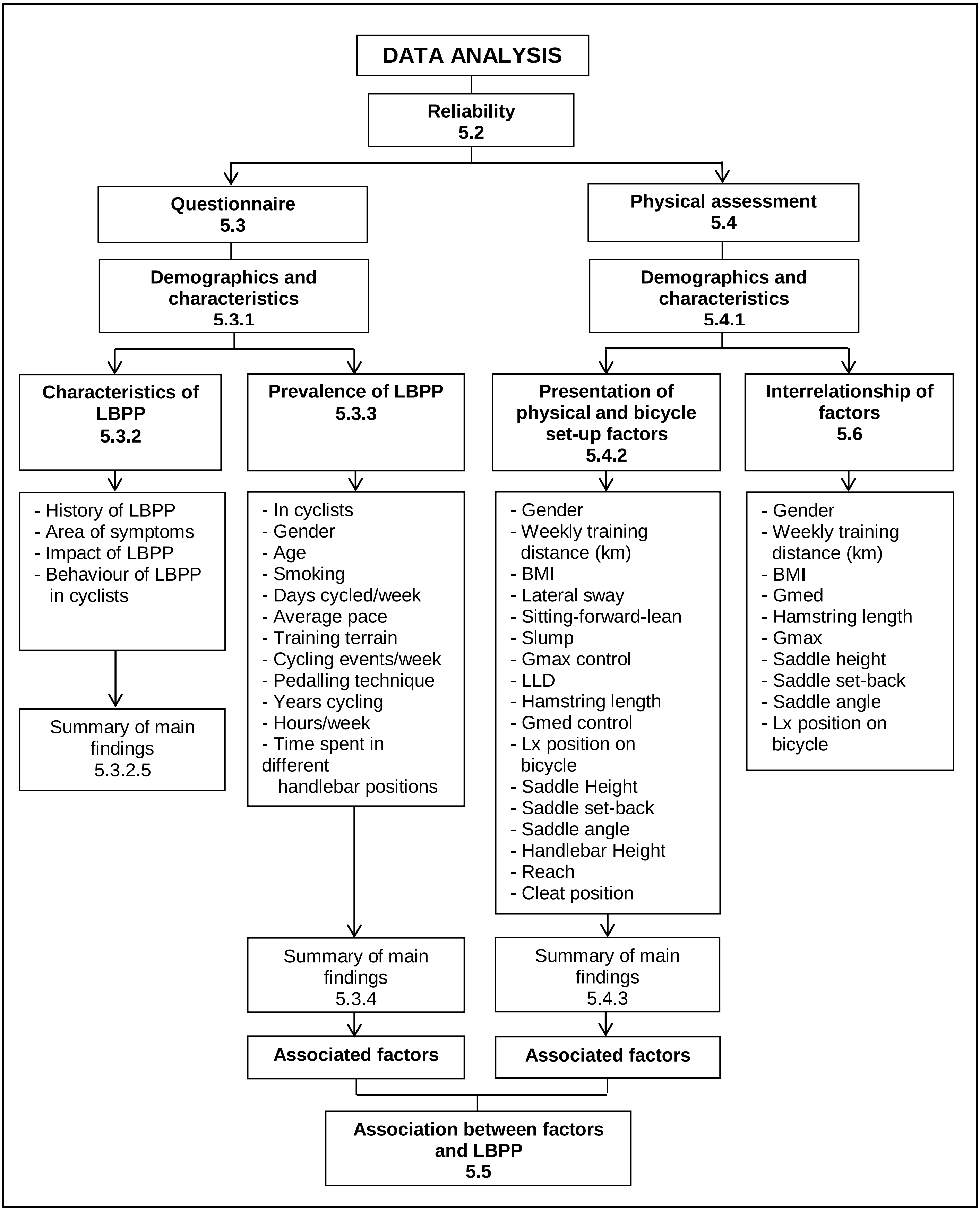

Figure 5.1 Schematic presentation of results

5.2 Reliability

5.2.1 Physical assessment

Intrarater reliability or repeatability was the measure used to establish the reliability of the measurements taken during the assessment. The reliability assessment was done on two occasions, seven days apart. The rater, namely the researcher, was blinded to any of the findings of the first assessment during the second assessment. A summary of the reliability of the factors measured in the physical assessment can be found in Table 5.1 and Table 5.2.

Table 5.1 Reliability of the physical assessment measures

Factor	Intra-class correlation (ICC)	Kappa (κ)	95%CI
Left arm length	0.99***	-	0.989-1.001
Right arm length	1.00***	-	0.991-1.000
Upper body length	0.95***	-	0.892-1.004
Lateral sway to the left	0.73**	-	0.461-0.988
Lateral sway to the right	0.19	-	0.000-0.728
Sitting forward lean average lean	0.76***	-	0.519-0.994
Sitting forward lean distance	0.76***	-	0.522-0.994
Leg-length left	1.00***	-	0.996-1.000
Leg-length right	0.99***	-	0.988-1.000
Hamstring KEA left	0.90***	-	0.795-1.005
Hamstring KEA right	0.83***	-	0.672-1.003
Lx position brake levers Tx/Lx	0.91***	-	0.802-1.019
Lx position brake levers Lx/Sx	0.86***	-	0.689-1.026
Lx curvature brake levers	0.85***	-	0.680-1.026
Lx position seated upright Tx/Lx	0.87***	-	0.714-1.017
Lx position seated upright Lx/Sx	0.74**	-	0.476-1.014
Lx curve seated upright position	0.79***	-	0.554-1.017
Lx position drops Tx/Lx	0.90***	-	0.777-1.028
Lx position drops Lx/Sx	0.90***	-	0.777-1.028
Lx curve drops position	0.90***	-	0.764-1.029
Slump final category	-	-0.11	-0.619-0.390
Gmax final category	-	0.63**	0.124-1.133
ASLR final category	-	0.68**	0.131-1.219
Gmed final category	-	0.43*	-0.014-0.883

Key: Excellent intrarater reliability (ICC / Kappa > 0.75) = ***; Substantial intrarater reliability (ICC / Kappa of >0.60) = **, Moderate intrarater reliability (ICC / Kappa of 0.40-0.60) = *; Poor intrarater reliability (ICC / Kappa < 0.4).

Final categories were derived from the combined outcomes of the left and right sides. If either measurement did not fall in the recommended range for that factor it was taken as a negative outcome. Further information on the measurements for the left and right sides can be found in Appendix 8 (Table A8.1 and Table A8.2).

The results of the repeatability assessment of the physical examination factors indicate excellent intrarater reliability/repeatability for the assessment of left and right arm length, upper body length, sitting-forward-lean average lean and lean distance, left and right leg-lengths, left and right KEA, thoraco-lumbar angle and spinal curvature in the brake lever, seated upright and drops positions and lumbo-sacral angle in the brake lever and drops position.

Two of the participants of the reliability study participated in endurance sporting activities (running marathon and endurance horse riding event) two days before the second measurement and first measurement respectively which, because of fatigue and lactose build-up, could act as confounding factors for the test-retest reliability of especially the measurements of Gmax, Gmed and the one-leg stance test.

5.2.2 Reliability of bicycle set-up measurements

The results of the intrarater reliability for the mearurement of bicycle set-up can be found in Table 5.2. Excellent intrarater reliability was obtained for the measurement of the saddle angle, saddle height measured from the floor, handlebar height measured from the floor, difference in the height of the handlebars and the saddle, reach from the rear of the saddle to the handlebars, and the final category of saddle set-back (classified following the measures obtained from the left and right leg as in limit or not in limit for both legs).

Table 5.2 Reliability of bicycle set-up measurements

Factor	ICC	Kappa (κ)	95% CI
Saddle height left leg	0.20	-	0.000-0.756
Saddle height right leg	0.75**	-	0.502-1.003
Saddle angle	0.89***	-	0.771-1.010
Saddle height (floor to top of saddle)	1.00***	-	0.996-1.000
Top handlebar height (floor to handlebars)	1.00***	-	0.996-1.000
Handlebar height (difference saddle height to handlebar height)	1.00***	-	0.989-1.001
Reach (rear saddle to handlebars)	1.00***	-	0.994-1.000
Saddle height final category	-	0.43*	-0.036-0.893
Saddle set-back final category	-	0.81***	0.233-1.394
Cleat position final category	-	0.65**	0.140-1.158

Key: Excellent intrarater reliability (ICC / Kappa > 0.75) = ***; Substantial intrarater reliability (ICC / Kappa of >0.60) = **, Moderate intrarater reliability (ICC / Kappa of 0.40-0.60) = *; Poor intrarater reliability (ICC / Kappa < 0.4).

In an attempt to increase the reliability of the lateral shift (one leg stance) test, a spirit level ruler was used to measure the lateral excursion of the navel. Markers were also positioned on the greater trochanter, lateral malleolus and lateral knee joint line in an attempt to measure the angle of the knee more accurately on the bicycle when assessing the saddle height. At the time of testing, no further measures could be thought of to increase the accuracy of the Gmax and Gmed measurements as inclinometers, PBF units and rods were already utilised to control for as many of the confounding factors as possible. Both these tests were considered as the best available for assessing muscular control and functioning and were subsequently used despite the lower reliability.

5.3 Questionnaire

5.3.1 Demographics

A link to the questionnaire on the Qualtrics website (Qualtrics 2012) was sent out via e-mail. A total of 414 people accessed the website of which 183 were automatically excluded on the Qualtrics website as they did not meet the inclusion criteria of the study. From the 414 cyclists who accessed the website, 231 were included in the study and completed the questionnaire. The mean age of the participants was 45 years (Standard Deviation (SD) = 11.12). Forty seven females (20%) and 184 males (80%) completed the questionnaire. The demographic factors and description of the population are summarised in Table 5.3 and Table 5.4.

Table 5.3 Demographic, anthropometric and training factors of the participants of the questionnaire

Factor	Category	Participants n (%)
Gender	Male	184 (79.7)
	Female	47 (20.3)
Smoking	Currently	7 (3.0)
	Previously, but quit	66 (28.6)
	Never	158 (68.4)
Daily activities	Manual labour	10 (4.3)
	Desk/computer work	178 (77.1)
	Driving	9 (3.9)
	Other	34 (14.7)
Work position	Sitting	131 (56.7)
	Standing	6 (2.6)
	Combination	94 (40.7)
Number of days cycling per week	1-2 days/week	52 (22.5)
	3 days/week	54 (23.4)
	4 days/week	59 (25.5)
	5-6 days/week	66 (28.6)
Average cycling pace	≤25km/h	56 (24.2)
	26-30 km/h	128 (55.4)
	>30 km/h	47 (20.4)
Type of training terrain	Mostly flat	20 (8.7)
	Mostly hilly	31 (13.4)
	Combination	180 (77.9)
Number of cycling events per year	0-2	24 (10.4)
	3-5	98 (42.4)
	6-10	76 (32.9)
	>10	33 (14.3)
Cycling technique mostly used	High cadence	126 (54.6)
	Low cadence	65 (28.1)
	Bigger gears	106 (45.9)
	Smaller gears	65 (28.1)

Table 5.4 Additional demographic and training factors for participants of the questionnaire

Factor	Sub-categories	Mean (SD)	95% Confidence interval (CI)
Age	-	45.20 (11.13)	43.76-46.65
Number of years cycling	-	10.87 (10.52)	9.51-12.23
Hours per week cycling	-	6.51 (2.68)	6.16-6.85
Percentage time spent per riding position	Seated upright position	37.13(26.36)	33.71-40.55
	Drops position	9.67 (12.04)	8.11-11.23
	Brake levers	48.09 (26.67)	44.64-51.55
	Standing position	9.87 (7.91)	8.85-10.90

5.3.2 Characteristics of lower back and pelvis pain in cyclists

5.3.2.1 History of lumbo-pelvic pain

The behaviour of the pain was investigated for all participants who reported lower back or pelvis pain during or after cycling. A summary can be found in Table 5.5.

Table 5.5 Low back pain history in participants reporting LBPP during or after cycling

History	Respondents (n=148) n (%)
Last episode of lower back or pelvis pain during or after cycling	
• Current pain	39 (26.4)
• During the last week	31 (21.0)
• During the last month	44 (29.7)
• During the past 6 months	23 (15.5)
• During the past 12 months	7 (4.7)
• More than 12 months ago	4 (2.7)
Number of episodes of lower back or pelvis pain during or after cycling in the last five years	
• 1-5 incidences	36 (24.3)
• 6-10 incidences	36 (24.3)
• 11-15 incidences	12 (8.1)
• More than 20 incidences	34 (23.0)
• Lower back or pelvis pain most of the time	30 (20.3)

The table above illustrates that the largest group of participants (n=44, 29.73%), reported experiencing lower back or pelvis pain during or after cycling in the last month. In addition to this, one to five episodes and six to ten episodes of lower back or pelvis pain in the last five years were reported by an equal number of participants, 24.32% (n=36). From the information obtained from the questionnaire, the majority of participants reported not experiencing any pain referral into other areas (n=115, 77.7%).

5.3.2.2 Area of lower back or pelvis pain symptoms

Table 5.6 illustrates the area of pain as reported by the participants.

Table 5.6 Report on the area of LBPP distribution

Area of pain	Respondents (n=148) n (%)
Central lower back pain	60 (40.5)
Unilateral lower back pain	40 (27.0)
Sacro-iliac joint pain	74 (50.0)
Other areas	8 (5.4)

Participants were allowed to select more than one option for this question in the questionnaire

Half the participants (50%, n=174) experienced pain in the sacro-iliac joint area during or after cycling.

5.3.2.3 Impact of lower back or pelvis pain experienced during or after cycling

The results of the impact of LBPP are illustrated in Table 5.7.

Table 5.7 Reported impact of lower back or pelvis pain on training

Impact on training	Respondents (n=148) n (%)
Training not affected	63 (42.6)
Trained through pain	59 (39.9)
Trained with the assistance of analgesics or anti-inflammatory medication	16 (10.8)
Unable to train for one week	4 (2.7)
Unable to train for 1-3 weeks	3 (2.0)
Unable to train for 4-8 weeks	2 (1.4)
Unable to train for 9-12 weeks	0
Unable to train for 3-6 months	1 (0.7)

The impact of LBPP on cycling training seemed to be limited as reported by the participants (Table 5.7). Forty three percent (n=63) reported that their training was not affected by the LBPP they experienced during cycling and forty percent (n=59) reported that they could train through the pain. Training was ceased for various time frames in only 7% of participants, indicating a limited impact of the LBPP on training.

5.3.2.4 Behaviour of LBPP with cycling

Table 5.8 illustrates the results of the behaviour of the LBPP during cycling as described by the participants.

Table 5.8 Relationship between lower back or pelvis pain and cycling

Behaviour of LBPP	Respondents (n=148) n (%)
Time to onset of lower back or pelvis pain while cycling	
• 0-10 minutes	3 (2.0)
• 11-30 minutes	7 (4.7)
• 30 minutes to 1 hour	19 (12.8)
• 1-2 hours	42 (28.4)
• More than 2 hours	75 (50.7)
• After cycling	2 (1.4)
Riding position associated with lower back or pelvis pain	
• Upright seated position	61 (41.2)
• Drop position	37 (25.0)
• Brake levers	92 (62.2)
• Standing position	8 (5.4)

Participants were allowed to select more than one option for this question on the riding position associated with the LBPP in the questionnaire

The table above illustrates that 50.7% (n=75) only experienced LBPP after they had been cycling for more than two hours. In addition to this, cycling was attributed as the cause of the lower back or pelvis pain in 68.9% (n=102) of participants who reported LBPP during or after cycling. Riding with the hands on the brake levers was reported as the riding position where the majority of participants (62.2%, n=92) experienced their lower back or pelvis pain.

5.3.2.5 Summary of the characteristics of LBPP in cyclists

The characteristics of lower back and pelvis pain experienced during or after cycling are summarised in Figure 5.2.

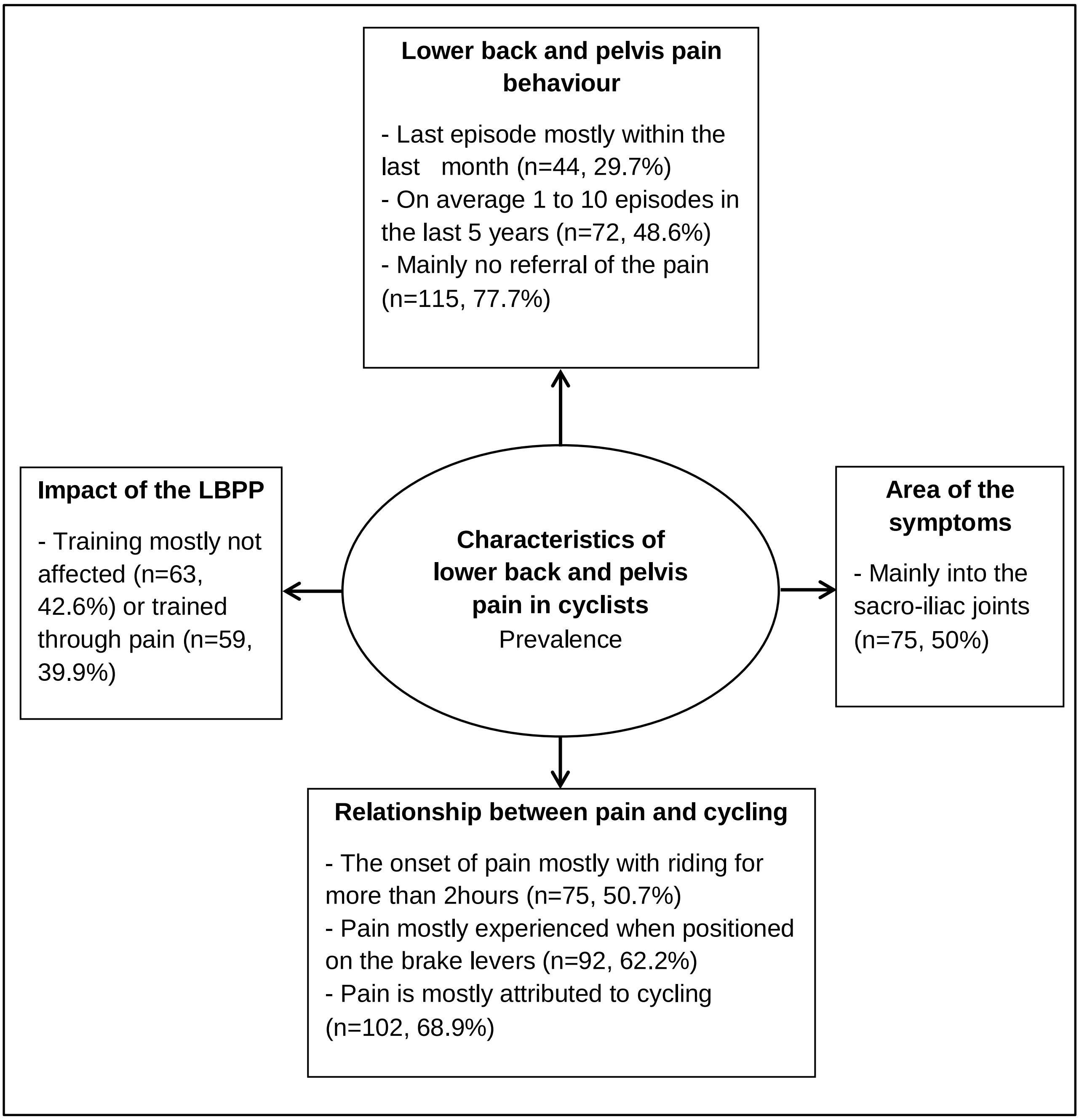

Figure 5.2 Characteristics of lower back and pelvis pain in cyclists

5.3.3 Prevalence of lower back and pelvic pain

The lifetime prevalence of LBPP in cyclists was 65.4% (n=151). Of the population that reported experiencing LBPP during or after cycling 117 (77.5%) were male and 34 (22.5%) were female. **Table 5.9** illustrates the prevalence of LBPP in cyclists.

