Systematic Review of the Sensitivity, Specificity and Validity of the Active Straight Leg Raise Test in Low Back Pain

By

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I, Andrew Lee, do declare that this dissertation is representative of my own work in both conception and execution (except where acknowledgements indicate to the contrary)

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ABSTRACT

Background

The active straight leg raise test (ASLR) is a commonly used clinical diagnostic test in a heterogenous group of conditions classified as low back pain. It may be used in a battery of tests to obtain a clinical diagnosis or to aid in the assessment of motor control in the lumbopelvic hip complex in the sagittal plane. A few variations of the ASLR exist in the literature. There is therefore a need to analyse the literature to determine to the most appropriate clinical application and interpretation of the test as the incorrect and/or ineffective application of the ASLR may influence patient outcomes.

Data sources

A systematic review of PubMed, Google Scholar, Cochrane Reviews, Cumulative Index to Nursing and Allied Health Literature (CINAHL) and Scopus.

Study selection

All electronic or paper, English articles, which possessed the required key indexing terms and represented randomised and non-randomised controlled study designs were included.

Data extraction and synthesis

The blind review of the 25 articles was conducted by three independent reviewers (nine reviewers in total) using the non-randomised controlled trials (NOS) and Liddle scales. This allowed the methodological rigour of the article to be ranked. This ranking was compared to a critical appraisal of the article in order to achieve an overall decision with regards to the contribution of the article to the level of evidence for ASLR test.

Results

The evaluations and combined evidence were then determined for the ASLR under the heading non-pregnancy related PGP, LBP, and LPP, and various lift heights

<10cm, 10-30cm, 30-60cm, full available range of motion, and unspecified range of motion. Due to study design (observational), no study exceeded level 3 evidence.

Conclusion

The ASLR was found to have a valid face construct, but assertions made in relation to its constructed validity in non-pregnancy related LBP is limited and conflicting. It is unclear if a positive ASLR result is from failure form closure of the public symphysis or the SIJ and if motor control is a contributing factor or product of pain.

Key words: “ASLR pelvic girdle pain”; “ASLR low back pain”; “ASLR sacroiliac dysfunction”; “ASLR sacroiliitis”; “ASLR pubic symphysitis”; “ASLR motor dysfunction”; “lumbar spine dysfunction”; “ASLR ultrasound”; “ASLR sensitivity”; “ASLR specificity”; “ASLR validity”, and “ASLR lumbar spine instability”.

DEDICATION

I wish to dedicate this thesis to my mother who passed during this time of great difficulty. I wish you were here to see not just the completion of the course but also the life lessons of perseverance and determination that I have learnt.

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I wish to thank Dr Charmaine Korporaal, for patiently putting up with my disorganised mind and life. I really appreciate the time and patience that was required to work with me.

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CHAPTER ONE INTRODUCTION

1.1 INTRODUCTION

The active straight leg raise (ASLR) test (see section 2.1 and figure 2.1) has been utilised in the screening and evaluation of pelvic girdle pain and dysfunction, and neurological lesions for well over a century (Mens *et al.* 1999; Sherrington 1910). The popularity of the ASLR has only gained traction with publications (Mens and Pool-Goudzwaard 2017; Mens *et al.* 2010; Mens *et al.* 1999) for orthopaedic assessment, primarily in pelvic girdle pain (PGP), and Cook (2010), for functional assessment and injury prevention, over the last two decades. While those authors have been proponents of the test, they have advanced two very different methods of the ASLR clinical application and interpretation. Mens *et al.* (1999) has advanced an ASLR that utilises a 20-degree range of motion and 6-point Likert scale, while Cook (2010) has advocated a full range of motion and utilises the Functional Movement Screen™ 3-point scoring. This dissertation evaluates and discusses both approaches and their supporting literature as they relate to low back, as defined by van Tulder *et al.* (2006)

Van Tulder *et al.* (2006) define low back pain as “pain localized below the ribs (12th), but above the inferior gluteal folds, with or without radiation down the legs”. This definition has been selected for this dissertation, as the 2006 COST B13, a European Commission programme for the development of European guidelines for the management of back pain and the 2008 European guidelines for the diagnosis and treatment of pelvic girdle pain, utilised the definition (Vleeming *et al.* 2008, van Tulder *et al.* 2006). European guidelines for the diagnosis and treatment of pelvic

girdle pain (2008) are of great significance in terms of defining and directing subsequent research in the fields PGP and lumbopelvic pain (LPP) and, therefore, the context and direction of the ASLR application within the orthopaedic setting (Stuge 2012). However, the Van Tulder *et al.* (2006) definition is not without its drawbacks. These drawbacks relate to the definitions of PGP and the lack of clarity of pelvic stability as it relates to low back pain (LBP) within the European guidelines (Davenport *et al.* 2019; Gutke *et al.* 2015; Nordin 2008). These pain syndromes and their referral zones will be defined in subsequent paragraphs. Accurate differentiation between these syndromes has been shown to influence clinical outcomes (Stuge 2012).

The European guidelines for the diagnosis and treatment of pelvic girdle pain (2008) defined the region of pain experienced in PGP as “pain experienced between the posterior iliac crest and the gluteal fold, particularly in the vicinity of the sacroiliac joint (SIJ). The pain may radiate into the posterior thigh and can occur in conjunction with/or separately from pain in the symphysis”. This definition requires that the lumbar spine be excluded as a source of pain. This definition clearly defines PGP as a separate clinical entity to LBP (Gutke *et al*. 2015). However, this delineation is undermined by some PGP studies failing to report the exclusion of lumbar spine as a source of pain in their methodology, especially when these are examined against the three different definitions of LPP (Davenport *et al.* 2019; Gutke *et al.* 2015).

The term LPP has three distinct connotations within literature which make the analysis and application of research papers using LLP problematic. The first interpretation of LPP is when no effort is made during the research processes to distinguish between PGP and LBP as a clinical entity and the source of the pain. The second is when there is a concomitance of LBP and PGP (Gutke *et al.* 2015). The last definition is when researchers consolidate LBP, PGP and concomitant LBP and PGP into a single population of subjects (Davenport *et al.* 2019). As a result of these definitions, it was decided to include all studies that reported pain down to the inferior gluteal fold, as this would allow a more comprehensive review and discussion of the evidence. This is especially true with a more evolved understanding of both the integration of lumbo-pelvic-hip biomechanics and newer research on the ASLR and LBP (Kahlaee *et al.* 2019; Sadeghisani *et al.* 2017; Sorensen *et al.* 2016).

LBP, hip and PGP all have a significant biopsychosocial burden due to functional limitations and pain (de Groot *et al.* 2008). The prevalence rates for these conditions are suggested by Arumugam *et al.* (2012) to range between 22% to 90% for pregnancy-related lumbo-pelvic pain, 9% to 32% for sports-related groin pain, and 8% to 22% for sports-related hamstring pain. Development of these conditions/injuries are usually multi-factorial with sub-optimal lumbo-pelvic joint stability being a clearly identified clinical element (Bruno *et al.* 2014; O'Sullivan 2002). As sub-optimal lumbo-pelvic joint stability may lead to asymmetrical loading of the SIJ ligaments, this may in turn contribute to pregnancy related PGP, LPP, or LBP. It is, however, important to note that experimentally induced pain via injection of hypertonic saline into the long posterior sacroiliac ligament has been shown to replicate altered movement patterns without causing instability (Palsson *et al.* 2012).

Arguably the best description of lumbopelvic stability is provided by Reeves, Narendra and Cholewicki (2007), who define lumbopelvic stability as "a behaviour critical for the spine to bear loads, allow movement, and at the same time avoid injury and pain". Lumbopelvic stability is produced by the complex interplay of neuromuscular control, respiration, and form-force closure (see section 2.3.5). Both local and global muscles are involved in the absorption and transfer force from the lumbo-pelvic area, with the contra-lateral extensor reflex being the primary reflex (Vleeming and Schuenke 2019; Willard *et al.* 2012; Arumugam *et al.* 2012). However, multiple ASLR studies have brought in question the correlation between instability and pain (Ericksen *et al.* 2010, Mens *et al*. 1999)

Thus, even though the gross of the ASLR consists of lifting a leg with the ipsilateral even extended and the contralateral limb extended in the supine position, the neuromuscular control of the ASLR is complex. As a small number of muscles are recruited synergistically to produce an infinity of movement patterns. The selected movement patterns are influenced by various factors that include individual anatomic differences, intensity of the leg lift, voluntary muscle recruitment (including motivation) and pain (Enders *et al.* 2015; Lan and Crago 1995). To simplify the study of motor control, researchers have used the principal of component analysis to develop a theory of optimal control (i.e. focus is placed on certain variables only) (Enders and Nigg 2015; Kaplan *et al*. 2001; Kalman 1960). As a result, the research of ASLR neuromuscular control been centred on five focal points: the abdominal

musculature, with the focus on the abdominals [transversus abdominus (TrA) and the internal oblique (IO)]; the ipsilateral hip flexors; contra-lateral hip extensors; and the pelvic floor.

There is significant debate over the relationship of pain and the recruitment of the TrA. Jansen *et al.* (2010) state that the TrA contraction is delayed in anticipation of pain, while Mens and Pool-Goudzwaard (2017) believe that the recruitment of the TrA is a delay resulting in pain and, as a result of the pain, there is an increase in muscle recruitment. It is likely that pain is also responsible for the delayed activation of pelvic floor during the ASLR, as observed by Stuge *et al.* (2013). Both the anticipation of pain and the perception of pain are capable of influencing motor patterns, and this may influence the timing of force-form closure via the deep fascial line (Myers 2020; Cook *et al.* 2010; Myers 2009; Hungerford *et al.* 2004). Palsson *et al.* (2012) expound that induced pain in healthy subjects supports the position of pain altering ASLR to those seen in the clinical setting but raises questions related to the pathological course of LPP and the application of force-from closure theory (see section 2.3.5) as no structural damage is present.

Similarly, the ASLR is a frequently used test to assess hamstring length in various populations, as less than ideal tissue length has been implicated in the development of pain and pathology (Muyor *et al.* 2014; Ayala *et al.* 2012). The validity of the ASLR is under question as the ability of the hamstring to lengthen is significantly influenced by lumbar spine stiffness, synergistic muscle contraction and hemipelvis rotation during hip flexion (Wattanon *et al.* 2020; Medeiros *et al.* 2019; Ayala *et al.* 2012).

Chiropractors utilise the ASLR, as a functional lower limb motion test in the assessment, monitoring and/or classifying low back pain, pelvic girdle pain and hip dysfunction (Fritz *et al.* 2007; Liebenson *et al.* 2009; Jansen *et al.* 2010). The correct classification of pain between the 12th rib and inferior gluteal fold is essential for directing appropriate rehabilitation to achieve best possible outcomes for patients (Davenport *et al.* 2019). Davenport *et al.* (2019) demonstrate that existing methods are capable of clearly differentiating between PGP and LBP but are less so with LPP. Bruno (2017) highlights the need for more research into the ASLR as it pertains to LBP as research has largely focused on PGP, especially pregnancy related PGP (Mens *et al.* 1999, Mens *et al.* 2017b).

A systematic review (SR) would inform clinical application and interpretation of the ASLR in a clear, unbiased/minimum bias, and transparent way (Moher *et al.* 2015; Shamseer *et al.* 2015; Bunn *et al.* 2011). This would be achieved by clarifying lift heights, muscle recruitment, potential mechanisms and variables influencing the performances of the ASLR.

1.2 RATIONALE AND RESEARCH PROBLEM

The ASLR is a commonly used assessment tool in chiropractic practice to screen for nerve root entrapment (NRE), transfer of load through the lumbo-pelvic-hip complex and altered motor control (Barcellona *et al.* 2017; Liebenson *et al.* 2009). Although studies have shown that the ASLR seems to be applicable in certain clinical settings (Fritz *et al.* 2007; Liebenson *et al.* 2009; Jansen *et al.* 2010), others have raised questions regarding the test (viz. sensitivity, specificity, and validity, and lift height) (Krkeljas and Kovac 2018; Mens and Pool-Goudzwaard 2017; Bruno 2017; Chang 2012; Jansen *et al.* 2010).

At present there is a limited but growing pool of ASLR studies that have examined this in a non-pregnant population, as such some assumptions are applied in the clinical setting, as LBP is caused by a heterogenous group of disorders (Fourney *et al.* 2011). While claims have been made regarding the validity and reliability of the ASLR in this population, the evidence to substantiate this argument calls for more research as the incorrect and/or ineffective application of the ASLR may influence patient outcomes through inappropriate treatment, management, and referral (Bruno 2017; Suzuki *et al.* 2016; Bruno, Millar and Goertzen 2014a). Accurate diagnosis of LBP is considered by Suzuki *et al.* (2016) to be vital before commencing treatment to provide the highest possible quality intervention and possibly the best outcomes.

This highlights the need to review the literature to determine the level and rigour of evidence behind the ASLR and its application in LBP, as this has a significant impact on the clinical assessment and, therefore, the treatment of patients within the chiropractic context (Bruno 2017; Fritz and Wainner 2001). To the researcher's knowledge, no systematic review has evaluated or compared the evidence to support the applications of the Mens' or Cook's ASLR techniques in LBP. The most

appropriate way to achieve this is through a systematic review (Gurevitch *et al.* 2018).

A systematic review would inform clinical application and interpretation of the ASLR in a clear, unbiased/minimum bias, and transparent way based on the totality and context of the evidence (Moher *et al.* 2015; Shamseer *et al.* 2015; Bunn *et al.* 2011). Despite the heterogenous nature of the studies, there were diverse subject characteristics rendering a meta-analysis of the statistical data unsuitable as this was likely to generate inapplicable results (Thompson 1994).

1.3 AIMS

To conduct a systematic review of studies analysing muscle recruitment during the ASLR, and to critique methods to determine specify, sensitivity and validity of ASLR in the context in how the data were gathered (Page and Moher 2017).

1.4 OBJECTIVES

1. To determine the level of methodological rigour of studies investigating sensitivity, specificity, reliability, and validity of the ASLR in the evaluation of LBP subjects.
2. To examine and present the quality of evidence investigating motor control, and muscle recruitment and thickness during the performance of the ASLR.
3. To examine how pain influence the performance of the ASLR.
4. To evaluate and present an evince based assessment of pelvic symmetry during the performance of the ASLR.

1.5 LIMITATIONS

The following limitations were imposed on the study:

1. Non-English and translated articles were excluded from the study and, as a result, some relevant subject matter articles were not eligible for review. Although this subjected the systematic review to language bias, this was

considered a lesser impact than translation bias (Moa and Li 2020; Valdez and Goodson 2020; Higgins and Green 2011).

2. The reviewers were not professionally trained to use the applied rating scales. In attempt to minimize the effect, the reviewers were provided with guidelines on how to utilise the scales and support from the researcher to clarify questions pertaining to the scale. Additionally, attempts were made to recruit reviewers with prior experience. While this may be seen as a limitation, the variance amongst reviewers in reviewing publications meant that if overall agreement was reached, that the outcome would be stronger based on the varied academic, clinical and research experience, as well as review experience.
3. Publication bias is always present in a systematic review (Moa and Li 2020), as the publications available for review are only those that made it into the public domain as peer-reviewed publications or grey literature databases. Often this is directly because of the outcomes attained in the publication, with positive outcomes being published more readily than negative outcomes (Callaham *et al.* 1998). Therefore, the conclusions of the study are considered in terms of the overall position of the published articles that form part of the systematic review.
4. A meta-analysis of the data was not undertaken as, although the studies were homogenous, the subjects were not, and the outcomes were not. As a result of the heterogenous nature of the subjects, this would have rendered any statistical analysis meaningless (Aromataris and Pearson 2014).

1.6 CONCLUSION

Chapter One introduced and situated the problem of the ASLR with regards to low back pain within the literature, as well as the aims and objectives of this study to provide clarity on this topic. Additionally, this chapter has demonstrated how this study contributes to the developing body of literature on the ASLR; motor control and functional movement assessments, while highlighting further scarcity within the literature that require attention.

In Chapter Two, the author provides a review of relevant literature in focusing on relevant anatomy; back pain; theories of motor control and stability; neurodynamics; and kinematic chain. Chapter Three reports the methodology employed in this study, while Chapter Four presents the statistical results with an accompanying discussion of these results. Chapter Five gives the conclusions and makes recommendations. To conclude the study, Chapter Six provides a summary of the findings.

CHAPTER TWO REVIEW OF LITERATURE

2.1 INTRODUCTION

The following chapter provides an overview of the pertinent literature related to the ASLR. It describes the methodology of the two main versions of the ASLR, as well as the main breakdowns to isolate sections of the kinematic chain for more informative diagnostic testing in the clinical setting. A brief outline of relevant anatomy, biomechanics and postulated pathomechanics of lumbo-pelvic-hip (LPH) complex is provided, and a discussion of the theoretical concepts related to the kinematic chain. These concepts include the self-bracing mechanism (form and force closure), core stability, spinal engine theory and myofascial slings. The chapter aims to provide a clear picture of the ASLR to aid in clinical reasoning and further the development of evidence informed practice.

Two distinct versions of the ASLR are described in the literature, each with their own breakdowns to isolate sections of the kinematic chain and to identify the involved tissues. The first, and most common application, utilises twenty degrees of hip flexion, and is focused on neuromuscular control and transfer of load through the pelvis (Bruno, Millar and Goertzen 2014a; Mens *et al.* 2010). This version is sometimes referred to as the Mens test (Hattam and Smeatham 2010).

Figure 2.1: Mens ASLR

(Adapted from Hattam and Smeatham 2010)

The second version utilises the full available hip flexion to assess active hip mobility, initial and continuous core stability, and contralateral hip extensors (Cook *et al.* 2010). The Cook ASLR technique is far more explicitly detailed, with a rigid yet partly subjective scoring system (Cook *et al.* 2010).

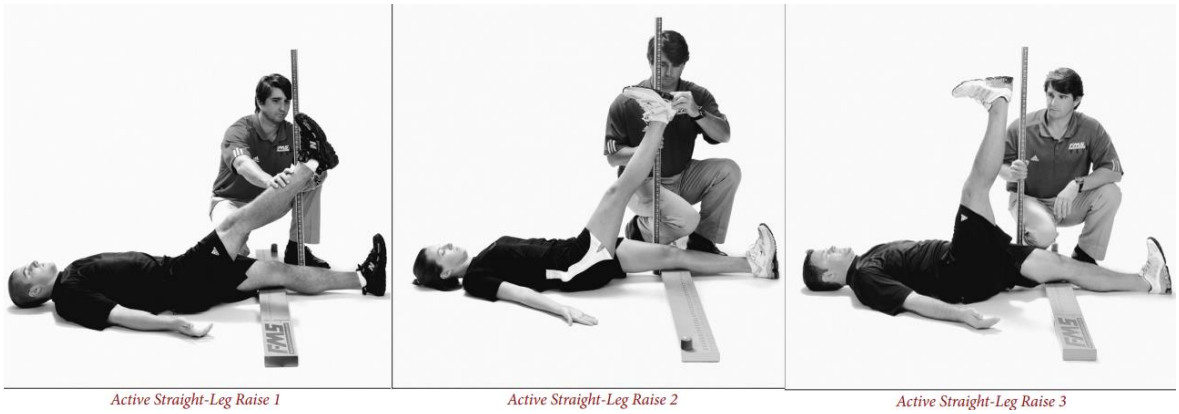

Figure 2.2: Cook ASLR

(Adapted from Cook *et al.* 2010)

While the Mens test is usually confined to a range of motion (RoM) below 30 degrees, this places the greatest strain on the sacroiliac joint (SIJ) and causes minimal if any lengthening of neural structures, the Cook test stretches the posterior neuromuscular structures and the loading of the articular structures of the hip joint (Dutton 2020; Corkery *et al.* 2014; Cook *et al.* 2010; Mens *et al.* 2010). This is in part due to the hip joint's structure, which provides significant mobility with stability. In contrast to other joints, the hip joint has the greatest musculoligamentous

contribution to stability in the position of least congruency and vice versa (Dutton 2020; Lewis *et al.* 2017).

Perhaps the most significant difference between the Cook ASLR and other forms of the ASLR is the explicit description of the Cook ASLR technique (Cook *et al.* 2010; Mens *et al.* 1999). This explicit description enhances the potential for inter and intra reliability of the test (Reiman and Manske 2009). In contrast, other ASLRs, such as the Mens ASLR, have differences within the literature (Mens *et al.* 1999). These differences include foot position, lift height, and whether the limb is held in a static position at maximal range (Cook *et al.* 2010; Mens *et al.* 1999).

To interrogate these elements more clearly in a clinical setting, the following section highlights the relevant anatomy that underpins the tests.

2.2 ANATOMY

The anatomy in this section is described in the context of the ASLRs, as described, with the aim of providing an understanding of the limitations and implications of each of the tests (namely, the Mens test and the Cook ASLR).

2.2.1 Lumbo-Pelvic-Hip (LPH) Complex

The LPH complex refers to the musculoskeletal structures that influence pelvic and spinal stability, as well as generate limb movement (Chaudhari *et al.* 2014). Optimal function of this region is essential for force transfer from the spine to the lower limbs and vice versa (Sadeghisani *et al.* 2017; Chaudhari *et al.* 2014). Dysfunction and loss of anatomical integrity of this interconnected system have been shown to reduce neuromuscular efficiency, leading to altered motor control and transfer of forces, which may ultimately lead to pain and injury (Sadeghisani *et al.* 2017; Shimamura *et al.* 2015; Tateuch *et al.* 2013). The relative contribution of each segment of the LPH complex, however, is still yet to be defined (Innmann *et al.* 2021).

The significance of the LPH complex was perhaps first highlighted within the literature by Gracovetsky (1984) in the spinal engine theory. In this theory, Gracovetsky observed that subjects without femurs were still capable of propelling themselves in the upright position. Since the publication there have been numerous theories to explain how this region is stabilized and then produces and transfers

forces. The three most important theories are those of core stability, self-bracing mechanism of the SIJ and the spinal engine. While all the theories have aided in conceptualizing the complex biomechanics of the LPH complex, it has been suggested by Booth and Morris (2019) that these theories have limited our focus to biomechanics and impaired our neurobiological understanding and thus management of pathologies within this region.

2.2.2 Articulations of Lumbo-Pelvic-Hip Complex

There are numerous joints involved in facilitating the undertaking of the ASLR, with the chief joints being lumbosacral, pelvic ring and femoro-acetabular joints (Hammer *et al.* 2019; Mens *et al.* 1999). The following section briefly discusses the anatomy of the lumbar spine, sacrum, and pelvic ring joints, with the exclusion of the myofascial components, which is discussed under its own section.

2.2.2.1 Pelvic Ring (Pelvic Girdle)

The pelvic ring encompasses four articulations of the pelvis: two SIJs, the sacrococcygeal symphysis and the pubic symphysis joint (PSJ) (Chaudhry, Nahian and Chaudhry 2020; Wurdinger *et al.* 2002). It includes the lumbosacral joint, as this joint greatly influences the movements of the SIJ; these joints function collectively to transfer force between the axial and appendicular skeletons while providing a stable yet mobile platform for movement (Chaudhry, Nahian and Chaudhry 2020). Without the limited movement of the SIJ, ambulation would be impossible, and the pelvic ring would fracture when placed under excessive forces that exceed intrinsic factors (Chaudhry, Nahian and Chaudhry 2020; Vleeming and Schuenke 2019; Bussey *et al.* 2015; Bussy, Bell and Milsoavljevic 2009). Critical to the stability of the posterior pelvic ring is the arrangement of strong ligaments and fascia, which insert into and overlay the SIJ, linking the sacrum, innominate and muscles of this region (Chaudhry, Nahian and Chaudhry 2020; Vleeming and Schuenke 2019; Booth and Morris 2019).

2.2.2.2 Sacroiliac Joint

The primary bones of the SIJ are the sacrum and ilia. The sacrum is triangular and wedged between the two ilia to from the keystone of the self-bracing mechanism. Usually formed by the fusion of the five sacral vertebrae, the ventral surface is concaved while the dorsal surface is convex. The apex of the sacrum is orientated

posteriorly, while the base is tilted anteriorly (Cheng and Song 2003). As a result of this, the sacral promontory is orientated at an angle of approximately 70º in adults on the anterior surface (Cheng and Song 2003). This orientation results in the assumption of lordosis by the lumbar spine, as well as tension of the ligaments in the upright position while providing economy of movement (Hasegawa *et al.* 2017; Huec *et al.* 2011; Aspdena, Rudmana, and Meakin 2006; Cheng and Song 2003).

Significant variations in the morphology of the sacrum have been described, with age, gender, and handedness all reported as influencing factors (Nishi *et al.* 2020; Nishi *et al.* 2018; Cheng and Song 2003; Plochocki 2002). Most of these variations are benign in early life and only become problematic in later life through asymmetrical joint loading and/or early joint degeneration, conditions of high loading, or age-related impairment of the self-bracing mechanism (Nishi *et al.* 2018; Feeny *et al.* 2018; Staude, Kondratyev and Karpinsky 2015).

The bilateral SIJs are modified synovial planar joints formed by the inverted triangularly shaped sacrum articulating with the auricular surface of the ilia (Vleeming and Schuenke 2019). However, the true classification of this is still open to debate based on the morphology and age-related changes observed within the SIJ (Poilliot *et al.* 2019; Paquin *et al.* 1983). The shape of the articulations may either be S-, C- or L-, with reciprocal corrugated surfaces on the articular surface of the ilium (Vleeming and Schuenke 2019; Nishi *et al.* 2016; Brolinson, Kozar and Cibor 2003). Findings by Nishi *et al.* (2017) and Jesse *et al.* (2017) have led to suggest that the L- and C- shape variants have a reduced surface area and, therefore, lower friction coefficient, which leads to increased instability and ultimately pain and degeneration. In their own study on SIJ morphology and conformity, Ito, Morito and Gamada (2020) found that the more triangular the shape of the sacral auricular surface, the lower the risk of degeneration.

In the L-shaped SIJs, the longer arm of the articulation is orientated posteriorly, while the shorter arm is directed superiorly (Nishi *et al.* 2018; Paquin *et al.* 1983). Only the inferior arm and lower section of the superior arm are synovial in design (Egund and Jurik 2014; Dreyfuss *et al.* 2004; Hansen and Helm 2003). The upper section of the superior arm is amphiarthrosis in composition (Egund and Jurik 2014). The sacral articular surface is usually derived from the first three sacral and is covered by thick hyaline cartilage. In contrast, and unique to the SIJ, the articular

surface ilia are cover in fibrocartilage (Egund and Jurik 2014; Bowen and Cassidy 1981). This fibrocartilage consists of type 2 collagen, which is usually a feature of hyaline cartilage (Paquin *et al.* 1983). Middleditch and Oliver (2005) speculate that this cartilage composition may be a contributing factor to the high incidence of joint sclerosis found in the SIJ.

The orientation of these joint surfaces allows two principal motions that may occur bilaterally or in combination, as in the case of gait when the lower limbs are moving in different sequences (Vleeming *et al.* 2012; Gibbon 2017; Brolinson, Kozar and Cibor 2003). These movements are sacroiliac and iliosacral motions. Sacroiliac motion is when the sacrum moves within the innominate bones, while iliosacral motion is the movement of the innominate bone on the sacrum (Vleeming *et al.* 2012; Brolinson, Kozar and Cibor 2003). Sacroiliac movements are subdivided into nutation and counternutation. In nutation, the sacral base moves in an antero-inferior direction while the sacral apex travels in a postero-superior direction relative to the innominate bone as the sacrum glides inferiorly along the shorter, vertical arm and posteriorly on the long, horizontal arm of the articular surface (Hammer *et al.* 2019). This movement is limited by the joints' structure (i.e. form closure), as the sacrum moves into the closed packed position. Vrahas, Hern and Diangelo (1995) suggests that in this position all the interosseous ligament (ISL) and posterior sacroiliac ligaments (PSL), apart from the long posterior sacroiliac ligament (LPSL), and the sacrotuberous ligament (STL) become tight. In contrast, during counternutation, the sacrum travels anteriorly along the long arm and superiorly up the short arm, moving the sacral base posteriorly and superiorly, and the sacral apex antero-inferiorly relative to the innominate bone (Hammer *et al.* 2019). The LPSL is the primary static restraint to limit this movement, and subsequently this is the more unstable of the two movements.

The soft tissue arrangement surrounding the SIJ is complex due to the numerous musculo-ligamentous attachments on and around the joint, as well as to the joint capsule (Bussey 2015). The complexity is in part due to the orientation of the articular surface, which is almost aligned in the direction of load, and to compensate for the inherently unstable, multisegmented design of the spinal column, particularly at the lumbosacral joint (Bussey 2015; Pel *et al.* 2008). Problematically, the ligaments of the SIJ are implicated in the generation PGP, LBP and SIJ related pain

and subsequent impairment of motor control mechanisms (Bussey 2015; Hammer *et al.* 2013; Palsson *et al.* 2012).

While Poilliot (2019) lists ten ligaments that are located at the SIJ, Vleeming and Schuenke (2019) identify several ligaments that are essential to the self-bracing mechanism (Section 2.3.5) and are believed by Mens *et al.* (2017) to be associated with the presence of pain during the ASLR. These ligaments are divided into intrinsic and extrinsic ligaments by Poilliot *et al.* (2019). The intrinsic ligaments include the anterior sacroiliac ligament (ASL), the ISL, PSL, and the LPSL, while the extrinsic ligaments include the iliolumbar ligament (ILL), STL, and the sacrospinous ligament (SSL) (Poilliot *et al.* 2019).

The ASL is a thin, weak ligament and is considered by Poilliot *et al.* (2019) to be essentially a thickening of the anterior and inferior aspect of the joint capsule. This ligament attaches to the medial border of the ilium, crossing the anteroinferior aspect of the SIJ to insert onto the periosteum of the ilium near the auricular margins (Poilliot *et al.* 2019). The ASL has three distinct portions and perhaps the most significant is the inferior strand, which is continuous with the PSL, SSL, and STL. The ASL together with the anterior joint capsule and ISL contain calcitonin gene-related peptide and substance P immunoreactive fibres, which are known nociceptive structures (Szadek 2016).

The ISL is a strong, short, multidirectional ligament that is divided into deep and superficial components (Poilliot *et al.* 2019; Palastanga *et al.* 2012). The superficial fibres attach from the iliac crest to the sacral crest, while the deep fibres insert on the lateral sacral crest and attach to the ischial tuberosity (Palastanga *et al.* 2012). Together with the more superficial LPSL, the ISL ligament encloses the dorsal rami of the sacral spinal nerves and vessels. The primary function of the ligament is to prevent sacral flexion and axial rotation. The PSL consists of superior, short and an inferior, long (LPSL) sections, of which the LPSL is the significant portion. The LPSL plays a significant role in the mechanical stability of the lumbosacral region, as well as being a potential pain generator within the region (McGrath and Zhang 2005). The ligament attaches to the intermediate and lateral crests of the sacrum running to the PSIS and medial tip of the dorsal iliac crest. The inferior fibres blend laterally with the STL, while the medial fibres fuse with those of the deep layer of the posterior layer of the thoracolumbar fascia (TLF) and aponeurosis of the erector spinae (ES)

(Palastanga *et al.* 2012). Contraction of the ES and/or the gluteus maximus (GM) leads to slackening of the LPSL (Foley *et al.* 2006). The LPSL functions to limit counternutation.

Besides the LPSLs importance in mechanical stability, the LPSL has a close association with the lateral branches of the sacral spinal nerves. According to McGrath and Zhang (2005), the LPSL is, therefore, a significant potential pain generator in lumbosacral pathologies. The effect of pain and hyperalgesia on the ASLR arising from the LPSL was investigated by Palsson *et al.* (2012). They injected hypertonic saline into 46 healthy volunteers and observed that the induced pain increased subjective effort of the ASLR and bilaterally increased the electromyography (EMG) activity of stabilizing trunk and thigh musculature. These adaptations were consistent with those observed in PGP and LPP (Palsson *et al.* 2015; Palsson *et al.* 2012). However, this study did not examine the TrA (Palsson *et al.* 2012).

Functionally, the STL is the most important ligament of the SIJ due to its role in transferring force from the ipsilateral lower limb to the contralateral upper limb. It consists of three bands, the superior, lateral, and medial, which attach from the PSIS and coccyx to the ischial tuberosity. The attachment is significant as the long head of the bicep femoris (BF) (LHBF) either attaches to the ischial tuberosity or may attach to the STL (Pool-Goudzwaard *et al.* 1998). As a result, the LHBF is capable of increasing tension in the STL via caudal traction through elongation and contraction (Pool-Goudzwaard *et al.* 1998). Additionally, the gluteus maximus (GM) and piriformis muscle attaches to the STL and can create tension through it (Pool-Goudzwaard *et al.* 1998; Willard 1997). As a result, the STL resists counternutation of the sacrum. Willard (1997) observed that the deep fibre of the multifidus muscles frequently attaches to the STL. Hammer *et al.* (2013) have calculated via finite element analysis, that the STL plays an important role with the ISL in reducing the stress placed through the sacral base.

The triangular SSL arises from the lateral aspect of the sacrum, coccyx, and inferior sacroiliac capsule to attach to the ischial spine. The anterior fibres of this ligament blend with the coccygeus muscle (Poilliot *et al.* 2019).

2.2.2.3 Pubic Symphysis Joint

The PSJ is a non-synovial joint formed between the left and right superior rami of the pubic bones (Becker *et al.* 2010). Similarly, to the SIJ, the PSJ structure is subject to gender dimorphism. In the female, this joint is shorter, broader, and more mobile, whilst in the male joint it is stiffer (Becker *et al.* 2010). As with the SIJ, surfaces of the PSJ are reciprocally ridged but are separated by fibrocartilaginous disc, which allows for a small degree of movement at the joint (Hammer *et al.* 2019; Becker *et al.* 2010; Dakin *et al.* 2001). These movements include a small amount of angulation, rotation, and displacement which occur in conjunction with SIJ movements (Hammer *et al.* 2019; Putnis *et al.* 2010). According to Bussey (2015), co-ordination of this movement with the SIJ is essential to movement of the pelvic ring.

The SIJ is primarily responsible for the transfer of vertical load, while the PSJ contributes to the transmission of horizontal forces (Lewis *et al.* 2017). Functionally, the PSJ is closely associated with the anterior longitudinal sling, as fibres from the AL attach to the pubic disc and desiccate across the joint (Dutton 2020; Lewis *et al.* 2017). These two features allow for dysfunction of the posterior chain to lead to adaptations of the anterior chain and vice versa (Tilvawala, Kothari and Patel 2021; Dutton 2020).

2.2.2.4 Sacrococcygeal Joint

The sacrococcygeal joint is formed by the articulation of the sacral apex with the base of the coccyx and may be either be amphiarthrosis, synovial or mixed in structure (Tetiker *et al.* 2017; Woon and Stringer 2012). The RoM at this joint is relatively small and limited to flexion and extension, where flexion is movement towards the ventral surface and extension is movement towards the dorsal surface (Woon and Stringer 2012). Flexion is produced by the levator ani (LA) and sphincter ani externus muscles, while extension results from increased intra-abdominal pressure (IAP).

It is likely that this movement is significant to the LPH region, as the coccyx serves as the posterior attachment for the pelvic diaphragm, STL and dural sac (Woon and Stringer 2012). Additionally, the anterior and posterior (superficial and deep) sacrococcygeal ligaments, which are extensions of the ALL, PLL and ligamenta

flava respectively, attach to the coccyx (Woon and Stringer 2012). Chen (2010), in an unpublished study, compared TrA, IO (internal oblique) and EO (external oblique) thickness of British and Taiwanese subjects, with and without coccydynia, at rest and during the ASLR. The protocol utilised an ASLR of 5cm. They noted that there was a significant difference between IO and TrA thickness in healthy young and healthy old control subjects during the ASLR, which they attributed in a decline in motor control ability. It is possible that this finding could be attributed to atrophy of the iliopsoas, which begins at approximately 40 years of age (Staugaard-Jones 2012). Patients also displayed increased thickness of the TrA at rest compared to controls with less thickening of the muscle during the ASLR. Chen (2010) therefore concluded that with coccydynia there is less ability to contract the TrA, and this supports the notion that there is a relationship between sacrococcygeal joint and LPH muscle function.

2.2.2.5 Hip Joint

The hip joint is a multiaxial spheroidal-socket joint formed by the articulation of the femoral head and acetabulum (Retchford *et al.* 2013; Navarro-Zarra *et al.* 2012). The O shaped acetabulum is formed by the union of the ischium (2/5th), ilium (2/5th), and pubis (1/5th), with the inferiorly placed transverse ligament. This configuration allows for six degrees of freedom of movement of the joint, while providing significant stability from passive structures. While this description is very simplistic, it provides an adequate anatomical description for the purpose of the ASLR, at present. This is due to the lack of study on the effect of gender dimorphisms and femoral-acetabular type/alignment on the ASLR. With regards to gender dimorphism, it has been shown that the male femoral head is the same size as the female femoral head, but the acetabulum has a small dimension, which displaces the axis of rotation laterally in males. The axis of rotation of the female hip is also suggested to vary dependant on the classification of pelvis and age (Huseynov *et al*. 2016).

Most significantly, the hip is the inferior section of the vertical chain of force transmission in the axial skeleton and the proximal section of the lower limb (Bussey 2015). Many of the muscles of the hip act both at the hip and the lumbar spine (Poilliot *et al.* 2019; Cheng and Song 2003). Additionally, muscles such as the AL

also act on the PSJ influencing the horizontal transmission of forces (Dutton 2020; Lewis *et al.* 2017).

The complex relationship of the LPH complex, extends to hip flexion, where reduced extensibility of posterior soft tissue structures may impair arthrokinematics as well as the movement of anterior soft tissue structures, leading to entrapment of the anterior joint capsule and pain (Miyachi *et al.* 2019). This phenomenon is known as femoral anterior glide syndrome (FAGS). At present, no publications have specifically studied FAGS in relation to the ASLR as a specific clinical entity or as a contributing element to other clinical conditions such as PGP or LBP. It is likely that due to the interconnectivity of soft tissue structures, that this may be a facet in LPH complex dysfunction. Conversely, anterior impairments can lead to compensations in the posterior chain of the hip, such as cases of primary hip osteoarthritis (OA).

In the presence of primary OA restriction(s) / impairment(s) to hip flexion in closed kinetic chain (CKC), it was observed that there was the development of compensatory spinopelvic hypermobility (Innmann *et al.* (2021). Innmann *et al.* (2021) found that there was an increased posterior pelvic tilt and lumbar flexion when moving from standing to relaxed sitting position. In addition, it was found that when transitioning from a standing to a deep flexed sitting position, in contrast to asymptomatic subjects, subjects with hip OA had no measurable anterior pelvic tilt, relying solely on posterior pelvic tilt and lumbar flexion to compensate for the impairment. To the author's knowledge, no studies have examined whether this rhythm is applicable in open kinetic chain (OKC) activities of the lower limb.

2.2.3 Motion Segment

Spinal motion segments are the basic anatomical and biomechanical unit of the spine. For this study, it was decided to discuss the intervertebral discs, intervertebral-and-facet joints under this heading as spinal pathology and dysfunctional movement occurs within the unit rather than at an individual joint (Sabnis, Chamoli and Diwan 2018). It must be acknowledged that a particular level and side may be causative structure (e.g. unilateral hypertrophied articular facet), but the ASLR with the exception of NRE testing, is not a pain provocation test but rather a functional test (Kökes *et al.* 2007). The ASLR therefore assesses movement and stability, requiring the entire motion segment to function efficiently (Corkery *et*

al. 2014). The lumbar spine, thoracolumbar junction, and lumbosacral joints will therefore be discussed within this section.

Each individual motion segment includes either one vertebral body and the sacrum, or two vertebral bones and the intervertebral disc located between them, as well as the two facet joints and associated soft tissue (Bergmann and Peterson 2013). The structure of the sacrum has been discussed in section 2.2.2.2 and, therefore, only a brief description of the structure lumbar vertebrae and the relevant thoracic vertebrae (thoracolumbar transitional zone) are given as they relate to the ASLR.

2.2.3.1 Lumbar Vertebrae

The lumbar vertebrae are larger and stronger than the more superior segments of the spine due the increased demand of weight bearing. The vertebral bodies (VB) are kidney shaped with short, strong pedicles that are almost completely posteriorly orientated. The spinous process (SP) project almost horizontally posteriorly and almost level with the inferior half of the VB. Apart from the L5, the SP have a thickened posterior edge (Palastanga, Field and Soames 2013). The L5 SP is frequently round and is shorter than the other lumbar SP (Dutton 2020; Palastanga, Field and Soames 2013). The transverse process (TVP) of the first four vertebrae are short and thin, and project almost laterally. The TVP of L5 in contrast is short and thick (Palastanga, Field and Soames 2013).

The articular processes are orientated superiorly and inferiorly from the area that the pedicle joins the lamina. According to Palastanga, Field and Soames (2013) the superior articular facets are orientated posteromedially, being concave transversely and flat vertically whilst the inferior facets are reciprocally shaped and are anterolaterally orientated. The orientation of these joints combined with the gross anatomical features of the motion segments leads to flexion, extension, and lateral flexion being the primary movements of these motion segments (Middleditch and Oliver 2005). These movements may be amplified when movements are restricted within the hip joint or complement with increase rotation when movement is restricted in the thoracic spine (Cook *et al.* 2010).

2.2.3.2 Thoracic Vertebrae of the Thoracolumbar Transitional Zone

The osseous structure of the transitional thoracic can vary significantly, greatly affecting the forces experienced within this region and the likelihood of degeneration

(Pal and Routal 1999). It is estimated that over ninety percent of people experience a gradual transition of T10 to L1. In the remaining seven percent, there is an abrupt transition (Mahato 2018; Pal and Routal 1999). This abrupt transition is suggested to greatly increase the force experienced and the development of degeneration within the region (Middleditch and Oliver 2005; Pal and Routal 1999). In a healthy young adult spine, this region is not considered to be kyphotic. Middleditch and Oliver (2005) state that kyphosis of the upper thoracic being responsible for the concave curve observed. With advanced age and with certain pathologies this lower region becomes kyphotic, limiting rotation and reducing lordosis of the lumbar spine if compensatory hyperlordosis does not occur (Singla and Veqar 2017; Yaman and Dalbayrak 2013; Briggs *et al.* 2007; Middleditch and Oliver 2005). Consequentially, this leads to increased rotation in the lumbar spine and may also cause posterior pelvic tilt (Briggs *et al*. 2007; Middleditch and Oliver 2005).

Perhaps the most significant motion segment of this region to the ASLR is the T12-L1 motion segment. This motion segment is directly related to the PMM attachment, always has transitional features, as well as having the 12th ribs attach (Palastanga, Field and Soames 2013; Pal and Routal 1999). The PMM is both a significant mover and stabiliser of the LPH complex (Joen *et al.* 2016; Yoshio *et al.* 2002). Furthermore, the PMM appears to have an intricate relationship to LBP, with fatty infiltration being associated with acute and chronic LBP, and atrophy being associated with disc herniation (Arbanas *et al.* 2013; D'hooge *et al.* 2012). The attachment of the 12th ribs is significant, as these ribs serve as attachment sites for stabilising muscles (e.g. quadratus lumborum) as well as global movers (Palastanga, Field and Soames 2013). Perhaps more significantly is the respiratory diaphragmatic attachment, and while the respiratory diaphragm also attaches to the 11th rib, the PMM usually does not. The significance of this area is discussed in further detail in Section 2.7.3.1, in which the diaphragm and intraabdominal pressure (IAP) is discussed, as this influences spinal stability.

2.2.3.3 Intervertebral Disc (IVD)

For this study, only the gross IVD structure is discussed. While it must be acknowledged that the pathophysiology is essential to pain production, both acute and chronic, the focus of this study is primarily related to the biomechanical relationship to the ASLR (Zhang *et al.* 2021). Therefore, only a brief discussion has

been undertaken in pain and relevant pathology sections. In terms of LBP, Lyu *et al.* (2021) suggests a positive relationship between the degree of disc degeneration and the likelihood of LBP. It is estimated that discogenic pain accounts for 40-50% of cLBP (Geurts *et al*. 2018) however according to Jensen *et al.* (1994) 27% of apparently healthy subjects examined had asymptomatic disc herniations.

The IVD is composed of the inner, nucleus pulpous (NP) and the outer, annulus fibrosis (AF). The AF is usually constructed of ten to twelve concentric collagen fibres with proteoglycan gel to bind them together and to prevent their buckling (Palastanga, Field and Soames 2013). The AF completely encapsulates the NP in healthy discs, while in degenerative or pathological discs, the contents of the NP may either extend into or pass through the AF (Dutton 2020).

The structure of the AF varies with from childhood to adolescence to adulthood. In children, the outer fibres of the AF adhere to the edges of the cartilage plates while in adolescents, these fibres attach to the ring apophysis. In adults, these outer fibres are attached to the outer vertebral ring (Middleditch and Oliver 2005). The internal fibres of the AF are attached to the cartilage end plates. Additionally, age is associated with the number of lamellar layers within the disc. The layers have been found to decrease but thicken with age (Dutton 2020). This fibre alignment is essential to the function of the spine, allowing for angular motion while resisting shear and torsion. The contribution to biomechanics is discussed in more detail in the spinal engine theory (Section 2.3). These age-related factors, contribute to age related presentation of spinal pathologies, which affect the interpretation of ASLR findings.

Pathologically, the disc may lead to pain via IVD protrusion or degeneration of the disc itself. Research has been conducted to examine the relationships between the ASLR and disc herniation, but there appears to be a dearth on studies that have purely examined disc degeneration related pain which is a separate subgroup of LBP (Yang *et al.* 2015). Additionally, research related to ‘high’ disc pathologies (i.e. L1 and higher in conjunction to the ASLR), is lacking. The significance of this would be in the tuberculosis population in which the *Mycobacterium tuberculosis* spread distally via the IVD and may reach the hip via the psoas tendon (Zychowicz 2010). Additionally, IVD prolapses occur more proximally in the older population (Dutton 2020).

2.2.3.4 Vertebral End Plates (VEP)

VEP are large, thin cartilages plates, which are located between the IVD and VB. They facilitate IVD nutrition while aiding in load transfer and influence the available RoM. The VEP are affected by age and gender, as adolescent and young females have shorter VEP than males. This subsequently allows for a greater potential RoM within the young females (Dutton 2020; Middleditch and Oliver 2005)

Pathological changes of the VEP are known as modic changes and are associated with pain and development of disc pathology (Duran *et al.* 2017; Jensen *et al.* 2010; Braithwaite *et al.* 1998). Conversely, according to Albert and Manniche (2007) disc herniation can lead to modic changes. Modic changes are discussed in further detail in Section 2.6.1.2. It is important to note however, that the relevance, influence, and relationship, if any, between modic changes and ASLR is still to be investigated and established.