Table 5.9 Prevalence of LBPP

History of lower back or pelvis pain	Respondents n (%)
General lifetime prevalence of LBPP in daily living	163 (70.6)
LBPP with cycling: lifetime prevalence	151 (65.4)
LBPP with cycling: one-year prevalence	144 (62.3)
LBPP with cycling: point prevalence	39 (16.9)

5.3.4 Association between anthropometric factors, training factors and LBPP in cyclists

None of the anthropometric or training factors assessed from the data provided in the questionnaire had a statistically significant association with the prevalence of LBPP (Table 5.10). All factors assessed from the questionnaire for their possible association with LBPP are summarised in Table 5.10 together with the significance of each factor. The individual results of the association of all the factors with the prevalence of LBPP in cyclists can be found in Appendix 9.

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Table 5.10 Summary of the association between various factors and LBPP as identified from the questionnaire

Factors	Category	Respondents no LBPP n (%)	Respondents with LBPP n (%)	p-value
Gender	Female	14 (17.5)	34 (22.5)	0.37
	Male	66 (82.5)	117 (77.5)	
Age	Mean (SD)	45.31 (11.16)	45.15 (11.15)	0.91
Smoking	Currently	2 (2.5)	5 (3.31)	0.96
	Previously, but quit	22 (27.5)	44 (29.1)	
	Never	56 (70)	102 (67.6)	
Number of days cycled per week	1-2 days/week	18 (22.5)	34 (22.5)	0.50
	3 days/week	16 (20)	38 (25.2)	
	4 days/week	25 (31.3)	34 (22.5)	
	5-6 days/week	21 (26.3)	45 (29.8)	
Average cycling pace	≤25 km/h	21 (26.3)	35 (23.2)	0.29
	26-30 km/h	39 (48.8)	89 (58.9)	
	>30 km/h	20 (25)	27 (17.9)	
Type of training terrain	Mostly flat	7 (8.8)	13 (8.6)	0.65
	Mostly hilly	13 (16.3)	18 (11.9)	
	Combination	60 (75)	120 (79.5)	
Number of cycling events per year	0-2	9 (11.3)	15 (9.9)	0.61
	3-5	32 (40)	66 (43.7)	
	6-10	30 (37.5)	46 (30.5)	
	>10	9 (11.3)	24 (15.9)	
Pedalling technique mostly used	High cadence	47 (58.8)	79 (52.3)	0.35
	Low cadence	19 (23.8)	46 (30.5)	0.28
	Big gears	35 (43.8)	71 (47)	0.64
	Small gears	22 (27.5)	43 (28.5)	0.88
Number of years cycled	Mean (SD) (years)	9.89 (9.73)	11.39 (10.91)	0.22
Number of hours cycled per week	Mean (SD) (hours)	6.51 (2.51)	6.50 (2.77)	0.78
Percentage of time spent in different handlebar positions Mean (SD)	Seated upright position	36.35 (25.8)	37.54 (26.73)	0.79
	Drop position	10.45 (12.89)	9.25 (11.58)	0.49
	Brake levers	47.81 (25.98)	48.25 (17.11)	0.81
	Standing position	9.79 (8.58)	9.92 (7.57)	0.34

None of these factors were further assessed as there were no statistically significant association between any of these factors and LBPP in cyclists.

5.4 Physical and bicycle set-up assessment

5.4.1 Demographics

5.4.1.1 Number of participants, gender and age

From the 231 cyclists who completed the questionnaire, 121 volunteers were included in the physical assessment. An analysis of the loss of participants from those who completed the questionnaire can be found in Table 5.11. Eighty percent (n=97) of the cyclists who volunteered to participate in the physical assessment were male and 20% (n=24) were female. The mean age per gender was 41.96 years for the females and 47.38 years for the males.

Table 5.11 Recalling of participants from questionnaire to physical assessment

Participants	Respondents n	%
Volunteered to participate in the physical assessment and were included	121	52.38
Did not volunteer to participate in the physical assessment	51	22.08
Did not meet the criteria for participation anymore	9	3.90
Could not be reached	4	1.73
Could not attend physical assessment during the data collection period	10	4.33
Excluded due to geographic location (out of Gauteng province)	32	13.85
Unable to participate due to unforeseen circumstances (emigrated, bicycle accident)	4	1.73
Total number of participants	231	100

5.4.1.2 Characteristics of physical functioning

A summary of the objective findings of the physical assessment and the bicycle-set up assessment can be found in **Figure 5.3** and **Figure 5.4**. For the table of full results refer to Appendix 9.

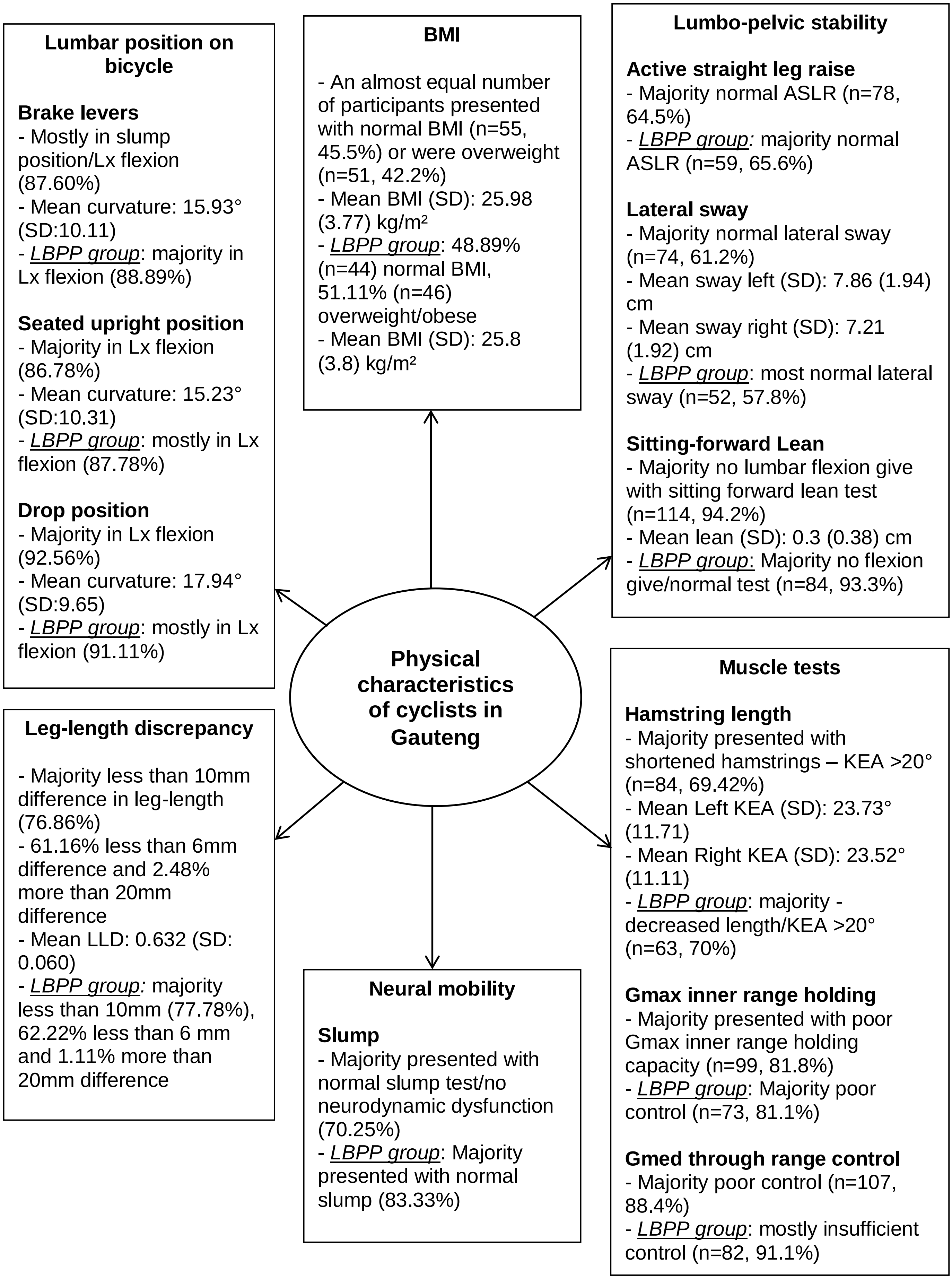

Figure 5.3 Summary of the physical characteristics of cyclists

Description of bicycle setup factors

Reach

- Majority of cyclists' have an incorrect reach distance (n=110, 90.9%)
- Majority of cyclists are too bunched up (reach forward too short) (n=52.9, 52.9%).
-<u>LBPP group</u>: Majority too bunched up (n=49, 54.4%)

Cleat position

- Majority of cyclists – cleats positioned incorrectly on shoes (n=68, 56.2%)
- <u>LBPP group</u>: Majority of cleats positioned incorrectly on shoes (n=52, 57.8%)

Position of the saddle

Saddle Height
- Majority of cyclists' saddle height out of the recommended range (n=78, 64.5%)
- Saddle too high in 10.7% (n=13)
- Saddle too low in 21.5% (n=26)
- Asymmetry between left and right sides in 33.9% (n=41)
- <u>LBPP group</u>: Majority presented with saddle height out of range (n=55, 61.1%), with the majority presenting with asymmetry between sides (n=26, 28.9%) or too low saddle (n=20, 22.2%)

Saddle set-back
- Majority presented with a saddle set-back out of the recommended range (n=73, 60.3%) of which the saddle was set too far forward for the majority
- <u>LBPP group</u>: Majority – saddle set-back not in recommended range (n=57, 63.3%).

Saddle angle
- Majority of saddles are tilted anteriorly (n=58, 47.9%) followed by 38.8% (n=47) tilted posteriorly.
- Mean (SD) tilt: 0.72° (2.5)
- <u>LBPP group</u>: Majority of saddles tilted anteriorly (n=45, 50%) followed by 35.6% (n=32) tilted posteriorly
- Mean (SD) tilt: 0.81° (2.6)

Handlebar height

- In the majority of cyclists the handlebar height was out of the recommended limit of 5-8 cm below the saddle (n=84, 69.4%)
- Majority of handlebars too high (n=66, 54.6%)
-<u>LBPP group</u>: Majority out of the recommended range (n=64, 71.1%), with the majority of handlebars again set too high (n=53, 58.9%)

Figure 5.4 Summary of the bicycle setup factors

5.4.2 Presentation of physical and bicycle set-up factors

Of the 121 participants who volunteered to participate in the physical assessment, 74.4% (n=90) reported experiencing LBPP during or after cycling of whom 21.1% (n=19) were female and 78.9% (n=71) were male. All the results of the physical and bicycle set-up assessments are summarised in Table 5.12, Table 5.13 and Table 5.14.

Table 5.12 Summary of the relationship between LBPP and lumbar angle and curvature on the bicycle

Position	Sub-categories	Mean (SD)		p-value	95% CI
		No LBPP	LBPP		
Brake lever position	Thoraco-lumbar (T12/L1)	47.13 (6.85)	49.8 (7.08)	0.06#	47.84-50.39
	Lumbo-sacral (L5/S1)	34.87 (7.38)	32.57 (8.21)	0.11#	31.71-64.60
	Lumbar curvature	12.23 (8.58)	17.20 (10.32)	0.01*	14.11-17.75
Seated upright position	Thoraco-lumbar (T12/L1)	42.26 (7.53)	44.48 (6.96)	0.15#	42.62-45.20
	Lumbo-sacral (L5/S1)	30.55 (7.16)	28.04 (8.68)	0.06#	27.18-30.19
	Lumbar curvature	11.65 (8.30)	16.46 (10.68)	0.01*	13.37-17.09
Drop position	Thoraco-lumbar (T12/L1)	56.77 (7.34)	59.8 (6.85)	0.05*	57.75-60.30
	Lumbo-sacral (L5/S1)	42.26 (6.61)	40.7 (8.24)	0.13#	39.69-42.51
	Lumbar curvature	14.59 (8.36)	19.10 (9.84)	0.02*	16.21-19.68

Key: Factors with significance <0.2 to be included in the logistical regression = #,
statistically significant relationship (<0.05) =*

Table 5.13 Summary of the relationship between physical factors and LBPP

Factor	Sub-categories	Respondents		p-value	95% CI
		No LBPP n (%)	LBPP n (%)		
Gender	Female	5 (16.1)	19 (21.1)	0.61	0.58-0.93
	Male	26 (83.9)	71 (78.9)		0.63-0.82
Distance cycled per week (km)	Mean (SD)	176 (116.14)	191.7 (92.68)	0.19#	169.94-205.65
Body mass index	Mean (SD)	26.62 (3.61)	25.76 (3.82)	0.24	25.30-26.66
	Final category: In limit Out of limit	 11 (35.5) 20 (64.5)	 44 (45.9) 46 (51.1)	0.20#	0.57-0.80
	Normal	11 (35.5)	44 (48.9)	0.27	0.67-0.90
	Overweight	14 (45.2)	37 (41.1)		0.58-0.84
	Obese	6 (19.4)	9 (10)		0.32-0.84
Lateral sway	In limit Out of limit	22 (71.0) 9 (29.0)	52 (57.8) 38 (42.2)	0.19#	0.67-0.91
Sitting forward lean	In limit Out of limit	30 (96.8) 1 (3.2)	84 (93.3) 6 (6.7)	0.68	0.42-1.00
Slump	Final category: In limit Out of limit	 29 (93.6) 2 (6.5)	 75 (83.3) 15 (16.7)	0.23	0.64-0.99
	Normal	24 (77.4)	61 (67.8)	0.38	0.61-0.81
	Covertly positive	5 (16.1)	14 (15.6)		0.49-0.91
	Overtly positive	2 (6.5)	15 (16.7)		0.64-0.99
Gmax	In limit Out of limit	5 (16.1) 26 (83.9)	17 (18.9) 73 (81.1)	1.00	0.64-0.82
	Asymmetry	6 (19.4)	23 (25.6)	0.49	0.60-0.92
Leg-length discrepancy	Mean (SD) (cm)	0.75 (0.92)	0.59 (0.55)	0.67	0.51-0.75
	> 6mm	13 (41.9)	34 (37.8)	0.68	0.57-0.84
	>10mm	8 (25.8)	20 (22.2)	0.68	0.51-0.87
	>20mm	2 (6.5)	1 (1.1)	0.16#	0.01-0.91
Active straight leg raise	In limit Out of limit	19 (61.3) 12 (38.7)	59 (65.6) 31 (34.4)	0.67	0.56-0.85
Hamstring length	Mean (SD) KEA left leg (°)	21.3 (10.0)	24.6 (12.2)	0.22	21.62-25.83
	Mean (SD) KEA right leg (°)	22.8 (9.6)	23.8 (11.6)	0.80	21.52-25.52
	In limit Out of limit	10 (32.3) 21 (67.7)	27 (30) 63 (70)	0.81	0.64-0.84
	Asymmetry	5 (16.1)	13 (14.4)	0.78	0.35-0.90
Gmed	In limit Out of limit	6 (19.4) 25 (80.7)	8 (8.9) 82 (91.1)	0.12#	0.67-0.84
	Asymmetry	8 (25.8)	32 (35.6)	0.32	0.64-0.91

Key: Factors with significance <0.2 included in the logistical regression = #, statistically significant relationship (<0.05) =*

Table 5.14 Summary of the relationship between bicycle set-up and LBPP

Factor	Subfactor	Respondents		p-value	95% CI
		No LBPP n (%)	LBPP n (%)		
Saddle height	Final category In limit Not in limit	 8 (25.8) 23 (74.2)	 35 (38.9) 55 (61.1)	0.19#	0.59-0.80
	In limit	8 (25.8)	35 (38.9)	0.45	0.67-0.92
	Asymmetry between KEA	13 (41.9)	26 (28.9)		0.50-0.81
	Too high	4 (12.9)	9 (10.0)		0.39-0.91
	Too low	6 (19.4)	20 (22.2)		0.56-0.91
Saddle set-back	In limit Not in limit	15 (48.4) 16 (51.6)	33 (36.7) 57 (63.3)	0.25	0.67-0.87
Saddle angle	Mean (SD)	0.42 (2.20)	0.81 (2.58)	0.44	0.26-1.17
	Final category In limit Not in limit	 16 (51.6) 15 (48.4)	 58 (64.4) 32 (35.6)	0.21	0.53-0.81
	Level	3 (9.7)	13 (14.4)	0.51	0.54-0.96
	Tilted anterior down	13 (41.9)	45 (50)		0.65-0.87
	Tilted posterior down	15 (48.4)	32 (35.6)		0.53-0.81
Handlebar height	Mean (SD)	5.23 (3.11)	4.50 (3.79)	0.15#	4.09-5.29
	Final category In limit Not in limit	 11 (35.5) 20 (64.5)	 26 (28.9) 64 (71.1)	0.49	0.66-0.85
	In limit	11 (35.5)	26 (28.9)	0.20	0.53-0.84
	Too high	13 (41.9)	53 (58.9)		0.69-0.89
	Too low	7 (22.6)	11 (12.2)		0.36-0.83
Reach	Average of limbs In limit Out of limit	 1 (3.2) 30 (96.8)	 10 (11.1) 80 (88.9)	0.29	0.63-0.81
	In limit	1 (3.2)	10 (11.1)	0.27	0.59-1.00
	Too short	15 (48.4)	49 (54.4)		0.64-0.86
	Too far	15 (48.4)	31 (34.4)		0.52-0.80
Reach ratio	Mean (SD)	1.57 (0.06)	1.57 (0.07)	0.52	1.56-1.58
Cleat position	In limit Out of limit	15 (48.4) 16 (51.6)	38 (42.2) 52 (57.8)	0.55	0.65-0.86

Key: Factors with significance <0.2 included in the logistical regression = #, statistically significant relationship (<0.05) = *

Of all the factors assessed, only lumbar curvature was significantly related to LBPP in cyclists in the univariate analysis. From the univariate analysis, all factors with a significance value of less than 0.2 were included in a multivariate analysis, as indicated in

Figure 5.5. The thoraco-lumbar (T12/L1) and lumbo-sacral (L5/S1) angles were omitted from the multivariate analysis as they constituted the lumbar curvature in all three handlebar positions. The results of all the factors assessed can be found in Appendix 9.

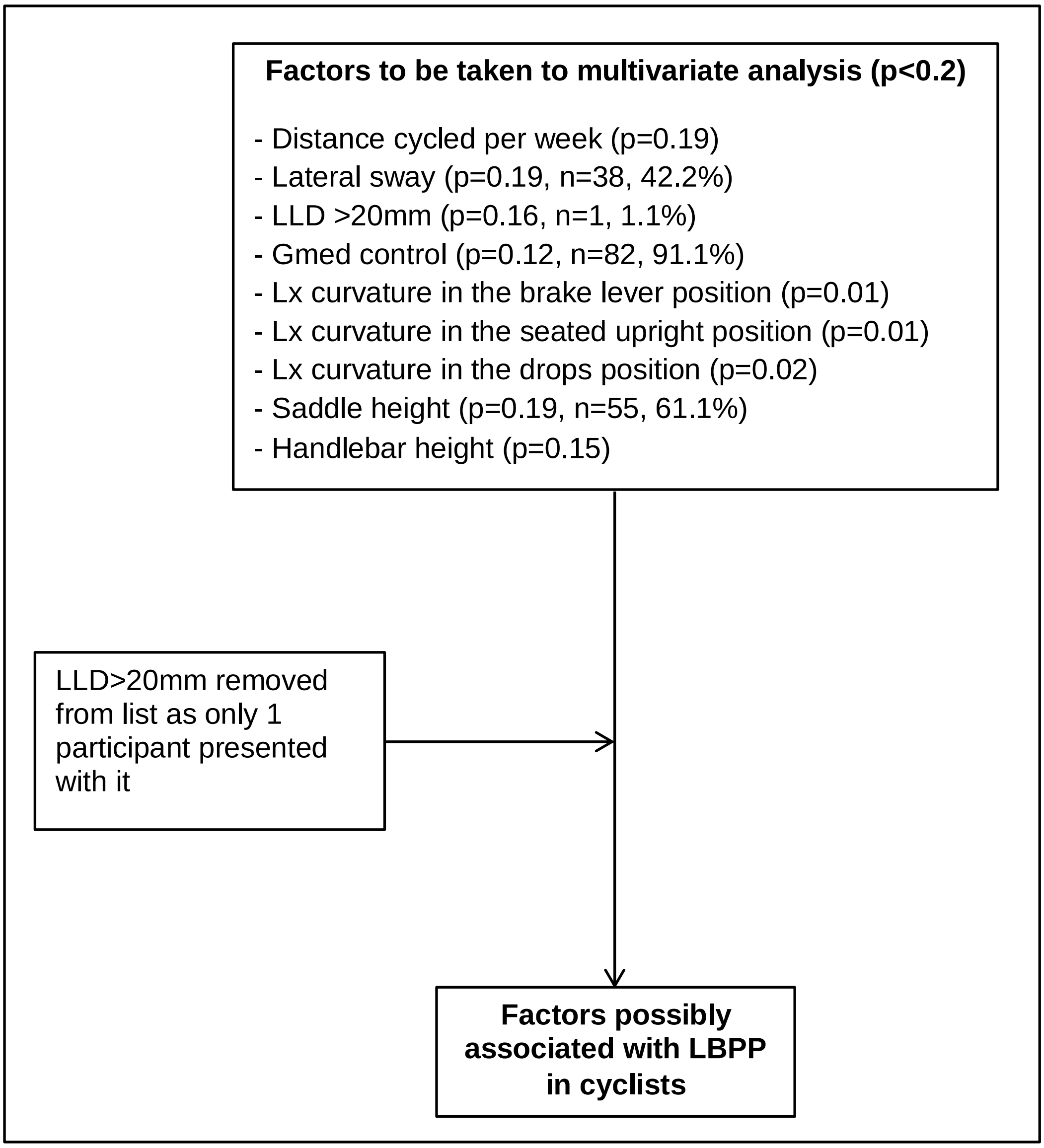

Figure 5.5 Summary of factors taken to the multivariate analysis

5.5 Exploratory analysis of the relationship between factors and LBPP

The results of the logistical regression of the factors that presented with significance lower than 0.20 in the univariate analysis is illustrated in Table 5.15. The category "LLD less than 20mm" was not included in the logistical regression as only one participant had a LLD greater than 20mm, which would skew the findings.

Table 5.15 Logistical regression of factors from the univariate analysis

Risk factor	Odds ratio	95% Confidence interval	p-value
Handlebar height	0.90	0.78-1.03	0.11
Saddle height	0.55	0.21-1.48	0.24
Lumbar curvature in brake lever position	1.01	1.00-1.09	0.03*
Gmed	3.43	0.98-11.94	0.05*
LLD <20mm	0.21	0.02-2.61	0.22

Key: Factors with a statistically significant relationship (<0.05) =*

In the multivariate analysis, only the lumbar curvature with the hands in the brake lever position (p=0.03) and weakness of Gmed (p=0.05) were significantly associated with LBPP in cyclists. The multivariate analysis indicates that the risk for LBPP increases by 1.01 times for every degree of lumbar flexion added when seated in the brake lever position. Cyclists with weakness of Gmed are also 3.4 times more likely to develop LBPP than those without.

The aim of this study was to investigate the association of various factors with LBPP. Those associated with LBPP can still not be regarded as risk factors as their sensitivity and specificity for identifying LBPP in cyclists need to be established, which is beyond the scope of this study.

5.6 Associations of various factors with each other

The significant relationships of all factors compared with each other in the univariate analysis are discussed in this section. A breakdown of the interrelationships of all relevant factors can be found in Appendix 10.

5.6.1 Gender

Gender was significantly related to BMI (p=0.005), Gmax inner range holding capacity (p=0.006), hamstring length (p=0.001), Gmed through range control (p=0.003) and to the thoraco-lumbar and lumbo-sacral angles and curvatures in all three handlebar positions (Table 5.16). Interrelationships between gender and various factors are illustrated in Table A10.1 (Appendix 10).

Table 5.16 Association between gender and lumbar position on the bicycle

Factor	Riding position	Sub-factor	p-value
Lumbar position	Brake levers	T12/L1	0.044*
		L5/S1	0.001*
		Lumbar lordosis	0.023*
	Seated upright	T12/L1	0.036*
		L5/S1	0.001*
		Lumbar lordosis	0.029*
	Drop position	T12/L1	0.001*
		L5/S1	0.001*
		Lumbar lordosis	0.042*

Key: Statistically significant relationship (<0.05) = *

5.6.2 Distance cycled per week

Distance cycled per week was significantly associated with gender (p=0.012) alone (Table A10.2, Appendix 10).

5.6.3 Body mass index

A statistically significant relationship was found between BMI and Gmed (p=0.01). Body mass index was also significantly associated with the thoraco-lumbar angle as well as the actual lumbar lordosis in all three riding positions on the bicycle. These relationships are illustrated in Table 5.17 and Table A10.3 (Appendix 10).

Table 5.17 Association between BMI and lumbar angle on the bicycle

Riding position	Lumbar position	p-value
Brake levers	T12/L1	0.001*
	Lumbar lordosis	0.002*
Seated upright	T12/L1	0.001*
	Lumbar lordosis	0.004*
Drop position	T12/L1	0.001*
	Lumbar lordosis	0.001*

Key: Statistically significant relationship (<0.05) = *

5.6.4 Gluteus Medius

Of all the factors compared to Gmed, only BMI (p=0.01), inner range holding capacity of Gmax (p=0.001) and the length of the hamstrings (p=0.02) had statistically significant relationships with Gmed (Table A10.4, Appendix 4). Most of the participants that presented with poor through range control of Gmed also presented with poor Gmax inner range holding (n=92; 85.98%) and with decreased flexibility of the hamstrings (n=78; 72.90%).

5.6.5 Hamstring length

Holding capacity of Gmax (p=0.01) and control of Gmed (p=0.021) had statistically significant relationships with the length of the hamstrings. If hamstring length was poor, the majority of participants also had insufficient inner range control of Gmax (n=74, 88.10%) and control of Gmed (n=78, 92.86%). Hamstring length was related to the lumbo-sacral angle (L5/S1) on the bicycle in the seated upright position (p=0.03), drops position (p=0.03) and the brake lever position (p=0.07) on the bicycle (Table A10.5, A10.8, A10.11 and A10.14, Appendix 10).

5.6.6 Gluteus maximus

Gmax inner range holding capacity was significantly related to lateral sway (p=0.031), Gmed control (p=0.001) and hamstring length (p=0.007) (Table A10.6, Appendix 10).

5.6.7 Saddle height, set-back and angle

Neither saddle height nor saddle set-back was significantly related to any other factors. The angle of the saddle was significantly related to the thoraco-lumbar angle (T12/L1) in the drops position (p=0.02) (see Table A10.13, appendix 10).

5.6.8 Lumbar angle and curvature on the bicycle

Some of the interrelationships between the lumbar angle and curvature and various other factors have been previously mentioned. Lumbar curvature in the drops position was also significantly related to the sitting forward lean test. Besides the associations between lumbar angle and curvature measured on the bicycle with the factors mentioned in the preceding section, lumbo-sacral angle and lumbar curvature was also consistently related to the sitting forward lean test. This can be seen in (Table 5.18). For the detailed results of the interrelationships of various factors with the thoraco-lumbar and lumbo-sacral angles, as well as the curvature of the lumbar spine in all three handlebar positions, see Tables A10.7-A10.15, Appendix 10).

Table 5.18 Association between lumbar angle and curvature on the bicycle and the sitting forward lean test

Riding position	Sub-factor	p-value
Brake levers	Lumbar lordosis	0.08
Seated upright	L5/S1	0.16
	Lumbar lordosis	0.10
Drop position	L5/S1	0.08
	Lumbar lordosis	0.04*

Key: Statistically significant relationship (<0.05) = *

5.7 Conclusion

The demographics and characteristics of the greater Gauteng cycling population are stated and illustrated in this chapter. The results of the relationships between various factors and LBPP from the univariate and multivariate analyses are also stated. The results of the logistic regression analyses are given and the factors possibly associated with LBPP in cyclists summarised. From the multivariate analysis only the lumbar curvature in the brake lever position (p=0.03) and the holding capacity of Gmed (p=0.05) were significantly related to LBPP in cyclists. The association between factors and LBPP in cyclists as well as the interrelationships between the relevant factors will be discussed in Chapter six.

CHAPTER 6: DISCUSSION

6.1 Introduction

The main findings of this study and how they relate to the literature are discussed in this chapter. The discussion will be based on the objectives of the study to include the prevalence of LBPP in cyclists, factors associated with LBPP, the interrelationships between the factors as well as a critical review of this study and recommendations for future research.

6.2 Prevalence of LBPP

The prevalence of LBPP in cyclists in this study was found to be high, with a lifetime prevalence of 65.4% and a one-year prevalence of 62.3%. The point prevalence was reported as much lower at 16.9% (Table 5.9, Chapter 5). A high prevalence of LBPP in cyclists has also been reported in other studies (Table 2.2, Chapter 2). Comparison of the results between studies is however limited because of methodological differences such as the definition of LBPP, the cycling populations studied (elite cyclists vs. competitive cyclists vs. long-distance tour cyclists) and differences in countries (De Bernardo et al 2012, Clarsen et al 2010, Schultz and Gordon 2010, Marsden 2009, Townes et al 2005, Salai et al 1999, Callaghan and Jarvis 1996, Dannenberg et al 1996, Wilber et al 1995, Weiss 1985, Kulund and Brubaker 1978). The cycling population (South African cyclists) in this study compares best to that of Marsden (2009) who reported the prevalence of LBPP in cyclists in South Africa (recreational and competitive cyclists) to be much lower at a 43% one-year prevalence and a 51% lifetime prevalence and Schultz and Gordon (2010) who reported a prevalence of 50% in recreational cyclists in Townsville, Australia.

The prevalence in this study was higher compared to other studies. The more stringent inclusion criteria used in this study might be a reason for this. Cyclists had to have completed at least one race of 90 km or more and had to have been cycling between three and 12 hours per week, for a minimum of one year, whereas other studies included any cyclist who would volunteer to participate in the study regardless of their training structures. The current study excluded novice cyclists and narrowed the population more down to competitive cyclists compared to the recreational cyclists mostly studied in other comparable studies (Schultz and Gordon 2010, Marsden 2009, Wilber et al 1995). In this study cyclists cycled on average further in a week compared to most other studies (191.7 km compared to 103-250 km per week for those with LBPP) which might be another reason for the higher prevalence observed. Nonetheless, the results of this study, as well as the results of other studies, indicate that LBPP is a common problem among cyclists.

In this study, 50% of cyclists experienced pain in the area of the SI-joints, followed by 40.5% central low back pain (Table 5.6, Chapter 5) The majority (50.7%) reported experiencing the pain after more than two hours on the bicycle which is similar to the 1.38 hours reported by Marsden (2009) (Table 5.8, Chapter 5). Most cyclists experienced LBPP while positioned with the hands on the brake levers (62.2%) which is similar to the findings of Schultz and Gordon (2010) (Table 5.8, Chapter 5). Training was generally not affected by the pain in 42.6% of cyclists while 39.9% trained through the pain and 10.8% trained with the assistance of analgesics (Table 5.7, Chapter 5). Similar findings were reported by Marsden (2009) and Schultz and Gordon (2010).

6.3 Factors associated with LBPP in cyclists

The results of this study indicate that flexion of the lumbar spine on the bicycle in the brake lever position and weakness of Gmed were significantly related to LBPP in cyclists (Table 5.15, Chapter 5). This is unexpected as multiple factors that could influence the lumbo-pelvic spine in the forward flexed position or induce an increase in lateral shift on the bicycle were assessed, and none of those factors were specificaly associated with LBPP.

6.3.1 Lumbar curvature in the forward flexed position on the bicycle

The curvature of the lumbar spine was significantly related to LBPP in all three handlebar positions in a univariate analysis. The thoraco-lumbar and lumbo-sacral angles were often related to LBPP but the relationships were not always significant (see Table 5.12, Chapter 5).

When taken to a multivariate analysis, only the lumbar curvature in the brake lever position was significantly related to LBPP (p=0.03) in cyclists. The majority of cyclists with LBPP reported experiencing pain when in the brake lever position which is similar to the findings of Schulz and Gordon (2010). This was also the most frequently adopted position with training (48% of time was spent in brake lever position by cyclists with and without LBPP). This position is midway between upright sitting and the drop position and might require more stability as the forward reach distance is increased.

Lumbar flexion curvature was the greatest in the drop position (19° in cyclists with LBPP compared to 15° in those without), yet the drops position was rarely used (10% of cycling time in cyclists with and without LBPP) during training. The curvature of the lumbar spine in the brake lever position (16.5° in cyclists with LBPP and 11.7° in those without) was very similar to that in the upright seated position (17° in cyclists with LBPP and 12° in those without). This is unexpected as riding with the hands in the brake lever position is thought to increase the reach distance towards the handlebars, thereby extending the posture and decreasing flexion of the lumbar spine. If cyclists are however positioned in a posterior pelvic tilt, the lumbar spine will have to hyper-flex instead of extend to reach the handlebars, which might in part account for the similar curve. The seated upright position might also be a more stable, supported position compared to the brake lever position and a better stabilising strategy might be required to maintain the position of the cyclist in the more unstable brake lever position.

Even though all cyclists were positioned with the lumbar spine in flexion on the bicycle, cyclists with LBPP assumed a position of greater lumbar flexion in all three handlebar positions compared to those without pain (see Table 5.12, Chapter 5). Muyor et al (2011a) and Usabiaga et al (1997) reported cyclists adopting a position of lumbar flexion on the bicycle while Van Hoof et al (2012) and Burnett et al (2004) observed that cyclists with LBPP assumed a position of greater lumbar flexion compared to those without. This is in contrast to the findings of Schulz and Gordon (2010) who found no relationship between lumbar curvature and LBPP. Van Hoof et al (2012) further observed that cyclists with LBPP spend more than 38.5% of their cycling time in a near end of range lumbar flexion position exceeding 80% of their total lumbo-pelvic flexion, compared to the 4% found in asymptomatic cyclists.

It has been well established that cyclists assume a position of lumbar flexion on the bicycle, regardless of the level of competing and that those with LBPP adopt a position of even greater lumbar flexion when on the bicycle (Van Hoof et al 2012, Burnett et al 2004). The mechanism by which this would lead to LBPP has however not been fully established. Several factors that could influence this forward flexed position of the spine, besides the influence of creep and flexion-relaxation partly investigated by others, have been assessed in this study, but none of them were significantly related to LBPP in cyclists. None of the factors, besides gender (p=0.03) and BMI (p=0.002), were also significantly related to the lumbar curvature in the brake lever position (Table A10.9, Appendix 10). Other studies have proposed that mechanical creep is not involved as there was no change in lumbar flexion while riding in a study done by Burnett et al (2004) nor over the duration of a two hour ride as in the study by Van Hoof et al (2012). However, Schulz and Gordon (2010) observed a change of -1° to 12° in lumbar flexion over a 10 minute stationary ride in cyclists (n=13.) The flexion-relaxation theory has also been proposed as a reason for LBPP in cyclists. Usabiaga (1997) observed relaxation in the abdominal and paravertebral muscles during relaxed pedalling (n=3). Similarly, Srinivasan and Balasubranamian (2007) observed increased fatigue in the right erector spinae muscles in cyclists with LBPP compared to those without. These factors were however all beyond the scope of this study.

Another reason for the observed increased lumbar flexion in cyclists with LBPP could be attributed to the influence of poor position sense (proprioception) with a subsequent spinal repositioning error in patients with LBPP (Petersen et al 2008, O'Sullivan et al 2003, Brumagne et al 2000). Following this theory, cyclists with LBPP might inherently assume a slumped position with increased lumbar flexion which could account for the increased lumbar flexion observed in cyclists with LBPP. The causative factor might therefore be initiated at the spine and not a result of what is happening further down the kinematic chain.

6.3.2 Control of Gluteus Medius

A lack of through range control of Gmed was significantly related to LBPP in this study (p=0.05). The majority of cyclists in this study were unable to concentrically shorten Gmed to inner range, isometrically hold an inner range contraction and eccentrically control the return (n=107, 88%) while controlling neutral alignment of the lumbar spine and pelvis. This was even more prevalent in cyclists with LBPP, where 91% (n=82) of cyclists were unable to do so. As far as could be determined, this is the first study that has investigated the stabilising capacity of Gmed in cyclists and hence no comparisons with other studies can be made.

Poor habitual postures in daily life with the hip positioned in relative adduction as with “hanging on one hip” in standing, sitting with legs crossed or sleeping with the leg falling into adduction has been associated with weakness of Gmed (Grimaldi 2011, Presswood et al 2008). Neumann (2010) reported an increase in hip internal rotation at greater ranges of hip flexion. Cyclists are positioned in hip flexion and use increasing ranges of flexion during the pedalling action. Habitual use of this increased hip internal rotation as well as hip adduction or lateral shift in cyclists will lead to weakness of Gmed which in turn will result in more hip adduction and lateral shift when cycling. This increased movement could induce an increase in lumbo-pelvic rotation and over time lead to micro- and macro-trauma of the lumbo-pelvic structures (Sahrmann 2012).