2.2.3.5 Lumbosacral Joint

The LSJ has distinctive morphological, motion and pathological characteristics in comparison to other lumbar motion segments (Dutton 2020; Abdu-Leil *et al.* 2016; Palastanga, Field and Soames 2013). It is unclear as to whether these unique features and morphological variations have been fully considered in the study and theories of the ASLR. In the absence of sacralisation, Bortelli syndrome, and lumbarisation, this LSJ is formed by the L5 articulating S1 with the L5/S1 IVD intervening (Yochum and Rowe 2005).

The L5/S1 IVD is wedge shaped with the anterior vertical height being at least 5mm higher than the posterior vertical height (Abdu-Leil *et al.* 2016). This is complemented by the L5 VB being wedged shaped, again with the anterior height being greater. These two factors make a significant contribution to the lumbosacral angle (Abdu-Leil *et al.* 2016). Additionally, The L5 SP is usually short and blunter in comparison to the other L/S vertebrae. This SP feature provides the lumbosacral joint a greater potential for hyper-extension when the ligamentous system fails (Dutton 2020; Palastanga, Field and Soames 2013).

Motion of the upper four lumbar motion segments usually consists of axial rotation accompanied by contra-lateral flexion, and lateral flexion is accompanied by contra-lateral axial rotation. However, in a healthy lumbosacral joint, axial rotation of the L5

is accompanied by ipsilateral lateral flexion. This coupled motion may however be altered in the presence of articular tropism (Dutton 2020; Middleditch and Oliver 2005; Gracovetsky 1988).

Significantly for the ASLR, abnormalities of the superior surface sacrum appear to be a neglected variable within the literature. The research has focused on asymmetries of the SIJ, analysing the range of movements within this joint and discussing conformity of the auricular surfaces.

2.2.3.6 Intervertebral Foramina (IVF)

The IVF contain the vertebral artery and veins, as well as allows the spinal nerve to exit the spinal canal. The boundaries of the IVF are the IVD and adjacent VB anteriorly, the facet joints posteriorly, and the pedicles superiorly and inferiorly. The boundaries extend form the spinal canal at the point the nerve root sheath exits the dural sac and ends where spinal nerve emerges laterally (Garfin *et al.* 2018). NRE may therefore occur from IVD extrusion into this space, hypertrophy of the facet joints and/or space occupying lesions (Dutton 2020).

2.2.4 Spinal Nerves

The spinal nerves lie in the lateral recess. This area is formed by the medial portion of the superior articular facet and lamina superiorly, the VB and adjacent IVD inferiorly, and the pedicle laterally (Garfin *et al.* 2018).

2.2.4.1 Sciatic Nerve

The sciatic nerve (SN) is formed by the ventral rami of L4, L5 and S1, and may include S2 and S3 (Kale *et al.* 2021). Even from the outset the terminal branches, the common fibular nerve (CFN) and tibial nerve (TN), are distinguishable within the SN's structure (Shewale, Karambelkar and Umarji 2013; Güvençer *et al.* 2009). The SN typically leaves the pelvis as one nerve via the greater sciatic foramen beneath the piriformis, descending between the greater trochanter and ischial tuberosity in the gluteal region (Tomaszewski *et al.* 2016). Thereafter, the SN usually separates into its terminal branches, CFN and TN. This division normally occurs at the superior angle of popliteal fossa. However, anatomical variations of the SN and surrounding structures may alter this route unilaterally or bilaterally (Tomaszewski *et al.* 2016; Güvençer *et al.* 2009).

As the SN and its branches course the length of the posterior lower limb, they are placed under tensile and compressive forces during hip flexion with a straight leg raise (SLR), such as the ASLR (Dutton 2020; Smoll 2010; Coppieters *et al.* 2006). During SLR, the SN moves adjacent to the sciatic notch, generating tension in the lumbosacral nerves, nerve roots and the plexus (Boland and Adams 2000; Goddard and Reid 1965). This tension may result in sciatica, from dural mechanosensitivity due to inflammation, or limit the available RoM of the ASLR (Dutton 2020; Andrade *et al.* 2018; Coppieters *et al.* 2006). The site of insult and potentially the structures responsible for the signs and symptoms that are produced are determined by the resultant vectors and the magnitude of force placed through the soft tissue (Sivasankari and Balasubramanian 2021; Wagnac *et al.* 2012; Ivancevic 2008; Amankwah *et al.* 2004).

During supine SLR different tissues are tensioned and preferentially loaded at various angles, including the SN. During the first 30-35º of hip flexion almost all slack is removed from the SN, thereafter, the dura of the SN is tensioned (Coppieters *et al.* 2006). Unless SN involvement is clinical, pain within this range is either myogenic or arthrogenic in nature (Dutton 2020). During the second phase of motion, the SN is tensioned over the IVD. Following 70º, minimal deformation of the nerve occurs. This third phase of motion is usually limited by tightness within the hamstring musculature and is normally equal in range. Unilateral reduction in RoM is suggested by Dutton (2020) to be more indicative of neural impairment. However, Cook *et al.* (2010) recommended that the PSLR be subsequently be applied to differentiate between myofascial and neurological causes. In contrast Dutton (2020), recommends comparing the slump test to the results to obtain differential diagnoses. This is due to the seated position creating axial compression that may sensitise small protrusions, especially disc herniation where internal structure is more aqueous. However, an alternate explanation to Duttons' supposition, may be found in the work of Kim *et al.* (2013) who found people with LBP restricted hip flexion experienced greater lumbar flexion kyphosis and posterior in the sitting position.

2.2.5 Myofascial

The following section primarily presents tabulations of the relevant muscles as they related to the ASLR. Muscle recruitment in healthy subjects during the ASLR is

briefly discussed with in-depth functional anatomy of other contributing muscles being discussed in the force-closure, myofascial slings, and pathology sections.

2.2.5.1 Muscle Recruitment

Muscle recruitment during the performance of the ASLR has been shown to differ between healthy subjects and pathological states (Nelson-Wong *et al.* 2013). Furthermore, numerous studies have shown that recruitment patterns differ between PGP and LBP, as well as between the different classifications of LBP. Various muscles have been theorised to be responsible for the dysfunction observed in the LPH complex and have been utilised to explain different paradigms. Of these, the most significant muscles are suggested to be the BF, RF, TrA, and PFM. Three additional muscles, the PMM, QL and AL, have either been shown to alter their recruitment patterns and/or have only been minimally studied.

The hip flexor and extensor recruitment are of great significance as unlike other joints within the body, the hip joint is in maximal congruence with lowest muscle contribution to stability in flexion, abduction, and small degree of internal rotation. In contrast the hip joint is in a position of least congruency when the musculoligamentous systems are most active, in the position of extension (Clarkson 2019; Palastanga *et al.* 2011).

Significantly, for the ASLR, if pain inhibition or weakness of the anterior abdominal wall or gluteal muscles are present, these muscles have been shown to assume a distal to proximal rather proximal to distal recruitment pattern (Nelson-Wong *et al.* 2013). This leads to either anterior rotation of the ilium in the former and posterior rotation of the ilium in the latter. The PMM is discussed first as this muscle functions as both a stabiliser as well as a prime mover during hip flexion (Hu et al. 2011).

The PMM (Table 2.1) is an important stabiliser during the ASLR however its optimal function is largely dependent on other muscles (Hu *et al.* 2011). The PMM has a complex function, which is frequently oversimplified to that of a hip flexor with a linear vector of pull despite the evidence detailing its complexity (Santaguida and McGill 1995). It may be argued that this muscle is frequently underappreciated during pathomechanical studies involving the use of the ASLR, as research largely

focused on the myofascial slings involved in the theory of force closure (Vleeming and Schuenke 2019; Booth and Morris 2019).

Table 2.1: Posterior abdominal wall (PAW)

Muscle	Innervation	Origin	Insertion	Action
Psoas major (PMM)	Anterior rami of lumbar nerves of L1, L2, L3	Transverse process (TVP) of lumbar vertebrae; sides bodies of T12-L5 vertebrae and intervening vertebral discs (IVD)	Via strong tendon to lesser trochanter of the femur	Hip flexion, hip and spinal stabiliser
Iliacus	Femoral nerve L2-L4	Superior 2/3 of iliac fossa, ala of sacrum, and anterior sacroiliac ligaments	Lesser trochanter of the femur and shaft inferior to it, and to the psoas tendon	Hip flexion
Quadratus lumborum (QL)	Anterior branches of T12 and L1-L4 nerves	Medial 1/2 of inferior border of 12th rib and lumbar tips of TVP	Iliolumbar ligament and internal lip of iliac crest	Extended and laterally flex vertebral column, fix 12th rib

(Adapted from Moore *et al.* 2018)

The first significant functional study on the function of the PMM was that of Santaguida and McGill (1995) in which the vector of action was defined, and the interaction of the lumbar lordosis and the creation of force in the iliolumbosacral region was clarified. The study utilised findings obtained from dissection to direct magnetic resonance imaging on living subjects. From the imaging, it was concluded that the resultant vector PMM contractions could only be explained through the application of centroid rather than linear geometry. This led to the conclusion that PMM contraction did not change with changes in lumbar lordosis and except for the L5-S1 joint, their contractions did not create large shearing forces, but rather acted to compress SIJs and lumbosacral joints when acting bilaterally.

Yoshio *et al.* (2002) conducted a phased heterogeneity study of the PMM in cadavers. In the supine position, they measured the angles at which the PMM tendon lost contact with the femoral head and pelvic surface, as well as the tension in the tendon every 15º up to 90º hip flexion. It was found that there were three distinct phases, which included the hip stabilisation phase (peak force through femoral head and pelvic surface of acetabulum), with the PMM focussed on lumbar spine movement and initiation of erect posture from the supine position (0°- 30° of hip flexion), the changeover phase (30°- 45°), where the PMM tendon loses contact with the bony elements of the femur and ilium reducing the stable hip (this variably can occur between 14° and 54° dependent on pelvic structure) and moving to phase three (45° - 60°) where the focus of the PMM is hip mobility and both tensile and pressure loads reduce markedly.

From these results, it can be concluded that the PMM is initially a lateral spinal stabiliser, when acting unilaterally, or spinal stabiliser, when acting bilaterally in for example the ASLR position. In addition, after 15º, the PMM function as a spinal

stabiliser, which decreases until 45º of hip flexion, thereafter, the muscle functions as a hip flexor up to 60º hip flexion. This concurs with Joen *et al.* (2016) who state that the ASLR involves both hip and, therefore, lumbar stabilisation followed by hip flexion as gravity has a large moment, which influences muscle contraction.

Hu *et al.* (2011) conducted EMG analysis of the hip flexors in healthy young women. During the ASLR, RF, AL, the iliacus, and PMM (in order on initiation on contraction) all contract prior to the initiation of the movement on the ipsilateral side. Given Yoshio *et al.*'s (2002) findings, it was expected that Hu *et al.* (2011) noted bilateral firing of the PMM at this time point, as the PMMs initial function is hip stability to allow an initiation of lumbar spine movement. The simplest explanation for the observed pattern is the PMM is bilaterally recruited to stabilise the lumbar spine, most likely in the frontal plane.

Jeon *et al.* (2016) examined the contralateral recruitment of the PMM during the ASLR in healthy male subjects, with and without uncontrolled lumbopelvic rotations (ULPR), with and without 1kg ankle weights using ultrasound. They concluded from the results, that during the ASLR, the contralateral PMM is an important stabiliser during the ASLR to prevent UPLR. This conclusion was achieved after the application of Bonferroni correction to determine interaction and simple effects. This statistical analysis found that the angle of lumbar rotation was statistically significant between the group's actions to mechanically pull the TVP to provide a counterbalancing force to the ipsilaterally rotated lumbar spine during ASLR.

Table 2.2: Thigh muscles

Muscle	Innervation	Proximal Attachment	Distal Attachment	Action
Pectineus	Femoral nerve (L2, L3)	Superior ramus of pubis	Pectineal line of femur, just inferior to lesser trochanter	Adducts and flexes; assists with medial rotation of thigh
Psoas minor	Anterior rami of lumbar nerves of L1, L2	Sides of T12-L1 vertebrae and IVD	Pectineal line, iliopectineal eminence via iliopectineal arch	
Sartorius	Femoral nerve (l2, L3)	Anterior superior iliac spine and superior part of notch inferior to it	Superior part of medial surface of tibia	Flexes, abducts, and laterally rotates thigh of hip joint
Adductor longus	Obturator nerve, branch of the anterior division (L2, L3, L4)	Body of pubis inferior to pubic crest	Middle 1/3 of linea aspera of femur	Adducts thigh
Semitendinosus	Tibial division of the sciatic nerve (L5, S1, S2)	Ischial tuberosity	Medial surface posterior part of tibia	Extended thigh
Semimembranosus	Tibial division of the sciatic nerve (L5, S1, S2)	Ischial tuberosity	Posterior part of medial condyle of the tibia	Extended thigh

Bicep femoris	Tibial division of the sciatic nerve (L5, S1, S2) Common fibular nerve (L5, S1, S2)	Long head: Ischial tuberosity Short head: Linea aspera and lateral supracondylar ridge of the femur	Lateral side of head of the fibula	Extended thigh

(Adapted from Moore *et al.* 2018)

As previously stated, the RF is the primary hip flexor in the early stages of movement, contracting before the other muscles. In their seminal article to validate the use of the ASLR to test for PGP, Mens *et al.* (1999) suggested that contrary to the 1930's study by Chamberlain, they observed that the ilium and, therefore, the SIJ rotated anteriorly during the ASLR. The explanation for this finding was that the anterior abdominal wall was weak and, therefore, unable to prevent the RF from pulling the ilium anteriorly. Problematically, the study utilised the PSJ as the centre of rotation rather than the SIJ and no EMG analysis was conducted to analyse muscle function. The problem of centring the rotation at the PSJ was highlighted by Kibsgård *et al.* (2017), who found that the rotation was posterior in direction when radiostereometric analysis was conducted and rotation was centred on the SIJ. Radiostereometric analysis is considered to be more accurate than the standard radiographs used by Mens *et al.* (1999). It must be noted that while some sources utilise Hungerford *et al.* (2006) to support Mens *et al.* (1999) findings, the study utilised the ASLR to diagnose posterior PGP but kinematic analysis to determine pelvic rotation was conducted in CKC, standing position and not while performing the ASLR. In contrast, to Hungerford *et al.* (2006), Sadeghisani *et al.* (2017) also noted posterior rotation in LBP subjects.

AL function has also been shown to alter in the presence of sacroiliac joint pain (SIJP) (Shadmehr, Jafarian and Talebian 2012). Subjects were demonstrated to have a greatly increased latency of the AL following the initiation of the ASLR (p=0.002) in comparison to the pain free controls, with values of −407.93 and 118 milliseconds respectively. During the ASLR in this study, activity of other muscles was also significantly lower in the EO (p=0.012), BF (p=0.008)), GM (p=0.43), and ES (p=0.029) compared to the control group. The reduced gluteal recruitment is consistent with results published by Krkeljas and Kovac (2018), the pain free subjects, were reported to have higher FMS ASLR score, better hamstring flexibility and gluteal activation. In contrast, pain was associated with greater restriction of trunk flexion and greater rate of pelvic tilt. An ASLR score of 1 was found to be associated with hypomobility of the trunk and posterior pelvic tilt.

Meijer *et al.* (2020a) in their paper deconstructing PGP have suggested that the abdominals are important to the transfer of force from the BF to the SIJ. However, a data study conducted by Mayhew, Norton and Sahrmann (1983) found that during the SLR the BF compensated for weak abdominals by increasing their activity. Nelson-Wong (2013) noted that the RF and contralateral extensors assumed an almost co-contraction quality and the EO contraction was altered.

Table 2.3 Antero-lateral abdominal wall

Muscle	Innervation	Origin	Insertion	Action
External Oblique (EO)	Thoraco-abdominal nerves (T7-11 spinal nerves) and subcostal nerve	External surface of 5th-12th ribs	Linea alba, pubic tubercle, and anterior half of iliac crest	Compression and support of abdominal viscera, flexes and rotates trunk
Internal Oblique (IO)	Thoraco-abdominal nerves (anterior rami of T6-T12 spinal nerves) and first lumbar nerves	Thoracolumbar fascia (TLF), anterior two thirds of ilia crest, and connect tissue deep to the lateral third of inguinal ligament	Inferior borders of rib 10-12, linea alba and pecten pubis via conjoint tendon	Compression and support of abdominal viscera, flexes and rotates trunk
Transversus Abdominus (TrA)	Thoraco-abdominal nerves (anterior rami of T6-T12 spinal nerves) and first lumbar nerves	Internal surface of 7th-12th costal cartilages (CC), TLF, iliac crest, connect tissue deep to the lateral third of inguinal ligament	Linea alba with aponeurosis of IO, pubis crest and pecten pubis via conjoint tendon	Compression and support of abdominal viscera
Rectus Abdominus (RA)	Thoraco-abdominal nerves (anterior rami of T6-T12 spinal nerves)	Pubic symphysis (PS) and pubic crest	Xiphoid process and 5-7th CC	Flexes trunk, compression of abdominal viscera, stabilises and controls the tilt of the pelvis

(Adapted from Moore *et al.* 2018)

2.2.5.2 Thoracolumbar Fascia

The TLF is described by Willard *et al.* (2012) as a corset like structure that consists of several layers that partition the paraspinal muscles from PAW, QL and PMM. The TLF is an essential component of force transfer in the LHP region, as several muscles attach to it. As such, the TLF has been of interest during studies of the ASLR. The TLF has been conceptualised as either two or three layers within the literature (Willard *et al.* 2012). Both concepts incorporate all the same structures, the primary difference between the two conceptualizations is that the three-layer paradigm allows for the concept of “hydraulic amplifier,” which assists with the function of the paraspinals (Willard *et al.* 2012). The two-layered structure is discussed, with a brief description of the concept of “hydraulic amplifier”.

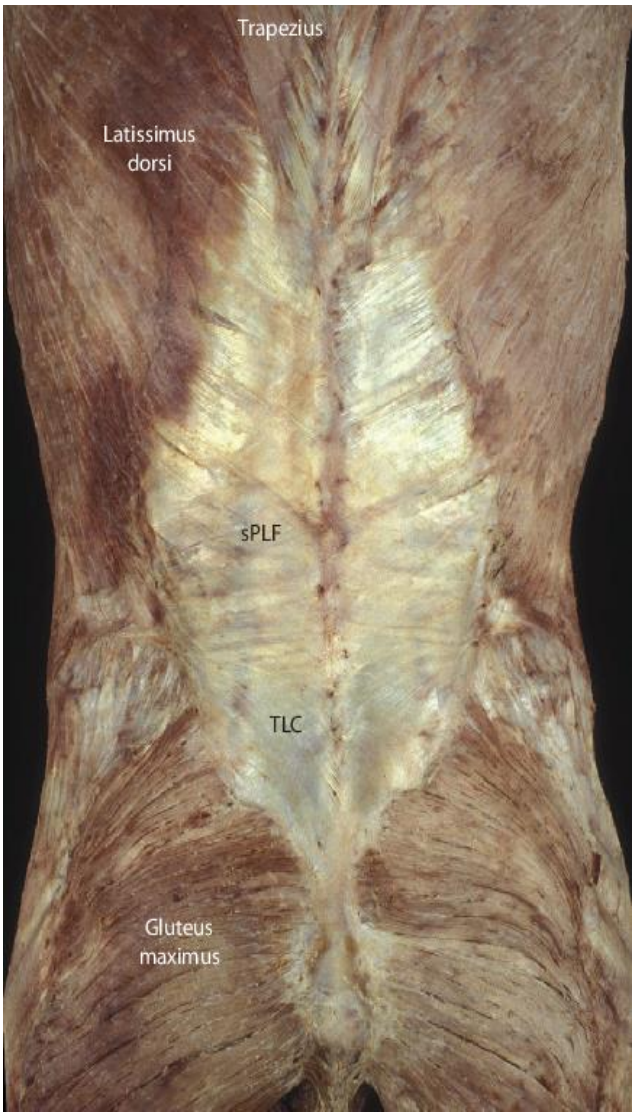

Figure 2.3: Thoracolumbar fascia

(Adapted from Willard *et al.* 2012)

The TLF is comprised of an anterior and posterior layer. The posterior layer attaches medially to the tips of the SP of the lumbar vertebrae and sacrum, and their supraspinous ligaments, enclosing paraspinal muscles to attach to the raphe laterally. This layer is composed of deep and superficial lamina. The superficial lamina is made up primarily of the LD and to a lesser extent the GM, with minimal contributions from the EO and trapezius muscles. As the contralateral LD and GM function together to form a force couple, the fibres are orientated in craniolateral to caudomedial direction (Willard *et al.* 2012). Barker *et al.* (1999) have also reported attachments to the rhomboids.

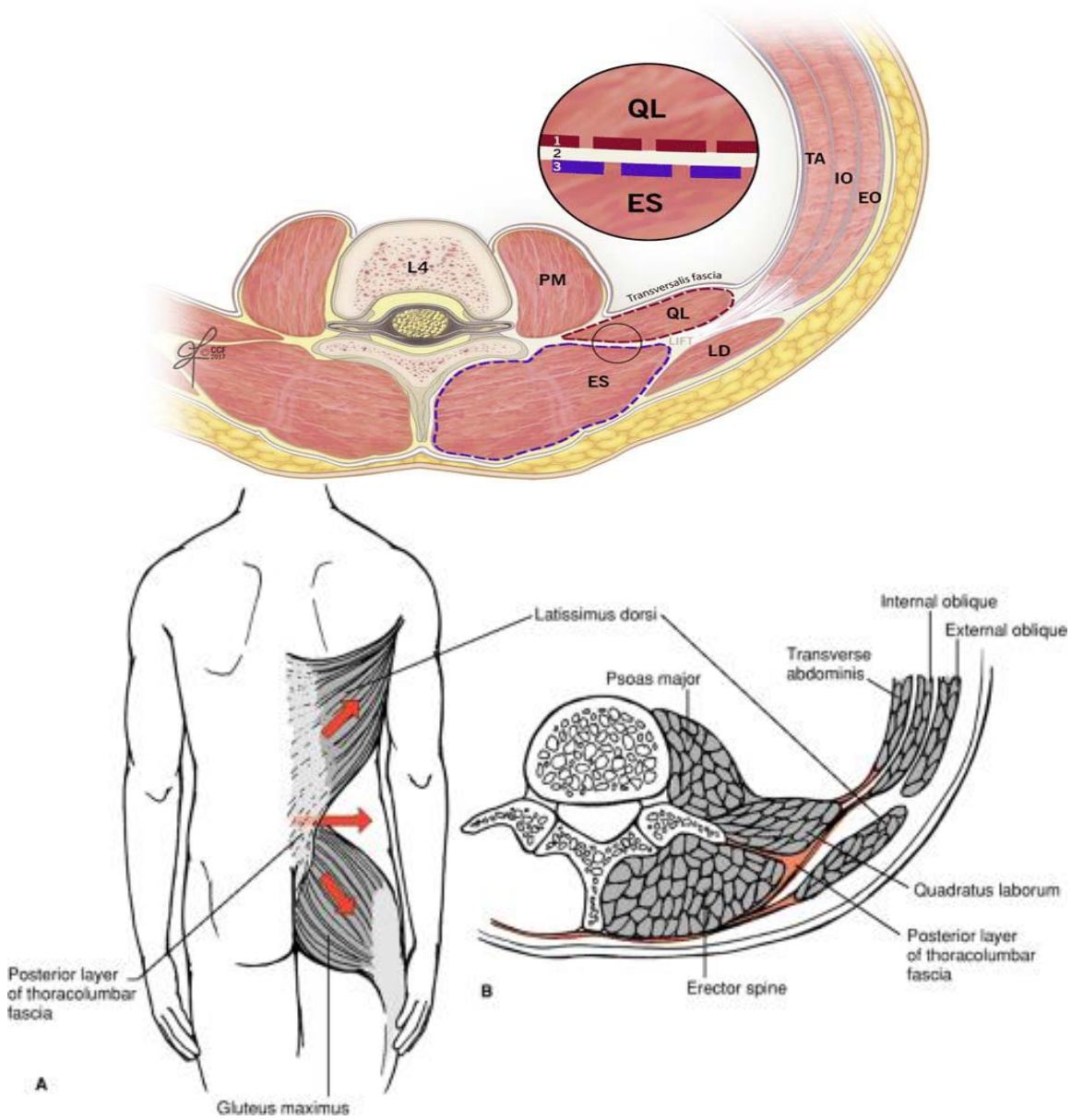

Figure 2.4: Thoracolumbar fascia cross section

(Elsharkawy, Pawa and Mariano 2018)

The deep layer has significant ligamentous attachments, as it attaches to the STL, interspinous ligament and LDSL. Laterally, the deep lamina is connected to the IO via the raphe while superiorly it is connected to the serratus posterior inferior in the lower thoracic region, and the tendons of the splenius cervicis and capitis (Barker *et al.* 1999). In contrast to the superficial lamina, the fibres of the deep lamina are orientated in craniomedial to caudolateral direction (opposite direction).

The hydraulic amplifier effect is suggested to be more important than core stability by Norris (1995) in stabilising the spine, as it increases the efficiency of the ES and LM contraction by up to 30% (Willard *et al.* 2012; Norris. 1995). This effect occurs when the ES and LM, which are both located within the posterior layer of the TLF,

contract. The TLF resists the lateral expansion of the muscle, leading to “inflation” of the posterior layer of the TLF and longitudinal tension in the TFL. This aids the paraspinal muscles support of the lumbosacral spine.

2.3 APPLICABLE BIOMECHANICAL CONCEPTS

2.3.1 Kinematic Chain Theory

Bio-mechanists have conceptualised the limbs and spine as rods connected by a series of joints since the 19th century (Svoboda *et al.* 2016). Since these observations, this model, has been updated to include the muscular system which act like chains to move the rods (i.e. the bones), with injury occurring at the weakest point in the kinetic chain (Apprentice *et al.* 2004). Concurrently, advancements in multiple fields have led to greater understanding of biomechanics and neuromuscular control as well as the development of more complex kinesiological, biomechanical, pathomechanical and neuropathological theories (Svoboda *et al.* 2016; Lu and Chang 2012; Turvey 2007; Gracovetsky 1984).

Despite the developments, the principle of a series of rigid links connected in such a way as to allow motion is still used to define movement and to enhance the understanding of pathomechanics (Lippert 2017; Lu and Chang 2012). This has perhaps, oversimplified the reasoning of certain pathologies and limited both our understanding and management of these pathologies, due to an over reliance on biomechanics. This is due to three factors. The first factor is that the few forces that act on the various segments are usually dismissed during the presentation of concepts applied using this model, such as viscoelastic forces of soft tissue. The final two factors are more important. These are that the presentation of movement in this model does not highlight the importance of neuromuscular control and/or sophisticated three-dimensional movement of human movement. Arguably though, despite its limitations, the model has aided in the learning of the core biomechanical concepts and significantly aided in patient education in clinical settings. Another benefit this model has to movement is that it is adaptable when newer theories, such as the theory of regional interdependence (Lu and Chang 2012; McMullen and Uhl 2000; Gracovetsky 1984) are applied.

Application of this kinematic chain theory to the ASLR primarily relates to the generation of torque to overcome inertia and lift the weight of the lower limb (LL) against gravity (Mens *et al.* 1999). The movement to attain the ASLR is a class 1 lever system, with a long arm and a relatively short effort arm (hip flexors) by comparison (Palastanga *et al.* 2011). As a result, the LPH complex is placed in a position of mechanical disadvantage, resulting in the application of significant forces to the region whilst trying to overcome inertia with the hip extended. This load begins to dissipate after 30º of flexion as the lever shortens in relation to both distance from the fulcrum and gravity (Palastanga *et al.* 2011). This concept is significant in the clinical interruption of the ASLR, as it allows causative tissues to be more readily identified and potential differential diagnoses to be generated. If pain is induced during the first 30º, it is likely due to dysfunctional loading of the SIJ. Thereafter, the pain is likely due to tensile stress of neural and myofascial soft tissue (Dutton 2020).

However functionally, this principle needs to be considered in relation to muscular function. Diarthrodial muscle function is least efficient when the muscles are in position where their proximal and distal segments are placed in positions requiring concentric-concentric and eccentric-eccentric contractions (Prentice *et al.* 2004). Optimal function of theses muscles occurs when eccentric-concentric recruitment occurs (Prentice *et al.* 2004). This is significant for the isolation of neural tissue during pathology, as well as the potential available range of motion[1]. From a purely myofascial involvement, the relative maintenance of lever length is essential to distal function, as both the hamstring, rectus femoris and calf (i.e. gastrocnemius) muscle groups are influenced by this principle. During the ASLR the hamstring is always placed in a position where the muscle group is lengthened as both its proximal and distal segments. In contrast, as the ankle is in an open chain configuration, it has the potential to alter the lever length depending on the applied ASLR technique. If the Cook ASLR is applied, a dorsiflexed position is utilised leading a “static” eccentric-eccentric gastrocnemius contraction, which is not attained in the Mens ASLR (Cook *et al.* 2010; Prentice *et al.* 2004; Mens *et al.* 1999). This has been demonstrated to both limit the range and alter muscle function at the hip joint.

[1] Isolation of neural tissue will be discussed later in the pathology sections as additional movements may be applied, via the head, and the hip and ankle, to discern between myofascial and neural tissue involvement.

2.3.2 Regional Interdependence Theory

Any alterations or dysfunction within the kinematic chain may lead to changes in length tension relationships and muscle recruitment during synergistic contractions (Takasaki and Okubo 2020; Goshtigian and Swanson 2016; Wainner *et al.* 2007). This may alter movement patterns throughout the chain to adapt/compensate and may ultimately lead to pain and/or injury during active movement (Goshtigian and Swanson 2016; Wainner *et al.* 2007). This phenomenon of adaptation is thought to occur throughout the kinematic chain and is known as the theory of regional interdependence. It has been demonstrated in two studies that have variable muscle recruitment during the ASLR in the presence of both experimental and pathological pain (Palsson *et al.* 2012; Wainner *et al.* 2007).

The effects of regional interdependence on the ASLR have been demonstrated by Takasaki and Okubo (2020) who examined the effect of head position in healthy, pain free subjects with a Cook ASLR-1-SMCD. EMG analysis of GM, rectus abdominus (RA), IO, EO and RF were obtained during the performance of the ASLR on the right leg with the head in three positions. These positions were neutral head position, head extended 25º, and craniocervical flexion test (CCFT) maintained with a 24mmHg target. The results obtained from subjects who demonstrated overactivity of the sternocleidomastoid muscle during the CCFT, (i.e. >39% reference voluntary at 24mmHg target on pressure biofeedback unit) were excluded from the analyses. The results indicated that head extension had no observable effect on abdominal activity. In contrast, selective activation of the DNF muscle resulted in a delayed onset of the RA during Cook ASLR. This may be due to alterations in respiratory parameters or to alterations in tension within the superior portions of the TLF and ES due reduced cervical lordosis.

The theory of regional interdependence as above, provides the rationale for the concepts of myofascial slings and force closure; and neuromuscular control of the ASLR (Goshtigian and Swanson 2016; Wainner *et al.* 2007; Vleeming *et al.* 2008).

2.3.3 Spinal Engine Theory

Gracovetsky's (1984) spinal engine theory was developed from Lovetts (1903) principles of coupled spinal movements. Lovetts principle views the spine as a single rod and when this rod is bent in one direction, it cannot be bent in another direction

without torsion occurring. The spinal engine theory purposes that the spine is not a passive structure during locomotion but rather an active structure that generates axial torque that propels the pelvis, legs, and shoulders.

Gracovetsky and Lacono (1987) suggest that axial torque is generated through lateral spinal flexion in the coronal plane occurring with concurrent flexion or extension of the spine in the sagittal plane. To optimise the utilisation of torque and achieve the greatest efficiency of use of the momentum generated, compensatory movements occur in all three planes. In the transverse plane, lateral spinal flexion is accompanied by rotation of the shoulder in the opposite direction. While in the coronal plane, contralateral shoulder rotation counters the pelvic rotation. The rotatory movement of the pelvis in the sagittal plane facilitates the movement of the leg as the acetabulum is rotated anteriorly. Additionally, the pelvis' rotation induces counter rotation of the shoulder. The shoulder rotation also has a countering flexion-extension motion in the sagittal plane. This theory is supported by EMG, and force and torque data presented by Gracovetsky (1985) and Gracovetsky (1997).

The concept of torsion presented in this theory goes against the convention that torsion is frequently responsible for herniation and prolapses. However, Gracovetsky and Lacono (1987) argue that the traditional view of fibre orientation has been interpreted and modelled on the principle that the annulus is designed to maintain disc pressure. They support their argument with Seyed *et al.*'s (1984) study that demonstrated that end plate rupture under static loading occurs before healthy disc fail.

The PMM is a central component of this theory. During gait cycle, the body attempts to minimise energy through the conservation of momentum (Popovic and Englehart 2004). This is achieved through the rotatory patterns previously discussed as well as the use of stretch-shortening-cycles (SSC) in the myofascial slings (Lamb and Pataky 2018; Vleeming *et al.* 2008). The SSCs occur when a muscle eccentrically contracts and then concentrically contracts. This process allows mechanical energy to be stored in the elastic elements of the muscle during lengthening as potential energy and reconverted during the concentric contraction, enhancing the contraction. During this process, lumbar reorientation, axial compression, and reduction of shear forces needs to occur (Ong 2017). This requires inferior pull on the lordotic curve, which Gracovetsky and Lacono (1987) suggest only the PMM is

positioned to provide. This action is enhanced by the contraction of the LD, ES, and the trapezius (Ong 2017, Starrett and Cordoza 2015).

The reaction of the posterior ligamentous system (PLS) is directly related to the amplitude of pelvic oscillation in the frontal plane and the flexion-extension displacement in the sagittal plane (Booth and Morris 2019; Vleeming and Schuenke 2019; Fey *et al.* 2010; DonTigny 2005). This implies that the PLS is a significant contributor to the structural integrity of the posterior SIJ especially during movement (Zlomislic and Garfin 2019).

2.3.4 Summation of Speed Theory

Putman's (1993) summation of speed principle states that the larger, heavier proximal segments of the kinematic chain initiate movement and that each succeeding part initiates movement at the time of maximum speed of its own proximal segment. Subsequently, greater distal endpoint speeds are achieved in the latter, as energy is transferred to the smaller, lighter distal segments (Burden *et al.* 1998). Video analysis on four athletes engaging in four different tasks to test this principle, found that this principle is dependent on rotational velocities to transfer the energy to the distal segment. They further observed that this principle only applied to the transfer of speed through the segments (Putman 1991). Therefore, this principle works on the following assumptions 1) load is transferred through the centre of the joint 2) torque-dependent interactions between the thigh and leg were observed to significantly influence in determining the sequential segment motion patterns in all three activities. The general nature of this interaction was consistent across all three movements except during phases in which there were large differences in the knee angle.

This principle is not likely to be applicable to the Cook ASLR which has a fixed non mobile foot position (Cook 2012). However, for the non-standardised forms of the test and the Mens version (which does not have a stated foot position) (Mens *et al.* 1999), there may be an influence in the outcome of the test. Upper limb injury studies have shown that in the fatigued state there is reduced neuromuscular control and a significant alteration in the generation of central fugal force leading to an increased risk of shoulder injuries. This appears to be due to the terminal elbow and wrist movements occurring at the same time, rather than the elbow followed by the wrist

(Han *et al.* 2019). This change increases both the lever length of the limb and the rate at which tissue is deformed, while potentially altering the way diarthrodial muscle's function. This may subsequently impede the ability of myofascial tissue to store and reverse force, leading to increased loading of joint structures (Clarkson 2019). This may be significant for the study of the ASLR for at least two reasons. The first it relates to EMG studies of the ASLR. Dysfunctional ASLR studies have not shown an increase in EMG activity rather they have shown alterations in the latency of muscle activity. The alterations in central fugal force creation via distal muscle contraction would not be observable in more proximal studies. Secondly studies have demonstrated that contrary to the normal assumption, that the ankle myofascial tissue is passive when the ankle is in the neutral position, the myofascial tissue of the posterior myofascial chain is active to achieve a degree of plantarflexion. This is known as the double spring theory and is likely due to the antigravity function of the posterior leg muscles in standing (Buchman *et al.* 2022; Haufe *et al.* 2020).

2.3.5 Self-Bracing Mechanism

The paradigms of form-and-force closure were developed from the self-bracing and dynamic stability theories and is the dominant theory used to explain the complex biomechanics, stability and loading of the SIJ (Vleeming and Schuenke 2019; Booth and Morris 2019; Snijders *et al.* 1993). This includes findings related to the ASLR (Mens *et al.* 1999). This paradigm can be broken into its static, form closure, and its dynamic, force closure, components. Static components are orientated to deal with vertical force transmission while the dynamic components deal with the production of horizontal compressive forces (Vleeming and Schuenke 2019; van Wingerden *et al.* 2004). The two components are inter-related, as the required force closure is dependent on the degree of form closure at the articulation (Booth and Morris 2019, Vleeming and Schuenke 2012).

Vleeming and Schuenke (2019) defines form closure as a "...*theoretical stable state of a joint with close fitting articular surfaces, where no extra forces are needed to maintain the stable state of the system during loading and unloading situations."*

As such, form closure deals with the SIJ's structure, orientation, and shape, and how these interact with the vertical forces applied to the body (Vleeming and

Schuenke 2019; Bussy 2015). The original works of Vleeming *et al.* (1990a, 1990b) which present the model in a static fashion, describe three mechanisms that contribute to form closure. These include the configuration of the joint surfaces, the reciprocal corrugation of the joint surfaces and ligamentous integrity (Bussey 2015). At present, many authors now include the ligaments under force closure. This is due to the anatomical inter-connectivity, which allows for the muscles to tension the ligament (Booth and Morris 2019).

The problem with conceptualising the model in this manner, is it ignores the concept of the closed pack position (Wong, Sinkler and Kiel 2018; Roussel *et al.* 2007) as it has been found that the recruitment of muscles was similar in the Trendleburg test and the ASLR (i.e. gravity eliminated (ASLR) and against gravity (standing)). Additionally, when a belt was added to a PGP subject, they experienced greater subjective difficulty in lifting the lower limb (Mens *et al.* 2002). For this paper, the ligaments are included later in form closure as they are a relatively passive structure. The effects of muscle contraction on the ligaments are however discussed in force closure.

Vleeming and Schuenke (2019) have attributed bone morphology and the articulation of the SIJ bones as the primary factors influence form closure. According to Booth and Morris (2019), the two primary morphological factors influencing form closure are the shape of the sacrum and profile of the joint surfaces.

Force closure is defined by Vleeming and Schuenke (2019) as a *"theoretical state where lateral force and friction resulting in joint compression, are required for the joint to withstand a vertical load".*

Due to the requirements to achieve mobility, the SIJ surfaces are not fully congruent (Booth and Morris 2019). As a result, force closure is required to provide joint stability and transfer forces, particularly vertical shear forces, during ambulation, activities of daily living, and functional activities (Vleeming and Schuenke 2019; Booth and Morris 2019). Force closure is achieved through ligament and myofascial tension creating lateral compression force, which increases friction. This allows the SIJ to absorb and transfer shear force via bone and cartilage (Vleeming and Schuenke 2019). For optimal transfer, a perpendicular compressive force is

required. This is achieved through reorientation of pelvic bones and myofascial tension (Vleeming and Schuenke 2019; Booth and Morris 2019).

Force closure via reorientation of pelvic bones can be achieved via nutation or posterior rotation of the innominate bones (Vleeming and Schuenke 2019; Bussey. 2015). Nutation of the sacrum occurs when the sacral promontory is slightly rotated in an anteroinferior direction. Both movements increase the distance and, therefore, tension of the dorsal sacral ligaments, apart from one, the long dorsal ligament (Vleeming and Schuenke 2019; Booth and Morris 2019; Bussey 2015). This increased ligamentous tension, draws the posterior iliac bones together leading to compression of the SIJ. Additionally, these movements lead to more optimal orientation and, therefore, appropriate lines of load transfer (Bussey 2015). In contrast to Vleeming and Schuenke (2019), who classify nutation as force closure, Bussey (2015) considered the effects of the orientation of the sacrum to be a component of form closure. This may be attributed to nutation increasing when the sacrum is vertically loaded in static sitting and standing, or in symmetrical postures.

The myofascial system enhances compression of the SIJ through a direct and an indirect mechanism. These mechanisms are driven by the effects and outcomes of changes in muscle tension in both the deep and superficial muscles of the LPH region (Booth and Morris 2019; Bussey 2015). The deep muscles do not cross the SIJ but can increase compression via fascial attachments, especially the TLF (Lee *et al.* 2020; Kim *et al.* 2013). The superficial muscles, which may cross the SIJ, are able to directly influence the compression as well as indirectly influence compression via fascia and ligament attachments. The superficial muscles together with the TrA and IO function synergistically in complex motor patterns with myofascial strain being applied along traceable facial lines (Myer *et al.* 2020). These traceable facial lines are called myofascial slings (Vleeming *et al.* 2008).

The myofascial slings are primarily composed of superficial muscles and are essential to the concept of force closure. Vleeming and Snijder (2018) have described four myofascial slings involved in both force closure and the transfer of force between the lower LPH and thoracic regions. These are the posterior oblique sling (POS), the anterior oblique sling (AOS), the deep longitudinal sling (DLS), and the lateral sling (LS). These slings utilise complex motor patterns of co-contractions and synergistic contractions to create force vectors proximally or distally to the prime

movers' sites of attachment, as well as resolving force to enhance joint stability (Lee *et al.* 2020; Kim *et al.* 2013). Any injury to, or lesion in any components of a sling will alter the length-tension relationships and force couples leading to instability or degradation of the quality of movement which must be compensated for in another plane (Joseph *et al.* 2014).

Central to the function of the myofascial slings is the TLF, which serves to connect various slings as well as connect the slings to the deep muscles (Joseph *et al.* 2014; Myers *et al.* 2012). The muscles of the myofascial slings are subsequently discussed as a collective in the following section (Section 2.3.6). The individual and deep core muscles are discussed in more detail in Section 2.3.7.

2.3.6 Myofascial Slings

The myofascial slings are composed of local, deep stabiliser and superficial, global muscles, which are typically linked by a common keystone structure, allowing for the creation of a force vector. These vectors may act to produce movement, transfer force and/or optimise skeletal alignment producing observable lines of strains through the myofascial system (Myers *et al.* 2020). Four sling systems have been described within the literature, each occurring bilaterally.

2.3.6.1 Posterior Oblique Slings

The POS are composed of the BF, GM, and LD, with the TLF connecting the contralateral GM to the LD (Lee *et al.* 2020; Vleeming *et al.* 1996 Vleeming *et al.* 1995). These slings are the primary generators of torque, which through their contralateral attachments lead to counter rotation mechanisms by their sagittal plane motion and also play an essential role in force closure and lumbar stability (Lee *et al.* 2020; Vleeming *et al.* 1996; Vleeming *et al.* 1995).

During synergistic contraction of the contralateral LD with GM, a partially coupled perpendicular force is created and with the tensioning produced on the sacrotuberous ligament by the GM contraction, which acts to compress the SIJ (Vleeming *et al.* 1995). Dysfunction of the GM has been demonstrated to increase the activity of the BF and the erector spinae (ES) in LBP, which act as a force couple within the POS (Lee *et al.* 2020; Wingerden *et al.* 2004). Tightness or overactive LD can lead to anterior rotation of the innominate and hyper-lordosis of the lumber spine (Sharma, Saiyad and Bid 2013).

2.3.6.2 Anterior Oblique Sling

The muscles of the AOS include AL, the TrA, and the contralateral IO and EO, and pectorals (Joseph *et al.* 2017; Joseph *et al.* 2014). The kinetic and stored energies of the oblique abdominal musculature, acting in conjunction with the core muscles are primarily responsible for generating the torque that drives the spinal engine, as they are best suited to do so (Gracovetsky 1985; Mungiole 1991). The anterior oblique sling is also essential in the compression of the PSJ via the adductors, the abdominal-adductor fascia and TrA, while the horizontal fibres of the TrA and IO play an important role in force closure (Lee *et al.* 2012).

In their biomechanical hypothesis on the myofascial slings influence on glenohumeral pathology, Joseph *et al.* (2017) assert, that AOS functions in concert with the POS. They theorise that any dysfunction in one sling must be compensated for as per the pretension / prestress models (Joseph *et al.* 2014; Joseph *et al.* 2017; Mungiole 1991). While this may be true in the upper limbs, which function primarily in an open chain configuration, it does not address the patterns observed in dysfunctional and/or painful patterns observed in LBP, PGP, and longstanding adduction-related groin pain (LAGP) subjects. This is likely due to SIJ transferring load diagonally from the LL to the contralateral UL, and the LL functioning in the closed kinetic chain in at least 50% for the time. Furthering, on Joseph *et al.'s* (2017) assertion, when the local stabilising muscles within a sling are dysfunctional, such as the TrA, the larger global muscles such as the EO increase their activity to compensate. Joseph *et al.'s* (2017) hypothesis, has partly been demonstrated in numerous PGP and LBP studies of the ASLR where dysfunction of the TrA has led to increase in the EO activation (Hu *et al.* 2011).

Two distinct patterns of AOS dysfunction affecting the ASLR have been reported within the literature. The first involves LAGP and while not the purview of this study plays a significant role in the understanding of the ASLR due to the various interactions of the joints of the pelvic ring. This interaction was demonstrated by Mens *et al.* (2006) who observed that 32% of subjects in their study on LAGP had pain in the posterior aspects of their pelvis. Additionally, 32% of subjects had positive ASLR. When belts were applied to subjects with positive ASLRs, their results improved. Consequently, Mens *et al.* (2006) concluded that a portion of subjects with LAGP had pelvic instability.

In contrast to Mens *et al.* (2006), Jansen *et al.* (2010) found that only 20% of subjects with LAGP and a positive ASLR improved their score from the application of a belt. Through the application of diagnostic ultrasound, it was observed that participants of this study with a positive ASLR demonstrated no difference TrA and IO thickness at rest and relative contraction between themselves and controls.

2.3.6.3 Deep Longitudinal Sling

The DLS consists of the tibialis anterior, peroneus longus, BF, multifidus, ES (Rendos *et al.* 2015). The DLS's primary function is to resolve ground reaction forces, however it also has significant role in core and hip stability, functioning synergistically with the POS to distribute transverse plan forces created during rotational actions. Low activation of the DLS provides functional stability in the pelvic rim joints, allowing for optimal function of the shallow slings.

Activation of the DLS begins with dorsiflexion of the ankle, which sequentially activates the BF, multifidus, and ES. The contraction of the BF tractions the sacrotuberous ligament leading to the sacral nutation. This has two effects; the first effect is the tensioning of the surrounding ligaments leading to force closure and the second is the activation of the deep multifidi attached to the sacrum. This subsequently leads to the tensioning of the thoracolumbar fascia.