Gmed is responsible for 70% of the medio-lateral stability of the pelvis and weakness in Gmed could result in poor lateral control of the pelvis, presenting as an increase in lateral pelvic shift as mechanical loads are transferred from the legs through the pelvis with pedalling (Grimaldi 2011). Lateral pelvic tilt (side-to-side rocking) happens naturally during cycling and is exaggerated at higher speeds (Farrell et al 2003) and with increased fatigue. Chapman et al (2008a) assessed lateral movement of the pelvis in nine male competitive cyclists using 36 retro-reflective markers and a 12 camera motion analysis system to collect 3D kinematic data for 10 seconds . They observed that the pelvis did not remain static during cycling, even though cycling requires a stable lumbo-pelvic region, but that an increase in lumbo-pelvic flexion occurred when the leg was at the 3 o'clock and 9 o'clock position and that an increase in side flexion occurred towards the leg in the BDC. With poor lateral control of the pelvis the side-to-side translation while pedalling will be exaggerated and possibly induce a side flexion and/or rotation moment through the lower back and pelvis as was observed by Chapman et al (2008a) and Burnett et al (2004). An increase in lumbo-pelvic rotation could over time lead to increased mobility in the area and result in micro-damage of the lumbo-sacral structures (Sahrmann 2012). The position of sustained flexion with rotation has been implicated in injury of the passive spinal structures such as the intervertebral disc because of the shear forces and resultant micro-damage to the annulus fibrosis (Chapman et al 2008a, Solomonow et al 2003a, Solomonow et al 2003b).

The one leg stance test was used in this study to assess the ability to control lateral shift of the pelvis during load-transfer. No relationship was found between the one leg stance test and Gmed (p=0.24) in this study, which is unexpected as Gmed is proposed to have the primary role of controlling frontal plane stability of the pelvis during one leg stance (Flack et al 2013, Semciw et al 2013, Reiman et al 2012, Grimaldi 2011). One of the reasons for this might be that Gmed primarily controls pelvic tilt, as proposed with the Trendellenburg test, and to a lesser extent pelvic shift where other muscles like Gmax are activated as well (Grimaldi 2011, Roussel et al 2007). The impact of muscle fatigue must also not be disregarded. Studies investigating the impact of fatigue in cycling populations have illustrated the occurrence of fatigue in both mono-articular muscles as well as a general decrease in muscle output/torque of the muscles involved with pedalling (So et al 2005, Lepers et al 2001, Hautier et al 2000). With increased muscle fatigue in Gmed, an increase in lateral pelvic shift might occur which with frequent repetition might induce an increase in lumbo-pelvic movement, hypermobility and result in micro-damage of the spinal structures (Sahrmann 2012).

Weakness in Gmed was significantly related to Gmax weakness (p=0.001) and decreased extensibility of the hamstrings (p=0.02) (section 5.3.4 and Table A10.4, Appendix 10) but neither extensibility of the hamstrings nor control of Gmax were significantly related to LBPP in cyclists. The relationship between these factors might be explained by dysfunction in the global muscle system where weakness in the global stabiliser muscles (Gmed and Gmax) increases the load on the global mobiliser muscles (hamstrings) leading to overuse of the muscle, hypertrophy and subsequent loss of extensibility. Other reasons for this will be explored in the following sections.

6.4 Factors not significantly related to the development of LBPP in cyclists

6.4.1 Training factors

None of the training factors assessed in this study were significantly related to LBPP (Table 5.13, Chapter 5). One of the reasons for this might be cyclists rode at a much higher intensity during races (with possible more lumbo-pelvic symptoms) compared to that during training which might account for the LBPP. Cyclists in this study also rode more competitively, possibly trained more and were in better form compared to the recreational or touring cyclists studied by others.

This is different from the findings of Schultz and Gordon (2010), Marsden (2009) and Wilber et al (1995) who all reported significant relationships between the distance cycled per week and LBPP. The results here indicate that cyclists with LBPP covered more kilometres per week compared to those without pain (191.7km/week compared to 176 km/week), but the relationship was not significant (p=0.19). The cyclists without LBPP generally cycled a greater distance per week compared to cyclists without LBPP in other studies. In most of the comparable studies reviewed, cyclists without LBPP cycled on average 150 km per week or less compared to the 176 km per week reported in this study. A mean of 158 km cycled per week for male cyclists and 103 km per week for female cyclists was reported by Wilber et al (1995). Marsden (2009) observed a mean cycling distance of 149.8 (SD:104.8) km per week for cyclists without pain compared to 175.8 (SD:106.9) km per week for those with LBPP. Schultz and Gordon (2010) reported a much higher mean weekly cycling distance for those with LBPP (250 km/week, SD:

131.0 km) compared to those without (150.0 km/week, SD:135.0 km) and proposed that cyclists who cycled more than 160 km/week are significantly more likely to experience LBPP.

The mean distance cycled per week in this study was more than 160 km for those with and without LBPP which might be the reason why no significant relationship was observed between the distances cycled per week and LBPP. The cycling population studied included competitive road cyclists, who on average cycled further than the recreational cyclists studied by others. In addition, training factors were controlled for and hence a more conditioned cyclist might have been included in this study who, because of the higher average mileage per week, is better conditioned for longer distance cycling than the previous populations with less weekly mileage. In the study by Marsden (2009) cyclists completed the questionnaires at the race expo, days before the actual race. Cyclists might have had an increase in mileage per week in preparation for the race and the unconditioned recreational cyclist might also have increased the mileage too quickly which might account for the LBPP experienced.

6.4.2 Anthropometric factors

None of the anthropometric factors assessed (height, weight, BMI, gender and age) were significantly related to LBPP which agrees with the findings of Schulz and Gordon (2010). Cyclists without LBPP presented with a slightly higher mean BMI compared to those with LBPP 26.6 kg/m^2, SD=3.61 compared to 25.8 kg/m^2, SD=3.82). This opposes the hypothesis that a high BMI is associated with LBPP (Heuch et al 2010). Overweight cyclists might train at lower intensities compared to those with normal weight, so even though they spend a similar amount of time on the bicycle, they might be much slower because of this lower cycling intensity and therefore experience less pain.

Of the studies reviewed on LBPP in cyclists, the majority only reported on the anthropometric characteristics of the cycling population without investigating the relationship between them and LBPP. Comparisons of the anthropometric factors of cyclists between different studies are again limited because of the different cycling populations, but most studies reported a normal range BMI (see Table 3.1, Chapter 3, p.46) opposed to the mean BMI in the overweight range as seen here (BMI 26.0 kg/m^2, SD=3.77).

Marsden (2009) investigated the relationship between height, weight, BMI and LBPP and reported significant relationships between LBPP and self-reported height and weight in a questionnaire, but no significant relationship was observed when height and weight were measured by the researcher in a smaller case-controlled study (n=80). The mean height of the cyclists in this study is similar to those in the study done by Marden (2009) (1.77m in both the LBPP and no pain group compared to 1.75m in the no pain group and 1.77m in the LBPP group). The cyclists however weighed on average more and had a higher BMI compared to those in the study by Marden (2009) (mean weight 81.7kg and BMI 26.0 kg/m^2 compared to weight of 77.1-74.6kg and BMI of 24.1 kg/m^2).

6.4.3 Factors influencing the forward flexed position on the bicycle

6.4.3.1 Inner range holding capacity of Gluteus Maximus

Eighty one percent of all cyclists presented with elongated Gmax, as evident through the poor inner range holding of Gmax which is similar to the findings of Richardson and Sims (1991) (Table 5.13, Chapter 5). Weakness of Gmax was hypothesised to be related to LBPP because of its stability role around the SI-joints, lower back and pelvis and the evidence of its inner range weakness, but no such relationship existed (Richardson and Sims 1991). One of the reasons for this might be that a high percentage of both cyclists with and without LBPP (81%) presented with an elongated Gmax and weakness in its inner range. Most cyclists use Gmax in a lengthened (outer range) position and only need an inner range Gmax contraction and increased Gmax strength when they stand up out of the saddle to adopt a position of greater hip extension, which might be another reason for the lack of a relationship (So et al 2005).

Gmax acts with the hamstrings and adductors to achieve hip extension in the position of hip flexion. Both the hamstring muscle group, Adductor Magnus and adductors as a whole might be better positioned for hip extension from the position of increased hip flexion due to a better length-tension relationship and a greater moment arm for extension (Neumann 2010). In this way weakness of Gmax could be compensated for and its impact on the lumbo-pelvic area minimized. The majority of participants with poor inner range holding of Gmax were positioned in a slumped/flexed position of the lumbar spine in the brake lever (87%) and drop (92%) position which agrees with the findings of Kisner and Colby (2002), that participants with weakness of Gmax will sit in a more slouched position.

Gmax is proposed to be active during the downstroke phase of the crank cycle at around 340-130° while hamstrings without biceps femoris function from 10-230° and biceps femoris is active from 350-230° of the pedalling cycle (So et al 2005). Gmax increases its activity from 340-180° when the cyclist stands up out of the saddle as is often seen in hill-climbing or for increased power production to stabilise the pelvis without the support of the saddle (Duc et al 2008, So et al 2005). Activation patterns of these muscles are influenced by relative muscle strength and weaker one-joint hip extensors (Gmax) will demand the assistance of the multi-joint hamstrings (especially biceps femoris) to forcefully extend the hip joint (So et al 2005). A lengthened, weak Gmax would therefore place an increased demand on the hamstring muscles which, in turn can become shortened (Chance-Larsen et al 2010, So et al 2005).

Poor inner range holding of Gmax was significantly related to decreased hamstring extensibility (p=0.007) with 69% of all the cyclists presenting with poor extensibility of the hamstrings (70% of cyclists with LBPP) and 81% with poor inner range holding of Gmax. The hamstring muscle group could therefore be accommodating for weakness in Gmax during the pedalling action and be another reason why Gmax was not associated with LBPP in cyclists. The impact of muscle fatigue during cycling should once again not be dismissed, as a weak and fatigued Gmax will further increase its demand on the hamstring muscles to compensate (So et al 2005).

6.4.3.2 Extensibility of the hamstring muscle group

Seventy percent of the cyclists with LBPP presented with decreased extensibility of the hamstrings, but the relationship between hamstring length and LBPP was not statistically significant (p=0.81) (Figure 5.3 and Table 5.13, Chapter 5). This is in contrast with the findings of Marsden (2009) who reported that cyclists with LBPP presented with significantly decreased flexibility of the hamstring compared to those without pain. This might again be due to the fact that 70% of all cyclists presented with decreased extensibility of the hamstrings and it is hence a problem for the entire cycling population and not only for those with LBPP.

Decrease in hamstring extensibility might be indicative of hypertrophy of the muscle as proposed by Sahrmann (2012). Cleated cyclists will have a substantial “pull” through the hamstrings with the knee flexion moment of pedalling to increase power output. The combined increased load from “pulling” and a possible overload on the hamstrings from a weakened Gmax might be part of the reason for the hypertrophy and subsequent shortening. The absence of a relationship between hamstring length and LBPP might also in part be explained by the dynamic functioning of the muscular system, where inefficiency in one muscle group will often be absorbed by another even if it is to the detriment of the other (as seen in the hamstrings and abdominal muscles and the hamstrings and Gmax).

During the pedalling action the knee reaches a maximum of 25-35° of extension as it approaches the BDC and with the knee extension moment cyclists have a concurrent hip extension moment and vice versa, which will further limit any tension on the hamstring muscles. The hamstring muscle group is therefore not placed in an elongated/tensioned position during cycling which might partly explain why no association was observed between hamstring extensibility and LBPP.

Previous studies have proposed that shortened hamstrings will keep the pelvis in a posterior tilt thereby limiting anterior pelvic tilt (Mellion 1994). Muyor et al (2011b) investigated the influence of hamstring extensibility on spinal curvature on the bicycle and found no relationship. It was initially hypothesised in the current study that pelvic inclination could be deduced from the lumbo-sacral angle (L5/S1), as proposed by Ng et al (2001). During the course of the study it however became clear that the lumbo-sacral angle does not necessarily accurately reflect the pelvic inclination and hence the influence of hamstring length on pelvic position could not be established in this study. The length of the hamstrings were however to some extent related to the lumbo-sacral angle in the seated upright ($p=0.03$), brake lever ($p=0.07$) and drops ($p=0.03$) positions with those with LBPP presenting with a smaller lumbo-sacral angle compared to those without, possibly indicating a pelvis positioned in a more posteriorly orientated direction (see Table 5.18, Chapter 5 and Table A10.8, Table A10.11 and Table A10.14 Appendix 9). Other studies on lumbar kinematics in the cycling population used the second sacral vertebra (S2) in their calculation of lumbar curvature which might be more appropriate in establishing pelvic inclination (Van Hoof et al 2012, Schulz and Gordon 2010, Burnett et al 2004).

6.4.3.3 Control of lumbar flexion

The position of increased lumbar flexion observed in cyclists with LBPP on the bicycle was proposed to be related to an inability to prevent/control flexion of the lumbar spine due to possible habitual slumped sitting. The cyclists' ability to control lumbar flexion was assessed with the sitting-forward-lean test as described by Comerford and Mottram (2012) and Enoch et al (2011) but there were no significant relationships between the sitting forward lean test and LBPP in the cyclists. As the sensitivity and specificity of this test has not yet been established it is possible that the test might not be sensitive enough to pick up, in isolation, uncontrolled lumbar flexion within the parameters recommended by Enoch (2013).

Of late, studies on the assessment of UCM have proposed the use of a battery of tests to assess a person's ability to control movement. Luomajoki (2008) used the summed total of six movement control tests in an attempt to differentiate between participants with LBPP and no pain. They found that participants with LBPP had 2.21 positive tests compared to the 0.75 positive tests in healthy controls. A battery of tests might therefore be better suited to assess control of lumbar flexion in future studies. Although most studies have found no change in lumbar flexion over a period of time riding, the effect of fatigue of the stabilising muscles in cyclists might be worth further investigation (Van Hoof et al 2012, Burnett et al 2004).

6.4.3.4 Neurodynamics

Dynamics of the neural system assessed with the slump test were not associated with LBPP in cyclists. Even though cyclists generally assume a supposedly provocative "slumped" position on the bicycle with the hips, thoracic and lumbar spine in flexion, they have extension of the neck and mostly keep the knee in flexion which will off-load tension on the neural tissues. Cyclists repetitively alternate hip and knee flexion and extension, which might simulate neural gliding and be a form of self-mobilisation. Both of the above-mentioned theories could account for the absence of a relationship between neural dynamics and LBPP.

6.4.3.5 Bicycle set-up factors

Saddle height, set-back, angle, handlebar height, reach, reach ratio and cleat position were assessed in this study. None of these factors were significantly associated with LBPP (Table 5.14, Chapter 5). Though similar to the findings of Marsden (2009), these findings were unexpected as most cyclists, bicycle shops and bicycle fitters regard bicycle set-up as the main reason for LBPP in cyclists (Silberman et al 2005, De Vey Mestdagh 1998). The findings of the present study indicate that the majority of cyclists do not have a bicycle set-up that is specific to their body measurements (Table 5.14, Chapter 5) following the set-up parameters used in this study. Because of the many ways of measuring bicycle set-up, many controversies exist in what constitutes an acceptable set-up, which might have also influenced the findings of this study.

The lack of a relationship between bicycle set-up and LBPP might also be explained by the fact that neither previous professional bicycle set-up nor self-set-up to improve riding comfort have been explored in this study. The more experienced cyclists probably have more knowledge about bicycle set-up and might be happy to change their own set-up as they deem fit in order to increase comfort or power output. The assessment of static bicycle set-up compared to dynamic bicycle set-up also needs to be considered as movement and position of the lumbo-pelvic spine could change substantially during active cycling.

Findings indicated that saddles were set too far forward in the majority of cyclists (60.3%) which will lead to a more “bunched-up” position of the cyclist on the saddle. This is associated with an increase in posterior pelvic tilt and subsequent increased lumbar flexion (Silberman et al 2005, Sanner and O'Halloran 2000, De Vey Mestdagh 1998). Even though this position is proposed to be associated with LBPP in cyclists, no such relationship was observed in this study.

Saddle angle was not significantly related to LBPP in cyclists. The mean saddle angle was 0.72° in the direction of a posterior tilt for the entire cycling population (0.81° for those with LBPP and 0.42° for those without LBPP), yet the majority of saddles were tilted anteriorly (48% for the entire population, 50% of those with LBPP). This is in conflict with the findings of Van Hoof et al (2012) who observed an increase in posterior tilt of the saddle in cyclists with LBPP compared to those without.

Forward reach on the bicycle is another aspect of bicycle set-up proposed to contribute to LBPP in cyclists (De Vey Mestdagh 1998). In this study, the majority of cyclists presented with an inadequate forward reach on the bicycle with the reach distance mostly too short and the cyclists too bunched up during the ride (48.4% without pain and 54.4% with LBPP). This again ties in with the proposition of De Vey Mestdagh (1998) that an inadequate reach distance (being too bunched up) positions the pelvis in an increased posterior tilt with subsequent increased flexion of the lumbar spine resulting in LBPP. In this study, no significant relationships were however found between either forward reach on the bicycle and LBPP ($p=0.29$) or forward reach and the lumbar curvature on the bicycle in the brake lever position ($p=0.21$). This might partially refute the proposition that the reach distance will influence the curvature of the spine, with a short reach distance being associated with LBPP in cyclists as proposed by De Vey Mestdagh (1998).

Marsden (2009) observed a significant relationship between the reach ratio and LBPP in cyclists (p=0.021), which is in contrast to these finding where no such relationship could be established (p=0.52). She proposed that the cyclists with LBPP and subsequent greater reach ratio will have to increase their reach and drop distance to match the asymptomatic controls. The reach ratio for both the LBPP and asymptomatic cyclists in this study was much lower than those observed by Marsden (2009) (1.57 for those with and without LBPP in this study compared to 1.99 for those with LBPP and 1.94 for those without LBPP in the study by Marsden). The full meaning and implication of reach ratio has however not been comprehensively described by Marsden (2009) and as far as could be determined, the concept was not discussed in any other literature which further complicates the interpretation thereof.

In this study, the height of the handlebars was also not significantly related to LBPP in cyclists. The handlebars were set too high in the majority of cyclists with LBPP (59%) and the average drop distance (distance from the top of the saddle to the top of the handlebars) was 4.50 cm in those with LBPP compared to 5.92 cm in those without. These findings are similar to those of Marsden (2009) who also did not observe a significant relationship between handlebar height and LBPP in cylists. She reported a drop distance of 5.09 cm in cyclists with LBPP compared to 5.92 cm in those without, which also indicates that cyclists with LBPP have handlebars that are generally set higher than those without.

6.4.4 Factors influencing the lateral position on the bicycle

In this study, neither the one leg stance nor the ASLR tests were significantly related to LBPP in cyclists.

6.4.4.1 Lateral shift of the pelvis

The one leg stance test was used in this study to assess the ability to control lateral shift of the pelvis during load-transfer. No increase in lateral shift was observed in cyclists with LBPP compared to those without and no significant relationship existed between the one-leg stance/lateral shift test and LBPP (p=0.19). As no previous studies have attempted to assess the relationship between lateral shift of the pelvis and LBPP in cyclists, no comparisons can be made.

The one leg stance test might not be the most appropriate test to measure side-to-side (lateral) shift and control of that shift in cyclists. The test was originally described by Luomajoki (2008, 2007) to assess control of lumbar extension/rotation and the parameters used in the test (shift magnitude of 10cm to either side) might be too lenient to assess control of side-to-side rocking in cyclists. During this test cyclists were also tested in a static standing position compared to the dynamic flexed position used on the bicycle when pushing and pulling through the pedals. This might be another reason for the lack of association observed and the lateral movement of the pelvis should rather be assessed with the cyclist on the bicycle to make it more appropriate to cycling.

Fatigue might also be the factor that influences the magnitude of lateral shift that occurs during cycling, which is plausible, with most cyclists indicating the onset of pain occurring after more than two hours of cycling. It might also be that lateral pelvic tilt or rotation of the lumbo-pelvic area opposed to lateral shift of the pelvis occurs during cycling which warrants further investigation.

6.4.4.2 Load transfer through the pelvis

The majority of cyclists with LBPP reported experiencing the pain in the region of the SI-joints, possibly indicating the presence of poor pelvic girdle control. Load transfer through the pelvis was assessed with the ASLR test and no relationship was found between the ASLR test and LBPP in cyclists (Table 5.13, Chapter 5). A positive ASLR test is proposed to be associated with an increase in movement of the pelvic bones in people with PGP (Mens et al 1999). LBPP experienced with cycling might not be due to increased pelvic bone movement but rather because of an inefficient stabilising strategy. The ALSR is interpreted based on a score of the perceived effort as reported by the individual which might not reflect the efficacy of lumbo-pelvic control. Some studies scored it according to the assessor’s observation of lumbo-pelvic control which might be more applicable to the cycling population (Mens et al 1999).

The effect of fatigue on muscle recruitment and inhibition should again not be disregarded. Many studies have indicated changes in recruitment and inhibition of stabilisers after fatiguing tasks that can last for prolonged periods after cessation of the task and fatigue might therefore be a reason for not observing an inadequate load transfer strategy (Allison and Henry 2002, Dolan and Adams 1998, Kankaanpää et al 1998).

6.4.4.3 Leg-length discrepancy

No association was established between LLD and LBPP in cyclists in this study. Against expectation, a LLD of greater than 20mm appeared to be protective for the development in LBPP in cyclists which is similar to the findings of Marsden (2009) where cyclists without LBPP presented with a greater discrepancy in leg-lengths compared to those with LBPP. This does not make logical sense as an increase in LLD is generally related to an increase in the development of pathology (Defrin et al 2005, Brady et al 2003, Krawiec et al 2003, Gurney 2002). Even though a high intrarater reliability has been illustrated for the clinical assessment of leg-lengths using the direct tape measure method, it has poor validity when compared to X-rays, which could explain these findings to some extent.

A discrepancy in leg-lengths could also be compensated for by lowering the saddle for the shorter leg or by pedalling with the ankle in plantar flexion (on the toes) on the side of the shorter leg. Increased side-to-side movement of the pelvis might therefore be absorbed by the kinematic chain during cycling or the cyclist might shift the pelvis towards the shorter leg on the saddle as compensation, both of which might explain why LLD was not associated with LBPP in cyclists.

6.4.4.5 Saddle height

The height of the saddle was not significantly related to LBPP in cyclists. More cyclists had a saddle that was set too low (21.5%) as to one set to high (10.7%) while the biggest group (34% of the general cycling population, 29% of those with LBPP) presented with a discrepancy in the KEA of the left and right lower extremities as measured on the bicycle. This might be indicative of a compensation strategy or an increase in pelvic shift and warrant further investigation.

6.5 Critical review of the study

6.5.1 Strengths of the study

- This study involved a larger cycling population than most others in the literature.
- As far as is known, this study is the first to investigate such a large number of possible risk factors as well as the association between risk factors. It is also the first study, as far as could be determined, that investigated control of Gmax and Gmed, control of lumbar flexion, influence of neural dynamics, control of lateral movement and control of load shift through the pelvis.

6.5.2 Limitations of the study

- A poor intra-rater reliability was obtained for the measurement of through range control of Gmed which would require attention in future studies. In an attempt to increase the test-retest reliability of the test, an inclinometer was used to establish the required angle of abduction and a rod was positioned as a guide for the required ROM. It was however difficult to control for movement of the lumbar spine and pelvis while ensuring that the participants maintained the required hip abduction/extension ROM for the required amount of time, which is in agreement with the findings of other studies (Lee and Powers 2013, Rabin et al 2013). The influence of Gmed on the development of LBPP in cyclists therefore also needs to be interpreted with caution and the reliability for assessing control of Gmed improved in future studies. A way to refine it would be to position the participant against a wall and instruct them to slide the upper leg up against the wall to control for the required hip extension during abduction. The required ROM could also be indicated for on the wall, which would enable the examiner to observe from a distance and thereby possibly increase the accuracy of the Gmed assessment.

- The outcome measures used in this study is what was considered to be the best outcome measures available at the time and most applicable to the aim of the study. There are however many other outcome measures available which could be considered for use in future.

- The “apparent” leg-length discrepancy (umbilicus to medial malleolus) was not measured in this study. Apparent leg-length could have been established to identify problems with leg-length that emanated from the hip.

- No attempt was made in this study to classify/characterize the LBPP cyclists which could probably have contributed to the understanding of LBPP in cyclists.

6.6 Recommendations for future research

- Cycling appears to be an unidirectional activity involving flexion-extension but it also involves side-to-side or a lateral pelvic movement (Chapman et al 2008a, Farrell et al 2003). In a dysfunctional situation, as with poor control of Gmed and/or Gmax, asymmetrical tightness in hamstrings, poor control of lumbar movement, LLD or an incorrect height of the bicycle saddle, a rotation-motion could be induced around the spine and pelvis, which could eventually lead to the development of pain and pathology. More lumbar rotation can occur in the seated/flexed position (Pearcy 1993) which, if repeated could also result in microscopic injury to the spinal structures. Cyclists are positioned in a flexed position of the spine and uncontrolled rotation-direction movement would be more feasible in this flexed position as more rotation is possible in the flexed position. An observation made during the assessment of the inner range holding capacity of Gmax in the prone hip extension test was that those unable to sustain an inner range contraction of Gmax often used rotation of the lumbo-pelvic area towards the weight-bearing leg to compensate for the weakness. Assessment of lumbar rotation dysfunction was not initially considered for inclusion into this study, but it is recommended that future studies explore the association between lumbar rotation dysfunction and LBPP in cyclists.

- Control of lumbar flexion, as assessed with the sitting forward lean test, was not significantly related to LBPP in cyclists. The sensitivity and specificity of the test has not been established and the test might not be sensitive enough to identify a lumbar flexion dysfunction in isolation. It is recommended that in future a battery of movement tests be used in order to assess control of lumbar flexion and not only one test in isolation.

- Length of iliopsoas was not included as a factor in this study. However, resistance against hip extension was noted in many of the participants during the assessment of passive hip extension range in the prone hip extension test. As cyclists repetitively use hip flexion during the cycling action and as the psoas muscle could also pull the lumbar spine into flexion due to its attachment to the lumbar spine, it is recommended that the length of the iliopsoas muscles in cyclists be assessed in future studies.

- Spinal curvature was measured with the cyclists positioned on a stationary bicycle (mounted on an A-frame). It is recommended that future studies measure spinal curvature before and after a long bicycle ride or even preferably for the duration of the ride with an instrument such as the spinal mouse system, to assess for changes in lumbar curvature throughout the ride.

- It is recommended that longitudinal cohort studies be done on cyclists in future to better determine the causal relationships of LBPP in cyclists. This study was a cross-sectional study and cross-sectional studies are limited in that they do not take time-sequence or long-term exposure into consideration and it would therefore be impossible to establish if LBPP is the cause or the effect of the associated risk factors, which could be established in a longitudinal randomised controlled trial (Abramson and Abramson 2000).

- There are many controversies in what should constitute an “optimal set-up” of the bicycle. The different ways of setting up the bicycle are often conflicting and very little evidence exists on what should be an ideal “static” set-up. It is recommended that the set-up of the bicycle, especially as it relates to LBPP in cyclists, be assessed in future with particular focus on what an “ideal set-up” should be. It is also recommended that future studies look at the dynamic set-up of the cyclist on the bicycle compared to only static set-up, as many factors might actually change during active cycling.

- Only one “intervention” study was identified in the literature. Salai et al (1999) assessed the impact of tilting the saddle anteriorly on LBPP experienced by cyclists. It is recommended that in future more studies be done assessing the impact of various intervention programs on LBPP in cyclists, which should include strengthening of Gmed and training and education on flattening the lumbar kyphosis on the bicycle as well as the impact of other factors like retraining the lumbar multifidi, increasing hamstring length, etc.

- Through the course of the study various other factors were identified as possible risk factors for LBPP in cyclists, which weren’t initially considered, but warrant further exploration. These included:
    - Strength of lumbar multifidi
    - Road vibration
    - Impact of fatigue
    - Spinal repositioning sense (proprioception) – kinaesthetic sense
    - Influence of various other sporting activities participated in

6.7 Clinical recommendations

As far as could be determined, this study was one of the first to assess for factors that could influence the lumbar position on the bicycle. Following the outcomes of this study, cyclists need to be educated on the impact of greater lumbar flexion during cycling. Retraining of the stabilising function of Gmed should also be emphasised in cyclists.

The findings of this study challenges the common belief that incorrect bicycle set-up is the reason for LBPP, which was an unexpected finding. From the findings on bicycle setup it is clear that the assumption cannot be made that “good” bicycle set-up will prevent or alleviate LBPP and “poor” bicycle set-up will cause LBPP, as there was no direct association between any of the bicycle set-up factors and LBPP. Because of the association between the flexed lumbar curvature in the brake lever position and LBPP, those involved in setting up bicycles should possibly rather focus on the influence of bicycle set-up on the lumbar position instead of only assessing the individual factors. In this way bicycle set-up might help to position the cyclist in a more neutral lumbar position with less lumbar flexion and thereby possibly influence the development of LBPP in cyclists.

6.8 Conclusion

The results of the study were discussed in this chapter according to the objectives of the study. The prevalence and the risk factors for LBPP in cyclists in Gauteng were given and the association between these risk factors was comprehensively discussed. The limitations of the study were identified and recommendations were given for future research. A summary of the findings will be provided in Chapter 7.

CHAPTER 7: CONCLUSION

The prevalence of LBPP, the risk factors for LBPP in cyclists in the greater Gauteng area, as well as the association between these risk factors was assessed in this dissertation. The study design was a cross-sectional descriptive study and consisted of an online questionnaire, a physical assessment and an assessment of static bicycle set-up. In this chapter the conclusions of this study will be presented, based on the objectives of the study.

- **Prevalence of LBPP in cyclists in South Africa**

The results indicate a lifetime prevalence of 65.4%, a one-year prevalence of 62.3% and a point prevalence of 16.9% LBPP in cyclists. This is a high prevalence of LBPP in cyclists in Gauteng which is similar to the findings of other studies.

- **Factors associated with LBPP in cyclists in Gauteng**

The following factors were significantly related to LBPP in cyclists in the greater Gauteng area:

  - Stabilising function of Gmed
  - Lumbar curvature on the bicycle with the hands in the brake lever position
  - In the univariate analysis, the lumbar curvature on the bicycle in the brake lever position (p=0.01), the seated upright position (p=0.01), the drops position (p=0.02) and the thoraco-lumbar angle in the drops position (p=0.05) were significantly related to LBPP in cyclists. Cyclists with LBPP adopted a position of increased lumbar flexion in all three handlebar positions and presented with a decreased lumbo-sacral angle indicating a possible posterior tilt of the pelvis.

None of the training factors assessed or any of the factors related to bicycle set-up were related to LBPP in cyclists in Gauteng.

- **Association between risk factors**

The noteworthy associations found between the various risk factors were:

  - Control of Gmed was significantly related to inner range holding capacity of Gmax (p=0.001) and the length of the hamstrings (p=0.02).
  - Length of the hamstrings was significantly related to the lumbo-sacral angle in the seated upright position (p=0.03) and in the drops position (p=0.03).

- Inner range holding capacity of Gmax was significantly related to the lateral sway test (p=0.03).

This study contributed to the understanding of factors that could lead to the development of LBPP in cyclists. Although many of the factors assessed were not significantly related to LBPP in cyclists, the influence of increased lumbar flexion in the brake lever position on the development of LBPP was confirmed. This raises two important issues: (1) the need for further exploration of the reason for this increased flexion, (2) the responsibility of cyclists to reduce and control flexion of the lumbar spine on the bicycle.This study is the first step towards developing preventative strategies and interventions to mimimise the occurance and recurrence of LBPP in cyclists. More research is however required to further understand this topic.

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APPENDICES

1. Demographics of cyclists in previous studies
2. Classification of functional muscle roles
3. HREC Approval
4. Patient Information sheet
5. Informed consent
6. Questionnaire
7. Data collection sheet
8. Additional results for reliability study
9. Additional results for physical assessment items
10. Additional results for interrelationships between factors

APPENDIX 1 – DEMOGRAPHICS OF CYCLISTS IN PREVIOUS STUDIES

Study	Participants n	Mean age (Range or SD)	Male (%)	Mean height/weight/BMI
Kulund & Brubaker (1978)	89 long-distance tour cyclists	Male: 27.9 (17-66) Female: 236 (17-54)	72	-
Weiss (1985) Arizona (USA)	113 long-distance tour cyclists	Male: 43 (11.5) Female: 36 (10.4)	69	4 males BMI>30, all others had normal BMI
Wilber et al (1995) California, USA	518 long-distance tour cyclists	Male: 40.4 (10.7) Female: 36.6 (9.1)	57	Male: Height (in): 70.2 (3.2) Weight (lb.): 171.4 (24.2) Female: Height (in): 65.6 (2.9) Weight (lb.): 134.2 (17.9)
Dannenberg et al (1996) Maryland, USA	1638 long-distance tour cyclists (30 female, 50 male)	39 (7-79)	67	-
Salai et al (1999) Israel	80	17-72	63	-
Bressel & Larson (2003) Utah, USA	10 novice and 10 experienced female cyclists	Experienced: 27.14 (5.15) Novice: 21.0 (1.41)	0	Experienced: Height (m): 1.65 (0.07) Weight (kg): 63.57 (9.38) BMI (kg/m^2) : Novice: Height (m): 1.67 (0.08) Weight (kg): 66.01 (8.85) BMI (kg/m^2):

Burnett et al 2004 (Australia)	18 mid-to high-level cyclists/triathletes (8 male, 10 female)	-	44	LBPP-group: Height: 1.70 (0.07) Weight: 67.0 (7.0) BMI: 22.9 (1.7) No LBPP-group: Height: 1.70 (0.07) Weight: 67.2 (7.0)kg BMI: 23.4 (2.0)
McEvoy et al (2006) Australia	17 elite cyclists (15 males, 2 females) 17 non-cyclists (15 males, 2 females)	Elite cyclists: 23 (4.16) Non-cyclists: 23 (4.1)	88	Cyclists: Height (m): 180 (5.7) Weight (kg): 80.1 (7.5) BMI (kg/m^2) : 24.8 (2.6) Non-cyclists: Height (m): 178 (6.2) Weight (kg): 75 (10.6) BMI (kg/m^2): 23.5 (2.7)
Abt et al (2007) (Pennsylvania, USA)	15 local cyclists category 2-4	34.5 (9.8)	-	Height (m): 1.77 (0.11) Weight (kg): 76.3 (11.1)
Srinivasan & Balasubramanian (2007) (India)	14 male cyclists	25.43 (1.87)	100	Weight (kg): 63.6 (8.87)
Chapman (2008) New Zealand	9 male cyclists	34.8 (10.9) years	100	Height (cm): 180.1 (6.0) Weight (kg): 79.7 (5.9)
Diefenthaeler et al (2008) Brazil	3 elite male cyclists	23-30	100	Height (m): 1.66-1.81 Weight (kg): 63.6-75.3
Marsden (2010) South Africa	460 competitive cyclists (70 female and 390 male)	LBPP group: 37.8 (11.4) No LBPP group: 36.3 (12.1)	85	LBPP group: Height (m): 1.77 (0.08) Weight (kg): 77.1 (13.1) BMI (kg/m^2): 24.1 (4.1) No LBPP group: Height (m): 1.75 (0.08) Weight (kg): 74.6

				(12.2) BMI (kg/m^2): 24.1 (3.7)
Clarsen et al (2010) Norway, Europe	109 professional road cyclists (teams from Australia, Denmark, France, Norway, and Switzerland, 23 different nationalities)	Europe tour cyclists: 25 (4) World tour cyclists: 28 (5)	-	Europe tour cyclists: Height (m): 182 (6) Weight (kg): 71 (6) World tour cyclists: Height (m): 181 (6) Weight (kg): 69 (6)
Muyor et al (2011a) Spain	96 highly-trained cyclists	30.36 (5.98) years	-	Height (m): 1.76 (0.06) Weight (kg): 76.05 (9.25)
Muyor et al (2011b) Spain	120 male cyclists 60 elite and 60 master cyclists	Elite: 22.95 (3.38) yrs Master: 34.27 (3.05) yrs	-	Elite Height (m): 1.77 (0.06) Weight (kg): 71.61 (9.66) BMI (kg/m^2): 22.62 (2.54) Master Height (m): 1.75 (0.05) Weight (kg): 77.12 (8.52) BMI (kg/m^2): 25.04 (2.48)
Van Hoof et al 2012 (Belgium)	17 male local cyclists (n=8 with LBPP, n=9 without LBPP	LBPP-group: 28.3 (8.7) No LBPP-group: 28.4 (9)	-	LBPP-group: Height (m): 184.9 (4.1) Weight (kg): 76.2 (8.5) BMI (kg/m^2): 22.3 (2.7) No LBPP-group: Height (m): 181.2 (2.7) Weight (kg): 75.1 (7.7) BMI (kg/m^2): 22.8 (1.9)

APPENDIX 2 – CLASSIFICATION OF THE OF MUSCLES

Table A2.1 Classification of the functional roles of muscles (Comerford and Mottram (2012)

Local stability muscles	Global stability muscles	Global mobility muscles
• Control of segmental translation through increased muscle stiffness • Controls the neutral position of the joint • No change in length with contraction – does not produce ROM • Anticipatory action to expected movement • Muscle activity not dependant of the direction of the movement • Muscle activity continuous throughout movement	• Control range of motion • Eccentric lengthening with contraction to provide control through range • Ability to (1) shorten through full inner ROM; (2) isometrically hold that position; (3) eccentrically control the return • Eccentric deceleration of movement • Muscle activity is direction dependent and therefore influenced by antagonist muscles • Muscle activity is not continuous	• Produce range of motion • Concentric shortening to produce movement • Concentric acceleration of movement • Muscle activity is direction dependent • Intermittent on-off muscle activity to accelerate movement
Dysfunction: • Delayed timing, deficiency in recruitment • Inhibited by pain and pathology • Decreased segmental control	**Dysfunction:** • Lack ability to (1) shorten through full inner range; (2) isometrically hold that position; (3) eccentrically control the return • Poor low threshold recruitment • Inhibited by antagonists • Changes in recruitment patterns • Inadequate control of high threshold movement	**Dysfunction:** • Decreased extensibility • Limits ROM • Overactive low threshold, low load recruitment • Spasm in response to pain and pathology

APPENDIX 3 – ETHICS CLEARANCE CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Mrs Merinda Rodseth

CLEARANCE CERTIFICATE	M110649
PROJECT	The Prevalence of Lumbo-Pelvic Pain and the Factors Associated with in in Cyclists Belonging to Groups V and D at Cycle Lab in Fourways,
Johannesburg	
INVESTIGATORS	Mrs Merinda Rodseth.
DEPARTMENT	Department of Physiotherapy
DATE CONSIDERED	24/06/2011
DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 26/08/2011 **CHAIRPERSON** ....
(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable
cc: Supervisor : Wendy Wood

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...