There is some discourse within the literature to whether dysfunction within this sling leads to SIJ dysfunction and LBP or whether the DLS compensates for LBP and SIJP (Krkeljas and Kovac 2018). Numerous studies have demonstrated an increase in BF activity with a delay in TrA activity (Krkeljas and Kovac 2018). The compensation reasoning goes as follows, that SIJP leads to pain inhibition of the gluteal muscles. To compensate, the hamstrings shorten to enhance their mechanical leverage (Krkeljas and Kovac 2018; Arab *et al.* 2014). With abdominal weakness, the contralateral leg is thus pressed into the base of support. Other researchers have countered this by blaming hamstring dysfunction as a cause of SIJP, and then pain inhibition of gluteal muscles.

2.3.6.4 Lateral Sling

The LS consists of the GM and minimus, tensor fascia latae (TFL), and the contralateral QL (Rendos *et al.* 2015). The lateral slings provide frontal plane stability through force couple of the gluteus medius and minimus pulling the iliac

crest towards the femur while the contralateral QL and abdominal muscles elevating the iliac crest.

To the researcher's knowledge, no studies have examined the QL during the ASLR. This muscle is likely to demonstrate some change in function, as its secondary function is to stabilise the inferior rib. O'Sullivan *et al.* (2007) state that during pain states such as PGP and LBP there is a change in both IAP and descent of the diaphragm. This would likely influence ribs position and subsequently QL activity. However, it must be acknowledged that the location of the muscle during the ASLR is a significant limiting factor for its study due to its lack of accessibility in the supine position.

2.3.7 Core Stability

Anatomically the core is defined by Akuthota and Nadler (2004) as a corset-like space formed by the muscular boundaries of the diaphragm superiorly; the TrA, RA, and IO and EO anterolaterally; the paraspinals and gluteal muscles posteriorly; and the pelvic floor and hip girdle inferiorly. More recent descriptions have likened the core to a pot, with the respiratory diaphragm forming the lid, the corset muscles forming the cylinder and the pelvic diaphragm the floor (Gharote *et al.* 2017). Functionally, there is no universally accepted definition of core stability but the definition provided by Kibler *et al.* (2012) encompasses most views:

> *"...the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the terminal segment in integrated athletic activities. Core muscle activity is best understood as the pre-programmed integration of local, single-joint muscles and multi-joint muscles to provide stability and produce motion. This results in proximal stability for distal mobility, a proximal to distal patterning of generation of force, and the creation of interactive moments that move and protect distal joints."*

The two diaphragms, the pelvic and respiratory, have an intricate and complicated relationship as both influence IAP and intrapelvic pressure as well as lumbar spine stability (Kwon *et al.* 2020; Mohan *et al.* 2020). The complexity and intricacy of these regions is in part due to both diaphragms being under both somatic and autonomic control with this innervation still not being fully understood (Lee *et al.* 2012).

Dysfunction of the diaphragms have been reported in all subgroups of LBP (Mohan *et al.* 2020; Leinonen *et al.* 2003; Leinonen *et al.* 2001).

2.3.7.1 Respiratory Diaphragm

The respiratory diaphragm is a musculotendinous sheath located between the abdominal and thoracic cavities. It is composed of two non-uniform left and right hemi-diaphragms due to organ location and their soft tissue attachments. Pickering and Jones (2002) suggested that the diaphragm should be considered as two parts, the crural and costal diaphragm, based on their embryological development and function. The inner fibres are suggested to be more closely associated with oesophageal function while the outer fibres are more closely associated with respiratory function.

Contraction of the diaphragm has been implicated in both protective and pathological mechanism when involved lumbar spine function (Kocjan *et al.* 2017; Hodges and Simon 2000). This is due to the synergistic relationship of the respiratory diaphragm with the pelvic diaphragm in the control of IAP as well as the respiratory diaphragm attachment sites. Palastanga, Field and Soames (2012), describe six main attachments of the crura within the lumbar region. The two major ones are the anterolateral aspect and IVD of L1-L3 on the right and L1-L2 on the left. The fibres of the two crura, which are initially separated by the lumbar aorta, run obliquely to decussate at the level of T12. At this level, the two crura are attached by the arcuate ligament. Following decussation, the crura surround the oesophagus before inserting onto the central tendon. The secondary four attachment sites are the left and right medial and lateral arcuate ligaments. The medial arcuate ligaments arise from the lateral vertebral body of L2 and insert to the TVP of L1. They are located immediately lateral to the crura and represent fascial thickenings of the PMM. As a result, the PMM is linked to the respiratory diaphragm, lumbar spine, pelvic diaphragm, and hip. The lateral arcuate ligaments are thickenings of the anterior layer of the TLF enclosing the QL. These ligaments span the TVP of L1 to the tip of the 12th rib. Because of the different functional aspects of the respiratory diaphragm reported by Pickering and Jones (2002), as well as the anatomy of the diaphragm, dysfunction may result from respiratory, gastric, emotional, and musculoskeletal sources.

Diaphragm dysfunction is suggested to lead to LBP via two mechanisms. The first mechanism involves the zone of apposition (ZOA). ZOA is the cylindrical area of the respiratory diaphragm which is contiguous to the inner aspect of the lower ribs and plays a significant role in force production of the respiratory diaphragm. Flattening of the ZOA can occur for many reasons. The primary factors involved are hyperinflation, apical breathing, muscle tightness, and posture. They all ultimately reduced the ability of the lower ribs to expand thereby inhibiting the respiratory diaphragm ability to descend and reducing appositional force production. This leads to reduced IAP and, therefore, stability of lumbar spine.

The second mechanism is biomechanical due to asymmetrical pull. This may occur because of a few factors (Boyle 2012). The first factor is location and attachment of the liver to the right hemi-diaphragm, which favours the maintenance of the ZOA. The second factor is handedness which, favours the development of one set of oblique muscles, thereby influencing both diaphragmatic and rib motion (Troyer and Wilson 2016). This would also lead to asymmetrical development of the gluteal muscles, which in combination with the abdominal imbalance would further exacerbate the dysfunction through pelvic asymmetry (Boyle 2012). The last factor is the asymmetrical distal attachment of the hemi-diaphragms, whereby the right hemi-diaphragm is attached to an extra vertebra inferiorly as well as having a greater thickness of the central tendon. As a result, the right hemi-diaphragm has a significantly greater mechanical advantage when acting on the lumbar spine. These factors lead to an altered orientation of the lumbar spine, innominate, SIJ and hip joint, and ultimately asymmetrical loading of the LPH complex (Boyle 2012).

This influence of the respiratory diaphragm has led the physical therapist Hruskato to propose that development of scoliosis is influenced by hemi-diaphragm function (Boyle 2012). ASLR studies conducted on idiopathic adolescent scoliosis add credence to this theory, as they demonstrated altered abdominal function in this cohort of patients (Linek *et al.* 2018). Indeed, Borna *et al.* (2017) have positively correlated Cobb's angle to asymmetrical abdominal function during abdominal drawing in manoeuvres.

The relationship between the respiratory diaphragm and the ASLR has been demonstrated in two studies (O'Sullivan and Beales 2007; O'Sullivan *et al.* 2002). O'Sullivan *et al.* (2002) examined the relationship between respiration and ASLR

motor control in subjects with SIJP utilising ultrasound and spirometry. They observed that there was increased descent of the pelvic diaphragm and respiratory rates with a decreased descent of the respiratory diaphragm in comparison to pain free controls. Motor learning intervention was applied leading to normalisation of the diaphragmatic movements and decreased respiratory rates. In a follow-up study where the involved side was compared to the uninvolved side in females with chronic PGP, O'Sullivan and Beales (2009) analysed and compared the recruitment anterior abdominal wall, right chest wall and the scalene, intra-abdominal pressure, intrathoracic pressure, respiratory rate, pelvic floor kinematics, and downward leg pressure of the non-lifted leg. It was observed that the involved side demonstrated muscle splinting. These studies both suggested that pain during the ASLR was associated with impaired motor control (O'Sullivan and Beales 2009; O'Sullivan and Beales 2007; O'Sullivan *et al.* 2002).

2.3.7.2 Pelvic Diaphragm

The pelvic diaphragm is formed by the muscles, fascia and ligaments stretching between the anterior surfaces of the sacrum and coccyx, and the medial surfaces of the hemi-pelves. The two LA are broad thin muscles that join in the midline to form the pelvic diaphragm with the coccygeus muscles (Giraudet *et al.* 2018; Zijta *et al.* 2013). The pelvic diaphragm is a funnel-shaped floor spanning the pelvis and constitutes the inferior border of the pelvic cavity and core. It partitions the pelvic cavity from the perineum and supports the pelvic viscera (Giraudet *et al.* 2018; Fritsch *et al.* 2004).

The anatomical and functional integrity of the neurovascular and mysofascial structures and the synergy between them, is vital for many of the primary physiological functions of life, including stability for the lumbo-pelvic-hip complex; support of the pelvic organs (e.g., bladder); continence and evacuation of urine and faecal matter; and sexual function (Thibault-Gagnon 2016). The pelvic diaphragm can increase IAP by either opposing the downward pressure created by the respiratory diaphragm or by contracting synergistically with the abdominal wall (Pool-Goudzwaard *et al.* 2004). Cadaver studies conducted by Pool-Goudzwaard *et al.* (2004) have suggested that tensioning of the pelvic diaphragm can produce SIJ movement in females but has no significant effect in males. However, in both sexes contraction of the pelvic diaphragm is capable of inducing counternutation.

The ability to detect pelvic floor abnormalities was first recognised in O'Sullivan *et al.* (2007), in which it was observed that those subjects with PGP had descent of the bladder during the ASLR. Other studies have also noted an increased urinary bladder descent in other forms of PGP when the pelvic floor function was studied (Lee 2012). Since this observation, studies have demonstrated delayed activation of the pelvic floor muscles in both PGP and LBP subjects, followed by an increased contraction in comparison of pain free subjects (Mens *et al.* 2019, Beales *et al.* 2008).

2.4 ACTIVE STRAIGHT LEG RAISE TECHNIQUES

The ASLR is utilised in multiple clinic settings to assess motor control, force transfer, flexibility, muscle strength, neurodynamics, NRE entrapment and crossed extensor reflex of the hip utilising Hoover's sign (Diukova *et al.* 2013; Cook *et al.* 2010). The selected RoM is perhaps the most important parameter of the ASLR as this determines the tissue that is placed under the greatest strain. While body position may preferentially recruit certain muscles, it does not change the tissue placed under greatest strain. Numerous variations of the techniques are reported within the literature and the variations described within the studies utilised are tabulated in Table 2.4.

All ASLRs provide an opportunity to assess the cross-extensor reflex i.e., Hoover's sign (Cook *et al.* 2010). The efficacy of the assessment of Hoover's sign without pressure feedback is questionable. The purpose of Hoover's sign is to differentiate between malingering, functional and non-organic causes of muscle weakness (Ziv *et al.* 1998). As such many within the clinical setting regard Hoover's sign a test on its own.

Hoover's sign will not be discussed within this paper as there are a few different techniques reported within the literature (Coebergh and Stanton 2020; Diukova *et al.* 2013; Kobori *et al.* 2007; Stone, Zeman and Sharpe 2002; Ziv *et al.* 1998). While Hoover's sign may be a useful adjunct to the ASLR in the clinical setting, the application of this technique leads one to consider it a test in its own right (Diukova *et al.* 2013).

2.4.1 Mens ASLR

The Mens ASLR begins with the subject in the supine position, with the legs relaxed in external rotation and the feet twenty centimetres apart. The subject raises the test leg with the knee in the extended position to a height of usually twenty centimetres and then holds the position for three seconds following which, the leg is returned to the starting position. While twenty centimetres is the standard, the heights reported within the literature varies between five and thirty centimetres (see Table 2.4) (Bruno *et al.* 2014a, Teyhen *et al.* 2009; Mens *et al.* 2001; Mens *et al.* 1999). Additionally, some studies utilise degrees of hip flexion. This may result in significant differences muscle recruitment and application of torque applied through the SIJ via the long lever of the leg (Joen *et al.* 2016; Hu *et al.* 2010; Mens *et al.* 2010; Yoshio *et al.* 2002). The literature consistently recognises the first 20º as producing the maximal load through the ipsilateral SIJ and contralateral leg, and that 10º of flexion is required to evaluate Hoover's sign (Kobori *et al.* 2007). Additionally, the time that the flexed ASLR is held for in the top position varies in the literature with no explanation for this variation (Mens *et al.* 1999).

2.4.1.1 Scoring

At least five methods of scoring are reported in the literature, with the predominate version being the 6-point Likert scale (Table 2.5). The second and third most common are positive/negative ratings and a numerical 5-point ordinal scale. Of these versions, only the 6-point Likert scale and positive/negative rating have been studied (Bruno, Millar and Goertzen 2014b; Mens *et al.* 2010).

During the performance of the ASLR with assessment using the 6-point Likert scale, the velocity of the leg; the development of a tremor, or lack thereof; the degree of trunk rotation; and non-verbal emotional expression of the subject are subjectively noted and compared bilaterally. The subject is then asked to provide a perceived rate of exertion assigning a numerical value out of five, and whether they felt any pain or unpleasant sensations during the test. Subjects are also asked to evaluate if they perceived any contralateral differences (Mens *et al.* 2002). The sum of the bilateral score is then used to determine the severity of dysfunction, and this accumulated total is occasionally referred to as the 10-point Likert scale. The Likert

Table 2.4: Technical variations of the ASLR

Author (Arranged chronologically)	Group	Ankle Position	Hip-foot position	Lift Height/degree of hip flexion	Lift Speed	Hold Time	REPs	Other	Scale	Article Cited in Text of Methodology
Mens *et al.* (1999)	LPP	-	Feet 20cm apart, legs laterally rotated	5cm	-	-	-	-	4-point scale, subject and assessor score	-
Mens *et al.* (2001)	Posterior PGP	-	Feet 20cm apart	20cm	-	-	-	-	5-point Likert scale	-
Mens *et al.* (2002a)	Posterior PGP	-	Feet 20cm apart	20cm	-	-	1 rep	Reps one after the other	6-point scale	-
Mens *et al.* (2002b)	Posterior PGP	-	-	5cm	-	-	-	-	4-point scale and 5-point Likert scale	-
O'Sullivan *et al.* (2002)	SIJP	-		5cm	-	-	-	-	-	-
Stuge *et al.* (2006)	PGP	-	-	20cm	-	-	-	Reps one after the other Additional categorisation of normal, bracing, bulging, or rotation	6-point scale	-
Roussel *et al.* (2007)	LBP	-	-	20cm	-	20s	-	-	6-point scale	-
Roussel *et al.* (2009)	LBP	-	-	20cm		10s	-	-	Borg score	-
Beales *et al.* (2009)	PGP	-	-	10-20cm	-	45s	2 reps	Alternating followed by a rest then repeated	-	-
Teyhen *et al.* (2009)	LPP	-	Feet 20cm apart	5cm	-	10s	3 reps	Hands resting on the chest, and elbows on the plinth.	-	-
Beales *et al.* (2010)	PGP	-	-	-	-	-	-	-	6-point scale	Mens *et al.* (2002)
Ericksen *et al.* (2010)	LBP	-	-	30.5 - 61cm	-	X	3 reps	-	-	-
Mens *et al.* (2010)	PGP		-	20cm	-	-	3 reps	-	6-point scale	
McDonald *et al.* (2011)	LBP	-	-	"Just clears the plinth"	"Slowly, gently"	-	6 reps	-	-	-
Sasaki *et al.* (2011)	LBP	-	-	30°	-	3s	-	HHD to distal leg	-	-
Palson *et al.* (2012)	LPP	-	Feet 20cm apart	20°	-	5s	-	-	5-point Likert scale	-
Shadmehr *et al.* (2012)	SIJP	-	Feet 20cm apart	20cm	-	-	3 reps (U)	-		
Lewis and Olivier (2013)	LBP	-	-	20cm	-	-	1 rep	Three PBU devices used	5-point Likert scale	-
Kwong *et al.* (2013)	LPP	-	-	20cm	-	-	3 – 4 reps	-	6-point scale	
Rabin *et al.* (2013)	LBP	-	-	20cm	-	-	-	-	6-point scale	-
Stuge *et al.* (2013)	PGP		-	20cm	-	-	-	Reps one after the other	6-point scale	-
Nelson-Wong *et al.* (2013)	LBP	-	-	20cm	-	-	-	-	Ordinal 0–5 scale	-
Whittaker *et al.* (2013)	LPP	-	-	5cm	-	-	3 trials 3 tests	-	-	-

Bruno, Millar and Goertzen. (2014a)	LBP	-	-	20cm	-	1 - 2s	3 - 5 reps	-	Positive / negative	-
Bruno, Millar and Goertzen (2014b)	LBP	-	-	20cm	-	-	3 - 5 reps	Assessors: Positive / negative	Subjects: 5-point scale	-
Corkery *et al.* (2014)	LBP	-	-	50.8cm	-	20s	5 reps	PBU used – 3 attempts with PBU results visible and 2 without	6-point Likert scale	Roussel *et al.* (2007)
Apeldoorn *et al.* (2016)	LBP	-		20cm	-	-	-	Scores were trichotomised	6-point Likert scale	-
Nelson-Wong *et al.* (2016)	LBP	-	-	20cm	-	-	-	-	Ordinal 0–5 scale	-
Sjödahl *et al.* (2016)	PGP	-	-	-	comfortable self-paced	-	5 reps	First 2 subjects UL, rest CL 40s rest between reps	4-point Likert scale	-
Vanti *et al.* (2016)	LBP			20cm	-	-	-	-	Positive / negative	-
Kibsgård *et al.* (2017)	PGP	-	-	20cm	-	-	-	-	5-point scale	-
Sadeghisani *et al.* (2017)	LBP	-	-	Results: average hip flexion +/- 63°	-	-	-	-	-	-
Castro *et al.* (2018)	Spondylo artitis	-	-	-	-	-	-	-	-	-
Krkeljas and Kovas (2018)	LBP	DF		> 0cm	-	-	-	-	FMS	-

(Key: - = no information provided, x = value not provided but journal stated action performed)

10-point scale is sometimes converted to a 2-point scale with a point given for a positive or negative finding on each side.

Table 2.5: The 6-point Likert scale

Numerical Value	Subjective Description
0	not difficult at all
1	minimally difficult
2	somewhat difficult
3	fairly difficult
4	very difficult
5	unable to perform

(Adapted from Mens *et al.* 2010)

Numerous studies have examined the subjectivity of the Likert scale against the objective findings of the ASLR (Mens *et al.* 2010; de Groot *et al.* 2008). De Groot *et al.* (2010) examined the effect of pregnancy related LPP on the performance of the ASLR, noting that the subjective findings demonstrate decrease force output and an increase in effort at 0cm and 20cm of lift height. A 2010 study conducted by Mens *et al.* concluded that the subjective scores correlated with the objective findings. Lee *et al.* (2002) examined Likert scale and found that culture influenced some aspects of the scale but, at present, no studies have examined whether culture influences values of subjective reporting during the performance of the ASLR.

Two variations of Mens ASLR are described within the literature to differentiate between intra-and-extra hip pathology during the ASLR (Hattam and Smeatham 2010). The first is the Stinchfield Resisted Hip Flexion Test (RSLR), which involves performing the ASLR against manual resistance applied by the therapist. The RSLR is considered positive for intra-articular pathology if pain is induced in a typical pattern related to the sensory innervation of the hip (McGrory 1999). McGrory's (1999) assertion that lumbar and SIJ pathologies cannot refer pain to the groin region during the description is problematic. Additionally, research into femoral acetabular instability by Fader *et al.* (2018) suggests that certain hip pathologies may be asymptomatic if the lumbar spine is able to compensate for the impairments.

The second test variation described by Hattam and Smeatham (2010) is the Ling straight leg raise test. This involves performing the ASLR to approximately 20º on the affected leg and determining whether the pain has been provoked. If pain is

experienced, the therapist supports the heel and resists active hip extension. Pain reduction is suggested to incriminate the hip whilst no pain reduction implicates a spinal pathology. No additional literature could be found on Google scholar, PubMed, Science Direct or Scopus pertaining to the Ling straight leg raise test.

The interpretation of the Mens ASLR is largely centred on the application of the self-bracing and myofascial sling theories. Clinically this has led to the development of a breakdown of tests to determine the dysfunctional segment of the kinematic chain. These techniques involve the application of manual pressure by the therapist to various segments of the kinematic chain to simulate muscle contraction. To the researcher knowledge, only the effect of the simulated transversus abdominus (TrA) has been examined in Beales *et al.* (2010) via manual compression. While the other techniques are described in textbooks and applied successfully in clinical practice, no empirical data exists on these variations (Lee *et al.* 2012). Table 2.6 details the site of compression and the hypothesised effect.

Table 2.6: ASLR breakdown tests

Site of Compression	Hypothesised effect of manual compression
At the level of or on the anterior superior iliac spines (ASIS)s	Simulation of the contraction of the lower fibres of the TrA and IO muscles
At the level of or the posterior superior iliac spines (PSIS)s	Simulation of the contraction of the lumbosacral multifidus and the compression of the TLF
At the level of the pubic symphysis	Simulation of RA
At or on the level of the ischial tuberosities	Simulation of BF
Lateral fascial edges of the RA when diastasis rectus present (leading to approximation)	Simulation of the contraction of the RA
Compression can also be applied obliquely, through the pelvis (one side anteriorly and the opposite side posteriorly).	Simulation of the AOS
Contralateral shoulder	Simulation of the contraction of the LD

(Compiled from Lee 2012; Lee *et al*. 2004; Mens *et al.* 2002)

2.4.2 Cook ASLR

The second method is a variation that is applied through the full range of motion of hip flexion, allowing the assessment of the ability to separate the lower limbs while engaging the pelvic stabilisers. As such, the extensibility of the contralateral anterior hip structures, and the ipsilateral hamstrings, GM and ITB, as well as the flexor strength and load, transfer through the pelvis (Cook *et al.* 2010).

The technique begins with the subject positioned with their arms at the side with the hands supinated and the feet in the neutral position with sole perpendicular to the floor.

The pelvis is required to be in a neutral position. If the lumbar spine is hyperextended, due to muscle spasm within the region, or due to limitation of hip extension, the pelvis will assume an anteriorly rotated position to allow the leg to lie flat. This pelvic position will pretension the hamstrings, leading to a perception of limited tissue extensibility during the ASLR. For the first of three repetitions, a dowel stick is placed midway between the ASIS and knee joint, perpendicular to the surface. The subject lifts the test limb maintaining the knee in the start position. During the test, the contralateral limb should be maintained in the starting position (Cook *et al.* 2010).

When the test limb reaches end RoM the position of the toes is noted. If the midpoint of the malleolus passes through the vertical line created by a dowel stick on all three repetitions, a score of 3 is awarded. If two of three attempts are successful, a score of 2 is awarded. If the subject is unable to achieve this, the vertical is moved to midway between the mid-thigh and knee joint. If the subject is still unable to achieve this consecutively with this range, the vertical line is reorientated to just inferior to the knee. This last alignment is correlated with a score of 1 (Cook *et al.* 2010).

A score of 1 may be further divided into two sub-groups, 1A and 1B. Subgroup 1A is given when both the limitations of the ASLR and PSLR are encountered. Subgroup 1B has also been designated ASLR-1-SMCD as the limitations are attributed to stability and motor control dysfunction (Takaski *et al.* 2020). Score of 0 is award to subjects with pain (Medeiros *et al.* 2019).

Concerns have been raised as to whether the Cook ASLR scoring system is truly capable of comparable stratification (Medeiros *et al.* 2019). In their examination, Medeiros *et al.* (2019) examined the accuracy of the FMS™ scoring of the ASLR of hamstring flexibility in soccer players; it was concluded that the construct of the FMS™ ASLR scoring did not equally represent the divergence between categorical scores. The rationale for the conclusion was based on the number of structures throughout the kinematic chain being capable of restricting the ASLR. An additional point of concern, with regards to the Cook ASLR was its low sensitivity of detecting small deficits between the categories. It was suggested that the inability may impair the significance for injury prevention as some studies have suggested that even a deficit of a few degrees may influence the risk of injury. This raises questions of whether the full RoM of the Cook ASLR should be used as a measure a return to activity or be used as a discharge tool. There may be concern about the appropriateness of the

Cook ASLR raised within the FMS™ scoring, but these are addressed within the SFMA™ system using a breakdown of tests so as to identify the potential offending structure. Additionally, the SFMA™ has subgrouping within the category 1 scoring. Problematically, there is still a significant dearth in objective data to explain potential physiological mechanisms occurring within the stratification.

The foot alignment at the end RoM is another important observation, as there is a significant reciprocal relationship between the hip, knee, and ankle joint complexes, which influence muscle recruitment in the lumbopelvic region (Chai *et al.* 2014; Hu 2011, Cook 2010; Mitchell *et al.* 2008; Mens *et al.* 2001). Movement of the foot may indicate neural or myofascial tightness, as well as altered abdominal recruitment.

By way of example, Chai *et al.* (2014) utilised the ASLR as a strengthening exercise and found that when ankle dorsiflexion co-contraction was added it resulted in greater thickness of the TrA and EO after six weeks, indicating increased recruitment. They hypothesised that this was the result of facilitated activation of the deep abdominal muscles.

2.5 PAIN THEORIES

There are numerous facets to the theory of how pain influences motor control. There are two main schools of thought on this topic: myofascial and neuromuscular. The older school (myofascial) of thinking predominately tends to use Travell *et al.* (1942), Korr *et al.* (1986), and Lund *et al.*'s (1991) theories to explain how soft tissue injury (myofascial) leads to pain, which alters movement patterns and leads to MTPs. Travell *et al.*'s (1942) model of pain-spasm-pain suggests that injury / overload leads to pain, resulting in muscle spasm to protect the region and due to various physiological mechanisms, and further leads to a positive feedback cycle of induced pain from the muscle spasm.

The second myofascial theorem, which has substantial evidentiary evidence support in PPGP, is Korrs' theory of asymmetrical loading leading to muscle spasm. The third and final main myofascial theory, used to explain change motor control is based on the work by Lund *et al.* (1991). Their pain-adaptive model suggests that pain leads to increased agonist and decreased antagonist muscle activity, ultimately altering

recruitment patterns. The similarity between these theorems is that there is a degree of tissue damage that results in altered myofascial function.

In contrast, the newer neuromuscular school of thinking uses neuroinflammatory science to explain motor control changes, in the presence of chronic pain and when there appears to be an absence of tissue damage (Matsuda, Huh and Ji 2018). Inflammation in the body results from either infection or injury, leading to a complex cascade within the somatosensory, immune, autonomic, and vascular systems due to the secretion of proinflammatory mediators. These chemicals include prostaglandin, proinflammatory cytokines, and chemokines, which act both locally and systemically to sensitise and activate nociceptors via neural and neuronal plasticity (Gu *et al.* 2015). Neuroinflammatory pain is usually characterised as spontaneous and burning in nature and may either be hyperalgesia or allodynic in nature (Finnerup, Kuner, and Jensen 2021).

Neuroinflammation is believed to be a significant driver in chronic pain and a contributor to poor scoring during the Mens ASLR, especially in PPGP population (Mens *et al.* 2010; Mens *et al.* 1999). Palsson *et al.* (2012) clearly demonstrates that pain is cable of causing dysfunctional muscle recruitment patterns during the absence of structural injury. Concurrently, for the PPGP population, increased estrogen levels have been shown to decrease pain threshold.

Unrelated and, at present, an unstudied aspect of the ASLR is leg length inequalities. No studies have examined whether leg length inequalities (structural and functional) have any relationship to the ASLR. Length inequalities have been demonstrated to lead to asymmetrical force loads through the SIJ, which has been associated with pain (Kiapour *et al*. 2021). This may be a factor in PPGP, as pregnancy can lead to changes in both the femoral head symmetry, in a small percentage of women, as well as changes in foot structure (Sifrig *et al.* 2021; Augustina *et al.* 2019; Riahi *et al.* 2017; Orr. 2014; Jelen *et al.* 2005). However, the changes in foot structure are suggested by Chiou *et al.* (2015) to be mainly due to high BMI.

2.6 LOW BACK PAIN

LBP results in a high prevalence of a heterogenous group of disorders with intricate patterns of biopsychosocial features (Widerstrom *et al.* 2021; Alexander and Varacolla

2017), which accounts for two-thirds of adult's experience of LBP during their lifespans (Alexander and Varacolla 2017). As such, LBP is associated with a high socioeconomic burden due to lost productivity, medical costs, and associated disability (Uritis *et al.* 2019; Brinjikji *et al.* 2015; Dagenais *et al.* 2010). This has led to intense study within the area, with multiple subgroups and classifications being developed due to the anatomical complexity, functional and biological integration, psychological and pathomechanical mechanisms, and the overlap of pain fields within the LPH region (Den Bandt *et al.* 2019; Russo *et al.* 2017; Beattie and Silfies 2015). This has in turn, led to the development of numerous approaches in management and treatment of patients, all with varying degrees of success (Hu *et al.* 2018; Synnott *et al.* 2015). This inconsistency of outcomes has been attributed to a combination of poor triage and interaction of multiple variables, which are not yet fully understood (Wilgenbusch *et al.* 2014; Murphy *et al.* 2013). As a result, numerous authors have observed that the keystone of best practice in LBP begins with efficacious diagnostic triage of patients (Bardin, King and Mahe 2017; Wilgenbusch *et al.* 2014; Murphy *et al.* 2013).

The first recommended step in diagnostic triage of LBP is the acquisition of a comprehensive history to determine if red flag features are present, necessitating immediate specialist referral. After the exclusion of serious pathologies that require immediate oncological and/or surgical intervention, Bardin, King and Mahe (2017) recommend the exclusion of non-spinal causes of LBP. This is achieved through the application of salient features attained from the history to objective testing (Widerstrom *et al.* 2021). The ASLR is seen to play an important role in this step, as the ASLR stresses the hip, SIJ and lumbar spine. The primary discerning features considered to differentiate the regions are the angle of painful arc, and the location and character of the pain (Dutton 2020).

In this context, "sciatica" may broadly be defined as a symptom comprising of lower limb pain, which may be discogenic or non-discogenic in origin (the latter from organic and/or non-organic factors) (Koh 2021; Valat *et al.* 2010; Dudeney *et al.* 1998). However, other authors, such as Oosterhuis *et al.* (2019), equate sciatica to only a lumbosacral radicular syndrome. The definition by Oosterhuis *et al.* (2019), unlike the first definition, assigns a diagnostic property to presence of "sciatica". However, differentiating between hip/pelvic "sciatica" and lumbar spine "sciatica" is that lumbar sciatica generates from the low back while extraspinal "sciatica" begins within the hip.

2.6.1 Lumbosacral Radicular Syndrome

Lumbosacral radicular syndrome is primarily characterised by radiating pain in at least one lumbosacral dermatome and may be accompanied by radicular irritation symptoms and/or functional impairment (Luijsterburg *et al.* 2007).

Traditionally, the ASLR is performed to establish the presence of and/or range of painful arc and motion before the PSLR is applied. However, a comparative study of the PSLR and ASLR for RoM and mechanosensitivity by Barcellona *et al.* (2017) has challenged the reasoning for this approach. In their study, Barcellona *et al.* (2017) applied the ASLR and PSLR to 20 adults who ranged in age from 23-79 years with radiographically confirmed lumbar neural impingement, and back and leg pain. About 60% of the subjects had disc herniation/protrusion while the remaining 40% of subjects had lumbar stenosis. RoM was established for both the affected and asymptomatic sides using digital inclinometer. Symptoms were reproduced in 55% of subjects with the ASLR on the symptomatic side compared to 75% in the PSLR, demonstrating a moderate agreement ($\kappa = 0.58$, (95% CI, 0.34–0.79), $P < 0.01$).

In comparison the non-pathological side, symptoms were reproduced in 60% and 40% of subjects respectively, thereby demonstrating good agreement ($\kappa = 0.62$, (95% CI, 0.43–0.79), $P < 0.01$) between the tests. These results represent ASLR: PSLR as a pain provocation specificity/sensitivity of 73%/100% and 100%/67% for the affected and healthy sides, respectively. No statistical difference was observed between PSLR and ASLR. In contrast, it was found that RoM at 95% level of agreement between PSLR and ASLR range was 55º and 58º for the affected and healthy sides, respectively. The correlation of the PSLR to the ASLR was $r = 0.80$, $P < 0.001$ and $r = 0.83$, $P < 0.001$ for affected and healthy sides, respectively. Due to the large variability between ASLR and PSLR RoM measurements, the ASLR cannot be used as a substitute for PSLR in terms of assessment of SLR range of motion.

2.6.2 Modic Related Low Back Pain

Modic changes (MC) represent degenerative changes of the VEP and adjacent vertebral bone marrow (Määttá *et al.* 2015). To date there have been no studies that have examined these changes and the ASLR however MC represent a significant clinical entity in LBP (Saukkonen *et al.* 2020; Määttá *et al.* 2015). Indeed, Saukkonen *et al.* (2020) have demonstrated that a significant and independent relationship exists between clinically relevant LBP and MC in middle aged Finnish population.

Concurrently, Saukkonen *et al.* (2020) have shown that when MC occur in conjunction with inflammation, greater pain is felt. However, a straight leg raise conducted by Herlin *et al.* (2018) has suggested that the evidence found in previous studies suggests that this relationship is inconsistent.

In their classification of MC, Mááttá *et al.* (2015) reported and overall prevalence of MC in middle-aged females (mean age 49 years) as 21.9%. What is potentially significant for the ASLR is that 76% of all MC found were in the L4–L5 and L5–S1 motion segments and more common laterally. Furthermore, MC are associated with disc displacement, Schmorl nodes, and DD at the motion segment they are located. The strength of association has been found to increase with the size of the lesion.

2.6.3 Pelvic Girdle Pain

Gutke *et al.* (2017) defined PGP as musculoskeletal pain located between the posterior iliac crest and the gluteal fold, especially near to the SIJ and/or PSJ, where gynaecological or urological conditions have been excluded as a cause. Meijer *et al.* (2020) have argued that PGP needs to be divided into anterior PGP, related to the pubic symphysis, and posterior PGP, related to the SIJ. PGP aetiology is still not clearly defined, and a sub-grouping of LBP is considered a unique clinical entity that requires specific management (Meijer *et al.* 2020). This relationship can be seen in motor control studies, where similarities and essential differences have been identified in anticipatory postural adjustments in PGP and NSLBP (Bussey *et al.* 2020).

An altered movement of the SIJ is believed to be a salient feature in many of the pathologies surrounding the lumbopelvic hip region (Arab *et al.* 2014). As such the joint has received significant investigation with numerous modalities (Meijer *et al.* 2020a; Kibsgård *et al.* 2017). Mechanical SIJP, however, appears to be attributable to two primary mechanisms: impaired force closure of the SIJ and locked SIJ (locked form closure).

Locked SIJP may essentially be considered as enhanced form closure (Meijer *et al.* 2020). This condition is associated with significantly less pain or no pain compared to joint laxity, perhaps due to the absence of increased load on the ligamentous structures and the presence of motion limiting fibrotic tissue (Meijer *et al.* 2020; Lee 2012). Perhaps the distinguishing feature of this presentation during manual testing is that manual compression or the use of belts is associated with an increased perceived exertion during the ASLR, rather than a decrease (Lee 2012).

The second mechanism is the compromise of force closure. The failure of force closure needs to be considered in two respects: either there is altered neuromuscular recruitment leading to pain or alter MC patterns that have failed to compensate for ligament laxity/instability to leading to asymmetrical loading of the SIJ (Bussey *et al.* 2020; Mens *et al.* 2018; Bussey 2015; Orr 2014). Ligamentous laxity may be caused by trauma, hormonal changes and/or chronic asymmetric loading (Dhongade and Varadharajulu 2020). While ligamentous laxity in, and of itself, is not a risk factor for PGP, as indicated by PPGP, where hormonal changes leading to increased ligament laxity bilaterally does not always present associated with pain (Bussey 2015; Orr 2014). In contrast, asymmetrical laxity has a high association with pain in PPGP, but a dated study by, Ferreira and Alburquerque-Sendı´ n (2013) questioned this. Mens *et al.* (2002) found that asymmetry in chronic PPGP did not lead to the same degree of complaint about pain. Pool-Goudzwaard *et al.* (2003) sectioned the iliolumbar ligaments of 12 cadavers, finding that bilateral sectioning produced a 3-fold increased load on the LDL, while unilateral sectioning increased loading by eight times. This led to increased instability in the sagittal plane. These finding is consistent with radiological studies on PPGP, which found that asymmetrical laxity was more frequently associated with pain (Mens *et al.* 1999). As previously discussed, the LDL is richly innervated with nociceptive fibres.

There is no definitive explanation or muscular recruitment sequence that explains how altered muscle recruitment may lead to pain. However, the following sequence may perhaps explain possible loading of pain sensitive structures. According to Bussey *et al.* (2020) PGP sufferers are overly reliant on their visual system for afferent information. This may be indicative of reduced proprioception and kinesthetic awareness. This subsequently reduces anticipatory motor control responses. As a result, due to asymmetrical loading, pain occurs, leading pain inhibition and / or flexion contraction to prevent injury. It has been demonstrated the PGP subjects have delayed TrA contractions. De Groot (2008) observed that there was increased recruitment of the PMM in the ASLR in PGP subjects and theorised that the PMM was working harder to achieve flexion. This theory was dismissed by Hu *et al.* (2010) who provided the plausible explanation that the increased muscle activation was likely due to weakness of the PMM because of pain inhibition leading to the activation of more fibres to accomplish the ASLR.

A dated study by Mayhew, Norton and Sahrmann (1976), utilising less sophisticated EMG machine, observed that inverse relationship between abdominal and hamstring muscle recruitment was during the SLR. This is consistent with Bussey and Milosavle (2015), who observed increased BF and EO recruitment in PGP in a variety of hip flexion activities. Meijer *et al.* (2020) highlighted the importance of BF compensation during impaired force closure. However, the BF contraction was noted to be delayed in PPGP subjects in the 90-90 test who went onto develop chronic PGP. Mens *et al.* (2017) observed that the TrA had increased contraction following delayed onset. Bussey *et al*. (2020) showed significantly longer muscle onset latencies in the BF, EO MF, with visual occlusion ($F2, 746 = 4.51$, $p < .0001$), concluding that the latency delays.

2.6.4 Non-Specific Low Back Pain

Balagué *et al.* (2012) defines non-specific LBP as LBP assigned to a identifiable, known specific pathology (e.g., infection, tumour, osteoporosis, fracture, structural deformity, inflammatory disorder, radicular syndrome, or cauda equina syndrome). De Bandt *et al.* (2019) demarcated the region that the pain is experienced between the lower ribs and gluteal fold. This term is often used interchangeably in the literature with axial LBP and mechanical LBP (mLBP) and may subsequently convey different meanings to different practitioners and disciplines (Dagenais *et al.* 2010). For this paper, non-specific LBP is applied, as LBP that has no known specific underlying pathology and, therefore, assumed to be related to underlying mechanical dysfunction. Subsequently, the term mLBP is used.

LBP may be a consequence of injury or due to inherent dysfunction (Ostwal and Wani 2014; Roland *et al.* 2004). This means that a particular activity may not be a causative factor but may be an aggravating factor (Roland *et al.* 2004). However, patients who have experienced CLBP may experience different facets of deconditioning syndrome, which may influence the perception and coping mechanisms of pain (Larivière *et al.* 2010). Additionally, repetitive activities may result in a lower threshold in reporting due to sensitisation of the neural pathways (Chen *et al.* 2000; Roland *et al.* 2004). In the short term, mLBP may be benign; in the long term, it may lead to or be a symptom of joint degeneration (Kamat *et al*. 2017; Roland *et al.* 2004). This is supported by Roland *et al.* (2004), in a study of elite endurance athletes, which although focussed on elite athletes and in particular cross-country skiing, shows a clear relationship between

specific load and/or loading patterns and LBP. The ASLR plays an important role in assessing force transfer through the SIJ, particularly in the sagittal plane. Research has thus focussed on the muscle recruitment patterns, breathing patterns, and associated factors to discern which factors may clarify the interpretation of the ASLR. No research has examined the significance of the pause at the end of the Mens ASLR, even though there is variation of the ASLR within the literature. It is likely that the test has received little attention as no validation tests have been performed and clinicians may believe that other tests already cover this dimension.

As discussed with the core stability and diaphragmatic sections, the diaphragm is a significant factor in core stability and LPH complex, as well as the LPH alignment (Norasteh 2012). As such, breathing has been analysed in many concurrent validity studies (Mohan *et al.* 2020; Kime *et al.* 2015; Cavaggioni *et al.* 2015; O'Sullivan *et al.* 2002). Numerous studies have demonstrated that breathing is altered in CLBP subjects while performing the ASLR as well as other motor control tests (Ostwal and Wani 2014; Rousel *et al.* 2007). Ostwal and Wani (2014), however, included subjects with both specific and non-specific LBP, and found no major difference indicating that adaptations to breathing may be more significantly related to either the chronicity or the severity of symptoms rather than the mechanism of the LBP.

Krkeljas and Kovac (2018) investigated the association between the ASLR and other clinical parameters in physically active South Africans with and without chronic LBP. Krkeljas and Kovac (2018) found subjects without pain had significantly higher Cooks ASLR score and demonstrated significantly greater hamstring flexibility, as well as better gluteal activation patterns. In contrast, subjects experiencing pain demonstrated a greater incidence of pelvic rotation during knee flexion, and hip internal rotation, relative to those who were pain free. Additionally, subjects with pain generally scored one on the scale and were also associated with hamstring tightness, calf tightness, limited trunk flexion, hypo-mobility of the trunk, and posterior pelvic tilt. However, when the results from the toe touch tests results were analysed, it was found that 52% of subjects with LBP were unable to touch their toes, while 86% of subjects without pain experienced problems touching their toes. This suggested that the restriction in RoM was related to other factors, such as weak gluteal muscles, and bore only a causal relationship to LBP. This was supported by Arab *et al.*'s (2011) study on subjects with SIJP, where they found that hamstring reduced hamstring extensibility was weakly related to weak gluteal muscles.

Due to the various types of LBP and the numerous biomechanical and anatomical structures involved in performing the ASLR, there is a need to identify and discuss the evidence and its quality to adequately identify the variables that need to be considered during clinical practice. This SR is primarily focuses on determining the influence lift height in the performance of the ASLR, and the quality of that evidence.

2.7 SYSTEMATIC REVIEW

SRs are centred on the positivist model using explicit and defined methodology, as well as the hierarchy of research methodology to create and primarily evaluate contextual internal validity (Bonache 2020; Hammersley 2001). They are often used to develop clinical practice guidelines (CPG) and inform research and evidence informed practice (EIP), as they ensure a higher level of scientific reasoning within the development CPG (Mulrow 1999).

Recently, there has been increased recognition that external validity, needs to be highlighted within the reporting of SRs to enhance CPG to improve clinical outcomes (Dyrvig *et al.* 2014). There is a case to be argued that the practice of EIP is only truly validated when CPG have either improved clinical outcomes, or when outcomes are fixed, improve the patient clinical experience.

2.7.1 Evidence Informed Practice and Research

Clinicians are often limited in their efforts to maintain up to date with EIP, by time and financial constraints (Straus and McAlister 2000). This is in part a result of copious volumes of research being produced, through different study methodologies, interpretations and applications of techniques, subject populations, and context of practise (Mulrow 1999). Some clinicians may, however, be less motivated to engage in EIPs due to the paucity of relevant literature, contradictory literature, and/or applicability of research within an area to their patient(s) (Straus and McAlister 2000).

SRs play an important role in addressing these concerns, as SRs inform clinicians and researchers alike, highlighting dearth’s within the literature, while providing concise and potentially unbiased summaries respectively (Straus and McAlister 2000; Mulrow 1999). This is achieved through systematic assembly, critical appraisal, and inference from the totality of evidence (Magarey 2001). These features of SRs, combined with

no need for a prerequisite knowledge base within a selected topic, provide SRs with a significant advantage over narrative reviews. Additionally, the narrative reviews have a significantly greater risk of internal bias due to selective inclusion of research (Fink 2019).

2.7.2 Clinical Guidelines

Clinical practice guidelines are informed, systematically developed statements, that aim to improve clinical decision making and processes which ultimately optimises the quality of clinical care (Siering *et al.* 2013; Vlayen *et al.* 2005). These guidelines usually analyse and translate various studies, identifying the benefits, limitations, and harms (Mulrow 1999).

Perhaps the most important contribution of SR in CPG development, is when there is an absence of high-quality evidence in a particular area of practice. These areas are often those that require guidance, as these are the areas of greatest uncertainty (Loblaw *et al.* 2012). This dearth within the ASLR literature base is seen within injury movement screening and LBP groups. Although functional movement assessment literature is not the preview of this paper, this subgroup of ASLR research highlights the need for more focus as numerous contradicting studies are located within the literature (Moore *et al.* 2019; Warren *et al.* 2018; Waldron *et al.* 2018). This is in part due to the emphasis being placed on various codes of sport leading to a significant lack of heterogeneity with the subject sample. More importantly, many of the studies, especially the older papers, have failed to statistically examine the relationships between many of the uncontrollable variables to allow for more comprehensive and informed interpretation of the findings.

In contrast, the LBP research has predominately focused on PGP, and in particular PPGP. With the recent move to classify PGP into anterior and posterior subgroups, there is perhaps a need to re-examine the data to determine whether possible relationships exist for these sub-groups. There is a high likelihood that this analysis would provide improvement of our understanding of those pathologies due to the functional/dysfunctional interaction between the PSJ and SIJ. Additionally, there has been an emphasis placed on the contribution of neural inflammation as a contributing factor, with increased pregnancy related estrogen levels being a highlighted as a contributing factor for the alterations observed in the ASLR. This, however, fails to fully

explain how male and nulliparous females have the same observable features during the ASLR.

Within the spinal LBP grouping, there has been recognition that increased research is needed. However, with the many subgroupings of LBP there is a need to clarify what pathologies have been objectively examined, as well as clarify how to interrupt these findings within the clinical setting. To provide some clarity within these areas, Loblaw *et al.* (2012) state that a credible process, such as SR, is required when developing CPG.

2.7.3 Internal Validity

In terms of critically evaluating SRs, perhaps the most important point is internal validity. The SR itself needs to contain a high degree of internal validity but the interpretation of the study by the reader needs to address the fact that SR focuses to a large degree on internal validity (Hammersley 2001). According to Shelton, Cooper, and Stirman (2018), this focus on internal validity of the studies being scrutinised occurs at the expense of external validity. The internal validity of the SR and the studies being examined are both the strength and limitation of SR (Hammersley 2001).

Internal validity of SRs is created by a transparent and detailed account of the methodology used to conduct the review (Mulrow 1999). This includes a description of search terms, inclusion and exclusion criteria, and how data were extracted and synthesised. To further strengthen internal validity and minimise/eliminate bias, all the relevant studies and their subsets are theoretically included (Hammersley 2001). However, despite best practise, meticulous searches do not allow for the inclusion of every study as some studies are published in obscured journals and foreign languages. Additionally, in the case of some studies, only abstracts are available. This is particularly true of ASLR research, where several foreign language studies, in particular Korean studies, have been published and are not available in English.

2.7.4 Study Design

During the process of reviewing studies for internal validity, the study design is the most significant factor in determining the quality and hierarchy of the studies (Borgerson 2009). Bluhm (2005) argues that the term hierarchy of the studies is a misnomer and is better reflected by the term hierarchy of methodologies. Within this hierarchy, population studies are rated higher than laboratory studies, while

randomised controlled studies are higher than non-randomised, and blinded over non-blinded (Mantzoukas 2007; Bluhm 2005). These rating are due to the potential introduction of bias through the different methodologies (Mantzoukas 2007). Furthermore, tightly controlled studies, such as RCTs, reduce the potential for confounding effects (Evans 2002).

Table 2.7: Hierarchy of methodology

Ranking	Study Type
Highest	Systematic review of systematic reviews
	Systematic review
	Randomised double blinded control study
	Randomised single blinded control study
	Nonrandomised control study
	Cohort studies
	Case control series/study
Lowest	Expert opinion/bench research

(Adapted from Borgerson 2009)

Perhaps the most important factor in study design in SR is whether the study examined utilises the principle of true randomisation of subjects, as this greatly influence's internal validity (Mantzoukas 2007; Kempthorne 1955). True randomisation significantly reduces the risk of bias within a study, thereby improving internal validity (Lee *et al.* 2011). As a result of this principle, case studies/series immediately receive lower evidence rating during the SR process, compared to RCTs. Further evaluation to see whether a study has adhered to this principle is achieved through expert opinion of trial design and empirical evidence of bias. The factors that reviewers are seeking to determine include whether a study has concealment of the allocation schedule and blinding of researchers and participants. Concealment of the allocation schedule is suggested to be one of the most important indicators of bias, as the failure to do so has the capacity to interfere with randomisation, as incomparable groups generate at baseline (Armijo-Olivo *et al.* 2020; Karanicola, Farrokhyar, and Bhandari 2010).

The next desired factor in limiting potential bias is blinding, either single or double, with the latter being preferential. Single blinding is achieved via the application of a placebo, which is believed to produce comparable placebo effect between the control and experimental groups. As a result, any observed effect within the study may be attributed to the intervention effect. The significance of blinding is the greatest when self-reported outcomes measurements are being utilised, as it removes potential

participant bias by removing differential reporting. Double blinding occurs when the researchers are blinded to which group subjects have been assigned to. This removes the potential of consciously or subconsciously communicating expectations to the subjects, creating bias within the study. The nature of the studies included within this SR due to the selected populations means that blinding is limited to none, creating a degree of inherent bias (Armijo-Olivo *et al.* 2020; Probst *et al.* 2019; Karanicola, Farrokhyar, and Bhandari 2010).

In the design of a study, high internal validity usually comes at the expense of external validity and vice versa (Reiss 2018). External validity is, however, very important in the clinical setting, as clinician need to be able to evaluate/infer whether a treatment protocol or assessment item is generalisable to patient groups outside of the sample used (Patino amd Ferreria 2018). The process of assessment in SR should determine if reliable inference can be drawn from a studys' outcome, thereby enhancing scientific reasoning (Reiss 2018).

2.8 SUMMARY

This chapter has demonstrated that numerous variations of the ASLR that have been researched and, even when the ASLR technique is the same, reported outcomes may differ (Kibsgård *et al.* 2017; Hu *et al.* 2012; Mens *et al.* 2002). This may be due to the different subgroups that have been studied. Indeed, some authors cite a difference in LBP subgroups' which affects validity, reliability, and sensitivity of the results in their studies. This supports the argument that a SR is required to clarify what evidence there is for the validity, sensitivity, and reliability of the ASLR for different techniques and different subgroups of the LBP.

CHAPTER THREE METHODOLOGY AND MATERIALS

3.1 INTRODUCTION

Chapter Three details the methodology used in the study. This includes a description of the study design, parameters of literature review, determining eligible publications, data extraction, evaluating article reviews, and synthesising and summarising the results, as well as the reviewer recruitment.

3.2 DEVELOPMENT OF RESEARCH QUESTION

The research question was designed using the PECO (population, exposure, outcome) framework (Morgan *et al.* 2018). The problem was identified by the primary researcher when attempting to apply evidence informed practice on the LBP population. The researcher identified inconsistent use of the pain syndromes definitions (LBP, PGP, LPP) when examining research papers. It was also noted that different lift heights were utilized (KrKeljas and Kovac 2018; Palsson *et al*. 2012; Mens et al. 1999). No papers had examined the significance of the differences in techniques and populations or their outcomes. Outcomes selected were related to muscle recruitment, pain, sensitivity, specificity, reliability, and validity.

3.3 STUDY DESIGN

This study was designed using a mixed method systematic review approach (Centre for Reviews and Dissemination 2008). A quantitative approach was used to analysing the level of rigour (internal validity) within each study, while a qualitative analysis of the context in which the data were obtained and its ability to be extrapolated to practice (external validity) (Higgins and Green 2011; Liberati *et al.* 2009). The review was conducted in accordance with PRISMA guidelines (see appendix L and M) (PRISMA checklist 2020).

Prospero registration was applied for on the 23rd of December 2020 (Appendix A) and confirmation of approval was received on the 26th of January 2021 – CRD 4202 1223370 (Appendix B).

3.4 STUDY PROCEDURE

The study procedure followed a process of determining inclusion and exclusion criteria for citation, abstracts, and articles. This was then followed by determining which tools were required to analyse the articles that were applicable to the study, followed by processing and analysing this data. The processing of the data followed a process of acquiring the relevant articles with the assistance of the subject matter specialist (i.e. health science librarian) and been hand reviewed by the primary researcher. When articles did not explicitly meet the parameters of the study (inclusion and exclusion

criteria, and definitions) the articles were checked by the secondary researchers before dissemination to reviewers. Reviewers were then allowed to recommend the exclusion or inclusion criteria.

3.4.1 Citations Eligibility

3.4.1.1 Data Sources and Search Terms

A systematic review (Liberati *et al.* 2009) of PubMed, Google Scholar, Cochrane Reviews, Cumulative Index to Nursing and Allied Health Literature (CINAHL) and Scopus was conducted by the primary research and the DUT health science librarian. The Cochrane date base was searched to obtain similar systematic reviews so that their reference list could be searched.

The following combination of Boolan and MESH terms were used in order to obtain the data: “ASLR pelvic girdle pain”; “ASLR low back pain”; “ASLR sacroiliac dysfunction”; “ASLR sacroiliitis”; “ASLR pubic symphysitis”; “ASLR motor dysfunction”; “lumbar spine dysfunction”; “ASLR ultrasound”; “ASLR sensitivity”; “ASLR specificity”; “ASLR validity”, and “ASLR lumbar spine instability”.

All relevant was data was stored on REF works.

3.4.1.2 Inclusion of Citations

All English electronic or paper citations, which possessed the required key indexing terms (noted in Section 3.4.1.1) and fulfilled van Tulder et al. (2006) definition of LBP, pain that was localised below the ribs (12th), but above the inferior gluteal folds, with or without radiation down the legs, were electronically saved.

3.4.1.3 Exclusion of Citations

Any citation that could not obtained electronically, as well as all opinion papers and web articles, were excluded (Mahood, van Eerd, and Irvin 2014). All papers that analysed pregnancy were excluded to improve homogeneity of the study population (viz. articles).

3.4.2 Abstract Eligibility

The abstracts of the citations that met the inclusion and exclusion criteria (in 2.3.1-3.4.1.3) were reviewed to ensure that they complied with the inclusion and exclusion criteria stated for citations. Any abstracts that referred to ASLR as an exercise or

initially screen citation that were systematic reviews; commentary papers or meta-analysis/systematic reviews subsequently were excluded.

3.4.3 Full Text Article Eligibility and Review of Literature

Articles were reviewed by the primary research to see if they met the criteria. If any questions arose, the article was reviewed by the secondary researchers. This was done for two articles, and they were excluded as the ASLR was an outcome measure.

3.4.3.1 Inclusion Criteria

1. Only full English text articles were included in this systematic review. This was done to avoid translation bias (Peña 2007). It is acknowledged that the exclusion of non-English introduced a language bias, this was, however, done to avoid translation errors which may have distorted outcomes and methodological rigour (Higgins and Green 2011).
2. Articles were required to be from electronic sources, so as to acquire citations and abstracts.
3. Articles needed to be obtainable from databases within the DUT library or accessible external networks.

3.4.3.2 Exclusion Criteria

1. Non-English articles due to translation bias (Higgins and Green 2011) and the lack of a multi-lingual reviewer team.
2. All previous systematic reviews and literature reviews; blogs, websites or articles containing any expert opinions; and book chapters (Harris 2013; Liberati *et al.* 2009).
3. Duplicate studies that were found during the search process.

3.4.3.3 Hand Search

A hand search of the included articles references was conducted by the primary researcher to ensure all relevant articles that met the inclusion and exclusion criteria (Sections 3.4.1 to 3.4.2), were located. No additional articles were added.

The hand search additionally included the external reviewers, who were each sent a list of articles included in this study. They were advised that they could source and supply further articles that they deemed appropriate for inclusion into this systematic review. No additional articles were submitted for consideration by the external

reviewers. Similarly, if reviewers were of the opinion that a study did not completely meet the inclusion criteria, they were at liberty to suggest an article be withdrawn. Exclusion needed to be unanimous, blinded suggestions that the article be removed; 12 articles were subsequently removed from the study.

3.4 DATA EXTRACTION

Each article was blind reviewed by three independent reviewers utilising the PEDro (for randomised controlled trials) (Appendix J), Liddle (for observational studies) (Appendix I) and New-castle Ottawa Scale (NOS) (Appendix L) (non-randomised controlled trials and case studies/series) (Quigley *et al.* 2019; Moher *et al*. 2015; Hartling *et al.* 2013; de Costa, Hilfiker and Egger 2013; Bhogal *et al.* 2005; Maher *et al.* 2003). This allowed for the methodological rigour (internal validity) of the article to be ranked (Liberati *et al.* 2009).

After the completion of all reviews, subjective data was extra and scored by the primary researcher as per scale instrument instructions (appendix L-M). These results were present in table 1s in conjunction with reviewer comments. Objective data was then extracted and presented in the table 2s. The following data points of objective data were extracted from the articles: author(s), year of publication, study design, subject population, outcomes and outcome measures, frequency of measure, number of participants and their gender, blinding of assessors, the use or not of controls, randomisation, percentage of agreement between reviewers. These factors were then used in conjunction with Guyatt *et al.* (2011a) (section 3.9) to evaluate the internal and external validity of each article by the primary researcher.le. The rankings were then compared to the critical appraisal of the article in terms of the context (external validity) in which it was applied (Liberati *et al.* 2009).

3.5 REVIEWER SELECTION AND RECRUITMENT PROCESS

3.5.1 Considerations in the Reviewer Process

To gain independent review outcomes, anonymity was sought throughout the process. This was achieved by ensuring that no reviewer was cognisant of the names of other reviewers; the reviewer's names were not disseminated publicly; and reviewers were

asked not to discuss the study with colleges (Appendix C). Additionally, reviewers were advised that regardless of if the study was published or just submitted for dissertation requirements, no comments would be credited to a specific reviewer to maintain anonymity and confidentiality.

To prevent/reduce author bias, no reviewer could review any article(s) that they authored or to which they contributed (Higgins and Green, 2011). Furthermore, a diverse set of reviewers with wide-ranging clinical experience, research experience, academic experience, as well as professions and geographical locations, were contacted and selected. This was undertaken to reduce the chance for communication, thereby creating greater significance of results when they were in agreement on the scales on methodological rigour (Higgins and Green 2011).

3.5.2 Identification of Reviewers for this Study

1. Identification of researchers was conducted based on the articles screened in the literature review.
2. Consideration was given to reviewer interest and knowledge pertaining to ASLR in clinical diagnostic, rehabilitation, and sports injury setting.

Table 3.1: Reviewer demographics

Reviewer number	Group allocation	Qualification	Clinical experience	Research experience	Academic experience
1	1	PhD	X	X	X
2		M	X	X	-
		Researcher	X	X	-
3	2	PhD	X	X	X
4		M	X	X	X
		Researcher			
5	3	PhD	X	X	X
6		M	X	X	X
		Researcher	X	X	-
7	4	PhD	X	X	X
8		M	X	X	X
		Researcher	X	X	-

(Clinical experience was defined as at least 2 years of clinical experience in a relevant healthcare filed such as physiotherapy/ biokinetics/athletic rehabilitation/kinesiology etc. Research experience consisted of at least one publication. Academic experience was defined as lecturing a minimum of one module at a reputable academic university)

3.5.3 Reviewer Recruitment

The reviewers were recruited via email after approval of PG2 by FRC and registration of the study with PROSPERO, to determine their interest in participating in this systematic review. The following points were outlined by means of email and MoA (Appendix C):

1. Introduction and description of study.
2. Research procedures – outlining the role and expectation of the reviewers.
3. Process anonymity and blinding.
4. Resolution of research and reviewer discrepancies.
5. Projected timelines for above procedures.

In addition to informed consent obtained via email or a signed scan MoA, the reviewers provided brief, biosketch/abridged curriculum vitae to verify their qualifications. Following receipts of these two documents, the researcher provided each reviewer with their assigned articles. Each reviewer was provided with a six-week deadline to review the articles and return their findings.

3.5.4 Article Allotment

To reduce possible influence of research bias, no reviewer was allocated an article to which they may have contributed. The use of two external reviewers, as well as the researcher in conjunction to this, further minimised the possibility of research bias. In the external reviewer pairing, one reviewer held a PhD and the other was a Master's degree level. This was undertaken to ensure a different perspective during the analysis, due to difference level of experience, and thereby enhancing the critique of the article (Higgins and Green 2011).

Table 3.2: Reviewer-article distribution

Reviewer number	Group allocation	Qualification	Article numbers as per the master list	Article type(s)	Review scale type(s)
1	1	PhD		Case study	Liddle
2		M			
		Researcher			
3	2	PhD Dr		Case study	Liddle NOS
4		M			
		Researcher			
5	3	PhD		Cohort	Liddle NOS
6		M			
		Researcher			
7	4	PhD		Case study	Liddle

8	M Researcher	Case Series Cohort	

3.5.5 Reviewer Instruction

Reviewers were sent instructions relevant to the study type they were reviewing (Appendix I), as well as checklists and scales (Appendix H-O). These instructions informed the reviewers of the single blinding; provided information on how the scales were to be applied; and how the results were expected to be returned to improve data collation, synthesis, and analysis (Moher *et al.* 2015).

After receipt of the relevant materials (Appendices M to H), the reviewers were asked to acknowledge receipt and confirm their understanding of the review process and their understanding and interpretation of the applicable scales. All reviews were submitted to the research supervisor to ensure that the researcher had no influence on the reviews (Liberati *et al.* 2009) and was not influenced in terms of their reviews.

Following completion of the review process and receipt of all articles, the individual article reviews were evaluated for a homogeneity of results. Accommodation was made for a lack of consensus between reviewers. In this instance a Zoom conference call, moderated by the research supervisor, was undertaken to resolve discrepancies. If resolution of the discrepancy and a census was not possible, a third reviewer (from among the additional reviewers approved) was approached to independently resolve the disagreement. This mechanism was not utilised.

3.6 REVIEWER EXCLUSION OF ARTICLES

Following the dissemination of the articles, 12 articles were withdrawn from the study, following recommendation and discussion with the reviewers.

Eleven articles were withdrawn from this systematic review as their sample group was six months postpartum. This was a result of concerns that certain pregnancy related hormonal adaptation could still be present and influence results. After reviewing the literature, it was that the definition postpartum is variable and sometimes defined up to six months (Thomson *et al.* 2018; Hamilton *et al.* 2018). Therefore, all article that contained subjects within six months of child delivery were excluded.

Stutchfield and Coleman (2006) was withdrawn as both external reviewers felt that the modification of the ASLR (a block placed under the lower spine) created a potentially significant change in biomechanics as to render this version of the ASLR a different test. Therefore, without at least a pilot study to compare the modified ASLR to a "standard", the ASLR result would not be comparable.

3.7 SCALES

3.7.1 PEDro Scale

The PEDro scale (Appendices J to L) was selected to evaluate the quality of the RCTs, as it is well established in the physiotherapy field (Yamato *et al.* 2017; Moseley *et al.* 2002). The PEDro scale is centred on the Delphi list (which was developed by the Delphi consensus to provide a criteria list for quality assessment of RCTs for conducting SR). The PEDro scale contains of 11 criteria. Criterion 1 aims to evaluate the applicability of the trial. Criteria 2–9 appraise the internal validity of the study, while criteria 10–11 weigh the statistical information of the RCT and determine if the statistics are interpretable.

The reliability of the items in this tool was established by Maher *et al.* (2003). This study found fair to substantial (0.36 to 0.8) reliability when applied by a single reviewer and fair to good (0.50 to 0.79) when the totals of 2 to 3 reviewers were added using the Kappa scales (Maher 2003). Two studies have established the validity of the scale. The first was de Morton (2009) who established the general validity of the scale using the Rash model. De Morton (2009) found that when the study scale was applied to different studies, there was no differential item functioning by year of publication. The initial PEDro ordinal scores were also demonstrated to be highly correlated with the transferred PEDro interval scores (r = 0.99). The second study conducted by Macedo *et al.* (2010) who showed that eight of the 11 items of the scale have convergent and construct validity.

3.7.2 Newcastle-Ottawa Scale

The Newcastle-Ottawa Scale (Appendices M to O) was selected to screen case studies and series as this tool allows for the identification of bias within these observational studies that influences causal inference. This bias can result from

uncontrolled methodology, specifically the lack of a contemporary comparison group, resulting in readers utilising historical controls or other less objective measures. Despite this limitation, these types of studies disseminate important generalised knowledge that play an important role in informing clinical practise by resolving questions that cannot be answered by other methods (Ka-Lok Lo, Mertz and Loeb 2014, Hartling *et al.* 2013).

While there have been some advocates to discard the NOS, namely Stang *et al.* (2018), who argued that the NOS uses arbitrary definitions of quality of items and neglect important elements of selection bias, others have demonstrated no additional benefit of other tools (Moskalewicz and Orenus 2020; Hootman *et al.* 2011). Additionally, Stang *et al.* (2018) reviewed mis-affirmative quotes related to the NOS have failed to address the newer versions of the scale (Cook 2015).

The NOS is composed of eight questions centred on four domains: selection, ascertainment, causality and reporting. For the selection and exposure sections, one response per question is required, while in the comparability section, multiple or no responses may be made. One asterixis can be presented per question, except comparability, where two asterixis may be assigned. With each study being limited to a maximum of nine asterixis.

3.7.3 Liddle Scale

The Liddle scale was selected to evaluate observational studies as the scale elicited different data compared to the NOS and PEDRO scales. It must be acknowledged that according to Valyen *et al.* (2005) no statistical information regarding the validity has been published within a peer reviewed literature. However, it was decided to utilise the scale, as Siering *et al.* (2013) highlighted that no single scale provides a comprehensive review of a scientific paper. This was after consideration of this statement, in conjunction with the Liddle scales' methodology of development (described below), that the scale was the most applicable to extract the relevant data (Liddle *et al.* 1996).

The Liddle scale was developed in response to most scales focusing on RCTs, as well as being resource intensive in terms of time and skill required. The driving factors in developing the scale were efficiency, consistency and use for health-related evidence, where RCTs were not available or were not practicable. The development of the scale

was achieved through the collaboration of Australian epidemiologists, the Cochrane Collaboration, and clinicians on the NSW Health Department Expert Panel on Diabetes Guidelines Working Group (Liddle *et al.* 1996).

Following initial development, the scale was piloted in the areas of clinical management of diabetes and the prevention, management, and rehabilitation of femoral neck fractures. Thereafter, the document was circulated for comments, which were then combined with the results from inter-rater reliability of the draft checklists leading to its evolution. A checklist for the various types of studies, namely RCTs, nRCTs, cohort, case-control, before and after studies, and interrupted studies, were introduced. Thereafter, the scale was again reviewed, and the findings of the Cochrane Collaboration on Effective Professional Practice and the University of York NHS Centre for Reviews and Dissemination were applied to the scale (Liddle *et al.* 1996).

The developers of this scale recommended that the scale be applied primarily in the review of individual studies, as well the assessment of the validity of CGLs and recommendations. The secondary uses that were recommended included the assessment of the quality research evidence in a plethora of settings, including peer review of scholarly articles. They suggest that scale could be substitute or used in conjunction with the Cochrane Collaboration Handbook in assessing nRCTs to project likely outcomes of each approach, based on the quality of the article being reviewed. Additionally, the tool explicitly presents the risks and benefits of the approach (Liddle *et al.* 1996).

3.8 REGISTRATION OF REVIEW WITH PROSPERO

The study was registered with PROSPERO, an international database of prospectively registered systematic reviews in health and social care on FRC approval. This data base was utilised to avoid unplanned duplication of research and to minimise the risk of biases in the systematic review. This study met the inclusion criteria for PROSPERO, as the study had health related outcomes and one outcome directed at patient care and clinical relevance. The title, aim, population, reviewer information and target date for the completion of the study were sent to the data base and approved before the study commenced. As per requirements, any alterations (such as

notification of completion) that occur with the study after registration were immediately updated on the database.

3.9 DATA ANALYSIS AND SYNTHESIS

As detailed in Chapter Four, during data analysis, the methodological rigour of the various studies was ranked. Following which, the analyses were synthesised so that clinical outcomes could be contextualised and compared (Liberati *et al.* 2009).

The criteria of evaluation included study design, risk of bias, imprecision, inconsistency, indirectness, and magnitude of effect. These criteria allowed for concise and transparent summaries of each study. The relative magnitude and absolute effect of each outcome was determined, and their evidence profiles developed. These factors included risk of bias, inconsistency, indirectness, and imprecision. Positive points were awarded, contributing to an upgrading if the reviewer found the effect was large (+1) or very large (+2); the dose response had evidence of gradient (+1); and all plausible findings reduced an effect (+1) or suggested a false effect when results showed no effect (+1) (Guyatt *et al.* 2011a).

In relation to grading the strength of the articles (Table 3.3), different types of articles began at different levels at the start of the review process, with the strength of evidence contained within each determining their final rating (internal validity and external validity). Randomised controlled trials started as higher rated evidence, while observational studies were initially considered to be lower quality evidence due to the potential for biases. If the studies demonstrated biases, they were subsequently downgrade. Cited reasons for downgrades included inconsistency between studies; lack of direct comparison (between interventions as well between subject populations); wide confidence margins; publication bias; and lack of methodological rigor (e.g. lack of blinding and randomisation) (Goldet and Howick 2013). However, Goldet and Howick (2013) state that if multiple high quality observational studies demonstrate consistent results, the evidence level should be upgraded. The factors citied to upgrade include large magnitude of effect, dose-response relationship, and when confounding variables are likely to only reduce treatment effect (Guyatt *et al.* 2012).

Table 3.3: Strength of evidence

Study Design	Quality of Evidence	Lower if	Higher if

Randomised Control	High	Risk of bias: -1 if serious -2 if very serious	Large effect: +1 large +2 very large
	Moderate	Inconsistent: -1 if serious -2 if very serious	Dose response: +1 if large gradient
Observational Study	Low	Indirectness: -1 if serious -2 if very serious	All plausible confounding variables: +1 would reduce demonstrated effect or
	Very Low	Imprecision: -1 if serious -2 if very serious Publication bias: -1 if serious -2 if very serious	+1 would suggest a spurious when results show no effect

(Adapted from Guyatt *et al.* 2012)

Table 3.4: Validity of studies

All studies will be ranked according to the level of evidence they provide	**Good internal validity**		**Poor internal validity**	
Good clinical outcomes	This represents a good study with good outcomes	If it has good external validity then it provides appropriate evidence	This represents a poor study with good outcomes	If it has good external validity then it provides inconclusive evidence
		If it has poor external validity then it provides inconclusive evidence		If it has poor external validity then it provides no evidence
Poor clinical outcomes	This represents a good study with poor outcomes	If it has good external validity then it provides appropriate evidence	This represents a poor study with poor outcomes	If it has good external validity then it provides inconclusive evidence
		If it has poor external validity then it provides inconclusive evidence		If it has poor external validity then it provides no evidence

This process was undertaken by the primary researcher and was then reviewed by a secondary researcher to ensure that the process was correctly followed. If there was a lack of consensus the article was then discussed and reappraised.

In Chapter Five, all articles that covered a similar content as outlined in the inclusion and exclusion criteria as the level of evidence in that domain (aggregated around 4 clinical categories: pain [none, pelvic, sacroiliac, lumbopelvic, and lumbar], motor control, pelvic symmetry, and muscle thickness) were collectively evaluated. The studies were analysed using the GRADE system, as this system provided a structured

approach for selecting outcomes, as well as explicit criteria for the evaluation and quality rating of the articles, irrespective of their quality (Guyatt *et al.* 2011b).

The five factors were used to determine the grading of the quality of studies, which placed the studies into one of four categories, ranging from high, moderate, low, and very low. These five factors contributed to a lower grading and could contribute to a single (serious) or double negative point (very serious).

On completion of the rating process, evidence profiles (EP) and the summary of findings (SoF) were tabulated (Guyatt *et al.* 2011a). The EP provided a record of the evaluations developed from the critiques of the reviewers, as well as answering any questions related to the quality of the articles. The SoF were tabulated to provide a summary of key information and factors influencing recommendations. A total of three SoF tables were developed as three populations (pelvic girdle pain, lumbopelvic pain, and low back pain) were examined. Recommendations were made according to the findings and was characterised as either strong or weak according to the quality of the supporting evidence (Guyatt *et al.* 2011a). Evidence with a higher rating was associated with stronger recommendations, compared to lower quality evidence. However, the level of quality does correlate to the strength of recommendations, as low or very lower quality evidence may have a strong recommendation (Balshem *et al.* 2011).

3.10 ETHICS

The Durban University of Technology Faculty of Health Sciences Research and Ethics Committee (FoHS FRC) provided both research and ethical approval for the study on 26th November 2020 (Appendix A). It was deemed that Institutional Research Ethics Committee (IREC) was not required as the study did not involve human participants and, therefore, exempt (FRC 2020).

Two distinct ethical spheres were considered for this study. The first sphere related to the design and methodology used to conduct the study. This included applying the four major ethical principles derived from the Nuremburg code, the Declaration of Helsinki, and the Belmont Report, namely autonomy, beneficence, principal of justice and non-malfeasance (Jokstad 2017; Petersen 2013; Pellegrino and Thomasma 1987).

Autonomy was achieved by providing the potential reviewers with an accurate and concise description of the rationale and methodology of the study, as well as the involved obligations involved with participation. They were then able to make an informed decision about their participation, and the wishes of those who declined due to other areas of interest or due to other commitments were respected (Cummings and Mercurio 2010; Wear 1992). Additionally, when reviewers returned their reviews, they submitted their data to the research supervisor to ensure anonymity and eliminate any potential for the introduction of bias to provide a review as they see fit. This also facilitated the conditions of liberty and agency which Beauchamp *et al.* (2001) states as being essential to achieve autonomy in biomedical research.

Beneficence, the ethical principle of promoting good, while problematic to truly achieve in a research project associated with personal academic achievement, was considered in the selection of the research problem (Murphy 1993). The topic was selected with the aim of improving clinical understanding and interpretation? of the ASLR thereby, hopefully, improving quality of care and outcomes of patients. This achieved the prosocial concept of beneficence provided by Martela and Ryan (2016). This interruption of beneficence acknowledges that acting in the benefit of others is of benefit to oneself.

The principle of justice was achieved by agreement that if the study was published, the reviewer's contribution would be acknowledged, thereby creating equality of recognition for the study output (Häyry 2019).

As the SR did not utilise research subjects but rather reviewers, the ethical principal of non-malfeasances was not considered to be an applicable ethic principle.

The second ethical sphere considered related to the articles being analysed. Vergnes *et al.* (2010) highlight that many the studies that are examined in SRs have bioethical deficiencies. The primary bioethical deficiency that has been repeatedly highlighted over the last decade is the lack of clarity by some authors regarding study approval by independent research ethical committees (Mertz, Nobile and Kahrass 2020; Vergnes *et al.* 2010). Jokstad (2017) suggests that this deficiency is a combination of ethical researcher attitude; IREC approval is a requirement, and systematic reviewers assume that primary studies follow a minimum research standard. It has, however,

been the responsibility of IREC approval should fall to the editors of various medical journals.

CHAPTER FOUR RESULTS

4.1 INTRODUCTION

Chapter Four includes a tabulated presentation of summary evaluation as provided by reviewers, as well as limitations and a concise summary and conclusion of the individual articles. The layout of the chapter 4 was determined by the style guidelines of DUT however all informatics requirements of PRISMA (2020) were met. Qualitative data primarily was collated and presented was in table “1s” while table “2s” presented the quantitative primarily focusing on internal validity.

The tabulation of data is presented in the form “overall ranking” and “percentage of agreement” obtained from averaging the three reviews (from the two external reviewers, as well as the researcher). The data from the articles were characterised as: type of measure, frequency of measure, duration of study, number of participants, blinding of assessors, the use of control group and blinding of participants.

Further discussion of limitations identified by both the authors of the articles and reviewers is then followed with a discussion of the article and a conclusion based on the data.

4.2 DATA

4.2.1 Primary Data

A total of 37 articles were sent out to reviewers for consideration and, following initial reading, 12 articles were withdrawn, leaving a total of 25 articles. The group compositions were two groups of seven, one of six and one of five. Each group was reviewed by the researcher and two different reviewers. The results were then tabulated, and the majority ranking, total score, percentage agreement, and overall percentage agreement being calculated.

The majority ranking represents most recurring reviewer score, while the percentage agreement was the average percentage of agreement for each criterion. The overall percentage agreement was then the average percentage of the percentage agreement. This score is significant, as the score indicates the degree of consistency between reviewers. Liberati *et al*. (2009) states that a good level agreement exists when the percentage is greater or equal to 70% and demonstrates that a consistency of identification and interpretation of the scales’ criterion to an article. In contrast to the

other scores, which were calculated from all three reviewers, the total score was calculated by adding all the scores from a single reviewer.

4.2.2 Secondary Data

To enable systematic evaluation of the articles, secondary data sources were used to facilitate evidence informed evaluation of the methodology and outcomes obtained in individual articles. This data was sourced from the DUT library and its subscribed electronic databases.

4.3 RESULTS

4.3.1 Non-Randomised Controlled Clinical Trials

4.3.1.1 Introduction

For the data capture of the NOS tables, the reviewers' ratings provided on the scales were converted to numerical numbers, with a 0 representing a negative (no star) and a 1, an affirmative (one star) (Appendix G-I). The sum of these scores were used to provide the total score and percentage of agreement for each criterion.

4.3.1.2 NOS Reviewed Articles

Table 4.1 provides the nRCT that were included in this study, as well as a description of their table numbers of tabulated review data and analysis of results.

Table 4.1: Articles reviewed with Newcastle-Ottwa Scale

Tabulated Review Data	Analysis of Article	Author(s)	Year	Title	Reviewers
Table 4.2	Table 4.3	O'Sullivan *et al.*	2002	Altered motor control strategies in subjects with sacroiliac joint pain during the active straight-leg-raise test.	1. Reviewer 3 2. Reviewer 4
Table 4.6	Table 4.7	Beales, O'Sullivan, and Briffa	2010	The effects of manual pelvic compression on trunk motor control during an active straight leg raise in chronic pelvic girdle pain subjects.	1. Reviewer 5 2. Reviewer 6

Table 4.2: Tabulated Data – Data Group 2 – Article 1 Table 1

Authors	O'Sullivan *et al.*		**Date**	2002		
Article Title	Altered Motor Control Strategies in Subjects with Sacroiliac Joint Pain During the Active Straight-Leg-Raise Test					
EVALUATION CRITERIA FOR THE STUDY	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority**	**Agreement**
Representativeness of the exposed cohort truly representative of the average _____ (describe) in the community * somewhat representative of the average _____ in the community * selected group of users no description of the derivation of the cohort.	*No description of recruitment process, only demographics. All pain subjects were post traumatic therefore may be representative of individuals with insidious onset.*	*B*	*B*	*B*	*B*	*100%*
Selection of the non -exposed cohort drawn from the same community as the exposed cohort * drawn from a different source no description of the derivation of the non-exposed cohort	*Controls were pain free but there were no continence complaints.*	*C*	*C*	*C*	*C*	*100%*
Ascertainment of exposure secure record* structured interview* written self-report no description		*A*	*A*	*D*	*A*	*67%*
Demonstration that outcome of interest was not present at start of study yes* no		*A*	*A*	*A*	*A*	*100%*
Total section points		*2*	*2*	*2*	*2*	*91.5%*
COMPARABILITY						
Comparability of cohorts on the basis of the design or analysis study controls for _____ (select the most important factor)* study controls for any additional factor (This criteria could be modified to indicate specific control for a second important factor).*	*SIJP with bladder dysfunction*	*A*	*A*	*A*	*A*	*100%*
Total section points		*1*	*1*	*1*	*1*	*100%*
Outcome						
Assessment of outcome independent blind assessment * record linkage* self-report` no description		*B*	*B*	*D*	*B*	*67%*
Was follow-up long enough for outcomes to occur yes (select an adequate follow up period for outcome of interest) * no		*A*	*A*	*A*	*A*	*100%*
Adequacy of follow up of cohorts complete follow up - all subjects accounted for* subjects lost to follow up unlikely to introduce bias - small number lost - > ____ % (select an adequate %) follow up, or description provided of those lost) follow up rate < ____% (select an adequate %) and no description of those lost no statement.		*A*	*A*	*A*	*A*	*100%*
Total section points		*3*	*3*	*2*	*3*	*89%*
OVERALL PERCENTAGE AGREEMENT						*87.6%*

Table 4.3 Tabulated Feedback - Data Group 2 – Article 1 Table 2

Authors	O'Sullivan *et al.*		**Year**		2002			
Title	Altered Motor Control Strategies in Subjects With Sacroiliac Joint Pain During the Active Straight-Leg-Raise Test							
Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
ASLR Respiratory function: Minute ventilation Tidal volume Respiratory rate Anthropometrics Spirometry Ultrasound: Respiratory diaphragm Pelvic diaphragm	Baseline	Not stated	n = 26 SIJP group: 11 females 2 males	No	Yes n = 13	No	Selection 2 Comparability 1 Outcomes 3	*87.6%*
Limitations	The study provided no information on the method and location of the recruitment of subjects. As a result, it is not possible to determine how representative of the general SIJP population the sample is, which reduces the general applicability of the results and external validity (Meinert and Piantadosi 2022). The design was a cohort observational study and, therefore, the study only had the potential for single blinding. As the article failed to state whether the assessors were blinded, it was assumed that no blinding had occurred. This increased potential for bias, reducing the applicability of results to the SIJP population (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. The results are, therefore, applicable to the SIJP population and not the general LBP population (Meinert and Piantadosi 2022). The sample was heterogenous in gender (n = 11 females, n = 2 males), with large standard deviations in age, weight, BMI, and symptom duration. While the sample is mixed gendered, the small number of males makes it questionable as to whether these results are applicable. All SIJP subjects were post traumatic and had bladder dysfunction. Therefore, results may not be applicable to individuals with insidious onset of SIJP or those without no bladder dysfunction (Meinert and Piantadosi 2022). The SIJP sample size was small (n = 13), with a female to male ratio of 11:2. The results are, therefore, not likely to be applicable to the male population. Indeed, as there are only 11 female subjects, the general applicability of the results to the female SIJP population is questionable. BMI was required to be less than 31kg/m2 and, therefore, the results may not be applicable to obese individuals (Meinert and Piantadosi 2022). The inclusion and exclusion criteria for the study were stricter, with a positive ASLR and 4 of 5 positive SIJ tests required. Pain was also limited to the sacral region. Additionally, general and specific exclusion criteria were applied. This limits the general applicability of the results of the study (Meinert and Piantadosi 2022). The article had strict inclusion and exclusion criteria which significantly reduced the external validity of findings. The inclusion criteria included: SIJP longer than 3 months with no ablation of symptoms; pain located over the SIJ with no proximal referral; a positive ASLR test; and at minimum four of five SIJ provocation tests [distraction and compression test / posterior shear test (thigh-thrust test) / pelvic torsion (right and left posterior rotation) / sacral thrust test / palpation of long dorsal sacroiliac ligament ((Meinert and Piantadosi 2022). As there was no blinding or randomisation, there is the potential for Hawthorne and assessor effect, which would alter the performance of the tests and, therefore, the outcomes. These effects would affect the general applicability of the results to the general population (Meinert and Piantadosi 2022).							

	As the ASLR lift height was 5cm, the findings of this article may not be applicable to higher lift heights (RoM).
Outcomes	Subjects with SIJP had increased minute ventilation, decreased diaphragmatic descent, and increased pelvic floor descent, in comparison to pain-free subjects. Significant variation was noted in respiratory patterns. Manual compression of ilia of pelvis to provide additional stability reversed the noted differences.
Discussions	The external validity of the article was poor due to a multitude of factors. The subject sample was small (n = 13) SIJP with well-defined inclusion and exclusion criteria. When this is considered, the SIJP sample all reported to be post traumatic with bladder dysfunction, it significantly narrowed the applicability of results to the general SIJP population, as the findings may not apply to SIJP patients with nontraumatic onset or without bladder dysfunction (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). Normally, the heterogeneity of the gender would improve the external validity but due to the female to male ratio been 11:2, the results were likely skewed to be more applicable to females. The large age range, while difficult to define due to the use of standard deviation, assisted the external validity but reduced internal validity due to the increased likelihood of confounding variables created by age related pathological processes (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The lack of blinding or randomisation potentially introduced Hawthorne and assessor effects, which are associated with altered subjected behaviour during assessment. The results may, therefore, not be generally applicable (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The outcomes suggest that SIJP is associated with altered respiratory function and PFM control however, it is not possible to determine if these are causative, contributing or an adaptive response in SIJP. Additionally, as the sample is composed of subjects who are post-traumatic with bladder dysfunction it is not clear if these findings are unique to this sample. The article demonstrated these altered MCS reverted to 'normal' when the ilia were manually compressed. The mechanism by which the compression improved MCS were not determined, as no EMG analysis was conducted. These factors, therefore, impair the applicability of the intervention finding to the general SIJP population.
Conclusion	The evaluation of Table 4.4 shows that the internal validity of the study was moderate, with sample selection being problematic. This is because the control and SIJP groups were dissimilar (no bladder dysfunction in the control group). The study design (cohort observational) introduced the potential for bias due to lack of blinding and randomisation. The most significant problem identified by the reviewers was that that the control and experimental groups were so dissimilar (no bladder control issues) as to be potentially not comparable. Evaluation of Table 4.5 shows that the external validity of the study was poor. This was due to a number of factors, starting with poor reporting of recruitment of subjects inhibiting the ability to assess representativeness of the sample in this domain. The strict inclusion and exclusion criteria further limit the general applicability of findings, especially when combined with all subjects being post traumatic with bladder dysfunction. The study design also gives the potential for altered performance of the test which may have altered the outcomes. The review finds moderate support for the conclusion of the article but finds that the application of results would be limited due to poor external validity.

Table 4.4: Tabulated Feedback Data Group 3 – Article 3 Table 1

Authors	Beales, O'Sullivan, and Briffa	**Year**	2010			
Article Title	The effects of manual pelvic compression on trunk motor control during an active straight leg raise in chronic pelvic girdle pain subjects					
EVALUATION CRITERIA FOR THE STUDY	**Comments**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
Representativeness of the exposed cohort truly representative of the average _____ (describe) in the community * somewhat representative of the average _____ in the community * selected group of users description of the derivation of the cohort.		*C*	*A*	*C*	*A*	*67%*
Selection of the non -exposed cohort drawn from the same community as the exposed cohort * drawn from a different source no description of the derivation of the non-exposed cohort		*C*	*A*	*C*	*A*	*67%*
Ascertainment of exposure secure record* structured interview* written self-report no description		*A*	*A*	*A*	*A*	*100%*
Demonstration that outcome of interest was not present at start of study yes* no		*B*	*A*	*B*	*B*	*67%*
Total section points		*3*	*5*	*3*		*67%*
COMPARABILITY						
Comparability of cohorts on the bias of the design or analysis study controls for _____ (select the most important factor)* study controls for any additional factor (This criteria could be modified to indicate specific control for a second important factor).*	*PGP*	*A*	*A*	N/A	*A*	*67%*
Total section points		*2*	*2*	*0*		*75%*
Outcome						
Assessment of outcome independent blind assessment * record linkage* self-report no description		*B*	*B*	*B*	*B*	*100%*
Was follow-up long enough for outcomes to occur yes (select an adequate follow up period for outcome of interest)* no		*A*	*A*	*A*	*A*	*100%*
Adequacy of follow up of cohorts complete follow up – all subjects accounted for* subjects lost to follow up unlikely to introduce bias - small number lost - > ____ % (select an adequate %) follow up, or description provided of those lost) follow up rate < ____% (select an adequate %) and no description of those lostno statement.		*A*	*A*	*A*	*A*	*100%*
Total section points		*3*	*3*	*3*	*3*	*100%*
OVERALL PERCENTAGE AGREEMENT						*79%*

Table 4.5: Tabulated Feedback Data Group 3 – Article 3 Table 2

Authors	Beales, O'Sullivan, and Briffa		**Year**		2010			
Title	The effects of manual pelvic compression on trunk motor control during an active straight leg raise in chronic pelvic girdle pain subjects							
Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
ASLR Pain and disability scales: 1. Quebec 2. McGill 3. VAS 4. Tampa Incontinence scales: 1. Continence dysfunction 2, UDI	Single measure	Not stated	n = 12	No	No	No	Selection 5 Comparability 1 Outcomes 3	79%
Limitations	Subjects were recruited from the Perth metropolitan region and, therefore, the results may not be applicable to rural dwellers (Meinert and Piantadosi 2022). Additional information on the location of recruitment and the methodology of sampling was not provided. No blinding was reported and, therefore, there is the potential in the study for altered behaviour that could have influenced subjected behaviour that would affect the generalisation of findings (Meinert and Piantadosi 2022). The study design (cohort observational) used a test-retest sample and no control group was used. As the placebo effect was not controlled for, it is difficult to extrapolate the potential effect vs actual effect of the compression and apply it to the general population (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The subjects were all chronic, unilateral, and were gender homogenous, i.e. all female subjects. Findings may, therefore, not be applicable to acute and subacute, and/or males as other mechanisms and adaptations may exist (Vannatta and Kernozek. 2018). The aitiology of PGP was heterogenous, including insidious onset, trauma and pregnancy related, improving the general applicability of findings and the external validity. The power of the article was low, n=12 females, impairing the generalisation of the findings (Neumayer and Plumper. 2017, Stommel and Willis. 2004). The exclusion criteria potentially excluded subjects with excessive force closure. In respects of aetiology, the porous, and bladder function, the subject sample was heterogenous improving external validity (Meinert and Piantadosi 2022). The ASLR technique utilised in this study is unclear if the lift was 10cm with 45s hold or a 10-20cm lift. Additionally, the use of nasogastric tubes may have altered the performance of the ASLR which may render the results non-transferable.							
Outcomes	External compression during the ASLR positively influence perceived exertion (paired t-test: $p < 0.001$) but had no statistically significant effect on muscle activation or pressure variables. Visual inspection of MCS showed to different patterns with compression. The seven subjects demonstrated decreased muscle activation while five had \increased muscle activation on their EMG profiles. It was concluded that the findings represent different mechanisms of PGP and not only responses to pelvic compression.							

Discussions	The sample was small, gender homogenous, of chronic duration and unilateral symptoms. Additionally, subjects with excessive force closure were excluded and there was poor reporting related to the recruitment of subjects leading to an inability to determine the representativeness of the sample. This limited the ability to determine the general applicability of results and the external validity (Meinert and Piantadosi 2022; Lee 2012). The results concur with those of PPGP subjects in other subjects, with greater EO activation compared to pain free subjects, this provides face validity to the findings of this study. However, the validity of chest wall and abdomen splinting are problematic as no pain free control group was used in this study therefore the findings were contrast against the result from another study. Subjects in this study demonstrated a MCS of bilateral tonic activation for IO and EO. This MCS contrasted to those displayed in nulliparous females with pain by having greater activation of the IO. This further reduces the external validity of the findings.
Conclusion	The internal validity of the study was poor. As the ASLR cited two different articles with differing lift heights, the articles' methodology is not reproducible, creating a significant challenge to the internal validity. The external validity was poor due to a small sample with high homogeneity. Additionally, the lack of clarity on the application of the ASLR renders the general application of findings problematic (Meinert and Piantadosi 2022; Lee 2012). Due to poor internal validity and poor external validity, there is no evidence to support the applications of the outcomes in clinical practice. Further investigation is required in other forms of LBP, as well as a validation study with a greater power.

4.3.2 Observational Studies

A total of 23 of 25 the articles examined in this SR were observational in design.

4.3.2.1 Introduction

For the data capture of the Liddle, the reviewers' ratings were transcribed with an alphabetic rating provided for the applicable grouping and a numeric rating when applicable to a subgrouping.

4.3.2.2 Liddle Reviewed Articles

Table 4.6 provides the observational articles that were included in this study, as well as a description of their table numbers of tabulated review data and analysis of results.