APPENDIX 4 – INFORMATION DOCUMENT

INFORMATION DOCUMENT

Study title: Prevalence of lumbo-pelvic pain and the factors associated with it in cyclists in the greater Gauteng area

Good Day, my name is Merinda Rodseth, I am a post graduate physiotherapist doing my masters dissertation at the University of the Witwatersrand on the prevalence of lumbo-pelvic pain and the factors associated with it in cyclists in the greater Gauteng area.

With this study, we want to learn how many cyclists experience low back pain or pain in the pelvic area as a result of cycling. We also want to establish which factors are associated with the lumbo-pelvic pain experienced by cyclists. The ultimate aim with identifying the risk factors associated with this lumbo-pelvic pain is to prevent the development of lumbo-pelvic pain as experienced by cyclists and comprehensively rehabilitate/correct these risk factors if identified in cyclists.

We would like to invite you to participate in Part 1 of the study which entails completion of a questionnaire in order to establish how many cyclists experience/have experienced low back pain or pain in the pelvic area. It will take you less than 10 minutes to complete the questionnaire. The questionnaire will consist of questions regarding your age, gender, training characteristics (including years of cycling, distance cycled per week, days cycled per week, number of cycling events per year, preferred cycling positions, cycling pace) and the history of no pain, low back pain or pain in the pelvic area experienced during or after cycling (including any referring symptoms, history of cycling position at onset of symptoms, frequency of symptoms, effect of pain on training schedule). Even if you have never experienced low back pain or pelvic pain, we would like to ask you to please complete the questionnaire.

At the end of the questionnaire you will get the opportunity to indicate if you would be interested in participating in Part 2 of the study which will entail a physical assessment looking at the risk factors postulated to be associated with lumbo-pelvic pain in cyclists.

The following factors will be assessed during part 2 of the study:

- Extensibility/length of the hamstrings muscles. During this test your knee will be passively extended by the researcher while the hip is maintained in a 90° flexion position. The test will be conducted to onset of hamstring resistance and not end of range. You might experience slight discomfort in the hamstring muscle at the end-test position.
- Ability to hold a contraction of the gluteus maximus muscle in a shortened/inner range position. During this test you will be positioned with your stomach on the treatment couch and legs on the floor. You will be ask to extend your hip as far as possible without allowing your lower back to move and then asked to maintain the position for two sets of 15 seconds. You might experience some muscle fatigue towards the end of the test
- Strength of Gluteus medius muscle. The strength of gluteus medius will be tested in side-lying. You will be asked to keep your feet together and lift your top knee of the bottom one (backwards) and hold it at the end of the range for two sets of 15 seconds. You again my experience muscle fatigue towards the end of this test

- Leg-length discrepancy. The length of both legs will be measured with a measuring tape while you lie on your back
- Mobility of the neural tissues. You will be asked to assume a sequence of positions of your neck, back and legs while in the sitting position and the presence or absence of symptoms will be noted.
- Ability to maintain a neutral position of your spine while asked to bend/lean forward from a sitting position
- Active straight-leg-raise test. You will be asked to actively lift a straight leg 20°of the bed while lying on your back and rate the level of effort for each leg.
- Lateral movement of the pelvis when asked to shift your weight from two legs to one leg while standing.
- Position of your lower back while sitting on your bicycle
- Measurements of height and weight
- Measurements of your bike set-up, including the amount of the height of your saddle, the fore-aft position of the saddle, the height of the handlebars, position of the cleats and the distance between the saddle and the stem of the handlebars.

The physical assessment will be conducted in Gallo Manor or in a venue closer to you if enough participants are from that surrounding area and will last approximately 60 minutes. All the respondents who indicated interest in Part 2 of the study will be contacted for participation in part 2 of the study. Both the completion of the questionnaire and the physical assessment will only be conducted once.

There are no risks of being involved in the study and no direct benefits. Detailed feedback will however be given to each participant after completion of the study and recommendations made according to the specific findings.

Participation in this study is voluntary and you are allowed to withdraw at any time.

All data will be put together from the information received during the study, it will be analysed and the results will be presented in my dissertation masters. The results might be published in a research paper for the scientific community. The individual results will not be made available to anyone without your express and written permission. All data will be coded and personal information will be kept separately and securely in order to guarantee confidentiality of the information received.

If you need any further information, please contact me on 083 661 8634 or at rodseth@internet-sa.co.za.

For reporting of any complaints/problems please contact The Chairman, Health Research Ethics Committee, Prof P Cleaton-Jones at 011-717-1234

APPENDIX 5 – INFORMED CONSENT FOR ASSESSMENT

UNIVERSITY OF THE WITWATERSRAND

PHYSIOTHERAPY

CONSENT TO ACT AS A PARTICIPANT IN RESEARCH

I,__________________________________ being 18 years or older, consent to participating in Part 2 of the research project entitled: "**THE PREVALENCE OF LUMBO-PELVIC PAIN AND THE FACTORS ASSOCIATED WITH IT IN CYCLISTS IN JOHANNESBURG**".

The procedure has been explained to me and I understand and appreciate their purpose, any risks involved, and the extent of my involvement. I have read and understand the attached information leaflet. I have received enough information to fully understand the extent of the study.

I understand that the procedures form part of a research project, and may not provide any direct benefit to me.

I understand that all experimental procedures have been sanctioned by the Committee for Research on Human Subjects, University of the Witwatersrand, Johannesburg.

I understand that my participation is voluntary, and that I am free to withdrawn from the project at any time without prejudice.

______________________________	________________
Participant name and signature	Date
______________________________	________________
Investigator name and signature	Date

APPENDIX 6 – QUESTIONNAIRE

Questionnaire

Thank you for taking the time to be part of establishing how many cyclists experience low back pain or pain in the pelvic area as a result of cycling. In this study we also want to establish which factors are associated with this pain in cyclists.

By identifying the factors associated with low back and pelvic pain in cyclists, preventative strategies and interventions can be developed to decrease the possible occurrences and re-occurrences of this pain in cyclists.

Even if you have never experienced lower back pain or pelvic pain, we would like to ask you to please complete the questionnaire.

At the end of the questionnaire you will get the opportunity to indicate if you would be interested in participating in the second stage of the study which will entail a physical assessment looking at the risk factors postulated to be associated with low back and pelvic pain in cyclists.

All data obtained from the participants will be kept confidential. This survey will be used for data collection for my Masters dissertation at the University of the Witwatersrand. Participation in this research study is completely voluntary, and by completing this survey you agree to participate in this study.

If you have questions regarding this study, you may contact Merinda Rodseth on 083 661 8634 or rodseth@internet-sa.co.za

Eligibility for the study

In order to participate in this study, the following criteria must be met. Please tick those listed below that are relevant to you.

- ☐ 18 years or older
- ☐ Cycling more than 3 hours but less than 12 hours per week on a racing/road bike
- ☐ Previous participation in at least one race of more than 90km
- ☐ Cycling with cleats
- ☐ Participation in less than 20 races per year
- ☐ Use of a road/racing bike when training or competing in races
- ☐ Have been cycling for more than one year
- ☐ No history of traumatic injury to the spine in the past two years
- ☐ No low back pain with a specific or known structural pathology (e.g. spondylolisthesis)
- ☐ No spinal surgery

1. Socio-and Demographic information

1.1 Age (in years):_____________

1.2 Gender: ☐ Male: ☐ Female:

1.3 Do you smoke?

☐ Yes ☐ Previously smoked but quit ☐ Never smoked

1.4 Which of the following activities do you spend most of your time on during working hours?

☐ Manual labour ☐ Desk- or computer work

☐ Driving ☐ Other, please specify __________________

1.5 What position do you spend most of your working day in?

☐ Sitting ☐ Standing ☐ Combination

2. Cycling history

2.1 How long have you been cycling (in years)? ☐

2.2 How many hours per week do you cycle on your road bike (average in the last 2-3 months)? ☐

2.3 How many hours per week do you spin/train indoors (average in the last 2-3 months)? ☐

2.4 On average, how many days per week do you currently cycle?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

2.5 What is your average cycling pace (kilometres/hour)?

☐ <20 ☐ 20-25 ☐ 26-30 ☐ 31-35 ☐ 36-40 ☐ >40

2.6 What type of terrain do you usually ride?

☐ Mostly flat ☐ Mostly hilly ☐ Combination

2.7 How many cycling events would you participate in per year?

☐ 0-2 ☐ 3-5 ☐ 6-10 ☐ 11-15 ☐ 16-19 ☐ 20+

2.8 Which cycling technique do you mostly use whilst cycling?

☐ High cadence ☐ Low cadence

☐ Bigger gears ☐ Smaller gears

2.9 What percentage of time do you spend cycling (total needs to add up to 100%):

- In a seated upright position: [ ]

- In a drop position: [ ]

- On the brake levers: [ ]

- In a standing position? [ ]

3. Clinical information

3.1 Generally speaking, have you ever experienced pain or discomfort in your lower back or pelvic area?

☐ No ☐ Yes

3.2 Have you ever experienced pain or discomfort in your lower back or pelvic area during or after cycling?

☐ No ☐ Yes

If you have answered **NO** to any of the above, please only answer form section number 4 onwards if you are female, or proceed to the last page of the questionnaire if you are male.

If **YES**, please answer the following questions. They all relate to pain/discomfort experienced DURING or AFTER CYCLING.

3.3 When did your last incident of low back or pelvic pain occur during or after cycling?

I have low back pain at the moment	
During the last week	
During the last month	
During the past 6 months	
During the past 12 months	
More than 12 months ago	

3.4 How many incidences of low back or pelvic pain have you had during or after cyclig in the last five years?

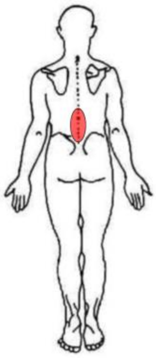
None	
1-5 incidences	
6-10 incidences	
11-15 incidences	
More than 20 incidences	
I have low back or pelvic pain most of the time	

3.5 How long does it take before the pain starts while cycling?

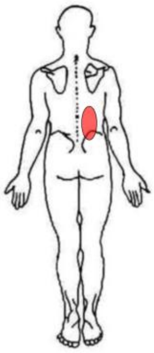
0-10 minutes	
11-30 minutes	
30 minutes – 1 hour	
1-2 hours	
>2 hours	

3.6 Where in your lower back or pelvic area did you experience the pain during or after cycling?

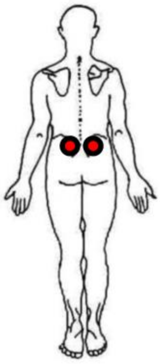
☐ Central lower back



☐ Pain on one side of lower back



☐ Pain over Sacro-Iliac joints



☐ Other

If other, please specify ____

3.7 Did the pain refer anywhere else?

☐ Yes, please specify: ____

☐ No

3.8 Do you attribute the cause of your lower back or pelvic pain to cycling?

☐ Yes ☐ No

3.9 Have you had X-Rays or other investigations for this pain?

☐ Yes, please specify: ____

☐ No

3.10 Are you aware if your low back or pelvic pain is experienced due to a condition which has been diagnosed by a doctor or physiotherapist?

☐ No ☐ Yes

If YES, please specify when and what: ____

____

3.11 What riding position had you been in or were you in when you experienced back pain?

☐ Upright position ☐ Drop position

☐ Brake levers ☐ Standing position

3.12 How long were you unable to train for as a result of the low back or pelvic pain?

Training not affected	
Trained through pain	
Trained with assistance of analgesics (pain) or anti-inflammatory medication	
<1 week	
1-3 weeks	
4-8 weeks	
9-12 weeks	
3-6 months	
>6 months	

4. If you are female, please answer the following questions:

4.1 When experiencing low back or pelvic pain, do you get it only during menstruation?

☐ No ☐ Yes

4.2 Do you get low back or pelvic pain during other times and during menstruation?

☐ No ☐ Yes

4.3 Have you had any children?

☐ No ☐ Yes

4.4 When was your last pregnancy? ______________________________

Thank you for taking the time to complete this questionnaire.

This information will be treated with the strictest confidentiality.

PHYSICAL ASSESSEMENT AND MEASUREMENTS OF BICYCLE SET-UP

If you are willing to participate in the second section of this study which includes a physical assessment and measurements of your bicycle set-up, please provide your name and contact details below .

Full name (please print):____

Phone number:____

Cellphone number:____

E-mail address:____

APPENDIX 7 – DATA CAPTURING FORM FOR ASSESSMENT

PHYSICAL ASSESSMENT FORM

Participant number: ____________________

1. **Lower back or pelvic pain:**

☐ Currently ☐ Only during or after cycling

☐ Previously ☐ Only at other times

☐ Occasionally ☐ During or after cycling and at other times

☐ No pain

2. **Km cycled per week:** ____________________________

3. **Gender**: ☐ Male ☐ Female

3. **Height:** _________________ **Weight:** _______________ **BMI:** ________________

5. **Lateral sway test** (feet 1/3 of trochanteric distance apart) – 3 trials before testing

	LEFT				RIGHT			
	1st shift	2nd shift	3rd shift	Average	1st shift	2nd shift	3rd shift	Average
Cm shift from BB								
Difference in sides								

☐ Normal (<2cm difference between sides; <10cm shift)

☐ Abnormal

6. **Arm length** (acromion to 2nd MCP)

	LEFT				RIGHT			
	1st	2nd	3rd	Average	1st	2nd	3rd	Average
Cm								

7. **Upper body length** (Manubrium to seat)

	1st	2nd	3rd	Average
Cm				

Reach:

8. Sitting forward lean test (5 practise runs, S1 and 10cm cranially, 120° hipfl)

Runs	1	2	3	4	5	Average
Distance (cm)						

☐ Normal ☐ Abnormal

9. Neuro-dynamic test (SLUMP)

LEFT:

Symptoms	Cx	Tx	Lx	Buttock	Post thigh	Post knee	Post leg	Calve
Cx ext	Nil change		Partial relief		Complete relief		No Sx's	↑ed Sx's

☐ Reproduction of Sx's ☐ Decrease in Sx's with Cx ext

☐ Overtly positive ☐ Covertly positive ☐ Negative

RIGHT:

Symptoms	Cx	Tx	Lx	Buttock	Post thigh	Post knee	Post leg	Calve
Cx ext	Nil change		Partial relief		Complete relief		No Sx's	↑ed Sx's

☐ Reproduction of Sx's ☐ Decrease in Sx's with Cx ext

☐ Overtly positive ☐ Covertly positive ☐ Negative

10. Gluteus Maximus inner range holding capacity (contact rod, no pressure change) 20mmHg ASIS

	LEFT		**RIGHT**	
	15 sec hold	15 sec hold	15 sec hold	15 sec hold
Achieved				
Active=passive				

☐ Normal ☐ Abnormal

11. Leg length (ASIS to medial malleolus) – bridge before

	LEFT			**RIGHT**		
	1st	2nd	Average	1st	2nd	Average
Cm						

☐ Normal (<10cm difference) ☐ Abnormal

12. **Hamstrings flexibility** (passive knee extension angle to firm resistance) – lining marks

	LEFT				RIGHT			
	1st	2nd	3rd	Average	1st	2nd	3rd	Average
Degrees								

☐ Normal (KEA <20°)   ☐ Abnormal (KEA >20°)

13. **Active SLR**

0	Not difficult at all
1	Minimally difficult
2	Somewhat difficult
3	Fairly difficult
4	Very difficult
5	Unable to do

	LEFT		RIGHT		
	No comp	Compr	No compr	Compr	
Effort					
Change with compression	Decrease	Increase	Decrease	Increase	**Score /10**
Pressure (mmHg)					

☐ Positive (1-10/10)   ☐ Negative (0/10)

14. **Gluteus medius through range control** (2x15 secs) sidelying ext/abd/ER

	LEFT		RIGHT	
	15 sec hold	15 sec hold	15 sec hold	15 sec hold
Achieved				
Active=passive				

☐ Normal   ☐ Abnormal

15. **Lumbar lordosis on bike** (30 sec cycle inbetween)

		1st	2nd	3rd	Average
Sitting bike	T12/L1				
	S1				
Brakelevers	T12/L1				
	S1				
Upright	T12/L1				
	S1				
Drops	T12/L1				
	S1				

☐ Flexion   ☐ Neutral   ☐ Extension

BIKE SET-UP

1. **Saddle height** (knee angle in BDC)

	LEFT				RIGHT			
	1st	2nd	3rd	Average	1st	2nd	3rd	Average
Degrees								

☐ In-limit (25-30° fl)　　☐ Out- of-limit

2. **Saddle fore-aft position** (plumb line: post patella in line with pedal spindle, pedal at 3 o'clock)

	LEFT		RIGHT	
Kn Over spindle	Yes	No	Yes	No
Kn ant to spindle	Yes	No	Yes	No
Kn post to spindle	Yes	No	Yes	No

3. **Saddle angle**

☐ Level　　☐ Ant down　　☐ Post down

4. **Handlebar height** (difference between top of saddle and stem of handlebars)

	1st measure	2nd measure	3rd measure	Average
Top of saddle				
Top of handlebar stem				

Distance between handlebars and saddle: ______________________

☐ In limit (5-8cm)　　☐ Out of limit

☐ In limit (DeVey)　　☐ Out of limit

5. **Posture length/reach** (rear of saddle to transverse bar of handlebar)

	1st measure	2nd measure	3rd measure	Average
Reach (cm)				

☐ In limit　　☐ Out of limit

6. **Cleat position** (head of 1st metatarsal directly above pedal spindle)

	LEFT	RIGHT
Cleat over ball of foot		

Torso + Arm length	**Reach**	**Handlebar level**
110	72	2.5
112	73	3.0
114	74	3.5
116	75	4.0
118	76	4.5
120	77	5.0
122	78	5.5
124	79	6.0
126	80	6.5
128	81	7.0
130	82	7.5
132	83	8.0
134	84	8.5
136	85	9.0
138	86	9.5
140	87	10.0
142	88	10.5

APPENDIX 8 – RESULTS OF THE RELIABILITY STUDY

Additional results related to intrarater reliability are presented in this appendix. Table 1 depicts additional data for the intrinsic factors of the cyclist while Table 2 illustrates additional bicycle set-up factors.