Table 4.6: Tables of articles assessed with the Liddle Scale

Tabulated Review Data	Analysis of Article	Author(s)	Year	Title	Reviewers
Table 4.9	Table 4.10	Macdonald, Dawson, and Hodges	2011	Behaviour of the Lumbar Multifidus During Lower Extremity Movements in People with Recurrent Low Back Pain During Symptom Remission	Reviewer 1 Reviewer 2
Table 4.11	Table 4.12	Lewis, Wood, and Olivier	2013	The Association between Trunk Muscle Endurance and Lumbo-Pelvic Stability in Adolescent Low Back Pain: A Cross Sectional Study	Reviewer 1 Reviewer 2
Table 4.13	Table 4.14	Kwong *et al.*	2013	Interrater Reliability of the Active Straight Leg Raise and One-Legged Standing Tests in Non-Pregnant Women	Reviewer 1 Reviewer 2
Table 4.15	Table 4.16	Corkery *et al.*	2014	Exploratory Examination of the Association Between Altered Lumbar Motor Control, Joint Mobility in LBP in Athletes	Reviewer 1 Reviewer 2
Table 4.17	Table 4.18	Bruno, Millar and Goertzen	2014a	Inter-rater Agreement, Sensitivity, and Specificity of the Prone Hip Extension Test and Active Straight Leg Raise Test	Reviewer 1 Reviewer 2
Table 4.19	Table 4.20	Bruno, Millar and Goertzen	2014b	Patient-reported Perception of Difficulty as a Clinical Indicator of Dysfunctional Neuromuscular Control During the Prone Hip Extension Test and Active Straight Leg Raise Test	Reviewer 1 Reviewer 2
Table 4.21	Table 4.22	KrKeljas and Kovac	2018	Relationship of ASLR and Motor Control Impairment Tests in Physically Active Individuals with and Without LBP	Reviewer 1 Reviewer 2
Table 4.23	Table 4.24	Nelson-Wong *et al.*	2016	Multiplanar Lumbopelvic Control in Patients with LBP: Is Multiplanar Assessment Better Than Single Plane Assessment in Discriminating Between Patient and Healthy Control?	Reviewer 3 Reviewer 4
Table 4.25	Table 4.26	Nelson-Wong *et al.*	2013	Neuromuscular Strategies for Lumbopelvic Control During Frontal and Sagittal Plane Movement Challenge Differ Between People with and Without LBP	Reviewer 3 Reviewer 4
Table 4.27	Table 4.28	Roussel *et al.*	2007	Low Back Pain: Clinimetric Properties of the Trendelenburg Test, ASLR Test, and Breathing Pattern During ASLR	Reviewer 3 Reviewer4
Table 4.29	Table 4.30	Sadeghisani	2017	Examining the Lumbopelvic-hip Movement Pattern in a Subgroup of Patients with Low Back Pain During the Active Straight Leg Raise Test	Reviewer 3 Reviewer 4
Table 4.31	Table 4.32	Shadmehr, Jafarian and Talebian	2012	Changes in Recruitment of Pelvic Stabilizer Muscles in People with and Without Sacroiliac Joint Pain During the Active Straight Leg Raise Test	Reviewer 3 Reviewer 4
Table 4.31	Table 4.32	Whittaker *et al.*	2013	Association Between Changes in Electromyographic Signal Amplitude and Abdominal Muscle Thickness in Individuals with and Without Lumbopelvic Pain	Reviewer 3 Reviewer 4
Table 4.33	Table 4.34	Castro *et al.*	2019	Assessing the Construct Validity of Clinical Tests to Identify Sacroiliac Joint Inflammation in Patients with Non-radiographic Axial Spondyloarthritis	Reviewer 7 Reviewer 8
Table 4.35	Table 4.36	Kibsgård *et al.*	2017	Movement of the Sacroiliac Joint During the Active Straight Leg Raise Test in Patients with Long-lasting Severe Sacroiliac Joint Pain	Reviewer 7 Reviewer 8
Table 4.37	Table 4.38	Rabin *et al.*	2013	The Interrater Reliability of Physical Examination Tests That May Predict the Outcome or Suggest the Need for Lumbar Stabilization Exercises	Reviewer 7 Reviewer 8
Table 4.39	Table 4.40	Sasaki *et al.*	2011	Muscle Strength During ASLR Correlates with Walking Capacity in Patients with Lumbar Spine Stenosis with Neurogenic Intermittent Claudication	Reviewer 7 Reviewer 8
Table 4.41	Table 4.42	Vanti *et al.*	2016	The Relationship Between Clinical Instability and Endurance Tests, Pain and Disability in Nonspecific Low Back Pain	Reviewer 7 Reviewer 8
Table 4.43	Table 4.44	Teyhen *et al.*	2009	Ultrasound Characteristics of the Deep Abdominal Muscles During the Active Straight Leg Raise Test	Reviewer 7 Reviewer 8
Table 4.45	Table 4.46	Roussel *et al.*	2009	Altered Breathing Patterns During Lumbopelvic Motor Control Tests in Chronic Low Back Pain: A Case–Control Study	Reviewer 7 Reviewer 8
Table 4.47	Table 4.48	Palsson *et al.*	2012	Experimental Pelvic Pain Impairs the Performance During the ASLR Test and Causes Excessive Muscle Stabilization	Reviewer 7 Reviewer 8
Table 4.49	Table 4.50	Ericksen *et al.*	2010	Gynaecological Surgery and Low Back Pain in Older Women: Testing the Association with Sacroiliac Joint Stiffness and Pelvic Floor Movements	Reviewer 7 Reviewer 8

Group 1

Table 4.7: Tabulated Data – Data Group 1 – Article 3 Table 1

Authors	Macdonald, Dawson, and Hodges		**Year**	2011		
Article Title	Behaviour of the Lumbar Multifidus During Lower Extremity Movements in People with Recurrent Low Back Pain During Symptom Remission					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?	*Control numbers (n=10) and LBP cases (n=8) are small, not clear where participants were recruited from.*	*B1*	*B1*	*B2*	*B1*	*67%*
2. What percentage of individuals refused to participate?		*A*	*A*	*A*	*A*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?		*A*	*A*	*A*	*A*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?	*No Intervention as such – LBP cases vs controls with no LBP*	*A*	*A*	*A*	*A*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Male / female ratio and breakdown in the study, different in LBP and non LBP groups. No subset analysis or gender or adjustment in comparison between them.*	*B1*	*B1*	*B2*	*B1*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)		*A*	*A*	*A*	*A*	*100%*
7. Is the analysis by intension to intervene (treat)?	*LBP Associative Observational study – not interventional*	*N/A*	*C*	*N/A*	*N/A*	*67%*
8. Are results homogeneous between sites? (multicentre / multisite studies only).	*Single centre study*	*N/A*	*A*	*N/A*	*N/A*	*67%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*Link between symptoms and outcome variables may be different*	B2	B1	B2	B2	67%
2. Is the overall effect of the study due to the study intervention?	*Observational Symptom Assessment and association study – not interventional / causal study*	A	A	N/A	A	67%
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*Cannot ethically induce LBP in individuals*	N/A	N/A	N/A	N/A	100%
4. Include any other comments						

Table 4.8: Tabulated Feedback Data Group 1 – Article 3 Table 2

Authors	Macdonald, Dawson, and Hodges	**Year**	2011
Title	Behaviour of the Lumbar Multifidus During Lower Extremity Movements in People with Recurrent Low Back Pain During Symptom Remission		

Study Properties

Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
USI lumbar multifidus in 3 conditions: 1. ASLR 2. Crook ASLR 3. Prone SLR at the L4-5 and L5-S1 levels	Baseline under the three conditions	Not stated	n = 18 Healthy n = 10 Recurrent LBP n = 8	No	Yes n = 10	No	3A	84%

Limitations	No information was provided on the location of recruitment, or the method of sampling was provided. It is therefore impossible to determine whether the sample was representative of the general LBP population, therefore impairing the general application of findings of the article. This ultimately undermine the external validity of the article (Meinert and Piantadosi 2022). No blinding was discussed in the article, it was therefore assumed that blinding was not undertaken, introducing the potential for bias and therefore undermining the external validity of the results (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. Results are therefore applicable to the SIJP population and not the general LBP population (Meinert and Piantadosi 2022). The sample was heterogenous for gender and chronicity / episodes of pain. The inclusion criteria for the rLBP group were more than 2 episodes of rLBP. It is likely that the rLBP who had experienced more episodes of pain were more likely to practice activity avoidance and therefore have greater deconditioning and therefore altered muscular characteristics and recruitment compared to those who had experienced less episodes. This would increase the variance in the sample (Meinert and Piantadosi 2022; Lee 2012). The sample size of the study was moderate n =18. The genders were unequally distributed and varied significantly between the control group and rLBP groups with male: female ratios of 6:4 and 2:6, respectively. The relatively young age range (23 +/- 4yrs) of the study sample is likely to reduce the applicability to older people who may have different pathological causes of pain and different biomechanics and tissue structure (Shur *et al.* 2021; Zimmerman *et al.* 2021; Dutton 2020). The inclusion criteria of pain free at time of testing and functional limitations are also likely to reduce external validity in the clinical setting. The requirement of functional limitation within 12 months suggest that the pain was at least moderate, and results may not be applicable to mild cases. Additionally, pain is one of the primary motivators for seeking treatment of LBP and can alter MC patterns independently of actual tissue damage (Palsson et *et al.* 2012; Walker *et al.* 2013). It is therefore unlikely that the subjects analysed in this study are representative of the majority patients in the clinical setting. The inclusion criteria limited pain between T12 and gluteal fold therefore results may not be applicable when pain is referred to other regions. Whilst the exclusion of rLBP subjects who have undergone some form of lumbar multifidi strengthen may further reduce the external validity of the findings to patients who have sought treatment in the clinical setting. This would decrease the external validity of findings (Meinert and Piantadosi 2022). The muscle function was examined using U/S results are therefore not applicable to muscle function but rather the thickness of the examined portion of the muscle. Furthermore, the findings are applicable to L4/5 and L5/S1. ASLR lift height was minimized to avoid artifacts, therefore results may not represent muscle function at greater RoM during ASLR.

Outcomes	Change of LM thickness was greater in the rLBP group than the healthy control group during the PSLR (P<.01). Both the control and rLBP groups demonstrated greatest change in thickness during the PSLR compared to the ASLR and CLR (P<0.01). Of the two levels examined, the L4-5 LM area demonstrated the highest percentage in both groups (P<.01) for all tasks (P<0.02). No difference was observed between the groups for the percentage of LM thickness change for the ASLR (P = 0.70) or CLR (P = 0.69).
Discussions	There were numerous factors that impaired generalisation of findings to the clinical setting, reducing the external validity. The primary factors were no description of recruitment of subjects, no pain at time of testing, and minimum lift height. These factors led inability to assess whether the subjects were representative, questions over whether results were applicable to symptoms and therefore transferable to clinical setting, and if whether the ASLR used in this study represented clinical application of the ASLR. As such the external validity was deemed to be poor (Meinert and Piantadosi 2022; Lee 2012). While the study infers that muscle contraction of the LM is best assessed with prone SLR rather than ASLR and crook lying ASLR, the lack of EMG analysis prevents any inference about which form of movement is best to assess the intermuscular coordination. This is a significant limitation of the study, as delayed TrA recruitment has been implicated as a potential generator in other studies (Mens *et al.* 2017b). However, this also highlights the need for use of functional tests in a battery format rather than standalone tests. These factors reduce the applicability of the article findings into the clinical setting.
Conclusion	The design of the study introduced the potential for bias due to lack of blinding and randomisation. While a control group was used the variations (healthy group males n = 6, females n = 4; pain group males n = 2, females n = 6) would likely influence the reliability of the findings. As subject were pain free at the time of testing, there is a significant question as to whether the outcomes are related to symptoms. These factors all reduce the internal validity of the findings. As such it was deemed that had these factors been adequately control the findings of the study would have altered. Therefore, the internal validity of the study was deemed to be low (Meinert and Piantadosi 2022; Lee 2012). External validity was poor due to low power and the likelihood that the results were not very transferable to the clinical setting (Meinert and Piantadosi 2022; Lee 2012). While the article suggests that ASLR is not associated with any significant change in LM thickness, and the results infer that the prone SLR is better suited for the assessment of the LM changes, this review finds that due low internal validity and poor external validity that the article provides no evidence to support this. Further research with the amended methodology is required.

Table 4.9: Tabulated Data – Data Group 1 – Article 5 Table 1

Authors	Lewis, Wood, and Olivier	**Year**	2013			
Article Title	The Association between Trunk Muscle Endurance and Lumbo-Pelvic Stability in Adolescent Low Back Pain: A Cross Sectional Study					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?		*B1*	*A*	*B1*	*B1*	*67%*
2. What percentage of individuals refused to participate?		*B1*	*B2*	*B1*	*B1*	*67%*
3. Are outcomes measured in a standard, valid and reliable way?		*A*	*A*	*A*	*A*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?		*A*	*A*	*A*	*A*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?		*B2*	*A*	*B2*	*B2*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)		*A*	*A*	*A*	*A*	*100%*
7. Is the analysis by intension to intervene (treat)?		*N/A*	*C*	*N/A*	*C*	*67%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).		*A*	*A*	*N/A*	*A*	*67%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?		*B2*	*B1*	*B2*	*B2*	*67%*
2. Is the overall effect of the study due to the study intervention?		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
4. Include any other comments						

Table 4.10: Tabulated Feedback Data Group 1 – Article 5 Table 2

Authors	Lewis, Wood, and Olivier	**Year**	2013
Title	The Association between Trunk Muscle Endurance and Lumbo-Pelvic Stability in Adolescent Low Back Pain: A Cross-Sectional Study		

Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
Questionaire developed for unpublished PHD Muscle Tests: 1. Sorensen test 2. Shirado test 3. Side bridge endurance test 4. ASLR with BFU	Baseline	Not stated	n = 80 LBP = 66 Pain free =14	No	Yes n = 14	No	3B	79%

Limitations	Subjects were recruited from grade 8-11, co-ed schools who were members of the Independent Schools Association of South Africa (ISASA), in the Central Gauteng region. The schools selected for this study are likely to contain a high socioeconomic demographic (i.e., recruited from private schools) in South Africa as a sample of convince was used. Sports programmes were a consideration for the selection of schools that subjects were recruited from. Subsequently, nutrition and physical fitness level are likely to be superior to the general population therefore reducing the applicability of findings and external validity (Wang *et al.* 2020; Huebschmann, Leavitt, and Glasgow 2019; Lee 2012). No blinding was discussed in the article, it was therefore assumed that blinding was not undertaken, introducing the potential for bias and therefore undermining the external validity of the results (Meinert and Piantadosi 2022). The study design (cross-sectional observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. Results are therefore applicable to the SIJP population and not the general LBP population (Meinert and Piantadosi 2022; Lee 2012). The sample was gender heterogenous. When this is considered with the age range (12-17 Y.o.A.) this creates significant variance in the sample because of the effects of puberty on anatomical structures as well physiological dependent neuromuscular parameters. This subsequently enhances the external validity of the findings. The subject sample was composed of n = 80 adolescences, with an age range of 12-17 Y.o.A. Findings are likely to therefore be specific growing individuals and not generalisable to mature adults (Potthoff *et al.* 2018). There was a failure to report subject demographical data, which is essential for both the evaluation and application of results. Additionally, no subset analysis was conducted to determine whether confounding variables (gender, weight, height, and age) influenced results (Lee 2012). Additionally, there was numerical disparity between the LBP (n=66) and control group (n=14). The ASLR was conducted using a PBU therefore the results may not be applicable if performed without a PBU. Additionally, results may not be applicable passed 20cm lift height.
Outcomes	Epidemiological analysis of demographics found the lifetime prevalence of LBP subjects to be 82.50% (n=66), one-year prevalence 78.80% (n=63), and point prevalence, 23.80% (n=19). Adolescents with a history of LBP had greater trunk flexor endurance than controls (mean = 56.95s vs 40.36s, p = 0.044). No direct association was found between reduced trunk extensor endurance and LBP (p = 0.304), although there was a trend for reduced endurance with LBP. No association was found for lateral trunk flexor endurance. PRE of the ASLR was found to have no association with LBP (left: p=0.275 and right: p= 0.373). Nor was there an association between LBP and either the right or the left pressure change (left: p=0.287 and right: and p= 0.719). However, a statistically significant association between the ASLR and trunk extensor muscle (p=0.031). Reduce pressure fluctuations on the BFU was associated with higher scores on all endurance tests.

Discussions	The study design reduced the external validity as lack of randomisation and blinding introduces the risk of bias. The use of convenience sample especially with the use of higher sociodemographic composition of the sample, in conjunction with the lack of reporting and subset analysis of confounding variables greatly reduces the external validity of the study. Due to the age range and mixed gender of the study there is a significant potential for individual subject variance as chronological and biological maturity are nonlinear (Pyrkov et al. 2018). Despite questionable methodology (e.g. lack of blinding etc), the study suggests that in LBP subjects an imbalance in muscular endurance exists favouring the flexors. As stated by the authors of this article, there is no way to determine whether this relationship was an adaptation or the cause of LBP from the results in this study. For the ASLR, the trunk extensor muscles have a significant relationship with the ASLR. It was suggested within the study that poor lumbo-pelvic stability bore no relationship to adolescent LBP within this study however with the marked difference in size between those with LBP and those without it to reach this conclusion. It must be acknowledged that the ASLR utilised within this study had greater objectivity due to the BFUs.
Conclusion	The internal validity of the study was poor due to the risk of bias and confounding variables. The study design introduced inherent risk of bias which was potentially increased by the lack of blinding. Additionally, there was a failure to report subject demographical data (gender, weight, height, and age), which is essential for both the evaluation for a relationship and given that the subject sample was adolescent, may have altered the outcomes of the study if subset analysis was conducted influenced results (Lee 2012). The review also noted a significant disparity in numbers between the LBP and pain free groups with each n = 66 and n =14 respectively. The external validity was deemed to be bad due to failure to report demographic data, and use of convenience sample of adolescents and PBU (Meinert and Piantadosi 2022; Lee 2012) . As a result, there is limited evidence to support the conclusions of lumbo-pelvic instability (ASLR) is associated with poor trunk extensor endurance in adolescent LBP. The study therefore requires replication with age, weight, height, BMI, and gender subset analysis. Additional studies in lower socioeconomic groups are also required to determine external validity of the findings. Additionally, the study suggests that extensor endurance needs to be assessed in the adolescent population if a positive ASLR is obtained due to the association.

Table 4.11: Tabulated Data – Data Group 1 – Article 6 Table 1

Authors	Kwong *et al.*		**Year**	2013		
Article Title	Interrater Reliability of the Active Straight Leg Raise and One-Legged Standing Tests in Non-Pregnant Women					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?		*A*	*A*	*A*	*A*	*100%*
2. What percentage of individuals refused to participate?		*A*	*A*	*A*	*A*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?		*A*	*A*	*A*	*A*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?	*No Intervention as such – LBP cases vs controls with no LBP*	*A*	*A*	*A*	*A*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?		*B1*	*A*	*A*	*A*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*3/34 = 9%*	*A*	*A*	*A*	*A*	*100%*
7. Is the analysis by intension to intervene (treat)?	*Inter-rater reliability / test sensitivity and specificity study – LBP Observational study – not interventional*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).	*Single centre study*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?		*A*	*A*	*A*	*A*	*100%*
2. Is the overall effect of the study due to the study intervention?	*Observational Symptom Assessment and association study – not interventional / causal study*	*A*	*A*	*N/A*	*A*	*67%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*Cannot ethically induce LBP in individuals*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
4. Include any other comments						

Table 4.12: Tabulated Feedback Data Group 1 – Article 6 Table 2

Authors	Kwong et *et al.*	**Year**	2013
Title	Interrater Reliability of the Active Straight Leg Raise and One-Legged Standing Tests in Non-Pregnant Women		

Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
Demographics <u>Pain and Disability</u>: 1. Numeric Pain Rating Scale (NPRS) 2. Roland-Morris Disability Questionnaire (RMDQ) 3. Neuropathic Pain Diagnostic Questionnaire (DN4) 4. The Functional Pelvic Pain Scale (FPPS) 5. Pain Location Diagram <u>Function</u>: 1. ASLR 2. Single leg standing test (OSL) 3. Squat Stress Modification	Baseline	Recruitment over one month period	n=31 No pain n = 11 LBP n = 13 LBP with PGP n = 7	Yes	Yes n = 11	No	3A	96%

Limitations	Subjects were from Calgary, Alberta, Canada over a 1-month period via advertisements placed at the Alberta Health Services Chronic Pain Centre (AHS CPC), the Advanced Spinal Care Centre, and in the community. Subjects recruited from the clinics are likely to be more severe and/or chronic than the general populace and results may not be applicable. There was no clarity as to where the pain free group was recruited from. These factors reduce the ability to generalise the findings of the article and therefor the external validity (Meinert and Piantadosi 2022). The study design (observational), only allowed for single blinding of the assessors which was undertaken. This decreased the potential for bias in the article, improving the general applicability and external validity of the results (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. This ultimately reduces the external validity of the articles results (Meinert and Piantadosi 2022). The article was gender homogenous (female) whilst been heterogenous for pain locations. As the sample was female, the results may not be applicable to men due to anatomical and physiological differences (Suputtitada *et al.* 2020; Johnson, Costa and Mont 2011). This reduces the general applicability of the article's findings and therefore the external validity (Wang *et al.* 2020; Huebschmann, Leavitt, and Glasgow 2019; Lee 2012). The heterogeneity of pain location (LBP, LBP with PGP) improves the external validity of the study as there is increased variance in the sample. The sample size of the study was n = 31 and the age range for subjects was between 18-65 (mean 41 Y.o.A). The sample size was moderate, however there were three states included in this (no pain, LBP and LBP with PGP). As no subset analysis was between the pain groups there is increased variance in the article improving the general applicability of results and the external validity. This is enhanced by the large age of the sample, which provides the potential for numerous pathological processes, from degeneration to systemic pathologies (Prather and van Dillen 2019). The methodology of the ASLR is not transparent. The test was conducted three to four times on each leg in alternating fashion. It is unclear if rest was provided between repetitions or if a pause was held at the top of the lift. Additionally, it is unclear if the ASLR was merely rated on the subject scoring, or a combination of subject scoring and assessor scoring was used. These factors therefore reduce the general applicability as performance of the ASLR in this manner may affect results (Lee. 2012, Mens *et al.* 2010, Mens *et al.* 2001, Mens *et al.* 1999).

Outcomes	The inter-rater reliability of the ASLR was 0.87 (95% CI 0.77–1.00). There was 90% agreement (28/31) on the rating of the ASLR, with 46% (13/28) of subject rated positive and 54% rated negative (15/28). The sensitivity and specificity based on the twenty-eight subjects was calculated as 71% (95% CI 44–90%) and 91% (95% CI 59–100%), respectively. When sensitivity was calculated for rater using all thirty-one subjects, the following sensitivities were found: rater 1: 65% (95% CI 41–85%), rater 2 and rater 3: 70% (95% CI 46–88%). Significant differences in the mean ASLR scores were found between the three pain groups (both PGP and LBP, LBP, and no pain). The scores progressively increased from no pain (10 of 11) negative scores to positive score with LBP. The highest pain scores when found when both LBP and PGP were present.
Discussions	The study design inherently reduced the external validity of the article due to the potential risk of bias due the lack of randomisation. The methodology of recruitment enhanced the external validity of the article as it offers significant chance for great variation within the sample. However, as the reporting failed to clarify where the subjects were ultimately recruited from (community vs clinic) there are unresolved questions over the subject pool. If the primary source of subject was from the clinics, the general applicability and therefore the external of results would have been reduced due the chances of the subjects been more severe cases. The article was gender homogenous (female) the results may not be applicable to men due to anatomical and physiological differences (Suputtitada et al. 2020; Johnson, Costa and Mont 2011). The sample was heterogenous for pain locations (LBP, LBP with PGP) and as no subset analysis was between the pain groups there is increased variance in the article improving the general applicability of results and the external validity. This is enhanced by the large age of the sample (18-65, mean 41 Y.o.A), which provides the potential for numerous pathological processes, from degeneration to systemic pathologies (Prather and van Dillen 2019). The sample size was moderate (Meinert and Piantadosi 2022; Lee 2012). The methodology of the ASLR is not transparent. The test was conducted three to four times on each leg in alternating fashion. It is unclear if rest was provided between repetitions or if a pause was held at the top of the lift. Additionally, it is unclear if the ASLR was merely rated on the subject scoring, or a combination of subject scoring and assessor scoring was used. These factors therefore reduce the general applicability as performance of the ASLR in this manner may affect results (Lee. 2012, Mens et al. 2010, Mens et al. 2001, Mens et al. 1999).
Conclusion	The study had moderate internal validity. Despite the authors of the article minimizing bias, the study design introduces inherent bias, which prevented a higher ranking of evidence. The primary area of concern was the ASLR technique due to not being fully transparent introduced the potential for confounding variables (Meinert and Piantadosi 2022; Lee 2012). The outcomes of this pilot study demonstrated good inter-rater reliability in non-pregnant females with a spectrum of severity. This reliability was demonstrated to extend to a variety of musculoskeletal professions. When these factors are taken into consideration with the age range, this study demonstrates that the ASLR has good external validity (Akobeng. 2008). The ASLR Sn and Sp for this population (LBP and / or PGP) was found to be 71% and 91% respectively. The mean ASLR score increased with increased analgesic intake as well as increased distribution of pain. Consistent to these findings was a positive correlation between the ASLR scores and various pain and disability assessments. These findings demonstrate the need to ensure that analgesics are not ingested before assessment. Problematically, though the sensitivity and specificity were calculated as a group rather than condition i.e., PGP, LBP and LPP. However, it is likely that the power of each condition considered individually may have been too low. The outcomes of this study demonstrated that OLS was shown to have poor inter-rater reliability. The internal validity of the study was moderate whilst the external validity of the study was deemed to be good. The main limitation of the article was the failure to conduct subset analysis sensitivity and specificity, as such this area requires further research to clarify. There is moderate evidence to apply the findings of the study with a degree of confidence that the ASLR is moderate and high for SN and SP respectively in LPP in non-pregnant females with a wide spectrum of severity.

Table 4.13: Tabulated Data – Data Group 1 – Article 7 Table 1

Authors	Corkery *et al.*		**Year**	2014		
Article Title	Exploratory Examination of the Association Between Altered Lumbar Motor Control, Joint Mobility in LBP in Athletes					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?		*A*	*B1*	*A*	*A*	*67%*
2. What percentage of individuals refused to participate?	*No dropout*	*A*	*A*	*A*	*A*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?		*A*	*A*	*A*	*A*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?	*No Intervention as such – LBP cases vs controls with no LBP*	*A*	*A*	*A*	*A*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Groups matched*	*B2*	*B2*	*B1*	*B2*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)		*A*	*A*	*A*	*A*	*67%*
7. Is the analysis by intension to intervene (treat)?	*Observational study – not interventional*	*N/A*	*C*	*N/A*	*N/A*	*67%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).	*Single centre study*	*N/A*	*A*	*N/A*	*N/A*	*67%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?		*B1*	*B1*	*A*	*B1*	*67%*
2. Is the overall effect of the study due to the study intervention?	*Observational epidemiological association study – not interventional / causal study*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*Cannot ethically induce LBP in individuals*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
4. Include any other comments						

Table 4.14: Tabulated Feedback Data Group 1 – Article 7 Table 2

Authors	Corkery *et al.*	**Year**	2014
Title	Exploratory Examination of the Association Between Altered Lumbar Motor Control, Joint Mobility in LBP in Athletes		

Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
Questionnaire: 1. Demographics 2. Activity level 3. Medical history 4. Need to self-manipulate spine Pain: 1. NPRS 2. ODI 3. FABQ - Physical Activity Subscale Flexibility: 1. PSLR 2. Lumbar RoM 3. Hip internal rotation ROM (HIR) Lumbar motor control: 1. ASLR with PBU 2. PIT 3. Observation of lumbar aberrant movements 4. Double leg lowering (LL) with PBU 5. Trendelenburg Beighton ligamentous laxity scale Arthrometric	Baseline	Not stated	n = 15	Yes	n = 15	No	3A	79%

Limitations	Subjects were recruited via convenience sample method. However, no further details were provided. It is therefore impossible to determine if the sample is representative of the general LBP population. This greatly reduces the external validity of the article (Meinert and Piantadosi 2022). The study design (observational), only allowed for single blinding of the assessors which was undertaken. This potentially reduces bias, thereby improving the general applicability and external validity of article (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. This ultimately reduces the external validity of the articles results (Meinert and Piantadosi 2022). The sample was gender homogenous (all female) but had heterogenous sports participation. The results may therefore not be applicable to the sedentary female or male populations, as different biomechanical and physiological conditions / process are found in athletic population. These factors reduce the general applicability of the study and therefore reduce external validity (Wang *et al.* 2020, Huebschmann, Leavitt, and Glasgow 2019, Lee 2012). Simultaneously, the heterogeneity of sports participation improves the external validity of the article's findings in the athletic female population (Meinert and Piantadosi 2022). The sample size of the study was low, n = 15. This reduces the ability to generalise the findings of the study, impairing the external validity of the article. The article only provides the mean age of subjects (LBP: 21.26 +/- 2.05 and control 20.87 +/-1.3) but not the age range of the sample. Extrapolating from the standard deviation, the age range is likely to be 15 Y.o.A to 28 Y.o.A., which creates the potential for growth related variables which would improve the external validity of the study (Maesteroni *et al.* 2020; Mantyh. 2019). However, as the article examines athletes and only has a relatively small age range,

	the results may not be applicable to sedentary females and / or older female athletes, reducing the external validity of the study (Meinert and Piantadosi 2022). The study lacked clarity over the experience of the tester, stating that testing was conducted by fifth year physical therapy doctoral students and two experienced clinicians. The qualification and experienced of the clinicians were not defined, it therefore impossible to determine the breadth of tester experience and the applicability of the findings to experience range. ASLR utilized a 20-inch lift height and a PBU, therefore results may not be applicable to other forms of ASLR.
Outcomes	RoM found that subjects with LBP were restricted for both lumbar flexion and PSLR compared to subjects without LBP but had greater lumbar flexion deficits. No significance was noted for ASLR and LL performance between groups. There was a significant difference in the AM test ($X2 = 4.66$, $P = 0.03$), where 40% of LBP subjects ($n = 6$) exhibited AM compared to 6% of controls ($n = 1$). Concurrently, 66% of LBP subjects with LBP ($n = 9$) reported frequently self-manipulating their spine, in contrast, to 40% without LBP ($n = 6$). For other outcome measures, no significant results were detected by independent t-test or Chi-Square analyses ($P > 0.05$)
Discussions	The study design, with the subject recruitment in particular, reduced the external validity. These factors introduced an inherent risk of bias in the sample and potential reduced the general representativeness of the sample. Additionally, the sample size was small ($n = 15$), which both reduces the general applicability of results while amplifying the effects of poor internal validity to the general applicability of results (Meinert and Piantadosi 2022; Lee 2012). While an athletic sample was selected, and this does reduce the general applicability of results to the sedentary population, the sample had a heterogenous sports composition. This would increase the applicability of results to the female sporting community. The applicability to male athletes is likely to be low (Wang et al. 2020, Huebschmann, Leavitt, and Glasgow 2019, Lee 2012). Additionally, the results may not be applicable to post-menopausal subjects as the age range is small. It is well accepted fact that hormones affect neuromuscular and myofascial variable are influenced by hormones.
Conclusion	The internal validity of the subject was moderate. Confounding variables were introduced by the variety of sports that the subjects participated in, as each has significantly different parameters (physical attributes, environments, equipment's, and demands) (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). This is problematic, as different pathophysiological and pathomechanical processes are present in land vs aqua, power vs endurance sports, running vs cycling etc). Study outcomes showed that LBP was associated with AM and reduced lumbar flexion ($63 \pm 11°$). The association between poor local MC strategies and LBP was low. The ASLR was found to be similar between the groups. Therefore, it is not possible to assume the presence or absence of AM in motion segments of the spine during the performance of the ASLR This may be in influenced by low power and the heterogeneity of the sample used in this study. However, it may either indicative of the first stages of degeneration or that that in active populations, relative strength may be significantly greater than other populations, therefore relevant loading of pain generating structure does not occur during global muscular testing. The methodology of this study does not provide any insight. Therefore, the outcome of the study suggest that practitioners should assess global and local MCS in active people. The study had moderate internal validity and bad external validity. Therefore, there is limited evidence to support the conclusion of the article. There is therefore a need to determine if relative strength is a variable to inducing a positive ASLR test. Additionally, the article however study highlights the need for research to assess for both local and global dysfunction to adequately stratify subgroups in LBP to aid in interrupting ASLR results.

Table 4.15: Tabulated Data – Data Group 1 – Article 8 Table 1

Authors	Bruno, Millar and Goertzen		**Year**	2014a		
Article Title	Inter-rater Agreement, Sensitivity, and Specificity of the Prone Hip Extension Test and Active Straight Leg Raise Test					
EVALUATION CRITERIA FOR THE STUDY	**Comments:**	**Reviewer**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?		*A*	*A*	*A*	*A*	*100%*
2. What percentage of individuals refused to participate?	*Not indicated – convenience sample of recruited participants*	*I*	*A*	*I*	*I*	*67%*
3. Are outcomes measured in a standard, valid and reliable way?		*A*	*A*	*A*	*A*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?		*A*	*A*	*A*	*A*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Not an intervention study* *Results did not provide subset analysis by gender, especially with male group containing 50% less subject the LBP group*	*B1*	*B1*	*N/A*	*B1*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)		*A*	*A*	*A*	*A*	*100%*
7. Is the analysis by intension to intervene (treat)?	*Not an intervention / RCT study*	*N/A*	*C*	*N/A*	*N/A*	*67%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?		*B1*	*B1*	*A*	*B1*	*67%*
2. Is the overall effect of the study due to the study intervention?	*Not an intervention study*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*The aim is a reliability and agreement study - not interventional.*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
4. Include any other comments	*Well conducted and controlled for a reliability and agreement study.*					

Table 4.16: Tabulated Feedback Data Group 1 – Article 8 Table 2

Authors	Bruno, Millar and Goertzen		**Year**		2014a		
Title	Inter-rater Agreement, Sensitivity, and Specificity of the Prone Hip Extension Test and Active Straight Leg Raise Test						
Study Properties							
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
Motor control: 1. ASLR 2. PHE Pain: 1. ODI 2. NPRS	Base line	Not stated	Total n = 70 LBP n = 30 Males n = 10 Females n = 20	Yes	n = 40 Males n = 20 Females n = 20	No	3A	88%
Limitations	The subjects were recruited using convenience sampling method from two different locations (pain vs control). The LBP sample was recruited from local medical, chiropractic, physiotherapy, and massage therapy clinics whereas the control group was recruited from students, faculty, and staff of the University of Regina. As the LBP group was recruited from clinics and medical centres, the sample is more likely to be severe and therefore not representative of the general populace therefore reducing the external validity. However, the recruitment of the sample from multiple sites and medical disciplines increases the likelihood of variance in the sample thereby improving the general applicability and external validity of the article (Meinert and Piantadosi 2022). The study design (observational), only allowed for single blinding of the assessors which was undertaken, reducing the potential of bias and improving the general applicability of results. This ultimately increases the external validity of the article (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. This ultimately reduces the external validity of the articles results. (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The sample was gender heterogenous, improving the external validity of the article, as the results include the anatomical and physiological variance between the genders (Meinert and Piantadosi 2022). The age range of subjects was 20 to 40 Y.o.A., therefore, findings may not be applicable to age groups outside of these ranges. Due to different pathological process and age-related changes to biomechanics. The distribution of males to females in the pain group was 1:2 and the pain groups for the males was half of the control group. Examiners were chiropractors with over thirty years of experience. Due to the high experience levels, results may not be applicable to inexperience practitioners (Almond, Zou and Forbes 2021; Forbes and Toloui-Wallace 2021). These factors ultimately reduce the general applicability of the findings and therefore external validity of the study (Lee 2012; Akobeng 2008). LBP subjects reported to be naïve to the ASLR. They were therefore familiarised themselves with each test and were then provided a minute's rest. Three to five repetitions, with alternate leg lift equating to a single repetition. This varies significantly from other applications of the test (Mens *et al.* 1999) and does not control for fatigue. Fatigue is a known variable in MCS. This difference is likely to be different to clinical practise where one repetition may be performed as a screening tool.							
Outcomes	The ASLR was found to have a higher inter-rater reliability (Kappa = 0.76, 95% CI = 0.57-0.96, p < 0.001). A low sensitivity of 0.20-0.25 was found with a high specificity 0.84-0.86. A positive OR classifications in the LBP group for examiner one was 1.72 (95% CI = 0.75-3.95) and examiner two 1.57 (95% CI = 0.64-3.85) Inter-rater reliability PHE like the ASLR was also found to be high (Kappa = 0.76, 95% CI = 0.57-0.95, p < 0.001). Sensitivity and specificity were found to be 0.18-0.27 and 0.63-0.78. respectively with a positive OR in the LBP group of 1.25 (95% CI = 0.58-2.72; Examiner 1) and 1.27 (95% CI = 0.52-3.12; Examiner 2).							
Discussions	While the study used convenience sampling to recruit subjects The recruitment from two different sites greatly increases the likelihood of variance of between the pain and non-pain groups. This poor internal validity however does not however improve the external validity as it does not increase variance between the subjects in the pain group. Rather,							

	this impairs the ability to contrast the two groups which will reduces the ability to apply the results in the clinical setting. The multisite, multidisciplinary recruitment of the pain subject does increase the likelihood of variance in the group. The study design contains inherent risk of bias, which reduces the external validity which ultimately reduces the external validity (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).
Conclusion	The internal validity of the study was moderate, this was a combination of the design of the study which introduced inherent bias and the presence of confounding variable which were unlikely to alter the outcome of the study if controlled for. Subset analysis, especially by gender would have removed the confounding variables (Meinert and Piantadosi 2022; Lee 2012). External validity of the study was bad. Results were only applicable to young adults and more likely to be applicable to moderate to severe cases due to recruitment. Additionally, the assessors in this article were highly experienced and results may not be applicable to less experienced practitioners. It must be acknowledged that the power and gender heterogeneity of the sample did improve the external validity (Meinert and Piantadosi 2022; Lee 2012). The study was focused on determining whether a “positive” or “negative” examiner-reported classification scheme had validity, sensitivity and specify to assess subjects’ ability or inability to maintain a neutral pelvic alignment during the 20cm ASLR. No correlation was conducted to the standard subjective assessment score provided by patients therefore the scoring of the ASLR is not applicable (Mens *et al.* 2010). The outcomes of the study demonstrate that both the ASLR and PHE test had a high specificity for LBP but have poor sensitivity. The results showed that the control group had a low probability of testing as a false positive whilst the LBP sample had a low possibility of testing as a false negative. This suggests that the test has a high face validity but low construct validity when a “positive” and “negative” is used for LBP. This, as the author highlight, findings bring into question the value of using the test to evaluate neuromuscular control. However, this study failed to objectively assess the LBP to determine whether subgroups that were not excluded from the study were present and the findings may also reflection the non-specific nature of the criteria used to classify MCS. (Palson *et al.* 2012).

Table 4.17: Tabulated Data – Data Group 1 – Article 9 Table 1

Authors	Bruno, Millar and Goertzen		**Year**	2014b		
Article Title	Patient-reported Perception of Difficulty as a Clinical Indicator of Dysfunctional Neuromuscular Control During the Prone Hip Extension Test and ASLR Test					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?		*A*	*A*	*A*	*A*	*100%*
2. What percentage of individuals refused to participate?	*Not indicated – convenience sample of recruited participants*	*I*	*A*	*A*	*A*	*67%*
3. Are outcomes measured in a standard, valid and reliable way?		*A*	*A*	*A*	*A*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?		*A*	*A*	*A*	*A*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?		*B1*	*A*	*B1*	*B1*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)		*A*	*A*	*A*	*A*	*100%*
7. Is the analysis by intension to intervene (treat)?	*Observational study*	*N/A*	*C*	*N/A*	*N/A*	*67%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).	*Single center study*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?		*B1*	*B1*	*A*	*B1*	*67%*
2. Is the overall effect of the study due to the study intervention?	*Observational epidemiological association study – not interventional / causal study*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*Cannot ethically induce LBP in individuals*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
4. Include any other comments						

Table 4.18: Tabulated Feedback Data Group 1 – Article 9 Table 2

Authors	Bruno, Millar and Goertzen		**Year**		2014b			
Title	Patient-reported Perception of Difficulty as a Clinical Indicator of Dysfunctional Neuromuscular Control During the Prone Hip Extension Test and Active Straight Leg Raise Test							
				Study Properties				
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
Motor control: 1. ASLR 2. PHE Pain: 1. ODI 2. NPRS	Baseline	Baseline	n = 70 LBP n = 30 Males n = 10 Females n = 20	Yes	n = 40 Males n = 20 Females n = 20	No	3A	88%
Limitations	See table 4.16 as this study utilizes the same sample and methodology.							
Outcomes	LBP subjects reported greater PRE for both tests compared to healthy controls, with both groups having a higher PRE for PHE test. Sensitivity and specificity for the PRE for PHE and ASLR tests were greatest with a cut off score of 1. Sensitivity was 0.69 and 0.60 respectively. In contrast the specificity for the PHE and ASLR tests were high with values of 0.82 and 0.76 (respectively). Sub-group analysis found gender differences to not be statistically significant (p = 0.22). The inter-rater agreement of the classifications all participants for both tests was “substantial” (PHE test: Kappa = 0.72, 95% CI = 0.57e0.86, p < 0.001; ASLR test: Kappa = 0.79, 95% CI = 0.65e0.92, p < 0.001). No relationship was found between the examiner and PRE rating for either group.							
Discussions	The points of discussion related to the external validity of the article mirror those of table 4.16. This study’s results mirror those found in the PGP population (both pregnant and non-pregnant females) for PRE (Mens *et al.* 2010). This suggest that if a non-specific diagnostic criterion is used for clinical diagnosis in all LBP subgroups the result for the ASLR would be similar, therefore showing that the ASLR needs to be interrupted in conjunction with other clinical test. Gender subgroup analysis did not demonstrate any significance between groups, however the LBP contained only half the male numbers, therefore increasing the potential for statistical error. However, this still needs to be viewed in the context that the power of the study is equal or greater than many in this group.							
Conclusion	The study had moderate internal validity, due to study design and the presence of some confounding variables which would not have altered the outcomes. External validity was poor for a variety of previously discussed reasons. In the conclusion of the study, the author questions the clinical significance of the findings, as there is a moderate correlation between the PRE and the presence of pain in the LBP group and a low association with asymptomatic group. This highlights the need for a study with significantly greater power that examines the validity of using the ASLR in LBP. The both the internal validity and external validity (See table 4.16) of the study were evaluated moderate. Therefore, there is limited evidence to support the articles conclusions of assessor subjective evaluation being of limited clinical benefit (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).							

Table 4.19: Tabulated Data – Data Group 1 – Article 10 Table 1

Authors	Krkeljas and Kovac		**Date**	2018		
Article Title	Relationship of ASLR and Motor Control Impairment Tests in Physically Active Individuals with and Without LBP					
EVALUATION CRITERIA FOR THE STUDY:	**Comments**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?	*It seems somewhat unusual that from a group of 100 participants, exactly half of them (n=50) presented with LBP and the other 50 did not.*	*A*	*A*	*A*	*A*	*100%*
2. What percentage of individuals refused to participate?		*A*	*A*	*A*	*A*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?		*A*	*A*	*A*	*A*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?	*No Intervention as such – LBP cases vs controls with no LBP*	*A*	*A*	*A*	*A*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Significant differences in age and body mass between LBP and non-LBP groups -should have been corrected / adjusted for.* *Arthrogenic pain inhibition leading to adaptive hamstring shortening not considered*	*B2*	*B1*	*B2*	*B2*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*3/34 = 9%*	*A*	*A*	*A*	*A*	*100%*
7. Is the analysis by intension to intervene (treat)?	*Inter-rater reliability / test sensitivity and specificity study – LBP Observational study – not interventional*	*N/A*	*C*	*N/A*	*N/A*	*67%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).	*Single center study*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?		*A*	*A*	*A*	*A*	*100%*
2. Is the overall effect of the study due to the study intervention?	*Observational Symptom Assessment and association study – not interventional / causal study*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*Cannot ethically induce LBP in individuals*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
4. Include any other comments						

Table 4.20: Tabulated Feedback Data Group 1 – Article 10 Table 2

Authors	Krkeljas and Kovac		**Year**		2018		
Title	Relationship of ASLR and Motor Control Impairment Tests in Physically Active Individuals with and Without LBP						
Study Properties							
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
ASLR – FMS Trendlenberg Specific hamstring tightness RoM: - IR - ER - Hip flexion - Knee flexion Lateral trunk bend test	Baseline	Not stated	n = 100 LBP n = 50 Males n = 41 Females n = 9	No	Yes n = 50 Males n = 29 Females n = 21	No	3A	92%
Limitations	The subjects were recruited from amongst the clients of Fitness Medico Clinic in Serbia. The sample is therefore more likely to be representative of the active, chronic, and/or severe LBP population and less likely to reflect sedentary population; as body composition, micro and macro trauma due to lifestyle, strength, and fitness levels are likely to be significantly different (Genin *et al.* 2018; de Santos *et al.* 2008). No blinding was discussed in the article, it was therefore assumed that blinding was not undertaken, introducing the potential for bias and therefore undermining the general applicability and external validity of the results (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. This ultimately reduces the external validity of the articles results (Meinert and Piantadosi 2022). The sample of the article was heterogenous for gender and pain chronicity, incorporating chronic and subacute pain. The gender heterogeneity improves the external validity as the results contain anatomical and physiological variations, while the heterogeneity of the pain states allows for potential variance in compensation strategies and pathophysiological processes (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The sample's age range was 18 to 59 Y.o.A, with a mean of 24.5 years (± 7.8 yrs) and the power of the study was n = 100. the mean age difference between the pain and control groups was 29.0 ± 8.4 and 20.1 ± 3.3 years respectively. The percentage of females in the LBP was significantly less than the males and while introducing variance in the sample that would reduce internal validity this improved external validity (Meinert and Piantadosi 2022). The LBP inclusion criteria were either a history of LBP for at least six weeks prior to study or at least three episodes of LBP. These inclusions allow for constant or episodic LBP 0.70% of the of all recruited subjects (pain and control groups) were male (n = 70). 82% of the pain group (n = 41) and 58% (n = 29) of the control group were male.							
Outcomes	Subjects with pain mainly scored 1 on the ASLR which also associated hamstring and calf tightness, limited flexion and hypomobility of the trunk, and posterior pelvic tilt. A strong association between LBP and functional movement impairment and weakness in motor control was found. It was recommended that in physically active people, the ASLR be applied in combination with other functional tests to isolate and discern the causes of LBP.							
Discussions	The results of this article are mainly applicable to the fit, active population, with more moderate to severe chronic and subacute LBP. The study design introduced the potential for bias, reducing the general applicability of results (Meinert and Piantadosi 2022; Lee 2012). While the age range of the sample was large, 18 to 59 Y.o.A, the mean age, 24.5 years (± 7.8 yrs), was relatively low. However, this is more representative of the athletic population generally, as athletic participation usually declines							

	with increasing age. The large sample size and gender heterogeneity of the article greatly improved the external validity of the article. However, the applicability of results is somewhat difficult to fully appreciate due to internal validity issues, namely the differences between the control and subject group. The control is younger than the cohort, potential influence the comparison of health to pain groups.
Conclusion	During the review process the sample composition was highlighted as being potentially problematic, with a potential for bias due to the precise 50-50 split of LBP and pain free subjects. This was highlight by one reviewer as being unusual, and it was suggested that this may indicate of the omission of part of the recruitment processes during write up. A further area of concern was the age (mean age for LBP vs no pain was 29.0 ± 8.4 vs 20.1 ± 3.3 Y.o.A.) and weight differences between the two groups, as the LBP group was older and had greater weight, potentially introducing confounding variables into the study. The older group has a higher potential for degenerative changes and reduced tissue elasticity thereby influencing soft tissue length and force expression (Shur *et al.* 2021; Zimmerman *et al.* 2021). Inclusion criteria allowed for the recruitment of both rLBP and cLBP, which is highly problematic as variation in adaptive MCS have been reported between in these sub types of LBP. While this enhances the external validity of the study, as the findings may be more generally applicable, it reduces the internal validity as it results in the reduction of the internal validity (Lee 2012; Akibeng 2008). The study shows that there is a relationship between both the ASLR and hamstring length and LBP. The heterogeneity of the subject groups is problematic as pathological mechanism, differences in physiological, and potential for degeneration exist. Additionally, no clinical testing was conducted to discern whether the hamstring shortening was an adaptation to pain or due to limitations in hamstring extensibility. The significance of the confounding variables was however considered to be mild by two reviewers. These two factors ultimately undermining the internal validity of the study, however the reviewers unanimously concluded that there was minimal potential for bias. As such, the study was deemed to have moderate internal validity. External validity of the study was moderate, this was due to the inherent bias of the studies design whilst the external validity of the study was good. Therefore, there is moderate evidence to support that subjects with pain tend to have a 1 score on the Cook ASLR and have associated limitations in motion.

Group 2

Table 4.21: Tabulated Data – Data Group 2 – Article 2 Table 1

Authors	Nelson- Wong *et al.*	**Date**	2016			
Article Title	Multiplanar Lumbopelvic Control in Patients with LBP: Is Multiplanar Assessment Better Than Single Plane Assessment in Discriminating Between Patient and Healthy Control?					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?	*Duration of the study is not defined*	*B1*	*B1*	*B1*	*B1*	*100%*
2. What percentage of individuals refused to participate?	*Data not provided*	*C*	*C*	*C*	*C*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?	*Methodology was described and referenced. Examiners not blinded. No repeatability or internal validity data provided. Number of examiners, degree of agreement and adjudication methods for conflict resolution apparently not stated.*	*B2*	*B2*	*B2*	*B2*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?	*Exclusion criteria differed between the groups. Controls did not complete Oswestry and fear avoidance.*	*B1*	*B1*	*B1*	*B1*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Large age range of subjects and results not grouped by gender. Majority of reviewers believed that this would only "likely" alter conclusions*	*B2*	*B2*	*I*	*B2*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*Data not provided*	*I*	*I*	*I*	*I*	*100%*
7. Is the analysis by intension to intervene (treat)?	*R1: The interpretation of data was largely provided in the discussion section rather than the analysis of results. The structuring of the report is problematic*	*B2*	*I*	*I*	*I*	*67%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).	*No data*	*I*	*I*	*I*	*I*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C, what is the likely direction in which bias might affect the study result?	*Controls/patients were known to examiners, no obvious blinding, who used subjective testing. Direction in favour of results produced.*	*B2*	*C*	*B2*	*B2*	*67%*
2. Is the overall effect of the study due to the study intervention?		*B2*	*B2*	*B2*	*B2*	*100%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*This was a simple comparison, no treatment therefore RCT is inappropriate.*	*I*	*I*	*I*	*I*	*100%*
4. Include any other comments	*LBP needs to be defined in more detail. The authors treated controls differently from participants in that the latter had the fear avoidance and OD1 to complete. Examiners were not blinded to control vs LBP patients.*					
OVERALL PERCENTAGE AGREEMENT:						92%

Table 4.22: Tabulated Feedback Data Group 2 – Article 2 Table 2

Authors	Nelson-Wong *et al.*	**Year**	2016
Title	Multiplanar Lumbopelvic Control in Patients with LBP: Is Multiplanar Assessment Better Than Single Plane Assessment in Discriminating Between Patient and Healthy Control?		

Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
Disability level: 1. ODI 2. Fear avoidance belief questionnaire (FABQ) Anthropometric Pain: 1. 100mm visual analogue scale (VAS) Motor control: 1. Active abduction test 2. ASLR	Baseline	Not provided, but testing appears to have been conducted on a single day	n = 37 LBP n = 19	No	Yes n = 18	No	Level 3B	92%

Limitations	The LBP sample was recruited by poster advertisement, from physiotherapist clinic, and word of mouth in the Denver metro area. The sample is therefore limited to those seeking care from clinics or know someone who is receiving care and is therefore not likely to be representative of the population, limiting the external validity of the study (Lee. 2012; Akobeng. 2008). Additionally, as subjects are recruited from a physiotherapy clinic, they are more likely to be moderate to severe cases thereby reducing the external validity of the results (Meinert and Piantadosi 2022). No blinding was discussed in the article, it was therefore assumed that blinding was not undertaken, introducing the potential for bias and therefore undermining the external validity of the results (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. This ultimately reduces the external validity of the articles results. The sample was heterogenous in the aetiology of pain. Subjects with radicular symptoms were included if no radicular signs were found on screening, therefore the sample is likely to consist of nLBP and sLBP. The article failed to disclose the gender composition of the article, rendering it impossible to determine if the results apply to one or both genders. The failure to provide this information reduces the external validity of the article, as it is impossible to determine the general applicability of the results (Meinert and Piantadosi 2022). Power of the study was n = 37, 19 with LBP and 18 controls. Subjects ranged from 18 to 70 Y.o.A. This creates the potential for significant variations in aetiology of LBP as well as physiological factors, such as neuromuscular efficiency and comorbidities, which may affect stability, pain perception, and force production (Shur et al. 2021, Zimmerman et al. 2021). The inclusion criteria were individuals seeking medical assistance and / or had missed three or more days from work / school / recreation within the previous five years of the commencement of the study. Subjects with radicular pain were recruited if neurological signs were not present. The inclusion criteria when considered in conjunction with the exclusion criteria makes it difficult to determine the severity and chronicity of the sample population. Lift height of the ASLR was 20cm therefore results may not be applicable to larger RoM. The tests were performed in a consistent sequence, right to left and AHAbd followed by ASLR. This may have introduced a sequence effect (Li et al. 2021).

Outcomes	The study demonstrated that while some LBP subjects present when uniplanar instability, a proportion of LBP subjects (40%) have multiplanar stability deficits. When the ASLR and AHAbd tests were used independently, they had sensitivities of 0.63 and 0.74 respectively. The specificity of the two tests were 0.61 and 0.50, respectively, with OR of 2.7 and 2.8, respectively. It was therefore concluded that to adequately screen subjects, the ASLR and AHAbd tests should be used in combination, as this provides greater diagnostic discrimination, with combined sensitivity, specify and OR of 50.89, 50.60, and 512.0, respectively.
Discussions	The study design reduced the external validity of the article. There was the potential introduction of bias due to lack of randomisation and blinding. The recruitment methodology, poster advertisement at a physiotherapy clinic and word of mouth likely reduced the external validity of the study. The subjects attending the clinic were likely more severe than the general population whilst the word-of-mouth recruitment also likely more serve. Additionally, the word-of-mouth recruitment are more likely to reflect individuals already attending the clinic in terms of sociodemographic profiles and characteristics. The subject characteristics contributed both positively and negatively towards the external validity. The failure to publish the gender composition not only reduced the external validity of the article but also the internal validity. However, the inclusion of subjects with radicular symptoms if no radicular signs were found on screening, greatly increases the applicability of results to the clinical setting, especially with the large age distribution, 18 to 70 Y.o.A (Shur et al. 2021, Zimmerman et al. 2021).
Conclusion	Internal validity of the article was low due to study design, reporting and poor methodology. Further threats to internal validity included an appearance towards producing a positive result, a failure to conduct a reproducibility study and a description of conflict resolution when assessors failed to agree. The study design introduced inherent challenges to the internal validity, via lack of blinding and randomisation. Factors created by the inclusion of radicular symptoms with no radicular sign's subjects reduced the internal validity of the study through the introduction of variance into the sample group. This however improved the external validity of the results as mechanical and radicular LBP subjects may different biomechanical adaptations in the performance of the ASLR (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The age range (17 to 70 Y.o.A) of the sample was large, and no gender breakdown was provided, creating additional confounding variables in the sample. This age range has significant variance in exercise capacity, reserve capacity and pathological process (van der Kruk *et al.* 2021a; van der Kruk *et al.* 2021b). The difference in exercise and reserve capacities potentially introduce confounding variables as aging is associated with a decline in neuromuscular function and therefore the ability to express and control force production (van der Kruk *et al.* 2021b). Degenerative, and systemic pathology are also more common in older population. Had variables been adequately controlled, the outcomes of the article would likely have changed. Similarly, the external validity was diminished by poor reporting and the likelihood that the sample was not representative (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The external validity was therefore rated as bad. Subsequently, there is limited evidence to support the conclusion of this article, that when the AHAbd and ASLR tests are used in combination, appear to have greater diagnostic discrimination. Or, that some LBP subjects have motor control deficits in one plane while other have deficits in two planes. While biomechanically, the outcomes of the study that multiplanar stability is present in certain subjects is likely, the specific findings of the study are questionable. It is recommended that a validation study should be conducted to resolve the methodological flaws contained within this study. Additionally, further study is required to determine if there is any respiratory pattern correlation with the findings of multiplanar instability.

Table 4.23: Tabulated Data – Data Group 2 – Article 3 Table 1

Authors	Nelson-Wong *et al.*		**Year**	2013		
Article Title	Neuromuscular Strategies for Lumbopelvic Control During Frontal and Sagittal Plane Movement Challenge Differ Between People with and Without LBP					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?	*Duration of the study is not defined*	*B1*	*B1*	*B1*	*B1*	*100%*
2. What percentage of individuals refused to participate?	*Data not provided*	*C*	*C*	*C*	*C*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?	*No blinding, repeatability or internal validity data provided. Number of examiners, Methods for conflict resolution apparently not stated.*	*B2*	*B2*	*B2*	*B2*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?	*Controls did not complete Oswestry and fear avoidance.*	*B1*	*B1*	*B1*	*B1*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Large age range and gender difference were not examined*	*B2*	*B2*	*I*	*B2*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*No follow up*	*I*	*I*	*I*	*I*	*100%*
7. Is the analysis by intension to intervene (treat)?	*No intension to treat and application to treatment is not clear*	*I*	*I*	*I*	*I*	*100%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).	*No data*	*I*	*I*	*I*	*I*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C, what is the likely direction in which bias might affect the study result?		*B2*	*C*	*B2*	*B2*	*67%*
2. Is the overall effect of the study due to the study intervention?		*I*	*I*	*I*	*I*	*100%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done		*I*	*B2*	*I*	*I*	*67%*
4. Include any other comments						
OVERALL PERCENTAGE AGREEMENT:						96%

Table 4.24: Tabulated Feedback Data Group 2 – Article 3 Table 2

Authors	Nelson-Wong *et al.*	**Year**	2013
Title	Neuromuscular Strategies for Lumbopelvic Control During Frontal and Sagittal Plane Movement Challenge Differ Between People with and Without LBP		

Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
Anthropometrics: 1. Height 2. Weight 3. BMI 4. Trunk width and depth 5. Pelvis width and depth Surface EMG Pain: 1. VAS Kinematics: 1. 3D motion capture	Baseline	Not provided, but testing appears to have been conducted on a single day	n = 34 LBP n = 17	No	n = 17	No	Level 3B	96%

Limitations	See table 4.22 with the exception of the power of the study, n = 34 all of the parameters and limitations are the same.
Outcomes	The study demonstrated that subjects with LBP utilized a variable muscle recruitment pattern in the frontal and coronal plans, while pain free subject consistently recruited muscles in a proximal to distal in both planes. This was demonstrated by the right GmD activating before the ipsilateral IO and EO during the right AHAbd test, and the left GmD activating before the left IO and right ES. In contrast to the AHAbd tests, both ASLR groups were initiated in a distal to proximal pattern. Significant differences ($p < .05$) were however still found between controls and LBP subjects in the timing of ipsilateral EO and contralateral ES and GMx relative to the RF. The LBP group was to have significantly shorter phase lag than controls, showing a near co-activation of right RF and contralateral left GMx, while controls had a proximal to distal strategy with these muscle groups.
Discussions	For discussion see table 4.22
Conclusion	There was a high consensus amongst the reviewers that the study had low internal validity due to questionable validity and reliability of findings. The reviewers concluded that had the methodology been of superior internal validity, the outcomes of this study were likely to change (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). As per table 4.22 the external validity was also deemed to be bad. As such there is limited evidence to that subjects with LBP variable MC strategy, while controls utilize a more consistent proximal to distal activation strategy in frontal and sagittal plane motions. While the findings likely represent the reality adaptations and / impairments due to pain inhibition and / or deconditioning from fear avoidance behaviour, further research with greater validity and reliability is required.

Table 4.25: Tabulated Data – Data Group 2 - Article 4 Table 1

Authors	Roussel *et al.*		**Year**	2007		
Article Title	Low Back Pain: Clinimetric Properties of the Trendelenburg Test, ASLR Test, and Breathing Pattern During ASLR					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?	*yes*	*A*	*A*	*B1*	*A*	*67%*
2. What percentage of individuals refused to participate?	*unknown*	*I*	*I*	*I*	*I*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?	*Yes, inter-examiner reliability performed using blinded examiners.*	*A*	*A*	*A*	*A*	*100%*
4. Are outcomes measured in the same way for both intervention and control groups?	*No intervention as such.*	*I*	*I*	*I*	*I*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*NO, n/a*	*B1*	*B1*	*I*	*B1*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*NONE, n/a*	*I*	*I*	*I*	*I*	*100%*
7. Is the analysis by intension to intervene (treat)?	*No treatment/intervention*	*I*	*I*	*I*	*I*	*100%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).	*n/a, recruited from multiple sites*	*I*	*I*	*I*	*I*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*Blinding and reliability*	*A*	*A*	*A*	*A*	*100%*
2. Is the overall effect of the study due to the study intervention?	*Not clear as no control group utilized*	*I*	*I*	*I*	*I*	*100%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*Inappropriate, this describes reliability of measurements used in RCTs.*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
4. Include any other comments						

Table 4.26: Tabulated Feedback Data Group 2 – Article 4 Table 2

Authors	Roussel *et al.*	**Year**				2007		
Title	Low Back Pain: Clinimetric Properties of the Trendelenburg Test, ASLR Test, and Breathing Pattern During ASLR							
	Study Properties							
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation of Participates**	**Ranking**	**Total % of Agreement**
Anthropometrics: 1. Height 2. Weight 3. BMI Pain: 1. 100mm visual analogue scale (VAS) Dutch versions of the following questionnaires: 1. ODI 2. BDI 3. Tampa Scale for Kinesiophobia 4. Pain Catastrophizing Scale (PCS) 5. Pain Coping Inventory (PCI) 6. Pain Vigilance and Awareness Questionnaire (PVAQ) 7. Baecke Questionnaire for Habitual Physical Activity Functional movement: 1. ASLR 2. Trendelenburg Visual breathing pattern assessment	Twice	Not stated, two separate sessions occurred for testing	n = 36 Male n = 15 Females n = 21	Yes	No	No	3A	92%
Limitations	Subjects were recruited from three different sites which enhances the external validity of the study as there is increased chance of variance within the sample. Additionally, as a private practise and two outpatient physical therapy units were used as sites of recruitment, there is increased potential for the sample to represent a greater distribution of the socioeconomic classes. However, the recruited from a private physiotherapy practice and the two-hospital outpatient physical therapy units, increases the chances that the sample represents more severe cases. This reduces the general applicability of the results to the general populace, thereby reducing the external validity of the article (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). Blinding was reported in the article, thereby reducing the potential for bias and improving the general applicability of results. This ultimately improves the external validity of the article (Meinert and Piantadosi 2022). The study design (observational) precluded randomisation of subjects, as only symptomatic subjects were recruited. This introduces the potential for bias, ultimately reduces the ability to generalize findings and therefore the external validity of the article (Meinert and Piantadosi 2022). The sample was gender heterogenous, improving the external validity as the results are applicable to both genders. As all subjects had chronic LBP, the results may not be applicable to acute and subacute LBP as different inflammatory processes would be occurring. This would reduce the external validity of the article (Meinert and Piantadosi 2022). The sample size of the article was n =36, with the age range of subject's being 18 to 65 Y.o.A. The sample size is moderate, being larger than most studies. This sample size improves the general applicability of the study, improving the external validity. The large age range of the sample							

	also improves the external validity of the article, as biomechanics, functional reserves, and pathological mechanism vary significantly between the lower and top end of the age range (Shur *et al*. 2021; Zimmerman *et al*. 2021). Hawthorne effect, reducing both the internal and external validity (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).
Outcomes	The repeatability values for the Trendelenburg and ASLR tests were greater than 0.75 and 0.70 respectively. Breathing pattern interobserver reliability during the ASLR was greater than 0.39. Internal consistency was greater than 0.73 for both tests. No significant relationship was found between the Trendelenburg and ASLR outcomes and self-reported pain or disability.
Discussions	The methodology of the article greatly aided the external validity of the study. The recruitment subjects from three different sites introduce variability in to the testing and subject pools increasing the general applicability of the results. The application of blinding reduced the potential for bias. These factors were however countered by the lack of randomisation and control group in the article which increased the risk of bias. As the LBP sample was not stratified according to type of functional deficit and / or gender subset additional variability was added to the sample further improving the external validity. The larger than average sample sizes in conjunction with wide age range of the sample further improved the study. The external validity was reduced by the inclusion of only chronic back pain subjects which may render the result in applicable to acute and subacute pain patient who would have different pathophysiological processes and more entrenched biomechanical compensations.
Conclusion	When analysing Table 4.25 it became evident that the study had moderate internal validity. The internal validity was inherently reduced by the study design, which conferred an inherent risk of bias. While the ASLR technique was cited from Mens *et al.* (2001), the study failed to follow the technique as described. In contrast, the external validity of the study was high. The article used multisite recruitment which introduces variance into the both the testing and subject groups. This was further aided by gender heterogeneity, wide age distribution and a moderate sample size. Therefore, there is moderate evidence to support the authors claims that the test-retest reliability of the Trendelenburg and ASLR tests is positive in LBP subjects. Additionally, the evidence supports the assertion that the high internal consistency of the outcome for both assessors suggest the test assess the same dimension. Furthermore, the interobserver reliability of the breathing pattern assessment was fair to moderate. Further study for validity of the test is require as highlighted by the studies researchers. Additional study is required in the various subgroups of LBP to determine whether these findings are valid.

Table 4.27: Tabulated Data – Data Group 2 - Article 5 Table 1

Authors	Sadghisani *et al*		**Year**	2017		
Article Title	Examining the Lumbopelvic-hip Movement Pattern in a Subgroup of Patients with Low Back Pain During the Active Straight Leg Raise Test					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
Are the study participants well-defined in terms of time, place, and person?	*Yes, small age range used, all male. Use term gender instead of sex. This meant some biological females who gender realigned could have been included. This could undermine their rationale for only studying males.*	*A*	*A*	*B1*	*A*	*67%*
What percentage of individuals refused to participate?	*unknown*	*C*	*C*	*C*	*C*	*100%*
Are outcomes measured in a standard, valid and reliable way?	*yes*	*B2*	*B2*	*B1*	*B2*	*67%*
Are outcomes measured in the same way for both intervention and control groups?	*No intervention, but apparently yes (except in relation to ODI and VAS).*	*B2*	*B2*	*B1*	*B2*	*67%*
Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Some declared that informed the participant selection/inclusion criteria.*	*B2*	*B2*	*B1*	*B2*	*67%*
What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*100% apparently*	*A*	*A*	*A*	*A*	*100%*
Is the analysis by intension to intervene (treat)?	*n/a*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Are results homogeneous between sites? (multicentre/ multisite studies only).	*n/a*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*No examiner blinding apparent, outcome biased in favour of expected finding.*	*B2*	*B2*	*B2*	*B2*	*100%*
Is the overall effect of the study due to the study intervention?	*n/a*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Explain if there is any practical/ethical reason why an RCT cannot be done	*This is a study to assess measurement tools of use in an intervention study.*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Include any other comments						

Table 4.28: Tabulated Feedback Data Group 2 – Article 5 Table 2

Authors	Sadeghisani *et al.*		**Year**		2017			
Title	Examining the Lumbopelvic-hip Movement Pattern in a Subgroup of Patients with Low Back Pain During the Active Straight Leg Raise Test							
	Study Properties							
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Demographics Pain and disability: OLBPQ Persian version of Baecke Habitual Physical Activity Questionnaire (PBHPAQ) VAS Movement system impairment model Kinematics: Motion capture system with seven cameras	Baseline (entry) Secondary test	Not stated, at least 2 sessions	n = 35 (All males) n = 20	No	Yes n = 15	No	3B	84%
Limitations	Subjects were recruited following an assessment by a physician to determine whether they met the inclusion and exclusion criteria of the study. No further data was provided about the location and method for recruitment. It is, therefore, likely that these cases may be more severe and/or chronic, however this is impossible to determine given the limited data. Subsequently, it is problematic to generalise the results of the article (Meinert and Piantadosi 2022). No blinding was discussed in the article; it was, therefore, assumed that blinding was not undertaken, introducing the potential for bias and, therefore, undermining the external validity of the results (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. This ultimately reduces the external validity of the articles results (Meinert and Piantadosi 2022). The study was gender homogenous, all male, and, therefore, results may not be applicable to females, reducing external validity. All LBP subjects were non-specific chronic LBP and screened using the movement system impairment model to ensure they were correctly classified as Flexion + Rotation subgroup. The results are, therefore, not likely to be applicable to other forms of movement disorders leading to LBP or to other chronicity's of LBP, which may have other MC strategies adaptations (Meinert and Piantadosi 2022). N = 35 subjects (n = 20 LBP; n = 15 control) were recruited for the study, aged between 18-50 years. The age distribution is wide, improving the external validity. However, the results may still not be applicable to adults in later life, >55Y.o.A, due to alterations in the disc morphology and segmental ankylosis, which may lead to changes in biomechanics (Meinert and Piantadosi 2022). ASLR technique varied significantly as subjects were instructed to lift the leg to the height, they were able, and at the speed that they wished. The variations in lift height and speed introduce cofounding variables. The variable lift height alters the function of muscles like the PMM as well as the structures that placed under stress (Hu. 2012). The variations in lift speeds create differences in the rate of soft tissue stretch and, therefore, the magnitude of strain on soft tissue the posterior kinetic chain (Earp *et al.* 2014). This may result in the engagement of protective physiological mechanisms or produce pain (Ahamedzadeh *et al.* 2014). This creates confounding variables which decrease the reliability of the findings and the ability to generalise the finding, therefore reducing the external reliability to other applications of the ASLR (Lee 2012; Akobeng 2008).							

Outcomes	During performance of the SLR with the non-dominate limb, the pain group displayed greater magnitude of lumbopelvic rotation in the first half of range [4.1° (3.2) vs 1.8° (1.3)] as well as the totality of the test [11.2° (4.9) vs 7.6° (3.4), P = 0.05] versus non-pain group. On the dominant side, no significance was observed. The study found that hip flexion angle on the non-dominate leg for the group without LBP and group with LBP were 61.4° (12.6) and 63.2° (8.6) respectively. In contrast on the dominate legs the report mean values were reported as 66.7° (10.2) and 64.6° (8.7) respectively. The significances of these finding were not compared as dominant - nondominant difference within the group and then compared between groups.
Discussions	The reporting of the conduct of the study contained in the article was variable. The reporting of the recruitment of subjects was poor, as significant variables which may have influenced the applicability of the articles were not included. In contrasts to the recruiting methods and many other ASLR studies, the sample analysed was well defined in terms of the functional deficit associated with LBP, i.e., Lumbar Flexion Rotation Syndrome. However, in practical terms, this specificity greatly limits the general applicability of the results, which reduces the external validity. Additionally, as the ASLR technique utilised in this article did not conform to the techniques described by Mens *et al.* (2002), Mens *et al.* (1999), or Cook (2010).
Conclusion:	The study found excessive lumbopelvic posterior rotation in subjects with Lumbar Flexion Rotation Syndrome during ASLR. Significantly, this counters Mens *et al.* (1999) findings of anterior rotation of the pelvis, the generally accepted biomechanical explanation for the ASLR findings, rather supporting Kibsgård *et al.* (2017) findings in severe PGP where posterior rotation was also observed. The authors observed that there was no significant difference in hip flexion with greater lumbopelvic motion being observed in the first half of motion (=/- 32 degrees of hip flexion). However, these findings are brought into question to potential internal validity and reliability questions raised by this review. The poorly reported and potentially bias recruitment practises were highlighted in conjunction with the unsupported ASLR technique as reducing the internal validity and reliability of the study. The internal validity was further reduced by the selected study design which introduce potential bias while reducing the general representations of the sample, thereby also reducing the external validity of the sample. The specificity of the sample, male with, Lumbar Flexion Rotation Syndrome, also significantly reduced the external validity. Therefore, the article provides limited evidence that when subjects with lumbar Flexion + Rotation syndrome perform the ASLR with their non-dominate leg, excessive posterior lumbopelvic tilt occurs first half of the RoM, as well as the movement being more synchronous than healthy subjects (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).

Table 4.29: Tabulated Data – Data Group 2 – Article 6 Table 1

Authors	Shadmehr, Jafarian and Talebian		**Year**	**2**012		
Article Title	Changes in Recruitment of Pelvic Stabilizer Muscles in People with and Without Sacroiliac Joint Pain During the Active Straight Leg Raise Test					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
Are the study participants well-defined in terms of time, place, and person?	*Reasonably, data given. Little on background of controls*	*B1*	*B1*	*B1*	*B1*	*100%*
What percentage of individuals refused to participate?	*No data given regarding those refusing to take part*	*I*	*I*	*I*	*I*	*100%*
Are outcomes measured in a standard, valid and reliable way?	*Description of techniques given (ASLR poorly defined), however no examiner detail (single or multiple examiners), no intra-reliability or repeated measures assessments and no mention of blinding of examiners regarding group of subjects*	*C*	*C*	*B2*	*C*	*67%*
Are outcomes measured in the same way for both intervention and control groups?	*Apparently, however as the side measured in the SIJP group was the side of the pain and that in the control was dominant side, this might have resulted in non-dominant side measurements being made in the SIJP group. No data presented regarding this issue.*	*B2*	*B2*	*B1*	*B2*	*67%*
Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Only females, yet no indication of place in the menstrual cycle at the time of each measurement. As tissue changes are associated with menstrual cycle changes, this could be a confounding variable.* *Dominant limb analysed in the control group while symptomatic side analysed in the test group.* *Systemic and neurological pathologies were not excluded.*	*B1*	*B1*	*B1*	*B1*	*100%*
What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*n/a*	*I*	*I*	*I*	*I*	*100%*
Is the analysis by intension to intervene (treat)?	*n/a*	*N/A*	*N/A*	*I*	*N/A*	*67%*
Are results homogeneous between sites? (multicentre/ multisite studies only).	*n/a*	*I*	*I*	*I*	*I*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?		*C*	*C*	*C*	*C*	*100%*
Is the overall effect of the study due to the study intervention?		*B1*	*B1*	*B1*	*B1*	*100%*
Explain if there is any practical/ethical reason why an RCT cannot be done		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Include any other comments						

Table 4.30: Tabulated Feedback Data Group 2 – Article 6 Table 2

Authors	Shadmehr, Jafarian and Talebian		**Year**		2012			
Title	Changes in Recruitment of Pelvic Stabilizer Muscles in People with and Without Sacroiliac Joint Pain During the Active Straight Leg Raise Test							
Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Surface EMG	Baseline	Not apparent but appears to be single assessment	n = 30 SIJP n = 15	No	Yes n = 15	No	3B	92%
Limitations	The article was unclear as to how subjects were recruited, as the only statement about recruitment was that a Dr H. Mazaheri was "responsible for introducing the patients." Subsequently there is no way to determine the representativeness of the sample (Meinert and Piantadosi 2022). No statement was provided as to whether the assessors were blinded or not. It is, therefore, assumed that the study was unblinded, introducing the potential for bias and reducing the external validity of the article (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. This reduces the external validity of the article (Meinert and Piantadosi 2022). The subject sample was gender homogenous (female n=30) therefore, results may, therefore, not be applicable to males, due to difference in biomechanics and physiology (Meinert and Piantadosi 2022). Additionally, the sample all had unilateral SIJP, therefore results may not be applicable to bilateral pain. However, the chronicity of the sample was heterogenous as it included subacute and chronic pain conditions, as pain had to be present for at least 2 months (Meinert and Piantadosi 2022) N = 30 subjects (n = 15 SIJP; n =15 control) were recruited. The age distribution is wide, improving the external validity. However, the results may still not be applicable to adults in later life, >55Y.o.A, due to alterations in the disc morphology and segmental ankylosis, which may lead to changes in biomechanics (Norasteh 2012).							
Outcomes	Subject with SIJP demonstrated a greatly increased latency of the AL following the initiation of the ASLR test (P = 0.002) in comparison to the pain free controls, with values of −407.93 and 118 milliseconds respectively. During the ASLR, activity of certain muscles was also significantly lower in the following groups, with the EO (P = 0.012), BF (P = 0.008)), GM (P = 0.43), and ES (P = 0.029) compared to the control group. The time to complete the ASLR was also significantly increased in the SIJP group (P = 0.034) with the mean duration and standard deviation of duration in the SIJP group -been greater than control, 1.79 ± 0.72 and 1.36 ± 0.27 respectively.							
Discussions	The external validity of the article was bad due to numerous factors. The poor reporting of subject recruitment made it impossible to determine if the recruited population was representative of the general populace, with subsequent factors compounding this. When the statement of Dr H. Mazaheri was responsible for introducing the patients is examined in conjunction with failure to blind the examiners and lack of randomisation, it is a high likelihood of bias. The subject sample is, therefore, not likely to be representative of the general populace. Therefore, the external validity is significantly reduced (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). Exclusion criteria did not exclude neurological or systemic pathologies which may influence results, as these may influence neuromuscular control. The article also made no reference to DMR assessments, so it is unlikely a neurological assessment was performed. Additionally, the wide age distribution (18-50) years and pain profile (subacute and chronic, pain had to be present for at least 2 months) further enhances the general applicability. Theses would be beneficial to the external validity as the results are more generally applicable (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).							
Conclusion	The internal validity of the study was low due to study design and very poor methodology. Bias was potentially introduced in the selection of subjects (see limitations), as well as the lack of blinding and randomisation. While anthropometric data was provided, the authors of the article failed to inform readers as to the severity of the pain. In addition, the chronicity of the pain included both subacute and chronic subjects, introducing variance into the sample. Further significant confounding variables was introduced by the failure to exclude							

	systemic and neurological pathology, and to conduct DMR examination. This is problematic in the use of EMG studies as peripheral and central neural pathologies may influence neuromuscular control. Furthermore, the muscle was not examined to exclude myofascial trigger point in the muscle, which may refer pain to the SIJ, altering muscle recruitment (Simmons and Travell. 2017). This was compounded by inconsistent study of the legs, as only the dominate leg was examined in the control group whilst the SIJP groups' symptomatic leg was studied. This is significant, as the dominated limb is usually more coordinated than the non-dominated limb leading to potentially greater force experience and, therefore, ease of lift (Hart *et al.* 2014; Ceroni *et al.* 2012). The reliability of the study is questionable, as no data pertaining to the testers experience or qualifications is provided nor were any retest studies undertaken. This reduces the external validity of the results (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). Due to missing data, in combination with introduction of confounding variables without reliability studies, and high risk of bias, the reviewers concluded that internal validity of the study was low and external validity of the study was poor (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). Therefore, there is no evidence to support the assertion that SIJP subjects have alterations in MC strategy that influence load transfer through the pelvis. The study needs to be replicated with the confounding variables been reported and with improved reporting. For a more accurate analysis, and, therefore, reliability, validity and general applicability, sub-analysis should have been conducted by limb dominance for both symptomatic and control groups.

Group 3

Table 4.31: Tabulated Data – Data Group 3 – Article 3 Table 1

Authors	Beales, O'Sullivan, and Briffa		**Year**	**2009**		
Article Title	Motor Control Patterns During an Active Straight Leg Raise in Chronic Pelvic Girdle Pain Subjects					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
Are the study participants well-defined in terms of time, place, and person?	*Based on the extremely small sample size, the study participant's characteristics could have been better described rather than in table format of Means and SD's only. No timeframe provided either, or trial setting.*	*B1*	*B1*	*B2*	*B1*	*67%*
What percentage of individuals refused to participate?	*Information not provided.*	*I*	*I*	*I*	*I*	*100%*
Are outcomes measured in a standard, valid and reliable way?	*Yes*	*A*	*A*	*A*	*A*	*100%*
Are outcomes measured in the same way for both intervention and control groups?	*A repeat measure study with no control group*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Single group study with poor subject characteristic description (i.e. table with SD and means), compromising reviewers' ability to discern possible influence of confounding variables.*	*B1*	*B1*	*B1*	*B1*	*100%*
What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*No statement of initial recruitment, only 12 recruited for examination. 2 subjects were unable to complete the repeated measures.*	*I*	*A*	*I*	*I*	*67%*
Is the analysis by intension to intervene (treat)?	*Yes.*	*A*	*A*	*A*	*A*	*100%*
Are results homogeneous between sites? (multicentre/ multisite studies only).		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*The extremely small sample size may in itself result in bias. This may have resulted in a type 1 error.*	*B2*	*B2*	*B2*	*B2*	*100%*
Is the overall effect of the study due to the study intervention?	*"It was hypothesized that PGP subjects would demonstrate (1) altered muscle patterning lifting the affected leg, (2) altered patterning would equate to a bracing strategy, and (3) these changes would be associated with the generation of higher levels of IAP and pelvic floor (PF) depression." "This study documents multiple facets of altered MC strategies in chronic PGP subjects during an ASLR. ● During an ASLR, lifting the leg on the affected side of the body, PGP subjects demonstrated bracing through the abdominal wall and CW, increased generation of IAP, and depression of the PF."*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Explain if there is any practical/ethical reason why an RCT cannot be done	*Repeated measures assessment*	*N/A*	*N/A*	*B2*	*N/A*	*67%*
Include any other comments	*Would have been less bias if there had been a control group assessed that did not suffer from PGP.*					

Table 4.32: Tabulated Feedback Data Group 3 – Article 3 Table 2

Authors	Beales, O'Sullivan, and Briffa	**Year**	2009					
Title	Motor Control Patterns During an Active Straight Leg Raise in Chronic Pelvic Girdle Pain Subjects							
	Study Properties							
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
EMG: IO EO RA Chest wall (CW) Scalene RR Pain and disability: The Quebec Back Pain Disability Scale McGill Pain Questionnaire VAS Tampa Scale for Kinesiophobia Urogenital Distress Inventory (UDI) Contralateral leg pressure	n=1, repetition n=3	Not provided	n=12 females	No	No	No	3A	92%
Limitations	The only recruitment data provided was that subjects were recruited from the Perth metropolitan region. This limited data makes impossible to determine if the outcomes of the article are applicable to the general population, therefore reducing external validity (Meinert and Piantadosi 2022). The design was a cohort observational study; therefore, the study only had the potential for single blinding. As the article failed to state whether the assessors were blinded, it was assumed that no blinding had occurred. This increased potential for bias, reducing the external validity of the study. The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not. This reduces the external validity of the articles results (Meinert and Piantadosi 2022). The sample was gender homogenous with well-defined inclusion criteria (pain location, no referral to lumbar spine, 3 out 5 SIJ pain provocation tests positive, positive ASLR relieved by compression, with no positive lumbar or neurological testing), therefore, findings may not be applicable to males, bilateral PGP, and/or individuals with excessive form closure (Meinert and Piantadosi 2022). The total sample size was small (n=12) which impairs the ability to generalisation the findings (Neumayer and Plumper. 2017, Stommel and Willis. 2004). The subjects had chronic (>6 months) unilateral PGP; therefore, results may not be applicable to acute and subacute, and/or bilateral pain states (Meinert and Piantadosi 2022). The protocol utilised three repetitions, therefore, introducing the for fatigue and irritation. The results of this article may, therefore, not be applicable in clinical setting which use other ASLR parameters. The EMG analysis did not include TrA and PFM, therefore results do not allow clinicians to applied data to these area of MC during the development of rehabilitation protocols.							
Outcomes	When ASLR was performed on the symptomatic side, the dominant MC pattern observed was bracing of the abdominal and chest walls with an associated increase in IAP and depression of the pelvic floor when compared to the non-symptomatic side.							

Discussions	External validity of the study was low as many variables were well controlled for. The inclusion criteria were well defined especially in relation to pain profile (pain location, no referral to lumbar spine, 3 out 5 SIJ pain provocation tests positive, positive ASLR relieved by compression, with no positive lumbar or neurological testing) therefore findings may not be applicable to subacute / acute, nonchronic, bilateral PGP, and/or individuals with excessive form closure. When the small sample size and gender homogeneity are considered, the pool of people the sample potentially represents is greatly reduced, significantly reducing the external validity of the study. The external validity of the sample was further reduced by the inherent risk of bias introduced by study design (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). However, the heterogenous aetiologies improved the external validity (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).
Conclusion	There was high consensus amongst the reviewers that the internal validity of the article was poor due to a combination of article design and reporting. The study design of the article imparted inherent bias due to lack of blinding, randomisation, and control group. Furthermore, the aetiologies of PGP varied greatly ((Meinert and Piantadosi 2022), potentially introducing confounding variables, as subsequent articles have reported variations in MC strategies. Poor reporting (no information on recruitment, use of standard deviations in reporting) were suggested by reviewers to impair the ability to adequately assess subjects as well as confounding variables. The reviewers also believed that these factors were of greater significance when considering the low power of the study. Subsequently, the reviewers concluded that had the articles design and/or reporting been of higher standard, the outcomes and conclusions were likely to change (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). While the subjects recruited in this study were gender homogenous and the power of the study was low, the findings of concur with those of PPGP subjects in other subjects, with greater EO activation compared to pain free subjects (de Groot *et al.* 2008), this provides face validity to the findings of this study (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). However, the validity of chest wall and abdomen splinting are problematic as no pain free control group was used in this study therefore the findings were contrast against the result from another study. Subjects in this study demonstrated a MCS of bilateral tonic activation for IO and EO. This MCS contrasted to those displayed in nulliparous females with pain by having greater activation of the IO. This study provides limited evidence on the MC strategies in the abdominal and chest walls during the performance of the ASLR due to poor internal validity and moderate external validity. The review determined that this study needs to be reproduced with higher power, stricter inclusion criteria for aetiology, and improved performance (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).

Table 4.33: Tabulated Data – Data Group 3 – Article 4 Table 1

Authors	Castro *et al.*		**Year**	2019		
Article Title	Assessing the Construct Validity of Clinical Tests to Identify Sacroiliac Joint Inflammation in Patients with Non-radiographic Axial Spondyloarthritis					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
Are the study participants well-defined in terms of time, place, and person?	*Well defined except for timing of study.*	*B1*	*B1*	*B1*	*B1*	*100%*
What percentage of individuals refused to participate?	*Not mentioned how many potential participants were recruited. Only mentions that total analysed sample size was 20.*	*I*	*I*	*I*	*I*	*100%*
Are outcomes measured in a standard, valid and reliable way?	*Yes*	*A*	*A*	*A*	*A*	*100%*
Are outcomes measured in the same way for both intervention and control groups?	*There is no control group in the form of participants without the condition. However, outcome measures are the same for both the groups with MRI changes and without.*	*B1*	*A*	*B1*	*A*	*67%*
Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*The baseline characteristics of both groups are assessed for statistical differences in age, gender, body mass and Body height based on their MRI findings. However, with the small sample size there is still the possibility of Type 1 error occurring.*	*B1*	*A*	*B1*	*B1*	*67%*
What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*The authors do mention that there was 1 participant excluded from analysis. "A total of 21 participants with nrAxSpA were enrolled in this study. One participant was excluded from data analysis as an adductor tear was observed in his MRI assessment. A final sample of 20 participants were included for analysis (Table 1)."*	*A*	*A*	*A*	*A*	*100%*
Is the analysis by intension to intervene (treat)?	*Yes*	*A*	*A*	*A*	*A*	*100%*
Are results homogeneous between sites? (multicentre/ multisite studies only).		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*The extremely small sample size may in itself result in bias. This may have resulted in a type 1 error. Would also have been good if the authors could have included a control group for comparison.*	*B2*	*B2*	*B2*	*B2*	*100%*
Is the overall effect of the study due to the study intervention?	*Due to the pathology*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Explain if there is any practical/ethical reason why an RCT cannot be done		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Include any other comments	*Would also have been good if the authors could have included a control group for comparison. However, cost of MRI may have been a factor.*					

Table 4.34: Tabulated Feedback Data Group 3 – Article 4 Table 2

Authors	Castro *et al.*	**Year**	**2**019
Title	Assessing the Construct Validity of Clinical Tests to Identify Sacroiliac Joint Inflammation in Patients with Non-radiographic Axial Spondyloarthritis		

	Study Properties							
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Imaging: MRI [Spondyloarthritis Research Consortium of Canada scoring system (SPARCC)] Motor control: ASLR Stalk stand Pain provocation tests: Gaenslens Posterior pelvic pain Patrick Faber Palpation of LPL Blood: CRP Human leukocyte antigen (HLA)-B27 Functional Indices: The Outcome Measures in Rheumatology (OMERACT) Ankylosing Spondylitis Disease Activity Score (ASDAS) Bath Ankylosing Spondylitis Disease Activity Index (BASDAI) Bath Ankylosing Spondylitis Functional Index (BASFI) AS Quality of Life (ASQoL)	Single	2 consecutive days	n=20(21) (Males n=7, females n=13)	Yes	No	No	3B	92%

Limitations	Subjects were recruited from a rheumatology outpatient clinic at Dunedin Hospital in New Zealand, as such that are likely receiving specialist care and are, therefore, more severe than the general axial spondyloarthritis population. The exclusion criteria of inability to tolerate a physical examination however may lead to results not been applicable to the most severe cases (Meinert and Piantadosi 2022). As the design was a cohort observational only single blinding of the assessor was possible and undertaken. This introduces the potential bias, reducing the general applicability of the study and, therefore, the external validity of the study (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The sample of this article was heterogenous due to the inclusion criteria, which generated two subsamples. The first subsample consisted of subjects with sacroiliitis on MRI and at least one feature of SpA (inflammatory back pain, arthritis, enthesitis, uveitis, dactylitis, psoriasis, ulcerative colitis), good response to nonsteroidal anti-inflammatory drugs (NSAIDs), family history for SpA, positive human leukocyte antigen (HLA)-B27, elevated C-reactive protein (CRP). In contrast, the second subsample had a positive HLA-B27 and two features of SpA. The homogeneity of the two also greatly differed as the group ratio of males to females in the inflammatory positive on MRI was 3:4 and 4:9 respectively. Additionally, the first subgroup had no subjects utilizing DMARDS whilst the second subgroup did. It is possible that the use of analgesic prevented pain perception and inhibition, altering MCS (de Azevedo Martins *et al.* 2018). These results would there

	only be applicable to patients on analgesic with similar biological outcomes, which reduces the general applicability of results the study and, therefore, the external validity of the study (Meinert and Piantadosi 2022; Lee 2012). As a clinical diagnosis of nrAxSpA within the last 2 years, results may not be applicable to those with longer duration diagnosis who are likely to have received greater intervention. As all surveys and physical testing was undertaken in the afternoon to minimize the effect of morning stiffness, results are less likely to be applicable to the morning patients (Meinert and Piantadosi 2022).
Outcomes	The article demonstrated that functional testing, which included the ASLR (Sn = 71%, Sp = 46%), had poor accuracy compared to pain provocation test. Additionally, pain provocation tests presented with greatest predictive value when used in combinations.
Discussions	The recruited sample was gender heterogenous and utilising medication. While the inclusion of subjects prescribed pharmaceutical created a significant variable in the study, as the site of recruitment (Rheumatoid clinic) suggests greater severity in pain and dysfunction, the administration of these products may have mitigated the symptoms and presentation altering the findings and conclusions of the article. While the internal validity may have been significantly affected, the external validity was greatly enhanced, as patient encountered in the clinical setting by health professional are frequently consuming some form of medication (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The limitation of subjects to under two years diagnosis while recruiting from a specialist rheumatoid clinic greatly reduces the external validity of the study, as many patients present with presentation of longer than two years if the condition is mild / well managed. As subjects were attending the rheumatology, they are likely to be serve. As the study did not look at domains such as neuromuscular control it is difficult to fully ascertain the value of the ASLR. Further study is required to determine if the ASLR provides any additional clinical value in these domains (Palsson *et al.* 2012).
Conclusion	The internal validity of the study was poor. This was primarily a result of the heterogeneity of the sample created by the inclusion criteria, which created two distinct subgroups and, therefore, confounding variables. While statistical analysis was performed and the results commented on the power of the subgroups was low, potentially rendering the interpretation of results problematic due to statistical error. The study design also did not account for the parameter of motor control during the performance of the motor control test (i.e. ASLR), rather comparing the functional test to pain provocation tests in the domains of pain and disability (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The requirement of a clinical diagnosis of nrAxSpA within the last 2 years influence both the internal and external validity of the study by creating confounding variables and perhaps reducing the applicability of results to life-long suffers of subclinical nrAxSpA. The study was found to have poor rigor, due to moderate internal validity and poor external validity (Lee 2012). The low power and the use of medication were considered to have the potential alter the outcomes of the study. In clinical practise, practitioner need to consider the ASLR findings in conjunction with other tests when examining axial spondyloarthritis.