Table A8.1Reliability of the measurements of intrinsic factors

Factor	Kappa
Slump Left	0.63**
Slump Right	0.30
GMax active=passive Left	0.41*
GMax holding Left	1.00***
Gmax active=passive Right	0.63**
Gmax holding right	0.32
Gmax final category	0.63**
ASLR Left	0.40
ASLR Right	0.25
ASLR Final category	0.68**
Gmed active=passive Left	0.26
Gmed holding Left	0.32
Gmed active=passive Right	0.03
Gmed holding right	1.00***
Gmed final category	0.43*

Key: Excellent intrarater reliability (ICC / Kappa > 0.75) = ***; Substantial intrarater reliability (ICC / Kappa of >0.60) = **, Moderate intrarater reliability (ICC / Kappa of 0.40-0.60) = *; Poor intrarater reliability (ICC / Kappa < 0.4).

Table A8.2Reliability of bicycle set-up measurements

Factor	Intra class correlation (ICC)	Kappa
Saddle Height left leg	0.20	
Saddle Height Right leg	0.75*	
Saddle set-back left leg		0.48*
Saddle set-back right leg		0.83**
Saddle set-back final category		0.81**
Cleat position left		0.32
Cleat position right		0.70*
Cleat position final category		0.65*

Key: Excellent intrarater reliability (ICC / Kappa > 0.75) = ***; Substantial intrarater reliability (ICC / Kappa of >0.60) = **, Moderate intrarater reliability (ICC / Kappa of 0.40-0.60) = *; Poor intrarater reliability (ICC / Kappa < 0.4).

APPENDIX 9 – FURTHER RESULTS FOR INTRINSIC FACTORS

Additional results related to the factors assessed in the physical examination (anthropometric, intrinsic and bicycle set-up) are presented in this appendix.

1.1Description of the physical and bicycle setup factors for the cycling population

A summary of the description of the sub-groups of the physical factors and the bicycle setup factors for the entire cycling population included in the physical assessment can be found in **Table 1** and **Table 2** respectively.

Table A9.1 Summary of the physical factors in cyclists

Physical Factors	Respondents n (%)
Gender	
Female	24 (19.8)
Male	97 (80.2)
BMI	
Normal	55 (45.5)
Overweight	51 (42.2)
Obese	15 (12.4)
BMI – Mean (SD)	25.98 (3.77)
Lateral sway	
Unequal shift left and right (>2cm)	41 (33.9)
Shift greater than 10cm	21 (17.4)
Normal lateral sway test	74 (61.2)
Lateral sway to Left – Mean (SD) (cm)	7.86 (1.94)
Lateral sway to Right – Mean (SD) (cm)	7.21 (1.92)
Sitting forward Lean	
Sitting forward lean with <10mm change in lumbar position (normal)	114 (94.2)
Sitting forward lean lumbar movement – Mean (SD) (cm)	0.30 (0.38)
Slump	
Normal	85 (70.3)
Covertly positive	19 (15.7)
Overtly positive	17 (14.1)
Gluteus Maximus	
Insufficient inner range holding capacity Left	91 (75.2)
Insufficient inner range holding capacity Right	83 (68.6)
Insufficient inner range holding final category	99 (81.8)
Asymmetry between sides	29 (24.0)

Physical Factors	Respondents n (%)
Leg-Length Discrepancy	
More than 6mm discrepancy	47 (38.8)
More than 10mm discrepancy	28 (23.1)
More than 20mm discrepancy	3 (2.48)
Active straight-leg-raise	
Normal	78 (64.5)
Impaired (sum of both legs ≥1)	43 (35.5)
Hamstring length	
Left KEA within limits (less than 20°)	47 (38.8)
Right KEA within limits (less than 20°)	45 (37.2)
Left KEA – Mean (SD) (°)	23.7 (11.7)
Right KEA – Mean (SD) (°)	23.5 (11.1)
KEA out of limit - final category	84 (69.4)
Asymmetry between sides	18 (14.9)
Gluteus Medius inner range holding capacity	
Insufficient inner range holding capacity left	83 (68.6)
Insufficient inner range holding capacity right	100 (82.6)
Insufficient inner range holding final category	107 (88.4)
Asymmetry between left and right sides	40 (33.1)
Lumbar position on bicycle	
Brake levers	
Angle thoraco-lumbar spine (T12/L1) – Mean (SD)	49.12 (7.09)
Angle Lumbo-sacral spine (L5/S1) – Mean (SD)	33.16 (8.04)
Lumbar angle – Mean (SD)	15.93 (10.11)
Seated upright	
Angle thoraco-lumbar spine (T12/L1) – Mean (SD)	43.91 (7.2)
Angle Lumbo-sacral spine (L5/S1) – Mean (SD)	28.69 (8.4)
Lumbar angle – Mean (SD)	15.23 (10.3)
Drops	
Angle thoraco-lumbar spine (T12/L1) – Mean (SD)	59.02 (7.1)
Angle Lumbo-sacral spine (L5/S1) – Mean (SD)	41.10 (7.9)
Lumbar angle – Mean (SD)	17.94 (9.7)
Distance cycled per week	
Mean (SD)	187.79 (98.79)

Table A9.2 Summary of the bicycle setup factors

Bicycle set-up Factors	Respondents n (%)
Saddle Height	
Normal (25-35° KEA)	42 (35)
Asymmetry between sides	39 (32.5)
Too high	13 (10.8)
Too low	26 (21.7)
Righte leg saddle height – Mean (SD) (°)	31.86 (7.89)
Left leg saddle height – Mean (SD) (°)	31.52 (7.69)
Saddle set-back Left	
In limit (knee over spindle)	66 (54.6)
Too far back	23 (19.0)
Too far forward	32 (26.5)
Saddle set-back Right	
In limit (knee over spindle)	55 (45.5)
Too far back	28 (23.1)
Too far forward	38 (31.4)
Saddle angle	
Level	16 (13.2)
Tilted anteriorly	58 (47.9)
Tilted posteriorly	47 (38.8)
Saddle angle – Mean (SD) (°)	0.72 (2.49)
Handlebar Height	
In limit (5-8 cm below saddle)	37 (30.6)
Too high	66 (54.6)
Too low	18 (14.9)
Handlebar height – Mean (SD) (cm)	4.69 (3.34)
Reach	
Normal	11 (9.1)
Too stretched out	46 (38.0)
Too bunched up	64 (52.9)
Cleat position – Left leg	
In limit (in line with 1st metatarsal head)	69 (57.0)
Too far back	45 (37.2)
Too far forward	7 (5.8)
Cleat position – Right leg	
In limit	66 (54.6)
Too far back	53 (43.8)
Too far forward	2 (1.7)
Cleat position – final category of left and right sides	
Correct cleat positioning	53 (43.80)

1.2 Further analysis between several factors and LBPP

Additional comparison between groups for anthropometric and bicycle set-up factors can be found in Tables 3 and 4 respectively.

Table A9.3 Additional information on anthropometric factors

Factor	No LBPP n=31 Mean (SD)	LBPP n=90 Mean (SD)	95% Confidence interval
Age (years)	46.97 (9.57)	46.08 (11.48)	44.33-48.37
Height (m)	1.77 (0.09)	1.77 (0.85)	1.75-1.78
Weight (kg)	83.87 (15.86)	80.90 (15.34)	78.88-84.45
Armlength (cm)	68.86 (3.60)	68.31 (3.78)	67.78-69.12
Upper body length (cm)	56.52 (3.10)	56.30 (3.31)	55.77-56.94
Upper length (sum)	125.26	124.62	123.35-125.87

Table A9.4 Additional comparison between groups for bicycle set-up factors

Factor	No LBPP n=31 Mean (SD)	LBPP n=90 Mean (SD)	95% confidence interval	p-value
Saddle height left leg	30.84 (9.27)	31.76 (7.10)	30.14-32.90	0.83
Saddle height Right leg	29.39 (8.40)	32.71 (7.57)	30.44-33.28	0.08*
Forward reach (cm)	79.85 (3.59)	79.30 (5.02)	78.60-80.28	0.43

APPENDIX 10 – FURTHER RESULTS FOR INTERRELATIONSHIPS

Details on the interrelationships of various factors with each other can be found in this appendix. The breakdown of the tables are as follows:

- Table A10.1: Association of factors with gender
- Table A10.2: Association of factors with distance cycled per week
- Table A10.3: Association of factors with BMI
- Table A10.4: Association of factors with Gmed
- Table A10.5: Association of factors with hamstring length
- Table A10.6: Association of factors with Gmax
- Table A10.7: Association of factors with thoracolumbar angle in the brake lever position
- Table A10.8: Association of factors with lumbo-sacral angle in the brake lever position
- Table A10.9: Association of factors with lumbar curvature in the brake lever position
- Table A10.10: Association of factors with thoracolumbar angle in the seated upright position
- Table A10.11: Association of factors with lumbo-sacral angle in the seated upright position
- Table A10.12: Association of factors with lumbar curvature in the seated upright position
- Table A10.13: Association of factors with thoracolumbar angle in the drops position
- Table A10.14: Association of factors with lumbo-sacral angle in the drops position
- Table A10.15: Association of factors with lumbar curvature in the drops position

Table A10.1 Association of factors with gender

Factor	Sub-factor	Female n (%)	Male n (%)	p-value
BMI	In normal limit	17 (30.91)	38 (69.09)	0.01**
	Out of limit	7 (10.61)	59 (89.39)	
	Mean (SD)	24.1 (4.05)	26.45 (3.57)	0.001**
Lateral sway	In normal limit	13 (17.57)	61 (82.43)	0.43
	Out of limit	11 (23.40)	36 (76.60)	
Siting forward lean	In normal limit	24 (21.05)	90 (78.95)	0.34
	Out of limit	0	7 (100)	
Slump	In normal limit	19 (18.27)	85 (81.73)	0.33
	Out of limit	5 (29.41)	12 (70.59)	
Gmax	In normal limit	9 (40.91)	13 (59.09)	0.006**
	Out of limit	15 (15.15)	84 (84.85)	
ASLR	In normal limit	15 (19.23)	63(80.77)	0.82
	Out of limit	9 (20.93)	34 (79.07)	
Hamstring length	In normal limit	14 (37.84)	23 (62.16)	0.001**
	Out of limit	10 (11.90)	74 (88.10)	
Gmed	In normal limit	7 (50.00)	7 (50.00)	0.01**
	Out of limit	17 (15.89)	90 (84.11)	
Saddle height	In normal limit	6	37	0.23
	Out of limit	18	60	
	In limit	6	37	0.12*
	Asymmetry between KEA of left and right leg	6	33	
	Too high	5	8	
	Too low	7	19	
Saddle set-back	In normal limit	6	42	0.10*
	Out of limit	18	55	
Saddle angle	In limit	17	57	0.28
	Not in limit	7	40	
	Level	4	12	0.57
	Tilted ant down	13	45	
	Tilted post down	7	40	
Handlebar height	In normal limit	3	34	0.05**
	Out of limit	21	63	
Reach	In limit	0	11	0.12*
	Not in limit	24	86	
LLD < 6mm	In normal limit	15 (20.27)	59 (79.73)	0.88
	Out of limit	9 (19.15)	38 (80.85)	
LLD < 10mm	In normal limit	18 (19.35)	75 (80.65)	0.81
	Out of limit	6 (21.43)	22 (78.57)	
LLD < 20mm	In normal limit	23 (19.49)	95 (80.51)	0.49
	Out of limit	1 (33.33)	2 (66.67)	

Table A10.2 Association of factors with distance cycled per week

Factor	Sub-factor	Mean (SD) (km)	z-value	95% CI
Gender	Female	143.13 (78.78)	0.01	109.86-176.39
	Male	198.96 (100.46)		178.60-219.31
BMI	Normal BMI	193.24 (89.00)	0.29	168.95-217.53
	BMI not in limit	183.33 (106.59)		158.13-209.54
Lateral Sway	In normal limit	184.38 (102.17)	0.43	160.55-208.22
	Out of limit	193.09 (94.13)		165.45-220.72
Sitting forward lean test	In normal limit	186.68 (98.09)	0.65	168.40-204.96
	Out of limit	205.71 (116.46)		98.011-313.42
Slump	In normal limit	186.73 (100.50)	0.65	167.19-206.27
	Out of limit	194.69 (89.51)		146.99-242.38
Gmax	In normal limit	168.41 (93.33)	0.30	127.03-209.79
	Out of limit	192.14 (99.91)		172.11-212.17
ASLR	In normal limit	196.54 (101.50)	0.19*	173.65-219.42
	Out of limit	171.55 (92.52)		142.72-200.38
Hamstring length	In normal limit	182.16 (103.88)	0.58	147.53-216.80
	Out of limit	190.30 (10.64)		169.13-211.48
Gmed	In normal limit	172.14 (118.64)	0.37	103.64-240.65
	Out of limit	189.86 (96.33)		171.31-208.41

Association of various factors with BMI

The results of the association of various factors with BMI are presented in **Table 3**.

Table A10.3 Association of factors with BMI

Factor	Subfactor	Respondents n (%)		p-value
		BMI in limit	BMI not in limit	
Gender	Female	17 (70.83)	7 (29.17)	0.01**
	Male	38 (39.18)	59 (60.82)	
Lateral sway	In limit	30 (40.54)	44 (59.46)	0.17*
	Not in limit	25 (53.19)	22 (46.81)	
GMax	Normal holding	9 (40.91)	13 (59.09)	0.64
	Insufficient holding	46 (46.46)	53 (53.54)	
ASLR	In limit	35 (44.87)	43 (55.13)	0.86
	Not in limit	20 (46.51)	23 (53.49)	
Hamstring length	In limit	20 (54.05)	17 (45.95)	0.21
	Not in limit	35 (41.67)	49 (58.33)	
Gmed	Normal holding	11 (78.57)	3 (21.43)	0.01**
	Insufficient holding	44 (41.12)	63 (58.88)	

Association of various factors with Gmed

The results of the association of various factors with Gmed are presented in **Table 4**.

Table A10.4 Association of factors with Gmed

Factor	Subfactor	Respondents n (%)		p-value
		Normal holding	Insufficient holding	
BMI	Normal	11 (20.00)	44 (80.00)	0.01**
	Overweight	3 (4.55)	63 (95.45)	
Lateral sway	In limit	11 (14.86)	63 (85.14)	0.24
	Not in limit	3 (6.38)	44 (93.62)	
GMax	Normal holding	7 (31.82)	15 (68.18)	0.001**
	Insufficient holding	7 (7.07)	92 (92.93)	
ASLR	In limit	9 (11.54)	69 (88.46)	1.00
	Not in limit	5 (11.63)	38 (88.37)	
Hamstring length	In limit	8 (21.62)	29 (78.38)	0.02**
	Not in limit	6 (7.14)	78 (92.86)	
Saddle height	In limit	7 (16.28)	36 (83.72)	0.23
	Not in limit	7 (8.97)	71 (91.03)	
Saddle set-back	In limit	7 (14.58)	41 (85.42)	0.40
	Not in limit	7 (9.59)	66 (90.41)	
Saddle angle	In limit	10 (13.51)	64 (86.49)	0.56
	Not in limit	4 (8.51)	43 (91.49)	

Association of various factors with hamstring length

The results of the association of various factors with the length of the hamstrings are presented in **Table 5**.

Table A10.5 Association of factors with hamstring length

Factor	Subfactor	Respondents n (%)		p-value
		Normal length	Insufficient length	
GMax	Normal holding	12 (54.55)	10 (45.45)	0.01**
	Insufficient holding	25(25.25)	74 (74.75)	
Gmed	In limit	8 (57.147)	6 (42.86)	0.02**
	Not in limit	29 (27.10)	78 (72.90)	
Slump	Normal holding	32 (30.77)	72 (69.23)	1.00
	Insufficient holding	5 (29.41)	12 (70.59)	
	Not in limit	22 (34.92)	41 (65.08)	
Sitting forward lean	In limit	36 (31.58)	78 (68.42)	0.67
	Not in limit	1 (14.29)	6 (85.71)	
Saddle height	In limit	16 (37.21)	27 (62.79)	0.24
	Not in limit	21 (26.92)	57 (73.08)	
Saddle set-back	In limit	15 (31.25)	33 (68.75)	0.90
	Not in limit	22 (30.14)	51 (69.86)	
Saddle angle	In limit	23 (31.08)	51 (68.92)	0.88
	Not in limit	14 (29.79)	33 (70.21)	

Association of various factors with Gmax

The results of the association of various factors with Gmax are presented in **Table 6**.