Table 4:35: Tabulated Data – Data Group 3 – Article 5 Table 1

Authors	Kibsgård *et al.*		**Year**	2017		
Article Title	Movement of the Sacroiliac Joint During the Active Straight Leg Raise Test in Patients with Long-lasting Severe Sacroiliac Joint Pain					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
Are the study participants well-defined in terms of time, place, and person?	*Very little description of participants provided. Only means and ranges. With such a small sample it would have been better if the authors were able to provide more information.*	*A*	*A*	*B1*	*B1*	*67%*
What percentage of individuals refused to participate?	*Not mentioned how many potential participants were recruited. Only mentions that total analysed sample size was 12.*	*I*	*I*	*I*	*I*	*100%*
Are outcomes measured in a standard, valid and reliable way?	*Yes*	*A*	*A*	*A*	*A*	*100%*
Are outcomes measured in the same way for both intervention and control groups?	*There is no control group in the form of participants without the condition.*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*It is mentioned that all patients had normal MRI findings, however there is quite a range in the patients characteristics. Outliers may influence small sample size.* *Small sample, but gold standard method of measurement*	*B1*	*B1*	*B2*	*B1*	*67%*
What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*Authors mentioned that of the 17 participants recruited, only 12 were analysed.*	*A*	*A*	*A*	*A*	*100%*
Is the analysis by intension to intervene (treat)?	*Yes*	*A*	*A*	*A*	*A*	*100%*
Are results homogeneous between sites? (multicentre/ multisite studies only).	*Information not provided* *Xray calibrations provided*	*A*	*A*	*I*	*A*	*67%*
OVERALL ASSESSMENT OF THE STUDY:						
How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*The extremely small sample size may in itself results in bias. This may have resulted in a type 1 error. Would also have been good if the authors could have included a control group for comparison.*	*B1*	*B1*	*B2*	*B2*	*67%*
Is the overall effect of the study due to the study intervention?		*A*	*A*	*N/A*	*A*	*67%*
Explain if there is any practical/ethical reason why an RCT cannot be done		*N/A*	*N/A*	*N/A*	*N/A*	*67%*
Include any other comments	*Would also have been good if the authors could have included a control group for comparison. However, cost of MRI may have been a factor.*					

Table 4.36: Tabulated Feedback Data Group 3 – Article 5 Table 2

Authors	Kibsgård *et al.*			**Year**		2017		
Title	Movement of the Sacroiliac Joint During the Active Straight Leg Raise Test in Patients with Long-lasting Severe Sacroiliac Joint Pain							
Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Radiostereometric analysis	1	3 years	12 (17)	No	No	No	3A	88%
Limitations	Subjects were recruited from one of two orthopaedic centres, Oslo University Hospital in Norway and Ängelholm Hospital in Sweden, from patients assigned for spinal fusion. These cases are likely to be the most severe and would not represent the general PGP population (Meinert and Piantadosi 2022). No blinding was undertaken during the undertaking of the study. No control group was utilised as the investigation technique was invasive therefore only symptomatic subjects could participate (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were recruited based on whether or not they meet the criteria for SIJ fusion. The sample was heterogenous in gender (n=1 male and n=11 females) and SIJP presentation (unilateral, n=4, and bilateral, n=8, SIJP). However, only a single male was included in the sample therefore the results are likely to have poor correlation to males and, therefore, poor external validity for this group (Meinert and Piantadosi 2022). The sample size of the article was small (n = 12) low, decreasing the ability to generalise findings. Duration of the presentations were all chronic (1.5 and 20 years, mean=8years) therefore results may not be applicable to acute and subacute LBP presentations. The age range of the sample was 29 to 47 Y.o.A. (mean = 39), therefore results may not be applicable out of these ranges in which different stages of pathological process may be present (Meinert and Piantadosi 2022).							
Outcomes	The article found that only small movements were detectable at the SIJ. The stationary limbs SIJ had greater movement compared to the active limb, with a mean backward rotation of 0.8° and inward tilt of 0.3° observed.							
Discussions	The article was well control, having good internal validity and, therefore, general applicability and poor external validity due to lack of variables. The sample was recruited at two hospitals and acknowledged as being severe and chronic, awaiting SIJ fusion. This reinforces the poor transferability of results to other severities of SIJ. The inclusion of unilateral and bilateral PGP allows the findings to be applied to all severe chronic PGP cases. While the sample was gender heterogenous, the inclusion of a single male introduces the potential for confounding variable while arguably not improving the general applicability of findings to the male populace (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).							
Conclusion	The internal validity of the study was good, with most variables being well controlled. While the sample size was small, rendering the potential for the introduction a type 1 statistical error, this must however be considered in regard of the quality of the measures. Studies that utilise high quality, quantitative measures that are invasive frequently use small samples due to the cost involved and clinical applicability. However, the authors of the article highlight that while radiostereometric analysis is a highly accurate measure of SIJ motion, currently being considered the gold standard, the small movements observed were so small that they fall beneath the accuracy of measure (Hansen *et al.* 2018, Keller, Hurschler and Schwarze. 2021; Kibsgård *et al*. 2017). A mean backward rotation of 0.8° and inward tilt of 0.3° were observed in the rested leg's sacroiliac joint. As the internal validity of the study was high, the external validity was poor this article provides (Lee 2012). The article findings challenge many of the paradigms utilised to explain the mechanism of the ASLR. The small movements observed at the SIJ challenge the accepted concepts of form closure as this small movement are consistent with those observed in the weight bearing position. Additionally, posterior rotation of the inanimate contradict							

	other radiographical ASLR studies, namely Mens *et al.* 1999, and supports the seminal work conducted by Chamberlain (1936). These findings may need to be viewed in the following context, the measure of movement centred on the SIJ rather than the pubic symphysis, the power of the study was similar to comparative studies, namely Mens *et al.* (1999), but used significantly more accurate equipment but the article had poor external validity. The invasive nature of the measurement technique creates significant questions as whether the replication studies can be undertaken in less severe forms of PGP, to improve external validity. However, the questions raise by this study should necessitate revaluation of assumptions made by Mens *et al.* (1999). Further study required to generate greater power to make the study more applicable, especially on male subjects.

Table 4.37: Tabulated Data – Data Group 3 – Article 7 Table 1

Authors	Rabin *et al.*.		**Year**	2013		
Article Title	The Interrater Reliability of Physical Examination Tests That May Predict the Outcome or Suggest the Need for Lumbar Stabilization Exercises					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
Are the study participants well-defined in terms of time, place, and person?	*Timeframe of the study is not provided. Other criteria are not well-defined either as these are not mentioned in the text clearly, and where placed in the tables, this seems to contradict sections in the text. "Thirty patients with low back pain, who participated in a larger randomized clinical trial, underwent all tests by 2 independent examiners" "Data were collected on 30 subjects overall. Due to time constraints, the examiners were not able to perform all tests on every subject" Table 1 " (females), n 15 "Previous LBP (subjects), n 20 "*	*B2*	*B2*	*B2*	*B2*	*100%*
What percentage of individuals refused to participate?	*Information not provided.*	*I*	*I*	*I*	*I*	*100%*
Are outcomes measured in a standard, valid and reliable way?	*The experience levels of the raters' varied significantly, along with the numbers of participants rated by each, which may have had some effect on the outcomes. Some measures were also self-reported which may be less reliable. Also, not all tests were performed on all participants which may have influenced the outcomes.*	*B2*	*B2*	*B2*	*B2*	*100%*
Are outcomes measured in the same way for both intervention and control groups?	*There was no control group in terms of assessing inter-rater reliability of the tests in asymptomatic individuals. The SD for the subjects also appears high for some characteristics*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*The experience levels of the raters' varied significantly, along with the numbers of participants rated by each, which may have had some effect on the outcomes. Not all tests were performed on all participants which may have influenced the outcomes. Its not mentioned which tests were performed and on how many participants.*	*B1*	*B2*	*B1*	*B1*	*67%*
What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*This information is not clearly provided as tables seem to contradict the text.*	*B1*	*B1*	*B2*	*B1*	*67%*
Is the analysis by intension to intervene (treat)?	*Study to be applied to rehabilitation*	*A*	*A*	*N/A*	*A*	*67%*
Are results homogeneous between sites? (multicentre/ multisite studies only).		*I*	*I*	*B1*	*I*	*67%*
OVERALL ASSESSMENT OF THE STUDY:						
How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	May be some bias as not all tests were rated and there is varied experience between raters.	B1	B1	B1	B1	100%
Is the overall effect of the study due to the study intervention?		B1	B1	N/A	B1	67%
Explain if there is any practical/ethical reason why an RCT cannot be done	It would be better if the study could have assessed all tests and had similar raters.	N/A	N/A	N/A	N/A	100%
Include any other comments	May be some bias as not all tests were rated and there is varied experience between raters.			B2		

Table 4.38: Tabulated Feedback Data Group 3 – Article 7 Table 2

Authors	Rabin *et al*.		**Year**		2013		
Title	The Interrater Reliability of Physical Examination Tests That May Predict the Outcome or Suggest the Need for Lumbar Stabilization Exercises						
Study Properties							
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Aberrant Lumbar Movements: Painful arc on flexion Painful arc on return Instability catch Gower sign ("thigh climbing") Reverse lumbopelvic rhythm Via: PSLR AHAbd ASLR PIT LELT PLET	Baseline	Not stated	n=30 (males n=15 females n=15)	Yes	No	No	3A	85%
Limitations	The subject sample was consecutively recruited a larger RTC. These subjects were attending one of four outpatient clinic of Clait Health Service in Tel Aviv metropolitan area in Israel. The sample is, therefore, not likely to represent the general population (Meinert and Piantadosi 2022). The design was a cohort observational study therefore the study only had the potential for single blinding and was undertaken (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). No controls were utilised in the study, and subjects were only included if they were symptomatic. This introduces the potential for bias, reducing the external validity of the article's findings (Meinert and Piantadosi 2022). The sample was heterogenous with the genders equally represented (N = 15 males, n = 15 females). This improves the external validity of the findings (Meinert and Piantadosi 2022). The sample size of the article was moderate, with n=30 (male n=15 females n=15) subjects with a wide age of 18 and 60 years. The inclusion criteria had a main complaint of LBP and/or related leg symptoms of any duration. Due to the exclusion criteria, the results may not be applicable to NRE or sLBP (Meinert and Piantadosi 2022). If the subjects were identified and recruited, it is then possible that they would not be naïve to the test. All tests were conducted in a specific sequence, thereby introducing the potential for order effect, via fatigue and irritability of painful structures (Li *et al.* 2021, Petty and Ryder. 2017). All examiners in the study had significance with clinical experience as physical therapists ranging from thirteen to twenty-five years of experience as physical therapist. This makes the application to less experienced practitioners problematic, thus effecting the external validity of the study (Huebschmann, Leavitt, and Glasgow 2019).							
Outcomes	The interrater reliability of the individual items of the CPR were found to be moderate however in combination to form the CPR the interrater reliability was good (κ = 0.86; 95% CI: 0.65, 1.00). Individual test's reliability varied PLE interrater reliability was found to be good (κ = 0.64-0.73 and κ = 0.76, respectively; 95% CI: 0.46, 1.00) whilst the ASLR's and LELT interrater reliability were moderate (κ = 0.53; 95% CI: 0.20, 0.84 and κ = 0.47; 95% CI: 0.14, 0.78, respectively). In contrast the interrater reliability of the AHAbd was poor (κ = –0.09; 95% CI; –0.35, 0.27).							

Discussions	The recruitment methodology of the article significantly reduces the general representativeness of the article, as the subjects were recruited from a larger RTC. There were no details provided for the recruitment methodology for the RTC, nor was an explanation given as to why this article's researchers decided to recruit in a consecutive manner from the RTC. This lack of transparency introduces a significant potential for bias in the recruitment process. Additionally, no information was provided on the RTC to allow for evaluation of the intervention on the sample therefore allowing further reducing the ability to evaluate the samples general representativeness of the general populace. These recruitment factors significantly reduce the overall quality of the article as both internal and external validity from the start (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The moderate sample size, gender heterogeneity, wide age distribution, and inclusion of subjects with and without radicular referral greatly improve the general applicability of the findings. All these factors create multiple variables which are more likely to be encounter within the clinical setting, improving the external validity of the study (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).
Conclusion	The internal validity of the study was poor as numerous criteria were found to be poorly define, chief amongst this was the recruitment process. It was highlighted amongst reviewers beside the problematic recruitment process, varied tester experience and not conducting test on all subjects significantly reduce the quality of the review and may have resulted in some bias. Additionally, the failure to control order effect and the inclusion of LBP subjects with and without referral may have introduce a confounding variable in the results. These factors may all account for the authors of the studied finding large confidence interval for some the tests examine. Subsequently, there is high consensus amongst the reviewers in this study that had the article had greater internal validity the results would have changed (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). While the study contained many variables that should have improve the external validity article (see discussion), the poor recruitment procedure ultimately undermines these factors from the outset and were deemed to be significant enough to be irredeemable. Therefore, the external was evaluated as poor (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). While the article suggests that apart from the AHAbd test, that all other clinical tests are sufficiently reliable for clinical application analysis of the tables demonstrate the study has poor internal and external validity as such this study provides limited evidence to support the use of the ASLR. The application of this study to clinical practise and a validation study is required in which the identified methodological errors are removed, and confounding variables controlled (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).

Table 4.39: Tabulated Data – Data Group 3 – Article 8 Table 1

Authors	Sasaki *et al.*		**Year**	2011		
Article Title	Muscle Strength During ASLR Correlates with Walking Capacity in Patients with Lumbar Spine Stenosis with Neurogenic Intermittent Claudication					
EVALUATION CRITERIA FOR THE STUDY	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
Are the study participants well-defined in terms of time, place, and person?	*Study subjects are well defined; however, place and time are not.*	*B1*	*B1*	*B2*	*B2*	*67%*
What percentage of individuals refused to participate?	*Information not provided.*	*I*	*I*	*I*	*I*	*100%*
Are outcomes measured in a standard, valid and reliable way?	*Measures appear to be fairly valid and reliable for the condition.* *ASLR use 30 degrees, and only conducted on the symptomatic side*	*B1*	*B1*	*A*	*B1*	*67%*
Are outcomes measured in the same way for both intervention and control groups?		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*This is not mentioned in the study; however, it appears the participants were purposively selected. There does however appear to be quite a difference in SD of the other parameters between the subjects.*	*A*	*A*	*B1*	*A*	*67%*
What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)		*A*	*A*	*N/A*	*A*	*67%*
Is the analysis by intension to intervene (treat)?	*Yes*	*A*	*A*	*A*	*A*	*100%*
Are results homogeneous between sites? (multicentre/ multisite studies only).		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
How well was the study done to minimise bias? If coded as B1, B2 or C, what is the likely direction in which bias might affect the study result?	*The study keeps referring to "we" but does not specify who the "we" consists of.*	*C*	*C*	*C*	*C*	*100%*
Is the overall effect of the study due to the study intervention?	*This is implied*	*B1*	*B1*	*B1*	*B1*	*100%*
Explain if there is any practical/ethical reason why an RCT cannot be done	*There is limited information on the subjects, but more so on the persons conducting the measurements.*	*N/A*	*N/A*	*C*	*N/A*	*67%*
Include any other comments						

Table 4.40: Tabulated Feedback Data Group 3 – Article 8 Table 2

Authors	Sasaki *et al.*		**Year**		2011			
Title	Muscle Strength During ASLR Correlates with Walking Capacity in Patients with Lumbar Spine Stenosis with Neurogenic Intermittent Claudication							
Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Anthropometrics Finger-floor distance (FFD) test (knee extended + knee flexion) ASLR muscle strength using HHD VAS – after upright standing 30s Walking capacity – 25m shuttle (So)	Twice	Not stated	n=56 females	No	No	No	4	85%
Limitations	No data was provided on the selection of participants other than the subjects were assessed by a physical therapist and then consented to their data being used. This suggest that that subjects were severe enough to seek medical attention and may not represent the general populace (Meinert and Piantadosi 2022). The design was a cohort observational study therefore the study only had the potential for single blinding. As the article failed to state whether the assessors were blinded, it was assumed that no blinding had occurred. This increased potential for bias, reducing the external validity (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The sample was homogenous, as all subjects were female and due to variances in some anatomical features, findings may not be representative of those in men (Chau *et al.* 2022). Additionally, all subjects were reported to have L4/5 stenosis. These factors may all reduce the external validity of the findings as results may not be generalisable to nLBP (Meinert and Piantadosi 2022; Huebschmann, Leavitt and Glasgow 2018; Akobeng. 2008). The article utilised a moderate sample size (n = 56), allowing good generalisation of the result, thereby enhancing the external validity of the study. The age range of the sample was 69.86 Y.o.A (+/- 8 years). The results may, therefore, not be applicable to younger subjects due to different pathological mechanisms (Meinert and Piantadosi 2022). The ASLR was only conducted on the symptomatic side. This excludes analysis of potential MCS adaptation on the unaffected side, this potentially reduces the applicability of the study to the clinical setting, as treating the adaptations is often as important as treating the cause to improve function, pain perception, reduce progression, and / or improve self-efficacy (Hu *et al.* 2012). The study only included stenosis of L4/L5 region and, therefore, may not be applicable to other regions of stenosis. As all subjects were able to walk unaided, with no symptoms at rest, it is possible that more severe cases may contain different findings. The experience of the tester of the study was not provided. This makes it impossible to determine to what level of clinical experience that the result may be applicable to, thus undermining the external validity of the study.							
Outcomes	The average WC was found to be 222.9m (+/- 162.3m) and was correlated to the ASLR (r = 0.5, p = 0.01). WC was not affected by age. Concurrently, the ASLR was also not related to age or BMI.							

Discussions	The external validity of the article was poor due to the gender homogeneity, age range of the sample and specificity of location which greatly reduced the general applicability of the results. The specificity of location means that the results may not be applicable to other areas of the lumbar spine (Meinert and Piantadosi 2022). Additionally, Kalichman *et al* (2009) reported that the incidence of lumbar spine stenosis is almost equal in the genders. However, in terms of age, stenosis occurs less frequently in the younger population, therefore the results sample is most likely to represent the majority of the female population in the clinical setting (Kalichman *et al.* 2009). The sample size was larger than most other study (n = 53), which greatly improves the external validity of the study (Meinert and Piantadosi 2022).
Conclusion	The reviewer of the study had moderate consensus generally but a unanimous consensus that the study had a high risk of bias and had poor internal validity (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The bias was introduced by the study design which lacked randomisation and a control group. It was not apparent in the write up whether blinding of the tester had occurred. Additionally, a single physiotherapist was used to conduct the test, with no information being provided about the individuals' experience, and the pronoun of "we" was utilised in the write up of the study. At no stage was the term "we: clarified but it may be that the incorrect pronoun was used as the authors of the study appear to be Japanese. Furthermore, variations of tests were utilised in the study (e.g. ASLR used 30 degrees of hip flexion) which have no evidence base in the literature. One reviewer concluded that the subjects appeared to be selected for the study. The study demonstrated a correlation between the symptomatic leg during ASLR and WC. Problematically, the non-symptomatic leg was not examined, potentially only half of the adaptation were observed (Hu *et al.* 2012). The study also suggests that the ASLR is more beneficial than the FFD and SLR test in the diagnosis of LCS, with the FFD test reported to have a negative value. The findings of the study were theorised to be due poor abdominal stabilization which allowed lumbar extension and, therefore, narrowing of the intervertebral canal. However, these findings are undermined by the numerous methodological and / or poor reporting of the study which lead the reviewers to attribute a high risk of bias within the study (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The study contained numerous methodological / write up flaws that significantly undermines the internal and external validity of the article, the article provides no evidence on the ASLR but does highlight the need for more study related to the extension component of the ASLR. Additional study is also required in acquired stenosis which generally affects the younger population (Kalichman *et al* 2009).

Table 4.41: Tabulated Data – Data Group 3 – Article 9 Table 1

Authors	Vanti *et al.*		**Year**	2016		
Article Title	The Relationship Between Clinical Instability and Endurance Tests, Pain and Disability in Nonspecific Low Back Pain					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority Ranking**	**Agreement**
Are the study participants well-defined in terms of time, place, and person?	*Location not well defined. However other parameters very clear.*	*B1*	*B1*	*B1*	*B1*	*100%*
What percentage of individuals refused to participate?	*Very clearly defined*	*A*	*A*	*A*	*A*	*100%*
Are outcomes measured in a standard, valid and reliable way?	*The examiners performing the tests appear to be well standardised. However, some of the tests themselves seem to have variable reliability.*	*B1*	*B1*	*B1*	*B1*	*100%*
Are outcomes measured in the same way for both intervention and control groups?	*This is a 1 sample study without a control group.*	*A*	*A*	*A*	*A*	*100%*
Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*The condition was that of non-specific LBP with or without referral. This may have had limited influence on the results. However, the sample size is larger than in some studies of this nature. It also appears from Table 1 that some of the participants were on medications which may have influenced the results, as the authors were looking at pain and disability outcomes.* *Possible sequencing effect*	*C*	*C*	*C*	*C*	*100%*
What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*Authors mention 101 out of the 115 completed the study.*	*A*	*A*	*A*	*A*	*100%*
Is the analysis by intension to intervene (treat)?		*A*	*A*	*N/A*	*A*	*67%*
Are results homogeneous between sites? (multicentre/ multisite studies only).	*Information not provided*	*A*	*A*	*I*	*A*	*67%*
OVERALL ASSESSMENT OF THE STUDY:						
How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*The condition was that of non-specific LBP with or without referral. This may have had limited influence on the results. However, the sample size is larger than in some studies of this nature. It also appears from Table 1 that some of the participants were on medications which may have influenced the results, as the authors were looking at pain and disability outcomes.*	*B2*	*B1*	*B2*	*B2*	*67%*
Is the overall effect of the study due to the study intervention?		*B1*	*B1*	*N/A*	*B1*	*67%*
Explain if there is any practical/ethical reason why an RCT cannot be done	*Would have been good if the study had not included those subjects on medications as this may have influenced the overall results*	*B1*	*B2*	*B2*	*B2*	*67%*
Include any other comments						

Table 4.42: Tabulated Feedback Data Group 3 – Article 9 Table 2

Authors	Vanti *et al.*	**Year**	2016
Title	The Relationship Between Clinical Instability and Endurance Tests, Pain and Disability in Nonspecific Low Back Pain		

Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Instability tests: 1. Aberrant movement 2. ASLR 3. PIT 4. PLET Endurance tests: 1. Prone bridge test 2. Supine bridge test Pain: 1. NRS 2. ODI – Italian version	Single Session	6 months	n=101 after the exclusion of 14 referrals Females n=58 (57.4%) Males n=43 (42.6%)	Yes	No	No	3A	92%
Limitations	All subjects were referred to the study by orthopaedic doctors or medical physicians to an outpatient rehabilitation centre and 2 affiliated physical therapy to receive conservative treatments of nLBP. Therefore, the subjects are more likely unrepresentative of the general population due to more severe pain or to sLBP (Meinert and Piantadosi 2022). The design was a cohort observational study therefore the study only had the potential for single blinding and was undertaken (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The sample was gender heterogenous (n = 43 males, n = 58 females). All subjects had nLBP but were heterogenous for referred symptoms. The sample size was large (n = 115), providing for good generalisation of findings and improving the external validity of the results (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). As such, the subjects may not have been naive to the tests and may have understood their significance thereby further increasing biases. These factors reduce the internal and external validity of the study (Lee 2012). The tests were executed in the same order on every participant; therefore, we may have introduced sequencing effects that were not controlled by counterbalancing (White and McBurney 2012). The examiners had more than ten years of orthopaedic MSK physical therapy experience. Therefore, results may not be applicable to inexperienced practitioners. This, therefore, reduces the external validity of the study (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).							
Outcomes	The percentages of subjects found have a positive test were 54.7% (n=55) for the aberrant movement test, 60.4% for the ASLR (n=61), 34.6% for the PIT (n=35), and 38.67% for the PLE (n=39). 19.8% of subjects (n=20) were negative for all instability tests. The percentage of the number of positive instability tests and subjects was 15.84% (n=16) for all, 19.8% (n=20) for 3, 20.79% (n=21) for 2, 20.79% for 1 test. The means (SDs) for the PBT and for the SBT were 24.32 (25.92) and 81.46 (65.36), respectively.							

	The relationship between clinic tests, pain and disability found that correlations for the pain and disability reported in NRS and ODI-I were similar and had a significant relationship with all tests apart from the PBT in the NRS. The relationships between the instability tests and pain were not significant, except for the PIT. The PIT was however significantly related to pain (P = .001). Both endurance tests (SBT and PBT) were significantly related to the duration of pain. Additionally, the PBT was significantly influenced by the frequency of pain (P = .0079) Low to moderate relationships were observed between the endurance tests (PBT and SBT) and instability tests (AMs, ASLR, PIT, and PLE). The test found to have the most significant relationship and highest correlation was the PBT.
Discussions	Good external validity was created by a large sample (n = 101) with gender heterogeneity, and the use of multiple sites and practitioners. Additionally, subjects with and without referred pain were recruited. All these factors combine to create significant variance in the sample (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). All testers were highly experienced, which may potentially alter the applicability of results to less experienced practitioners or practitioners who do not specialize in MSK.
Conclusion	The internal validity of the study was poor due to combination of study design and the introduction of confounding variable. These factors were largely introduced in the selection and recruitment of subjects. Inclusion criteria allowed for the recruitment of nLBP with or without referral, which may have influenced results. The tests were conducted by three different examiners at three different sites and the data then being aggregated to increase sample size. This introduces the possibility of variance of execution and interpretation of clinical tests. The conclusion of this study was problematic as it appears some subjects were utilising analgesic during this study. This was highlighted a significant confounding variable by reviewers. The results within this study were further undermined by the lack of transparency about testing procedures at the different sites, as it is unlike that the testing was homogenous (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The large sample size and the potential variance create by multisite testing, created good external validity in the sample. Even though the testers were all highly experienced MSK practitioners, this did not detract from the external validity of the sample (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The study suggests that both the endurance and instability are related to the amount of pain and disability in nLBP. The ASLR only had a significant relationship to the prone test and not the supine bridge test. Additionally, there was a significant relationship between the pain and disability scales. The rigor of the study was limited due to potential for bias and confounding variables, which if controlled for would alter the outcomes of the study. This study requires replication with clear reporting on analgesic use and conformity between multisite testing to improve the quality of information (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).

Group 4

Table 4.43: Tabulated Data – Data Group 4 – Article 2 Table 1

Authors	Teyhen *et al.*		**Year**	2009		
Article Title	Ultrasound Characteristics of the Deep Abdominal Muscles During the Active Straight Leg Raise Test					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?		*A*	*A*	*A*	*A*	*100%*
2. What percentage of individuals refused to participate?		*A*	*A*	*A*	*A*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?	*Slight variation in the ASLR technique may affect validity*	*B1*	*B1*	*A*	*B1*	*67%*
4. Are outcomes measured in the same way for both intervention and control groups?		*N/A*	*N/A*	*N/A*	*N/A*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Possible positioning effect was highlighted in the study* *7:8 female to male subject ratio with no subset analysis*	*B1*	*A*	*A*	*A*	*67%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)		*A*	*A*	*A*	*A*	*100%*
7. Is the analysis by intension to intervene (treat)?	*Yes, intention was to determine TrA and OI muscle activation/thickness during ASLR and its use as a reliable test in subjects with unilateral lumbopelvic pain in the sacroiliac region.*	*B1*	*B1*	*A*	*B1*	*67%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).	*Single centre*	*N/A*	*N/A*	*B1*	*N/A*	*67%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*Researchers used a small sample size and selected subjects only if they met the criteria.* *No blinding or randomisation*	*B1*	*A*	*A*	*A*	*67%*
2. Is the overall effect of the study due to the study intervention?	*Yes, small sample size used and would be interesting to see if similar results were achieved if this was increased.*	*A*	*B1*	*A*	*A*	*67%*
3. Explain if there is any practical/ethical reason why an RC cannot be done		*A*	*A*	*A*	*A*	*100%*
4. Include any other comments	*Study appeared to be done in a non-bias way. Selection criteria was specific and only subjects used who met this. Small sample size and only those with unilateral lumbopelvic pain was selected. Would be interesting to see if the criteria was to be done on bilateral lumbopelvic pain subjects with a bigger sample size.*					

Table 4.44: Tabulated Feedback Data Group 4 – Article 2 Table 2

Authors	Teyhen *et al.*	**Year**				2009		
Title	Ultrasound Characteristics of the Deep Abdominal Muscles During the Active Straight Leg Raise Test							
Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Ultrasound Imaging (USI) 1. Internal oblique 2. Transversus abdominus Anthropometrics Functional: 1. ODI Psychometrics: 1. Fear-avoidance belief questionnaire (FABQ)	Single Session USI measurements were undertaken at three different points during the ASLR: 1. immediately on lifting the leg 2. following a 10-second hold period at maximal hip flexion 3. 5 seconds after returning to the starting position	Single session	n=30	No	Yes n=15	No	3A	84%
Limitations	Subjects were recruited from beneficences of the American Department of Defence Healthcare (active-duty military, family members, and retirees), who completed the Health Insurance Portability and Accountability Act privacy forms approved by the Brooke Army and Wilford Hall Medical Centres' Institutional Review Board. As a result, the population may not be representative of the general population, reducing the external validity (Meinert and Piantadosi 2022). The design was a cohort observational study therefore the study only had the potential for single blinding. As the article failed to state whether the assessors were blinded, it was assumed that no blinding had occurred. This increased potential for bias, reducing the external validity (Meinert and Piantadosi 2022). The study design (cohort observational) precluded randomisation of subjects, as subjects were allocated to their respective groups based on whether symptoms were present or not (Meinert and Piantadosi 2022). The sample was homogenous for site of pain, only subjects with unilateral LPP with symptoms over the sacroiliac region, therefore results may not be applicable in patients bilateral LPP and/or diffuse pain in other locations (Meinert and Piantadosi 2022; Froud *et al.* 2012). The gender composition of the sample was heterogenous with n=8 males and n=7 females. As this was a pilot study, the power of the study (n = 30) was low, especially with the gender heterogeneity. The age range of the sample was 18-50 Y.o.A., therefore results may not be applicable to patient out of this range due age-related changes in biomechanics, differences in physical capacities, and different pathological mechanisms (Meinert and Piantadosi 2022; van der Kruk *et al.* 2021a; van der Kruk *et al.* 2021b). The ASLR test utilised in this article had a lift height of 5cm therefore results may not be applicable to heights greater than this. As muscle function was only examined using USI of the TrA and IO muscle contraction therefore only allowing hypotheses of gross muscle function of the imaged section to be developed. Subjects were not naïve, as basic information was provided on abdominal musculature, and the application of the tests which may have introduce Hawthorne and / or researcher effect (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).							
Outcomes	Analysis of objective measure found that the LPP subjects had an ODI score of 22.7 (+/-11.9%) and a FABQ (work subscale) score of 14.1 (+/-9.3). No significant differences in the thickness of the TrA and IO was noted between LPP and healthy subjects at rest on USI. Similarly, no difference was noted for both the TrA and IO when the interaction effect for group, side, and time was analysed for all three stages of the ASLR. Additionally, the muscles responses were							

	symmetrical bilaterally during the ASLR. Post-hoc analysis of results found two-way interaction for side and time indicated lower power output for the TrA and IO (TrA = 0.20, IO =0.35 respectively). When muscle thickness was compared between the two groups, it was noted that the control group demonstrated a greater ability to reduce the relative thickness [Control: 20-24% vs LPP: 6-7% (mean relative thickness)]. The mean difference between the groups from rest to leg lift was 17.3% (95% CI, 9.0%–25.6%), and the mean difference between the groups from rest to the end of the 10-second hold time was 12.9% (95% CI, 4.5%–21.3%). However, when age and gender were accounted for, the LPP subjects demonstrate a smaller increase in muscle thickness compared to control subjects. Controls demonstrated the TrA (23.7%) thickness is approximately twice as thick as the IO (11.2%) during the ASLR. In contrast, subjects with a positive ASLR / unilateral LPP were reported to have an increase in muscle thickness of the TrA and IO muscles of 6.4% and 5.7% respectively during the flexion hold portion of the ASLR. Both groups of subjects demonstrated symmetrical changes of the TrA or IO muscle thickness during the ASLR test, irrespective of whether measurements were ipsilateral or contralateral to the side of symptomatic side.
Discussions	The subjects recruited for this study greatly improved general applicability of the results, as there was the potential for active and retired military personnel of various units and / or branches of the military and their family members to be included (Meinert and Piantadosi 2022). As there is the potential for different branches and specialities, there is likely a wider distribution of physical abilities presents in the sample, increasing the general applicability of the results. The external validity of results was further enhanced gender heterogeneity and wide distribution of reoccurrence of the pain profiles. It was reported that, six subjects had, had greater than ten prior episodes, two had between five and ten episodes, three had three to five prior episodes, and four had less than three prior episodes of lumbopelvic pain. This potentially alters the muscle quality and the thickness of the muscle during contraction as well as the CNS sensitivity to pain (Neumayer and Plumper 2017; Stommel and Willis 2004). The selected sample had had a heterogenous gender composition (female n = 7 and males n = 8). The homogenous pain location (unilateral, over the SIJ), may render the results non-applicable to diffuse or bilateral LPP, as adaptations may significantly differ as force transfer patterns and thus length-tension relationships of muscles may differ.
Conclusion	The study contained numerous methodological issues that reduced the internal validity of the study. The sample selection lacked transparencies as to the location of the study and information on how subjects were recruited. All subjects were beneficiaries of the American Department of Defence Healthcare, subsequently active and retired military personnel, as well as their family members were eligible for recruitment. However, no breakdown of the sample was provided (i.e. active/retired military personnel, aetiology of pain), gender homogeneity, or the severity and chronicity of LPP. These factors introduced confounding variables into the article which reduce the internal validity but improved the external validity. The power of the article was low, and no subset analysis was undertaken by gender, introducing the potential for statistical error (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). There was disagreement over the potential for bias within the study. One reviewer cites that the lack of blinding and randomisation in conjunction with low power of the study introduced the potential for bias but would not alter the findings. In contrast the remaining two reviewers felt that these factors were controlled for. Subsequently the study was classified as a 3A. The lack of subset analysis of results by gender in combination with low power may also potentially have introduce variables that may have alter the outcomes of the study (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). The study provided needed information to fill the dearth in deep abdominal muscular recruitment (viz, decreased ability to contract muscles) however the methods of investigation, USI, still left unanswered questions regarding the inter-and-intramuscular coordination that can only be resolved via EMG analysis. Problematically, the study did not utilise the ASLR methodology outlined by Mens *et al*. (1999) and Mens *et al.* (2001) which the studied citied, potentially introducing confounding variables that reduced both internal and external validity. The ratio of thickening between the IO and TrA was suggest being significant, but no data was obtained to infer what the significance may be. Subsequently the authors of the study highlighted the need for further study, as statical validity is lacking (Ahlawat 2020; International Road Transport Form 2012). The study contained moderate internal validity and reviewer consensus as a result, the It is, therefore, recommended that a replication study be conducted with a higher power and / or gender-based subset analysis is provided. The external validity was good (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).

Table 4.45: Tabulated Data – Data Group 4 – Article 3 Table 1

Authors	*Roussel et al..*		**Date**	*2009*		
Article Title	Altered Breathing Patterns During Lumbopelvic Motor Control Tests in Chronic Low Back Pain: A Case–Control Study					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?		*A*	*A*	*A*	*A*	*100%*
2. What percentage of individuals refused to participate?		*A*	*A*	*A*	*A*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?	*ASLR did not follow Mens study – 10s hold at top*	*B1*	*A*	*B1*	*B1*	*67%*
4. Are outcomes measured in the same way for both intervention and control groups?	*Pain scales not conducted on the control group*	*B1*	*B1*	*B1*	*B1*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Methodologies*	*B1*	*B1*	*B1*	*B1*	*100%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)		*A*	*A*	*B1*	*A*	*67%*
7. Is the analysis by intension to intervene (treat)?		*A*	*A*	*B1*	*A*	*67%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).		*B1*	*B1*	*B1*	*B1*	*100%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*Unlikely to alter the conclusion of the study*	*B1*	*B1*	*B2*	*B1*	*67%*
2. Is the overall effect of the study due to the study intervention?		*A*	*A*	*B1*	*A*	*67%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*Subjects know if they have pathology or not*	*N/A*	*N/A*	*B1*	*N/A*	*67%*
4. Include any other comments						

Table 4.46: Tabulated Data – Data Group 4 – Article 3 Table 2

Authors	Roussel *et al.*	**Year**	2009
Title	Altered Breathing Patterns During Lumbopelvic Motor Control Tests in Chronic Low Back Pain: A Case–Control Study		

Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Anthropometrics Pain: 100mm VAS Psychometric properties: Dutch versions of the pain catastrophising scale (PCS) Pain, vigilance, and awareness questionnaire (PVAQ) Perceived exertion: Borg scale (BS) Breathing Pattern: Subjective palpation Visual observation during motor tests Motor Control Test: ASLR with BS Knee lift abdominal test (KLAT) with PBU Bent knee fall out (BKFO) with PBU	Single measure	Not clear	n=20 (Healthy n=10 LBP n=10) Male n=4 Female n=6	Yes	Yes Male n = 6 Female n = 4	No	3A	86%

Limitations	The sample was recruited from a private physiotherapy practise and hospital outpatient physical therapy division, with a diagnosis of non-specific low back pain by a physician. As a result, the population may not be representative of the general population or applicable to other forms of LBP, reducing the external validity. In contrast the control group was recruited from amongst researcher acquaintances, creating the potential for assessor effect in the control group (Meinert and Piantadosi 2022. The design was a cohort observational study therefore the study only had the potential for single blinding and was undertaken (Ahlawat 2020). No randomisation was used in the study design introducing the potential bias and reducing the external validity (Meinert and Piantadosi 2022). The sample was gender heterogenous (n = 6 males, n = 4 females). The sample was homogenous in terms of chronicity and aetiology, containing only chronic, nLBP subjects, which may render the results non-applicable to sLBP and acute / subacute LBP. This would reduce the external validity of the study (Meinert and Piantadosi 2022). The small sample size, n = 10, reduces the ability to generalize findings, therefore reducing the external validity. The age range of the sample was 18-65 Y.o.A. therefore results may not be transferable to age ranges outside of this. However, age distribution is wide which would enhance the external validity of the results (Meinert and Piantadosi 2022; Ahlawat 2020). The ASLR utilised a 10s hold at the top of the lift, therefore results may not be applicable to ASLR techniques that do not utilise the same duration. Those that use a shorter duration hold are less likely to have depleted the ATP-PC supply of the muscle (Vardali *et al.* 2021). All subjects were native Dutch speakers, therefore cultural influence and perception of pain may influence (Millar *et al.* 2019).
Outcomes	No significant differences were noted for breathing in the supine position, under all conditions, and in standing with quite breathing between healthy and LBP subjects (P >0.05). During deep breathing in standing (P <0.05) and during motor control testing (P <0.05) significant alteration in breathing patterns were observed. Five and

	six of the LBP subjects demonstrated altered breathing patterns during the performance of the ASLR and BKFO respectively, while one healthy patient had an altered breathing pattern during their left ASLR. Severity of pain was reported to be unrelated to breathing pattern. LBP subjects demonstrated increased pressure deviations from baseline during the KLAT and BKFO tests. However, only the right BKFO test shown statistically significant results (>0.05) whilst the left reported to tended towards significance. Analysis showed that the BKFO test significantly correlated to breathing pattern (r >0.50, P = 0.01 – 25% of the r value was attributed to breathing pattern). Analysis of psychometric properties and VAS scores demonstrated no significant relationship to test scores.
Discussions	The recruited sample was likely to be poorly representative of the general population as the sample was diagnosed with chronic, nLBP by a physician and recruited from patients at physiotherapy / physical therapy settings. The subjects are more likely to have a higher severity of pain and potentially may have been aware of the significance of the ASLR. While the gender homogeneity and wide age distribution favoured the external validity of the study, the small sample size likely negated any benefit (Meinert and Piantadosi 2022). Indeed, the sample size was likely to have introduced a statistical error which would have reduced the external validity of the findings (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012).
Conclusion	When analysing Table 4.45 it was apparent that there was only moderate consensus amongst the reviewers on this articles' internal validity. Significantly, there was no consensus as to whether the methodological flaws of the study would likely alter the outcomes of the study, as two reviewers believed that they would not while believed that it would. The design of the study contained inherent bias, with additional risk of bias being introduced by the recruitment of the researcher acquaintances as control group, creating the potential for assessor effect in this group. The low power of the study was the greatest threat to internal validity, introducing the potential for a type 1 error (Lee 2012). The review noted that there was small methodological practise further detracted from the quality of the study but were unlikely to influence the conclusion of the study. There included a heterogenous gender of the small sample, not applying pain scales to the control group and utilising a 10s hold at the top of the ASLR. the internal validity was aided by ensuring the order effect of testing was controlled for (Grazette *et al.* 2020). As the sample size was so small and poorly representative, despite a gender heterogeneity and wide age distribution, the article had poor external validity (Meinert and Piantadosi 2022). Therefore, there is limited evidence that significantly altered breathing patterns are observed in chronic LBP-patients during motor control tests (P = 0.01), and in reference particular reference for this study, the ASLR. These changes are not related to pain severity (P = 0.01), but to motor control dysfunction (P = 0.01). It is therefore recommended that the study should be reproduced with greater power.

Table 4.47: Tabulated Data – Data Group 4 – Article 4 Table 1

Authors	*Palsson et al.*		**Date**	2012		
Article Title	Experimental Pelvic Pain Impairs the Performance During the ASLR Test and Causes Excessive Muscle Stabilization					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority**	**Agreement**
Are the study participants well-defined in terms of time, place, and person?	*Yes*	*A*	*A*	*A*	*A*	*100%*
What percentage of individuals refused to participate?	*None all participated*	*A*	*A*	*A*	*A*	*100%*
Are outcomes measured in a standard, valid and reliable way?	*Yes*	*A*	*A*	*A*	*A*	*100%*
Are outcomes measured in the same way for both intervention and control groups?	*Yes, both the same*	*A*	*A*	*A*	*A*	*100%*
Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Slight variation of the ASLR technique*	*B1*	*B1*	*B1*	*B1*	*100%*
What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*2.9% - 1 subject were fully excluded*	*A*	*A*	*A*	*A*	*100%*
Is the analysis by intension to intervene (treat)?	*No*	*N/A*	*N/A*	*N/A*	*N/A*	*100%*
Are results homogeneous between sites? (multicentre/ multisite studies only).	*Yes*	*N/A*	*A*	*N/A*	*N/A*	*67%*
OVERALL ASSESSMENT OF THE STUDY:						
How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*Researchers attempted to ensure that all steps were followed the same for each subject. All subjects were selected using specific criteria.*	*A*	*A*	*A*	*A*	*100%*
Is the overall effect of the study due to the study intervention?	*Study did not intend for an intervention, more to determine if pain is present in the SI-Joint region that this may impact the subjective or objective outcome of the ASLR test in clinical or research setting.*	*A*	*A*	*A*	*A*	*100%*
Explain if there is any practical/ethical reason why an RCT cannot be done	*Experimental*	*N /A*	*N/A*	*N/A*	*N/A*	*100%*
Include any other comments	*The conclusion confirmed the impact pain has on the using of bracing by muscles surround the SI-joint / Trunk in an attempt to reduce pain or discomfort during a ASLR.*					

Table 4.48: Tabulated Feedback Data Group 4 – Article 4 Table 2

Authors	Palsson *et al.*		**Year**		2012			
Title	Experimental Pelvic Pain Impairs the Performance During the ASLR Test and Causes Excessive Muscle Stabilization							
Study Properties								
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Anthropometrics Kinematic recordings Electromyographic recordings Pain: 100mm VAS Peak Area (peak vs time) Pressure pain thresholds (PPTs) - handheld algometer	Each measure was repeated three times in all conditions (baseline, during and post injection states) bilaterally	Single session	n=35 (females=15 males=20) One subject of the 35 was excluded analysis of result as no experimental pain was experienced.	No	Yes	Yes – cross over	3A	96%
Limitations	No data was provided on sample recruitment therefore it is not possible to determine if the sample has characteristics that reflect the general population. This reduces the external validity, as it makes it impossible to generalise findings (Meinert and Piantadosi 2022). The design was a cohort observational study therefore the study only had the potential for single blinding. As the article failed to state whether the assessors were blinded, it was assumed that no blinding had occurred. This increased potential for bias, reducing the external validity of the study (Meinert and Piantadosi 2022). While a control group was utilised the study design precluded randomisation of subjects, therefore the article contains the potential for bias, reducing the external validity (Meinert and Piantadosi 2022). The sample was gender heterogenous (females n = 15; males n = 20). Which would improve the general applicability of the findings (Meinert and Piantadosi 2022). The sample size was originally n = 35 (females=15 males=20) however due to various reasons the data sample analysed was significantly smaller, one subject of the 35 was excluded because no pain was experienced during the experiment. Additionally, two EMG and ten kinematic results were corrupted, preventing their analysis. This represents an almost 30% loss of kinematic data significantly reducing the power of the findings and the ability to generalise findings. The age range of subject was 20-31 Y.o.A. The narrow age would reduce the applicability of results to older age groups who are more likely to have degenerative changes and systemic pathologies (Meinert and Piantadosi 2022). The ASLR utilised in this study was “standardized further,” subjects were instructed perform the ASLR with the ankle in neutral position up to 20 degrees of hip flexion rather than 20cm lift height. No pilot study was conducted to determine whether this variation would influence outcomes. The results may, therefore, not be applicable to other variations of the ASLR, reducing the external validity of the findings. All subjects were naïve (Ahlawat 2020).							
Outcomes	The injection of hypertonic saline injections resulted decreased PPTs at the injection site and lateral to S2, higher VAS and Likert scale scores, and bilateral stabilizing trunk and thigh muscles activity on EMG compared to control condition and baseline.							
Discussions	While no data was provided on the recruitment of the subjects, this is relatively insignificant as the aim of the study was to examine the effects of pain on the ASLR. The demographics of the study are, therefore, likely to be of greater significance (Meinert and Piantadosi 2022). The young adult sample (20-31 Y.o.A), reduced the likelihood of the presence of degenerative or systemic pathologic effects on the ASLR however the significance of the presences of these factors are not addressed in this article. A comparison study of experimental versus pathological pain is, therefore, required to fully appreciate the findings of this article. Additionally, a sample with a wider age range is also required to determine if these findings are applicable to other range groups.							

	The sample size of the kinematic data was significantly reduced by the corruption of 30% of the data. The general applicability of the kinematic results is therefore significantly less generalisable than other findings in the article.
Conclusion	Three points of question were raised in relation to the internal validity of this article. The first and minor points pertained to whether or not the study was conducted at a single or multisite (Meinert and Piantadosi 2022). The reporting of this was unclear but in the context of the study, this was considered insignificant. The other two point were deemed to be significantly more important. The first was the methodology of the ASLR, which varied significantly from those originally described in Mens *et al.* (1999) And the significance of these changes was not addressed in the article. The corruption of data also raises concerns. While the loss of EMG data was relatively minor, the loss of kinematic data was significant. However, all these factors were deemed to be sufficiently insignificant to not alter the outcomes of the study. The study demonstrate that pain and hyperalgesia may contribute to altered MCS in people with chronic pain and those without pathological impairment of SIJ function. Perhaps problematically, respiration parameters were not recorded. Other studies have reported altered respiratory patterns in various subgroups of LBP, suggesting a relationship between altered MCS, and pain has been shown to alter respiratory patterns (Roussel *et al.* 2007). Further investigation is required to determine whether experimentally induced pain may influence respiration and whether or this may subsequently have a relationship to the ASLR. Additionally, there is a need to compare experimental and pathological pain. The review had a high consensus between reviewers, that the article had high internal validity with moderate external validity (Meinert and Piantadosi 2022; Ahlawat 2020; Lee 2012). Although some difference in the ASLR technique compared to the standard sources within the literature were noted, the reviewers considered these differences to be relatively insignificance as they would not alter the findings of the study if controlled. The article provided moderate evidence in understanding of the pain mechanisms in the performance of the ASLR and suggest that some factors are unrelated to pain.