Table A10.6 Association of factors with Gmax

Factor	Subfactor	Respondents n (%)		p-value
		Gmax in limit	Gmax not in limit	
Lateral sway	In limit	18 (24.32)	56 (75.68)	0.03**
	Not in limit	4 (8.51)	43 (91.49)	
Sitting forward lean	Normal holding	21 (18.42)	93 (81.58)	1.00
	Insufficient holding	1 (14.29)	6 (85.71)	
ASLR	In limit	15 (19.23)	63 (80.77)	0.69
	Not in limit	7 (16.28)	36 (83.72)	
Hamstring length	In limit	12 (32.43)	25 (67.57)	0.01**
	Not in limit	10 (11.90)	74 (88.10)	
Gmed	Normal holding	7 (50.00)	7 (50.00)	0.001**
	Insufficient holding	15 (14.02)	92 (85.98)	
Saddle height	In limit	11 (25.58)	32 (74.42)	0.12*
	Not in limit	11 (14.10)	67 (85.90)	
Saddle set-back	In limit	8 (16.67)	40 (83.33)	0.73
	Not in limit	14 (19.18)	59 (80.82)	
Reach	In limit	1 (9.09)	10 (90.91)	0.69
	Not in limit	21 (19.09)	89 (80.91)	

Association of various factors with thoraco-lumbar angle (T12/L1) in the brake lever position

Table A10.7 Association of factors with thoracolumbar angle in the brake lever position

Factor	Subfactor	Participants n	Mean (SD) (°)	p-value	95% Confidence interval
Gender	Female	24	51.75 (6.01)	0.04**	49.21-54.29
	Male	97	48.46 (7.22)		47.01-49.92
BMI	In limit	55	51.91 (6.86)	0.001**	50.06-53.76
	Not in limit	66	46.79 (6.46)		45.20-48.38
Lateral sway	In limit	74	49.10 (6.65)	0.72	47.55-50.63
	Not in limit	47	49.15 (7.82)		46.85-51.44
Sitting forward lean	In limit	114	48.99 (6.99)	0.27	47.69-50.29
	Not in limit	7	51.14 (9.04)		42.78-59.51
Slump	In limit	104	48.88 (7.15)	0.27	47.48-50.27
	Not in limit	17	50.59 (6.76)		47.12-54.06
Gmax	In limit	22	50 (6.41)	0.54	47.16-52.84
	Not in limit	99	48.92 (7.25)		47.47-50.37
Hamstring length	In limit	37	50.19 (7.26)	0.28	47.77-52.61
	Not in limit	84	48.64 (7.01)		47.12-50.16
ASLR	In limit	78	48.94 (7.00)	0.95	47.36-50.51
	Not in limit	43	49.44 (7.33)		47.19-51.70
Gmed	In limit	14	51.07 (6.68)	0.30	47.21-54.93
	Not in limit	107	48.86 (7.14)		47.49-50.23
Saddle height	In limit	43	50.19 (6.87)	0.38	48.07-52.30
	Not in limit	78	48.53 (7.19)		46.91-50.15
Saddle set-back	In limit	48	49.69 (6.22)	0.61	47.88-51.49
	Not in limit	73	48.74 (7.63)		46.96-50.52
Saddle-angle	In limit	74	50.04 (7.25)	0.10*	48.36-51.72
	Not in limit	47	47.66 (6.65)		45.71-49.61
Handlebar height	In limit	37	50.19 (7.35)	0.17*	47.74-52.64
	Not in limit	84	48.64 (6.97)		47.13-50.16
Reach	In limit	11	49.91 (4.04)	0.69	47.20-52.62
	Not in limit	110	49.04 (7.34)		47.65-50.42

Association of various factors with lumbo-sacral angle (L5/S1) in the brake lever position

Table A10.8 Association of factors with lumbosacral angle in the brake lever position

Factor	Subfactor	Resp N	Mean (SD) (°)	p-value	95% Confidence interval
Gender	Female	24	40.29 (10.10)	0.001**	36.03-44.56
	Male	97	31.39 (6.36)		30.11-32.67
BMI	In limit	55	33.09 (8.37)	0.79	30.83-35.35
	Not in limit	66	33.21 (7.82)		31.29-35.14
Lateral sway	In limit	74	33.47 (8.38)	0.74	31.53-35.41
	Not in limit	47	32.66 (7.54)		30.44-34.87
Sitting forward lean	In limit	114	33.34 (8.08)	0.35	31.84-34.84
	Not in limit	7	30.14 (7.20)		23.49-36.80
Slump	In limit	104	32.90 (8.02)	0.70	31.35-34.46
	Not in limit	17	34.71 (8.27)		30.46-38.96
Gmax	In limit	22	35.05 (8.08)	0.25	31.46-38.63
	Not in limit	99	32.74 (8.01)		31.14-34.34
Hamstring length	In limit	37	35.81 (9.00)	0.07*	32.81-38.81
	Not in limit	84	31.99 (7.34)		30.40-33.58
ASLR	In limit	78	32.81 (8.41)	0.40	30.91-34.70
	Not in limit	43	33.79 (7.37)		31.52-36.06
Gmed	In limit	14	35.5 (9.98)	0.27	29.74-41.26
	Not in limit	107	32.85 (7.76)		31.36-34.36
Saddle height	In limit	43	32.53 (6.62)	0.56	30.50-34.57
	Not in limit	78	33.5 (8.75)		31.53-35.47
Saddle set-back	In limit	48	32.73 (8.07)	0.29	30.39-35.07
	Not in limit	73	33.44 (8.06)		31.56-35.32
Saddle-angle	In limit	74	33.14 (8.15)	0.79	31.25-35.02
	Not in limit	47	33.19 (7.94)		30.86-35.52
Handlebar height	In limit	37	33.76 (6.90)	0.25	31.46-36.06
	Not in limit	84	32.89 (8.52)		31.04-34.74
Reach	In limit	11	30.27 (7.20)	0.19	25.44-35.11
	Not in limit	110	33.45 (8.09)		31.92-34.97

Association of various factors with the lumbar curvature in the brake lever position

Table A10.9 Association of factors with lumbar curvature in the brake lever position

Factor	Subfactor	Resp N	Mean (SD) (°)	p-value	95% Confidence interval
Gender	Female	24	11.35 (10.88)	0.03**	6.75-15.94
	Male	97	17.06 (9.63)		15.12-19.01
BMI	In limit	55	18.82 (9.96)	0.002**	16.13-21.51
	Not in limit	66	13.52 (9.66)		11.15-15.89
Lateral sway	In limit	74	15.64 (9.54)	0.74	13.43-17.85
	Not in limit	47	16.38 (11.03)		13.14-19.62
Sitting forward lean	In limit	114	15.62 (10.03)	0.08*	13.76-17.48
	Not in limit	7	20.91 (10.91)		10.83-31.00
Slump	In limit	104	15.94 (10.34)	0.89	13.93-17.95
	Not in limit	17	17 (8.80)		11.34-20.39
Gmax	In limit	22	14.89 (9.61)	0.67	10.63-19.15
	Not in limit	99	16.16 (10.24)		14.12-18.20
Hamstring length	In limit	37	14.31 (10.65)	0.25	10.76-17.87
	Not in limit	84	16.64 (9.84)		14.51-18.78
ASLR	In limit	78	16.12 (10.24)	0.76	13.81-18.43
	Not in limit	43	15.59 (9.97)		12.52-18.66
Gmed	In limit	14	15.47 (12.69	0.95	8.14-22.80
	Not in limit	107	15.99 (9.79)		14.11-17.87
Saddle height	In limit	43	17.65 (9.20)	0.13*	14.81-20.48
	Not in limit	78	14.98 (10.51)		12.61-17.35
Saddle set-back	In limit	48	16.90 (9.13)	0.38	14.25-19.56
	Not in limit	73	15.29 (10.71)		12.79-17.79
Saddle-angle	In limit	74	16.85 (9.81)	0.21	14.58-19.12
	Not in limit	47	14.48 (10.50)		11.40-17.56
Handlebar height	In limit	37	16.37 (11.52)	0.66	12.53-20.21
	Not in limit	84	15.74 (9.49)		13.68-17.80
Reach	In limit	11	19.65 (8.85)	0.15*	13.70-25.59
	Not in limit	110	15.56 (10.18)		13.63-17.48

Association of various factors with thoraco-lumbar angle (T12/L1) in the seated upright position

Table A10.10 Association of factors with thoracolumbar angle in the seated upright position

Factor	Subfactor	n	Mean (SD) (°)	p-value	95% Confidence interval
Gender	Female	24	46.54 (5.13)	0.04**	44.39-48.71
	Male	97	43.26 (7.44)		41.76-44.76
BMI	In limit	55	46.44 (6.77)	0.001**	44.61-48.27
	Not in limit	66	41.80 (6.80)		40.13-43.48
Lateral sway	In limit	74	44.24 (6.83)	0.70	42.66-45.83
	Not in limit	47	43.38 (7.67)		41.13-45.63
Sitting forward lean	In limit	114	43.88 (7.11)	0.67	42.56-45.20
	Not in limit	7	44.43 (8.26)		36.79-52.07
Slump	In limit	104	43.58 (7.28)	0.18*	42.16-44.99
	Not in limit	17	45.94 (6.10)		42.91-49.08
Gmax	In limit	22	44.68 (6.34)	0.48	41.87-47.49
	Not in limit	99	43.74 (7.33)		42.28-45.20
Hamstring length	In limit	37	45.27 (7.90)	0.22	42.63-47.91
	Not in limit	84	43.31 (6.75)		41.85-44.77
ASLR	In limit	78	43.68 (7.29)	0.88	42.04-45.32
	Not in limit	43	44.33 (6.94)		42.19-46.46
Gmed	In limit	14	46.07 (7.16)	0.19*	41.94-50.21
	Not in limit	107	43.63 (7.13)		42.26-44.99
Saddle height	In limit	43	45.02 (7.00)	0.44	42.87-47.18
	Not in limit	78	43.29 (7.20)		41.67-44.92
Saddle set-back	In limit	48	44.81 (6.16)	0.37	43.02-46.60
	Not in limit	73	43.32 (7.71)		41.52-45.11
Saddle-angle	In limit	74	44.64 (7.12)	0.22	42.98-46.29
	Not in limit	47	42.77 (7.11)		40.68-44.85
Handlebar height	In limit	37	44.97 (7.65)	0.14*	42.42-47.52
	Not in limit	84	43.44 (6.91)		41.94-44.94
Reach	In limit	10	44.73 (3.98)	0.79	42.06-47.40
	Not in limit	110	43.83 (7.40)		42.43-45.22

Association of various factors with lumbo-sacral angle (L5/S1) in the seated upright position

Table A10.11 Association of factors with lumbo-sacral angle in the seated upright position

Factor	Subfactor	Resp N	Mean (SD) (°)	p-value	95% Confidence interval
Gender	Female	24	35.88 (10.68)	0.001**	31.37-40.38
	Male	97	26.91 (6.31)		25.57-28.24
BMI	In limit	55	28.67 (8.36)	0.79	26.41-30.93
	Not in limit	66	28.70 (8.43)		26.62-30.77
Lateral sway	In limit	74	29.23 (8.76)	0.34	27.20-31.26
	Not in limit	47	27.83 (7.71)		25.57-30.09
Sitting forward lean	In limit	114	28.97 (8.32)	0.16*	27.43-30.52
	Not in limit	7	24 (8.25)		16.37-61.63
Slump	In limit	104	28.40 (8.26)	0.69	26.80-30.01
	Not in limit	17	30.41 (9.03)		25.77-35.05
Gmax	In limit	22	30.77 (8.57)	0.29	26.97-34.57
	Not in limit	99	28.22 (8.29)		26.57-29.88
Hamstring length	In limit	37	31.84 (9.25)	0.03**	28.75-34.92
	Not in limit	84	27.30 (7.59)		25.65-28.94
ASLR	In limit	78	28.51 (8.68)	0.65	26.56-30.47
	Not in limit	43	29 (7.85)		26.58-31.42
Gmed	In limit	14	31.21 (10.28)	0.30	25.28-37.15
	Not in limit	107	28.36 (8.08)		26.81-29.90
Saddle height	In limit	43	28.07 (7.54)	0.40	25.75-30.39
	Not in limit	78	29.03 (8.81)		27.04-31.01
Saddle set-back	In limit	48	28.21 (8.35)	0.28	25.78-30.63
	Not in limit	73	29 (8.41)		27.04-30.96
Saddle-angle	In limit	74	28.57 (8.36)	0.46	26.63-30.50
	Not in limit	47	28.87 (8.46)		26.39-31.36
Handlebar height	In limit	37	29.35 (6.70)	0.29	27.12-31.59
	Not in limit	84	28.39 (9.02)		26.44-30.35
Reach	In limit	10	25.18 (8.65)	0.14*	19.37-30.99
	Not in limit	110	29.04 (8.29)		27.47-30.60

Association of various factors with the lumbar curvature in the seated upright position

Table A10.12 Association of factors with the lumbar curvature in the seated upright position

Factor	Subfactor	Resp N	Mean (SD) (°)	p-value	95% Confidence interval
Gender	Female	24	10.67 (11.40)	0.03**	5.86-15.48
	Male	97	16.36 (9.76)		14.39-18.33
BMI	In limit	55	17.84 (10.01)	0.01**	15.13-20.54
	Not in limit	66	13.06 (10.13)		10.57-15.55
Lateral sway	In limit	74	15.01 (9.72)	0.86	12.76-17.27
	Not in limit	47	15.57 (11.28)		12.26-18.88
Sitting forward lean	In limit	114	10.90 (10.26)	0.10*	13.00-16.81
	Not in limit	7	20.56 (10.56)		10.79-30.33
Slump	In limit	104	15.17 (10.60)	0.89	13.11-17.23
	Not in limit	17	15.59 (8.60)		11.16-20.01
Gmax	In limit	22	13.95 (10.54)	0.72	9.27-18.62
	Not in limit	99	15.52 (10.30)		13.46-17.57
Hamstring length	In limit	37	13.46 (11.29)	0.23	9.70-17.22
	Not in limit	84	16.01 (9.83)		13.88-18.14
ASLR	In limit	78	15.18 (10.47)	0.82	12.81-17.54
	Not in limit	43	15.33 (10.14)		12.21-18.45
Gmed	In limit	14	14.95 (11.82)	0.93	8.13-21.77
	Not in limit	107	15.27 (10.16)		13.32-17.22
Saddle height	In limit	43	16.95 (9.76)	0.14*	13.95-19.96
	Not in limit	78	14.28 (10.55)		11.90-16.66
Saddle set-back	In limit	48	16.61 (8.76)	0.28	14.07-19.16
	Not in limit	73	14.32 (11.18)		11.71-16.93
Saddle-angle	In limit	74	16.09 (10.12)	0.21	13.74-18.43
	Not in limit	47	13.88 (10.58)		10.78-16.99
Handlebar height	In limit	37	15.59 (12.08)	0.57	11.56-19.61
	Not in limit	84	15.07 (9.51)		13.01-17.14
Reach	In limit	11	19.48 (9.69)	0.12*	12.97-25.99
	Not in limit	110	14.81 (10.32)		12.86-16.76

Association of various factors with thoraco-lumbar angle (T12/L1) in the drops position

Table A10.13 Association of factors with the thoracolumbar angle in the drops position

Factor	Subfactor	n	Mean (SD) (°)	p-value	95% Confidence interval
Gender	Female	24	63.42 (4.76)	0.001**	61.41-65.43
	Male	97	57.94 (7.15)		56.50-59.38
BMI	In limit	55	61.82 (6.31)	0.001**	60.11-63.52
	Not in limit	66	56.70 (6.87)		55.01-58.39
Lateral sway	In limit	74	58.97 (7.12)	0.73	57.32-60.62
	Not in limit	47	59.11 (7.08)		57.03-61.19
Sitting forward lean	In limit	114	58.96 (7.04)	0.39	57.66-60.27
	Not in limit	7	60 (8.25)		52.37-67.63
Slump	In limit	104	58.70 (7.16)	0.21	57.31-60.09
	Not in limit	17	61 (6.41)		57.70-64.30
Gmax	In limit	22	59.81 (7.33)	0.40	56.57-63.07
	Not in limit	99	58.85 (7.04)		57.44-60.25
Hamstring length	In limit	37	60.70 (7.25)	0.15*	58.28-63.12
	Not in limit	84	58.29 (6.91)		56.79-59.79
ASLR	In limit	78	58.73 (6.86)	0.72	57.18-60.28
	Not in limit	43	59.56 (7.50)		57.25-61.87
Gmed	In limit	14	61.57 (6.62)	0.14*	57.75-65.39
	Not in limit	107	58.69 (7.10)		57.33-60.05
Saddle height	In limit	43	59.86 (7.49)	0.70	57.56-62.16
	Not in limit	78	58.56 (6.85)		57.02-60.11
Saddle set-back	In limit	48	59.44 (6.35)	0.88	57.59-61.28
	Not in limit	73	58.75 (7.55)		56.99-60.51
Saddle-angle	In limit	74	60.27 (7.06)	0.02**	58.63-61.91
	Not in limit	47	57.06 (6.71)		55.09-59.03
Handlebar height	In limit	37	59.68 (7.44)	0.36	57.19-62.16
	Not in limit	84	58.74 (6.94)		57.23-60.24
Reach	In limit	11	60.36 (3.64)	0.48	57.72-62.81
	Not in limit	110	58.89 (7.33)		57.51-60.28

Association of various factors with lumbo-sacral angle (L5/S1) in the drops position

Table A10.14 Association of factors with the lumbo-sacral angle in the drops position

Factor	Subfactor	Resp N	Mean (SD) (°)	p-value	95% Confidence interval
Gender	Female	24	49.38 (8.70)	0.001**	45.70-53.05
	Male	97	39.05 (6.13)		37.82-40.29
BMI	In limit	55	40.89 (8.11)	0.65	38.70-43.08
	Not in limit	66	41.27 (7.70)		39.38-43.16
Lateral sway	In limit	74	41.5 (8.27)	0.64	39.58-43.42
	Not in limit	47	40.47 (7.20)		38.35-42.58
Sitting forward lean	In limit	114	41.42 (7.83)	0.08*	39.97-42.87
	Not in limit	7	35.86 (6.79)		29.57-42.14
Slump	In limit	104	40.87 (7.60)	0.81	39.39-42.34
	Not in limit	17	42.53 (9.37)		37.71-47.35
Gmax	In limit	22	42.90 (7.24)	0.32	39.70-46.12
	Not in limit	99	40.70 (7.96)		39.11-42.29
Hamstring length	In limit	37	43.97 (9.02)	0.03**	40.97-46.98
	Not in limit	84	39.83 (6.97)		38.32-41.35
ASLR	In limit	78	40.90 (8.15)	0.70	39.06-42.74
	Not in limit	43	41.47 (7.36)		39.20-43.73
Gmed	In limit	14	43.21 (10.15)	0.28	37.35-49.08
	Not in limit	107	40.82 (7.52)		39.38-42.26
Saddle height	In limit	43	39.93 (7.14)	0.17*	37.73-42.13
	Not in limit	78	41.74 (8.19)		39.90-43.59
Saddle set-back	In limit	48	40.40 (8.03)	0.22	38.06-42.73
	Not in limit	73	41.56 (7.76)		39.75-43.37
Saddle-angle	In limit	74	41.53 (8.26)	0.74	39.61-43.44
	Not in limit	47	40.43 (7.20)		38.31-42.54
Handlebar height	In limit	37	41.11 (6.17)	0.48	39.05-43.17
	Not in limit	84	41.10 (8.52)		39.25-42.95
Reach	In limit	11	38.82 (7.72)	0.25	33.63-44.00
	Not in limit	110	41.33 (7.87)		39.84-42.81

Association of various factors with lumbar curvature in the drops position

Table A10.15 Association of factors with the lumbar curvature in the drops position

Factor	Subfactor	n	Mean (SD) (°)	p-value	95% Confidence interval
Gender	Female	24	14.11 (10.05)	0.04**	9.87-18.35
	Male	97	18.89 (9.36)		17.00-20.78
BMI	In limit	55	20.99 (9.27)	0.001**	18.49-23.50
	Not in limit	66	15.40 (9.28)		13.12-17.68
Lateral sway	In limit	74	17.50 (9.31)	0.70	15.35-19.66
	Not in limit	47	18.64 (10.23)		15.63-21.64
Sitting forward lean	In limit	114	17.58 (9.49)	0.04**	15.82-19.34
	Not in limit	7	23.87 (11.09)		13.61-34.13
Slump	In limit	104	17.87 (9.79)	0.78	15.96-19.77
	Not in limit	17	18.41 (9.03)		13.77-23.05
Gmax	In limit	22	16.95 (9.85)	0.78	12.58-21.31
	Not in limit	99	18.17 (9.64)		16.24-20.09
Hamstring length	In limit	37	16.77 (10.28)	0.34	13.34-20.20
	Not in limit	84	18.46 (9.38)		16.42-20.49
ASLR	In limit	78	17.89 (9.82)	0.98	15.68-20.11
	Not in limit	43	18.03 (9.45)		15.12-20.94
Gmed	In limit	14	18.49 (11.83)	0.85	11.65-25.32
	Not in limit	107	17.87 (9.39)		16.07-19.67
Saddle height	In limit	43	19.91 (9.05)	0.11*	17.13-22.70
	Not in limit	78	16.86 (9.85)		14.64-19.08
Saddle set-back	In limit	48	19.06 (8.49)	0.33	16.60-21.53
	Not in limit	73	17.21 (10.33)		14.80-19.62
Saddle-angle	In limit	74	18.77 (9.71)	0.18*	16.52-21.02
	Not in limit	47	16.64 (9.51)		13.85-19.43
Handlebar height	In limit	37	18.61 (11.16)	0.51	14.88-22.33
	Not in limit	84	17.65 (8.96)		15.71-19.60
Reach	In limit	11	21.44 (8.74)	0.18*	15.57-27.31
	Not in limit	110	17.59 (9.70)		15.76-19.43