Table 4.49: Tabulated Data – Data Group 4 – Article 5 Table 1

Authors	Ericksen *et al.*		**Date**	*2010*		
Article Title	Gynaecological Surgery and Low Back Pain in Older Women: Testing the Association with Sacroiliac Joint Stiffness and Pelvic Floor Movements					
EVALUATION CRITERIA FOR THE STUDY:	**Comments:**	**Reviewer 1**	**Reviewer 2**	**Reviewer 3**	**Majority**	**Agreement**
1. Are the study participants well-defined in terms of time, place, and person?	*No place defined*	*A*	*B1*	*A*	*A*	*67%*
2. What percentage of individuals refused to participate?	*All participated with no refusals.*	*A*	*A*	*A*	*A*	*100%*
3. Are outcomes measured in a standard, valid and reliable way?	*Testing conducted by one person. Potential for order effect. Lift heights of ASLR potentially ranged from 12 to 24 inches.*	*C*	*B1*	*C*	*C*	*67%*
4. Are outcomes measured in the same way for both intervention and control groups?	*Lift heights of ASLR potentially ranged from 12 to 24 inches.*	*B1*	*B1*	*B1*	*B1*	*100%*
5. Are factors other than the intervention, e.g. confounding factors, groups and if not comparable, are they adjusted for in the analysis?	*Groups were small introducing the risk of type 1 error. Potential for order effect. Lift heights of ASLR potentially ranged from 12 to 24 inches.*	*B1*	*B1*	*B1*	*B1*	*100%*
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up)	*8 % (2 subjects out of 25 as data was unusable).*	*A*	*A*	*A*	*A*	*100%*
7. Is the analysis by intension to intervene (treat)?	*No, analysis was to determine if there was SIJ compliance was affected by a history of any gynaecological surgeries.*	*B1*	*B1*	*B1*	*B1*	*100%*
8. Are results homogeneous between sites? (multicentre/ multisite studies only).	*This appears to the case although some differences may have occurred unintentionally.*	*N/A*	*B1*	*N/A*	*N/A*	*67%*
OVERALL ASSESSMENT OF THE STUDY:						
1. How well was the study done to minimise bias? If coded as B1, B2 or C2, what is the likely direction in which bias might affect the study result?	*Albeit one person conducted the testing, there is still room for inaccurate testing. The methods used was very specific in its administration but using imaging to gauge positioning and to establish a specific point for reference can be unreliable.*	*B1*	*B1*	*A*	*B1*	*67%*
2. Is the overall effect of the study due to the study intervention?	*Study did not intend for an intervention.*	*B1*	*B1*	*B1*	*B1*	*100%*
3. Explain if there is any practical/ethical reason why an RCT cannot be done	*Association study*	*N/A*	*A*	*N/A*	*N/A*	*67%*
4. Include any other comments	*The results are mostly like due to researchers using a relatively small sample size with having one criterion as LBP and advanced age (over 65 years only) only may have inadvertently not given a true reflection as mentioned in their discussion and conclusion.*					

Table 4.50: Tabulated Feedback Data Group 4 – Article 5 Table 2

Authors	Ericksen *et al.*			**Year**		2010	
Title	Gynaecological Surgery and Low Back Pain in Older Women: Testing the Association with Sacroiliac Joint Stiffness and Pelvic Floor Movements						
Study Properties							
Form of Measurement	**Frequency of Measurement**	**Duration of Study**	**Number of Participants**	**Assessor Blinded**	**Control Used**	**Randomisation**	**Ranking**	**Total % of Agreement**
Doppler U/S: 1. Pelvic floor during ASLR 2. Vibrations of the SIJ (DIV) Pain: 1. 100-mm VAS 2. 11-point NRS Functional activity: 1. MODQ	1	Single session	n=25 (n=2 excluded from result analysis) no GS and no LBP n=4 GS and no LBP n=8 GS and LBP n = 3	Yes	Yes n = 8	No	3B	88%
Limitations	Subjects were recruited by university medical centre flyers (location not stipulated), online journals circulated to geriatric population, retirement facility lectures, and word of mouth. The sample is, therefore, limited to those seeking care from clinics or know someone who is receiving care and is, therefore, not likely to be representative of the population, limiting the external validity of the study (Meinert and Piantadosi 2022; Lee 2012; Akobeng. 2008). The design was a cohort observational study, therefore, the study only had the potential for single blinding which was undertaken (Ahlawat 2020). Randomisation was precluded due to due to study design, cohort observational, which meant that subjects were assigned / recruited based on whether symptoms were present. This subsequently introduced an inherent risk of bias and reduce the external validity of the study (Meinert and Piantadosi 2022). The article had gender homogeneity, n = 25 were females, therefore outcomes are unlikely to be applicable to males and reduces the external validity of findings (Meinert and Piantadosi 2022). The sample size of the article was problematic, as four subgroups were utilised which were not homogenous (no GS and no LBP n = 8, no GS and no LBP n = 4, GS and no LBP n = 8, GS and LBP n = 3). These subgroups are small, therefore, it is problematic to generalize findings reducing the external validity of the article. The recruited subjects recruited (in both the both the GS and no-GS groups) demonstrated mild LBP on mean VAS score (33.0 mm and 33.3 mm respectively), therefore results may not be applicable to more severe cases further reducing the external validity of the study. Additionally, all subjects were over the age of 65, therefore the results may not be applicable to younger females as different pathological mechanisms (systemic and biomechanic) may have influence findings. (Piasecki *et a*l. 2019). The use of a single tester was seen as reducing the risk of variation in testing by one reviewer but was seen to reduce general applicability of findings by the other two (Ahlawat 2020). Order effect was introduced by all subjects commencing on their right leg, regardless of affected side (Ahlawat 2020). The lift height of the ASLR was 12-24 inches (30 – 60cm) therefor results may not be applicable to other RoM for the ASLR (Dutton 2020).							
Outcomes	Outcomes suggest that prior GS and LBP are not significantly associated with unilateral variations in SIJ compliances and symmetry, or with significant deviations in pelvic floor movements (P=0.4259) during load transfer during the ASLR in older women. There was no significant difference in the amount of pelvic floor motion across groups during either the right- or left-sided ASLR: right side, F(3, 18) = 0.82, P = 0.4976; left side, F(3, 18) = 0.77, P = 0.5253							

	The Doppler U/S of vibrations had a moderate to high reliability (ranging from 0.701 to 0.898) for the detection of vibrations on the ilium and sacral aspects of the SIJ. Internal reliability for the ilium of the SIV was reported to be Cronbach α = 0.852 (right) and 0.701 (left). Whilst the sacral values were Cronbach α = 0.898 (right) and 0.810 (left). The ilium to sacral DIV difference for the SIJ demonstrated moderate internal reliability with Cronbach αvalues of 0.757 (right) and 0.705 (left). No significant difference was observed in the SIJ compliance (right to left) between subgroups, F(3, 19) = 0.17, P = 0.9124. Additionally, no significant difference in the mean absolute SIJ compliance measurement for either SIJ across groups: right side, F(3, 19) = 0.25, P = 0.8613; left side, F(3, 19) = 0.99, P = 0.4159.
Discussions	The study design inherently reduced the external validity of the results, as no randomisation and only single blinding the sample occur, reducing the general applicability of results. Further sample related factors impairing the external validity of the article include narrow gender, age range. As only mild nLBP subject were recruited to the study, altered MCS may either have not been a significant feature or were not detectable due to the method of analysis. This subsequently limits the external validity and applicability of findings to the moderate and severe cohorts, as pain generating mechanisms in moderate and severe cases may be different (Schneider *et al.* 2019; Huebschmann, Leavitt, and Glasgow 2019). The outcomes of this study however bring into question whether pain generation within this cohort is due to increased force closure or excessive force tone of the pelvic floor as the methodology of the study limits inferences in this area. The use of a single tester was seen as reducing the risk of variation in testing by one reviewer but was seen to reduce reliability of findings by the other two. Order effect was introduced by all subjects commencing on their right leg, regardless of affected side.
Conclusion	The findings of Ericksen *et al* (2010), challenged the hypothesis that altered MCS characteristic to LBP or resulting from GS are expressed by greater pelvic floor motion under increasing load. These findings need to be view within the context of the quality of research methodology. The study design, cohort observational, reduced both the internal and external validity of the study. This was due to single blinding and lack of randomisation introducing the potential for bias. Additional threats to internal validity included, a small subgroup size introducing the potential for statistical error, potential confounding variables (small age range), and not utilising the best measure (Harbour and Miller 2001). A cross sectional study with a large cohort and a larger age range may have detected whether age was a confounding variable (Wang *et al.* 2020; Huebschmann, Leavitt, and Glasgow 2019). Additionally, the use of single tester while reducing the variance in testing, introduced the potential for a testing fault to be transferred throughout the study without been detected. Analysis of pelvic floor motion during the ASLR was achieved using an indirect measure of the movement of the perceived floor of the bladder. This method has is not considered to be as reliable or the gold standard for the assessment of the PFM, as transperineal U/S or 3D U/S respectively (Stuge, SætreIngeborg and Brækken 2012; Whittaker *et al.* 2007). Additionally, this form of measure excludes excessive pelvic floor tone and increased stiffness of the ligaments as potential drivers of MCS. It is recognised that analysis muscle tone and activation is best achieved using electrophysiological methods (i.e., EMG) (Yang *et al.* 2019; Glazer, Romanzi and Polaneckzy 1999). The study used the PSIS as a landmark for U/S investigation. As such, this was only area imaged during the study and as identified by the authors of the study, may not be reflective of the whole connective tissue. Therefore, is it possible that more mobile segments responsible for asymmetry may not have been visualised (Ericksen *et al.* 2010). However, there was only moderate agreement between reviewers as to the influence of these factors on results. Subsequently, the internal validity of the study was rated as moderate. External validity of the results was inherently reduced by the study design and risk of bias. Additional factors included gender homogeneity, narrow age range, single tester, order effect of testing and use of only mild severity nLBP (Wang *et al.* 2020; Huebschmann, Leavitt, and Glasgow 2019, Schneider *et al.* 2019; Huebschmann, Leavitt, and Glasgow 2019). The external validity was thus deemed to be poor. The study, therefore, only provides limited data to support the use of ASLR.

4.4 Conclusion

A total of 25 articles were examined in this chapter. All articles were of observational design, with two articles being assessed with the Newcastle-Ottawa Scale and the remaining 23 by the Liddle scale. As a result, the level of evidence was not assessed to be greater than 3 for any study (Ahlawat 2020).

CHAPTER FIVE DISCUSSION OF RESULTS

5.1 INTRODUCTION

Based on the aggregation of reviews and the discussion of the articles, the strength of evidence to support the use of the ASLR in various subgroups of LBP is discussed. This discussion centres on sensitivity, validity, reliability, pain, muscle recruitment, and pelvic symmetry.

It must be highlighted that pain is clearly a confounding variable in the study of the ASLR. Most studies utilise pain to diagnose a condition however the ASLR is a load transfer and motor control test (Mens *et al.* 1999).

5.2 CRITERIA OF EVIDENCE RANKING

From the studies reviewed in Chapter Four, each outcome/combination of outcomes (detailed in Table 5.1) were ranked according to the level of evidence. In the following sections, these ranking are examined according to the criteria presented by Murad *et al.* (2016) and Foley *et al*. (2003) to collectively evaluate the ASLR to determine the tests' validity, reliability, and specificity for each subgroup of LBP.

The collective levels of evidence are stratified as follows:

Strong evidence: This ranking is awarded when the finding of studies within one domain are collaborated by the findings of two or more RCTs of fair or moderate quality.

Moderate evidence: This ranking is attained when the finding of studies within a single domain are collaborated by the results of one RCT of at least "fair/moderate" quality.

Limited: The level of stratification when the findings of studies within one domain are supported by the results of one or more nonexperimental study (nRCT).

Consensus: This ranking was an issue in one of two contexts:

1. If there was an absence of evidence and a group of experts was able to achieve agreement (consensus) on available data for an appropriate course of action, this ranking could be awarded. As this is the least sound methodology, it is the lowest form of evidence.
2. Occurs when the data from a few studies provides consistent inference on a course of action, i.e. it is either for or against the action.

Conflicting: This level of rank of evidence represent disagreement between RCTs. If multiple publications exist and only a single paper contradicts these findings, the single paper only surpasses the majority if the paper is of greater methodological quality.

No evidence: This is applied when studies are of poor quality showing limited or no evidence or if high-grade studies that show that the tested ASLR was no no better the control group.

5.3 ANALYSIS OF ASLR BY PATHOLOGY

This section will present the analysis of the articles grouped by pathology.

5.3.1 Pelvic Girdle Pain and Sacroiliac Joint Pain

To facilitate data analysis and discussion, all SIJP articles were consolidated with the PGP articles. This was done due to a combination of biomechanical considerations, and sample compositions of various studies (i.e comparing location of pain and definitions of PGP and SIJP).

5.3.1.1 Introduction

All articles are analysed and discussed where applicable under the following headings: sensitivity, validity, reliability, pain, muscle recruitment, pelvic arthrokinematics, and manual pelvic compression; eight studies were examined under these domains.

Two studies (Table 5.1) examined the arthrokinematics of the ASLR in the PGP and SIJP populations, Kibsgård *et al.* (2017) and Ericksen *et al.* (2010). Both articles were assessed as having moderate internal validity and poor external validity therefore producing the same level of evidence, limited. However, the outcomes were different, with Kibsgård *et al.* (2017) finding asymmetry of the pelvic girdle while Ericksen *et al.*

(2010) reported none. Significance the measurement of SIJ compliance by Ericksen *et al.* (2010) was taken by applying sinusoidal vibration force to ASIS of prone subjects. This represents a significantly different position to the ASLR and undermines the validity of this finding (Cook *et al.* 2010). However, based on the totality of the findings there is limited conflicting evidence.

5.3.1.2 Pelvic Arthrokinematics in PGP and SIJP

Table 5.1: Sof of pelvic arthrokinematics of the ASLR in PGP and SIJP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Ericksen *et al.*	2012	Cohort	US	Moderate	Bad	Negative asymmetrical pelvic motion					x	
Kibsgård *et al.*	2017	Cross-sectional	RA	Moderate	Bad	Positive asymmetric pelvic motion			x			

(Grey highlight = negative outcomes)

5.3.1.3 Muscle Recruitment

A total of six articles (see table 5.2) detail outcomes related to muscle function. Various studies reported intra-and-inter group variations in pain and control groups as well between muscle groups (Palsson et al. 2012). These differences were reported for all lift heights, severities (mild, moderate, and severe), and chronicity. As no RTCs were performed, only limited conflicting evidence was provided for the use of the ASLR in non PPGP related population.

In their article, Palsson *et al.* (2012) reported that experimental pain led an increased in EMG activity of the IO, EO, RA, BF and LD mm. during ASLR, independent to tissue damage. The article was assessed as having moderate external validity and high internal validity therefore provides moderate evidence. Beales *et al.* (2009) also reported when the ASLR was performed on the symptomatic side, the dominant MC pattern observed was bracing of the abdominal and chest walls with an associated increase in IAP and depression of the pelvic floor when compared to the non-symptomatic side. The quality of the article was assessed as being poor quality, as both the internal and external validity was low therefore the article provides no evidence. In contrast to these studies, Shadmehr *et al.* (2012) observed a decrease in BF, GM, EO, IO and RA mm. activity during the performance of the ASLR in SIJP subjects. Additionally, they reported a significant increase of the latency of adductor

longus compared to healthy controls. The quality of this study was also poor due to low internal and external validity therefore this study also provides no evidence.

Table 5.2: Sof of muscle recruitment in ASLR in PGP and SIJP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Beales *et al.*	2009	Observational	EMG U/S	Low	Bad	Positive increased mm activation						
Beales *et al.*	2010	Observational	EMG U/S	Medium	Bad	Positive increased mm activation						
Ericksen *et al.*	2012	Cohort	US	Moderate	Bad	Negative bilateral asymmetry					x	
Palsson *et al.*	2012	Experimental	EMG	High	Good	Positive bilateral increased mm activation						
O'Sullivan	2002	Observational	US	Moderate	Bad	Positive: altered thoracic and pelvic motion			X			
Shadmehr *et al.*	2012	Cross-sectional	EMG	Low	Bad	Positive increased latency and tonicity						

(Grey highlight = negative outcomes)

The result of Ericksen *et al.* (2010) study of pelvic floor motion also conflicted with those of Beales *et al.* (2009). In their study, Ericksen *et al.* (2010) reported no significant difference in the pelvic floor motion. The most significant difference between these studies was that all Beales *et al.* (2009) subjects had incontinence issues, which may indicate neuromuscular issues of the PFM. The internal validity of Ericksen *et al.* (2010) was rated as moderate while the external validity was evaluated as low subsequently the article was deemed to provide limited evidence.

Two studies, Beales *et al.* (2010) and O'Sullivan *et al.* (2002), utilized manual compression of the ileum in their studies. Both studies have moderate internal validity and poor external validity therefore provide only limited evidence that manual compression can normalize muscle function.

5.3.1.4 Pain and Psychometrics

A total of six studies gathered data on pain and psychometrics related to the ASLR. Of these studies, only two studies (Table 5.3) examined the correlation of the assessment tools with the ASLR. The evidence from these two articles is limited and conflicting. Palsson *et al.* (2012) demonstrated that changes in VAS, were linked to

increased RPE and changes in muscle function, whilst Ericksen *et al.* (2012) reported no correlation between pain and PFM recruitment. The difference in findings may be attributable to the Palsson *et al.* (2012) group having pain induced experimentally, without the presence of tissue damage while Ericksen *et al.* (2012) represented a clinical population. Therefore, Ericksen *et al.* (2012) may represent a population in which pain accommodation and adaptation may have occurred. Further research is required to expand this area of interest to improve the clinical interpretation of the ASLR.

Table 5.3: Sof for pain and psychometrics for the ASLR in PGP and SIJP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Ericksen *et al.*	2012	Cohort	US	Moderate	Bad	Negative association to pain and disability			x		x	
Palsson *et al.*	2012	Experimental	VAS RPE	High	Moderate	Positive association to pain						

(Grey highlight = negative outcomes)

5.3.1.5 Sensitivity and Specificity

Castro *et al.* (2019) was the only study whose results fulfilled the studies criteria and reviewers' specifications that examined Sn and Sp (Table: 5.4 and Table 5.5). In their article, Castro *et al.* (2019) found that Sn was moderate (71%), while the Sp was low at (46%). These findings are consistent with other studies that examined Sn and Sp of the ASLR (Mens *et al.* 1999). However, the study was evaluated as having poor internal and external validity, therefore providing no evidence to draw conclusions in axial spondyloarthritis populations. It is therefore necessary to apply and interrupt the ASLR as a secondary test in a test battery until additional research can be undertaken.

Table 5.4: Sof for ASLR sensitivity in PGP and SIJP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Castro *et al.*	2019	Cross sectional	MRI Blood analysis	Low	Low	Positive moderate Sn						x

(Grey highlight = negative outcomes)

Table 5.5: Sof for ASLR specificity in PGP and SIJP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Castro *et al.*	2019	Cross sectional	MRI Blood analysis	Low	Low	Negative low Sp						X

(Grey highlight = negative outcomes)

5.3.1.6 Reliability

This SR found that there was no direct evidence to support the reliability of the ASLR. Two articles examined the repeatability of the ASLR, these were O'Sullivan *et al.* (2002) and Beales *et al.* (2009). The distinction between these two is important, as reliability represent the quality of being reliable, dependable, or trustworthy, whereas repeatability is the quality of being repeatable, i.e. being done again. The reliability of the ASLR may however be extrapolated from the fact that the Sn and Sp are like those of PPGP, LBP and LPP.

5.3.1.7 Validity

The validity of the ASLR from the body of evidence related to PGP needs to be considered in the context of application (i.e. whether the ASLR is being used to diagnose a pathology, assess load transfer or MC), and the type of validity (face vs construct validity). It must be noted that there was a complete absence of reliability studies to support the validity of the ASLR. Additionally, only a single study examined the Sn and Sp of the ASLR. The Sn and Sp of this article focused on the ability to diagnose axial spondyloarthritis and not motor control or load transfer. The article reported that the ASLR performed poorly at this task. However, the quality of the article was such, as to provide no evidence.

5.3.1.7.1 Load Transfer Validity

The use of the ASLR with varying lift heights to assess load transfer through the SIJ in non-pregnancy related PGP has limited evidence to support the face validity. This evidence, however, raises questions about the construct validity of the underlying theorems to explain the genesis of pain during the performance of the ASLR, namely the self-bracing mechanism (Kibsgård *et al.* 2017; Ericksen *et al.* 2010).

Two studies (Table 5.1) met the criteria for this SR examined the arthrokinematics of the SIJP, by Kibsgård *et al.* (2017) and Ericksen *et al.* (2010). The outcomes and quality of these studies are discussed and contrasted against the findings of Mens *et al.* (1999), which is the generally accepted seminal study that provides the theory for the genesis of pain and dysfunction during the performance of the ASLR.

Mens *et al.* (1999) reported that in arbitrarily defined unilateral PGP females in the post-partum period, the ipsilateral hemipelvis rotated anteriorly due to slippage of the PSJ due to ligament laxity of the PSJ and SIJ. Mens *et al.* (1999) theorised that during the ASLR that the abdominal muscles were unable to counteract the pull of the hip flexors, leading to anterior rotation of the pelvis. It is suggested that if this occurred on the right leg, it could pull L4 and L5 into right lateral flexion to the right and posterior to anterior rotation to the left. This then increased loading of the SIJ structures, namely the ilio-lumbar ligament, leading to a positive test. This rationale has since been used to support the self-bracing theory. The alignment of the x-ray was centred on the PSJ and not the SIJ which may have altered measurements SIJ movement due to magnification.

Kibsgård *et al.* (2017) analysed the movement of the SIJ using RA, centred on the SIJ in severe long term unilateral PGP patients who were scheduled to undergo surgical fusion of the SIJ. The study found that, in contrast to Mens *et al.* (1999), the ileum contralateral of the SIJ to the leg lifted rotated posteriorly. This would suggest that the contralateral or stationary leg (hip) was being extended to enhance pelvic stability during the ASLR. Additionally, Kibsgård *et al.* (2017) observed that movements at the SIJ were miniscule (less than 0.8mm). More significantly the x-ray was conducted in the ASLR position. Therefore, the measurement of SIJ motion is significantly more accurate than Mens *et al.* (1999). The evaluation of the Kibsgård *et al.* (2017) article found that it had moderate internal validity and bad external validity. Therefore, this study only provided limited evidence.

Concurrently, Ericksen *et al.* (2010) found that there were no changes in SIJ compliance (SIJ asymmetry). This result is consistent with the findings of Kibsgård et al. (2017) finding that no significant motion occurs at the SIJ. However, the result is problematic as the study of SIJ was performed in the prone position which is a significantly different functional position to the ASLR. Like Kibsgård *et al.* (2017),

Ericksen *et al.* (2010) only provides limited evidence that failure of form closure does not appear to be a factor in pain generation.

These findings cast doubt that non PPGP is associated with impaired movement of the SIJ during the performance of the ASLR, rather there is likely an increase of movement at the PSJ, leading to increased loading of muscles and ligaments (Kibsgård *et al.* 2017; Ericksen *et al.* 2010). Further research is required to determine if Kibsgård *et al.* (2017) applies to other severities of non PPGP as well as improve the face and construct validity in this population.

There is also limited evidence that the force closure dimension of the self-bracing mechanism may not be applicable to this subject sample. In their study, Palsson *et al.* (2012) induced experimental pain, leading to increased EMG activity of the IO, EO, RA, BF and LD mm. during ASLR. In contrast, Shadmehr *et al.* (2012) observed a decrease in BF, GM, EO, IO and RA muscle activity while performing the ASLR in SIJP subjects. They also reported a significant increase of the latency of adductor longus. Unlike Palsson *et al.* (2012), which was Shadmehr *et al.* (2012) appraised as providing moderate evidence, Shadmehr *et al.* (2012) quality was assessed as poor and therefore the article provides no evidence. While it is easy to dismiss Shadmehr *et al.* (2012) findings, when viewed within the context of O'Sullivan *et al.* (2002) and Beales *et al*. (2010), which were both appraised as providing limited evidence, Shadmehr *et al.* (2012) findings gain more significance. Additionally, increased PSJ motion observed in Kibsgård et al. (2017) would also be consistent with delayed onset of AL muscle and inferior fibres of the RA failing to aid the stabilization of the PSJ.

It was theorised following the findings of O'Sullivan *et al.* (2002) that pain during the performance of the ASLR could result from a failure of muscles to stabilize the SIJ (failure of force closure) or from excessive muscle contraction (excessive force closure). while it is usually argued that contraction of the horizontal fibres of the IO and TrA help to compress the SIJ, a counter argument could be made that these same fibres compress and stabilize the PSJ. The findings of muscle facilitation or inhabitation through the application of manual compression by Beales *et al*. (2010) was suggested to support this theory. However, an alternate explanation based on the results of Palsson *et al.* (2012) and Shadmehr *et al.* (2012) is possible. It could be argued that sensitisation of nociceptors without damage to muscle and ligamentous architecture may lead to increase muscle activity while damage to the architecture

may lead to inhibition to prevent further damage. The observed effects of compression could therefore be explained by two different mechanisms and plausible mechanisms. Firstly, compression would increase proprioceptive input and active the pain gate, inhibiting nociceptive input, thereby reducing EMG output. Secondly, compression would stabilise the PSJ and provide increased proprioceptive information, thereby facilitating muscle contraction. This would lead to an increase in muscle activity observed in EMG studies, reduce pain and RPE. However, the quality of evidence at presence is such to prevent inference and additional research is required.

It must therefore be concluded that the ASLR does have face validity as a load transfer test, the construct validity of the test is problematic.

5.3.1.7.2 Motor Control

Limited evidence was found to support the used of ASLR in the assessment of motor control in non-pregnant PGP population due to study design types. While the ASLR is primarily a measure of sagittal plane stability, limited evidence was found within this population to support the use of the ASLR.

Two studies, Beales *et al.* 2010 and O'Sullivan *et al.* 2002, examined the effects of manual compression within this group, comparing EMG studies with and without the compression. When manual compression was applied to the ileum while performing the ASLR, two patterns of recruitment (inhibition and facilitated recruitment) were observed (Beales *et al.* 2010; O'Sullivan *et al.* 2002). No studies examined manual compression of other regions of the body despite EMG studies showing that muscle activity may be altered in the shoulder girdle during the performance of a painful ASLR. Inter and intra variability of muscle recruitment patterns were observed between pain and pain free subjects, with trends noted, but no definite patterns reported (Beales *et al*. 2010). Subsequently, only limited evidence exists for the application of manual compression to determine alter motor control. However, no conclusion can be drawn as to the mechanisms underlying the effects of this compression. Additionally, no evidence exists to support compression in other regions of the body.

Despite these conflicting findings, certain muscular recruitment trends were observed. These trends were bracing through the abdominal wall muscles and increased RPE to perform the ASLR (Palsson *et al.* 2012; Beales *et al.* 2010; O'Sullivan *et al.* 2002). However, the evidence to support this was still limited. It can be concluded that

additional research is required to determine if these trends are more apparent in certain chronicity and severities of PGP.

5.3.2 Low Back Pain

5.3.2.1 Introduction

A total of 15 articles were analysed in the LBP section: three articles examined sLBP, while 12 studied nLBP. The nLBP articles were composed of recurrent back pain and two on chronic LBP, the remaining studies did not limit to a specific occurrence or chronicity of pain. All articles were analysed according to sensitivity, validity, reliability, pain, muscle recruitment, and arthrokinematics.

5.3.2.2 Lumbopelvic-Hip and Spinal Arthrokinematics

This SR found that there was limited evidence to explain the joint biomechanics during the ASLR in LBP subjects. This was due to the number, type, and rigor of the studies. A total of two observational articles, one on LPH complex and one on spinal segments, were reviewed (Sadeghisani *et al.* 2017; Corkery *et al.* 2014 respectively). The articles were found to present limited conflicting evidence (table 5.6).

Table 5.6: Sof for arthrokinematics in ASLR in LBP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Corkery *et al.*	2014	Cohort	PBU	Moderate	Bad	Negative association to aberrant movement			x		X	
Sadeghisani et al.	2012	Cross-sectional	EMG	Low	Moderate	Positive in muscle recruitment						

(Grey highlight = negative outcomes)

Sadeghisani *et al.* (2017), who examined LPH-complex motion of men in flexion-rotation subgroup of chronic LBP reported two significant findings. These were LBP subjects exhibited greater posterior pelvic rotation during the ASLR on the non-dominate limb which was associated greater angular velocity during the first phase of hip flexion. This suggest that the hemipelvis may be anteriorly tilt initially, and therefore undergoes greater and faster posterior rotation during initial hip flexion. In contrast, Corkery *et al.* (2014) found that even though aberrant spinal movements were more common in athletes with LBP than the pain free group (40% vs 6%), the performance

of the ASLR was similar between groups. Both studies were of limited evidence as they contained risk of bias with the potential to alter outcomes.

5.3.2.3 Muscle Recruitment

While multiple studies examined muscle recruitment (Table 5.6), the evidence to support the findings is limited in both specific and non-specific LBP due to study design. The quality of the studies also varied significantly; however, certain commonalities were observed. These included that respiratory mechanics were altered in the LBP population, and LBP subjects demonstrated greater variability in muscle recruitment (Nelson-Wong *et al.* 2013; Rousel *et al.* 2009).

Table 5.7: Sof for muscle recruitment during the ASLR in LBP

Author(s)	Year	Study Type	Test Type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
KrKeljas and Kovac	2018	Observational	Functional RoM	Good	Good	Positive Decreased muscle activation			x		x	
Lewis, Wood, and Olivier	2013	Cross-sectional	PBU	Moderate	Poor	Negative PRE						
Macdonald, Dawson, and Hodges	2011	Cross-sectional	U/S	Moderate	Poor	Negative no difference in muscle thickness						
Nelson-Wong *et al.*	2013	Observational	EMG	Poor	Poor	Positive Increased lag times Change recruitment patterns						
Nelson-Wong *et al.*	2016	Observational	Objective scoring	Poor	Poor	Positive For decrease pelvic stability						
Roussel *et al.*	2007	Observational	Functional	Good	Poor	Positive Altered respiratory mechanics						
Roussel *et al.*	2009	Case control	Visual Borg score	Moderate	Poor	Positive altered breathing patterns and motor deficits						
Saskai *et al.*	2011	Observational	HHD Walking capacity	Poor	Moderate	Positive						
Vanti *et al.*	2016	Observational	Functional	Poor	Good	Positive						

(Grey highlight = negative outcomes)

Roussel *et al.* (2007), compared the ASLR to the Trendelenburg test, finding that the tests had a Cronbach alpha coefficient for internal consistency of greater than 0.73 and therefore compared the same dimensions of sagittal plane stability. As the appraisal of the study found that the internal validity was moderate, and the external validity was low the article only supplies limited evidence to support its conclusions on sagittal stability assessment. In their follow-up study, Roussel *et al.* (2009), found significantly altered breathing patterns in chronic LBP-patients during the performance of the ASLR. These changes were not related to pain severity (P = 0.01), but to motor control dysfunction (P = 0.01). Similarly to their first study, this article presence only limited evidence.

Three studies examined planar stability during the performance of the ASLR. Nelson-Wong *et al.* (2013) examined muscle recruitment in the ASLR and AHAbd tests, and cross-correlated results. The study demonstrated that subjects with LBP utilized a variable muscle recruitment pattern in the frontal and coronal plans, while pain free subject consistently recruited muscles in a proximal to distal in both planes. Additionally, the LBP group was to have significantly shorter phase lag than controls, showing a near co-activation of right RF and contralateral left GMx, while controls had a proximal to distal strategy with these muscle groups. In their follow up article which analysed the same data, 60% of subjects were found to have uniplanar instability while 40% had multiplanar instability. As both studies utilized the same data, their appraisals were the same. They were both found to provide no evidence, as both had poor internal and external validity.

In their study, Krkeljas and Kovac (2018) also found significant changes in the function of LPH complex muscles in athletic subject with nLBP. The most significant change was the tightness in the posterior chain tightness. Inflexibility hamstring and calf, hypo-mobility of the trunk, and increased posterior pelvic tilt were all reported. Additionally, pain free subjects were shown to exhibited greater flexion and internal rotation in other tests. These factors were found to correlated to a higher incidence of a Cooks ‘score of 1 during the ASLR in LBP subjects.

Similar importances of the extensor muscles were noted by Lewis, Wood, and Olivier (2013); and Vanti *et al.* (2016). Lewis, Wood, and Olivier (2013) found that trunk extensor muscle endurance correlated to the performance of the ASLR in adolescence. However, these findings are likely to have poor applicability (external

validity) to adult subjects. Vanti *et al.* (2016) found that the ASLR had a low to moderate correlation to extensor muscle endurance, but these was only significant in the prone bridge test. In contrast Macdonald, Dawson, and Hodges (2011) found limited evidence that lumbar multifidus muscle thickness is not correlated to the ASLR in the presence of LBP. The article was appraised as having moderate internal validity and poor external validity.

Sasaki *et al.* (2011) demonstrated a high correlation (r=0.50, p,0.01) between ASLR strength and walking capacity in female subjects with intermittent neurogenic claudication due to stenosis at L3/4 level. This article varied greatly from the others in this section, as it was the only article that examined a functional outcome i.e. walking. The article however provided no evidence due to poor internal and external validity.

5.3.2.4 Pain and Psychometrics

All studies analysed in this SR utilised observational assessment of breathing patterns during the performance of the ASLR in the presence of LBP. Due to the subjective nature of these assessments, the quality of evidence is greatly reduced. Roussel *et al.* (2009) observed that the breathing did not correlate to the severity of pain but rather to motor control deficit (p = 0.01).

Table 5.8: Sof for pain and psychometric tests for ASLR with LBP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Roussel *et al.*	2009	Case control	Visual Borg score	Moderate	Poor	Positive altered breathing patterns and motor deficits			x			

5.3.2.5 Sensitivity and Specificity

Sn and Sp are discussed together in this section due to their relationship in the studies.

5.3.2.5.1 Subjective Scoring

There is limited evidence that the six-point Likert point has moderate correlation to LBP during the performance of the ASLR. Only a single study (Bruno, Goertzen, and Millar 2014a) examined this relationship between LBP, Likert scale and the performance of the Mens' ASLR (Table 5.7). There were two components examined in the study for Sn and Sp, that of the subjective rating by subjects and examiners,

and the comparison to painful state (i.e. LBP). The study found that the scale had the greatest sensitivity when 0 and 1 or positive and negative were utilised. When further values were assigned, the sensitivity decreased but specificity increased. The study also found no statistically significant difference in the perceived difficulties of the positive and negative examiner classifications for the ASLR. In their follow up article, Bruno, Goertzen, and Millar (2014b), which reanalysed the data, no significant differences were noted between gender. Therefore, in the clinical setting a positive/negative rating scale should be assigned until additional research can be undertaken to expand the evidence base.

Table 5.9: Sof of subjective scoring of ASLR in LBP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Bruno, Millar and Goertzen	2014a	Cross-sectional	Functional Pain indices	Medium	Bad	Positive Good specificity Moderate sensitivity	x					
Bruno, Goertzen, and Millar	2014b	Cross-sectional	Functional Pain indices	Medium	Bad	Positive Good specificity Moderate sensitivity						
KrKeljas and Kovac	2018	Observational	Functional RoM	Good	Good	Functional rating						

Similarly, only a single article assessed the Cooks' ASLR scale (Krkeljas and Kovac 2018). This study found that subjects with LBP scored lower and had a decreased ability to perform the ASLR. This article also provided limited evidence to score the ASLR. However, the results of both articles suggest that the ASLR be score as positive or negative for pain and quality of movement be score by well-defined criteria.

5.3.2.5.2 Sensitivity and Specificity of the ASLR

The Sn and Sp were examined by and Bruno, Goertzen and Millar (2014a); Bruno, Goertzen and Millar (2014b); and Nelson-Wong *et al.* (2016). All three studies examined the ASLR sensitivity (Table 5.9.) and specificity (Table 5.10.) to detect abnormal motion during the performance of the ASLR. The results for Sn of the ASLR was found to be limited and conflicting. Bruno, Goertzen and Millar (2014a) found that the Sn was low (0.20-0.25) in their first article while their second article reported moderate Sn (0.6) (Bruno, Goertzen and Millar 2014b). While both articles appeared to have utilized the same subjects, the methods of classifying a positive result differed. No explanation could be found to determine why the Sn values were different between

articles. The appraisals of the articles found that they both had moderate internal validity and poor external validity therefore provided only limited evidence.

In their study of multiplanar instability, Nelson-Wong et al. (2016), found the ASLR to have a Sn 0.63. When the ASLR was considered in conjunction with the AHAbd test the Sn increased to 0.89. This article was appraised as having poor rigor, as both the internal and external validity was poor therefore the article deemed to provide no evidence. Therefore, the ASLR has a low-to-moderate Sn.

Table 5.10: Sof for sensitivity of ASLR in LBP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Bruno, Millar and Goertzen	2014a	Cross-sectional	Functional Pain indices	Medium	Bad	Positive Sn and Sp			x		x	
Bruno, Millar and Goertzen	2014b	Cross-sectional	Functional Pain indices	Medium	Bad	Negative Sn						
Nelson-Wong *et al.*	2016	Observational	Objective scoring	Poor	Poor	Positive Sn and Sp						

(Grey highlight = negative outcomes)

Bruno, Goertzen and Millar (2014a) and Bruno, Goertzen and Millar (2014b), reported the Sp to be high, 0.84-0.86 and 0.76 respectively. Nelson-Wong *et al.* (2016), found the ASLR to have only a moderate Sp of 0.61 which declined to 0.60 when considered in conjunction with the AHAbd test. Therefore, there is limited evidence to suggest that the ASR has moderate to high specificity to detect motor control deficits in LBP.

Table 5.11: Sof for specificity of ASLR in LBP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Bruno, Millar and Goertzen	2014a	Cross-sectional	Functional Pain indices	Medium	Bad	Positive Sp			x			
Bruno, Millar and Goertzen	2014b	Cross-sectional	Functional Pain indices	Medium	Bad	Positive Sp						
Nelson-Wong *et al.*	2016	Observational	Objective scoring	Poor	Poor	Positive Sp						

5.3.2.6 Reliability

The inter-tester reliability was found to be conflicting in this study, as Bruno, Goertzen and Millar (2014a) reported a high reliability, while Rabin *et al.* (2013) and Roussel *et*

al. (2007) only found a moderate correlation. However, the rigor of the Bruno, Goertzen and Millar (2014a) was high compared to that of Rabin *et al.* (2013) but had lower internal validity than Roussel *et al.* (2007). This suggests that there is at least moderate inter-tester reliability, but additional research is required to clarify if there is high or a moderate correlation. Until the evidence base has been expanded, clinicians should bear in mind that when they perform ASLR testing, differences may be observed.

Table 5.12: Sof for the reliability of the ASLR in LBP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Bruno, Millar and Goertzen	2014a	Cross-sectional	Functional Pain indices	Medium	Bad	Positive reliability	x					
Rabin *et al.*	2013	Inter-rater reliability	Functional	Bad	Bad	Positive reliability						
Roussel *et al.*	2007	Observational	Functional	Good	Bad	Positive reliability						

5.3.2.7 Validity

While the totality of the evidence to support the face and construct validity is limited, it is apparent that the LBP group has both face and construct validity for motor control testing and load transfer. This is because there is Sn, Sp, reliability, pain and motor control data.

The while the data relating to arthrokinematics is limited and conflicting, it needs to be considered in its component parts to be of benefit. Sadeghisani *et al.* (2017) found that the hemi-pelvis rotated posteriorly with greater speed and in terms of degrees. This data is supported by Krkeljas and Kovac (2018) findings utilizing functional testing. While Corkery *et al.* (2014) was appraised at the same level of evidence as Sadeghisani *et al.* (2017) the joints assessed were significantly different. This article was assessing to see if AM of spinal segments correlated to the ASLR. Three plausible reasons for the test not been able to find a correlation are the subjects were young and athletic, and when performing the ASLR the test there was insufficient load to produce a positive result alternatively the AM test lacked the sensitivity to be able to produce an accurate result.

5.3.3 Lumbopelvic Pain

5.3.3.1 Introduction

Three studies were analysed in this grouping, Kwong *et al.* (2013), Teyhen *et al.* (2009), and Whittaker *et al.* (2013). Kwong *et al.* (2013) was included in this group due to the lack of no distinction was made between LBP, PGP, and LBP with PGP subjects. There was discussion with the reviewers as to whether Whittaker *et al.* (2013) should be included into the PGP group. The reviewers felt that despite Whittaker *et al.* (2013) defining the region of pain to meet the definition of PGP, they failed to adequately screen the lumbar spine. Therefore, the decision was taken to keep with the article's authors decision to categorise the study as LPP. Teyhen *et al.* (2009) was included in the group as their inclusion criteria was a single positive SIJ pain provocation test and a positive ASLR without determining whether the lumbar spine was the source of pain. Similarly, to Whittaker *et al.* (2013), the authors defined the study as LPP.

5.3.3.2 Muscle Recruitment

Two papers examined muscle recruitment during the ASLR in subjects with LPP, Whittaker *et al.* (2013) and Teyhen *et al.* (2009). As such there is only limited evidence to support the conclusions drawn from these studies findings. Teyhen *et al.* (2009) reported that individuals with LPP have a symmetrical deep abdominal muscle (TrA and IO) recruitment pattern bilaterally with a reduced ability to thicken on the painful side on U/S investigation (Teyhen *et al.* 2009). Thickening of the TrA and IO of the control group was reported to be 23.7% and 11.2% respectively, while LPP subjects demonstrated a 6.4% and 5.7% increase, respectively. This suggests that the contralateral abdominal muscles are recruited to compensate for pain inhibit of the ipsilateral abdominals, leading to abdominal bracing to prevent pain or in response to pain. The findings of Teyhen *et al.* (2009) also needs to be viewed in the context those of Whittaker *et al.* (2013) who examine the association between U/S and EMG findings during the ASLR and reported that only a weak association ($r = 0.28 +/- 0.09$); exists between the muscle recruitment ($\tau = 0.69 +/- 2.56$ seconds) and muscle thickening. Additionally, it is recognised that U/S only provides data on the section of the muscle being examined. As such the data suggest that the timing of muscle recruitment is far more significant however more study is required.

Table 5.13: Sof muscle recruitment in LPP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Teyhen *et al.*	2009	Cross-sectional	US	Medium	Bad	Positive for unilateral difference muscle thickness change			x			
Whittaker *et al.*	2013	Validation	US EMG	Medium	Bad	Positive muscle thickness and EMG changes			x			

(Grey highlight = negative outcomes)

5.3.3.3 Sensitivity and Specificity

Kwong *et al.* (2013) reported Sn and Sp of 71% and 91% respectively in their study in which PGP and LBP were not analysed by sub-grouped (Table 5.10). The Sn varied between 65% and 70% for individual rater and the confidence interval vary significantly, ranging from 44% to 80% at 95% confidence level. While the rigor of the study was high (medium internal validity and good external validity), the lack of collaborating papers and study design means that there is limited evidence in the LPP grouping. However, these Sn and Sp findings were consistent with those in other subgroups in examined in this study.

Table 5.14: Sof for sensitivity and specificity of ASLR for LPP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Kwong *et al.*	2013	Cross-sectional	Disability and pain indices	Medium	Good	Positive Sn and Sp			x			

(Grey highlight = negative outcomes)

5.3.3.4 Pain

Only a single study examined the relationship between pain and the ASLR in LPP, Kwong et al. (2013). Kwong *et al.* (2013) reported a correlation between the ASLR and the Functional Pelvic Pain Scale (r=0.77) and Roland-Morris Disability Questionnaire of r=0.77 and r=0.70 respectively.

Table 5.15: Sof of psychometric in ASLR with LPP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Roussel *et al.*	2009	Case control	Visual Borg score	Moderate	Poor	Positive altered breathing patterns and motor deficits			X			

(Grey highlight = negative outcomes)

5.3.5 Reliability

A single study, Kwong *et al.* (2013), compared the inter-rater reliability of the ASLR to the single leg stand. The inter-rater reliability of the ASLR was high, having a 90% agreement, with a Kappa coefficient of 0.87 compared to single leg stand poor inter-rater reliability with kappa values of –0.02 and 0.14 for the left and right sides, respectively. While these results suggest that it is more reliable for practitioners to use the ASLR to assess sagittal stability than the single leg stand, the lack of additional articles to support the articles' evaluation of moderate evidence means that there is only limited evidence to support the use of the ASLR in this manner.

Table 5.16: Sof of reliability of the ASLR in LPP

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Kwong *et al.*	2013	Cross-sectional	Disability and pain indices	Medium	Good	Positive inter-rater reliability			X			

(Grey highlight = negative outcomes)

5.3.6 Validity

The LPP studies examined provide limited support for limited support of face validity of the ASLR. The interruption of the evidence to support construct validity needs to be considered whether the SLR is being used to examine motor control or load transfer. The evidence related to motor control is conflicting (Whittaker *et al.* 2013, Teyhen *et al.* 2009), whilst the use of the ASLR to evaluate load transfer in LPP. Additionally, the findings of Kwong *et al.* (2013), were consistent with the LBP and PGP groups.

5.4 ANALYSIS OF RESULT BY LIFT HEIGHT

In this section, the sensitivity, specificity, reliability, and validity will be examined by lift height. These heights will be discussed in the following divisions: below 10cm (<10cm), 10-30cm, 30-60cm, full RoM, and unspecified. This section will only discuss relevant information provided by the combination of lift height with various pathologies, as individual articles were already discussed in tables in chapter 4 and as a combination of a pathology in previous section.

5.4.1 ASLR <10cm

5.4.1.1 Introduction

The articles were included in this RoM as this range primarily loads the SIJ during the lifting processes (Dutton 2020). Four studies that were included in this SR examined the ASLR below 10cms of lift. Two studies examined LPP, one SIJP and one rLBP. None of the studies examined Sn, Sp, reliability, pelvic symmetry, or the association to pain and disability.

5.4.1.2 Motor Control of ASLR <10cm

A total of four articles examined the motor control of the ASLR below 10cm of height (Table 5.11). The appraisal of articles found that two articles provided limited evidence while two provided no evidence, with the two articles that provided limited evidence examining LPP. The two articles providing limited evidence suggest that abdominal bracing occurs within the first 10cm (Teyhen *et al.* 2009 and Whittaker *et al.* 2013). This is consistent with PPGP findings where the TrA firing is delayed, resulting in significant overcompensation by the muscles (Mens et al. 2019).

O'Sullivan et al. (2002) compared the muscle recruitment in the absence and presence of SIJP, and then examined the effect of manual compression of the ilia during the performance of the ASLR. This study provided limited evidence that SIJP is associated with increased minute ventilation, decreased diaphragmatic excursion, and increased pelvic floor descent, compared with control subjects. Additionally, the changes in ventilation patterns were associated to the change in mechanics and not pain. Both the respiratory function and the muscle function involved with the ASLR were normalised with compression. While Macdonald et al. (2011) found minimal changes LM function in rLBP, the quality of the article was such as to provide no evidence.

Table 5.17: Sof of motor control of ASLR <10cm

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
O'Sullivan *et al.*	2002	Observational	US Spiro metry	Low	Bad	Positive altered respiratory mechanics						
Macdonald *et al.*	2011	Cross-sectional	US	Low	Bad	Negative for difference LMM thickness changes						
Teyhen *et al.*	2009	Cross-sectional	US	Medium	Bad	Positive for unilateral difference muscle thickness change			X		X	
Whittaker *et al.*	2013	Validation	US EMG	Medium	Bad	Positive muscle thickness and EMG changes						

(Grey highlight = negative outcomes)

5.4.1.3 Validity of ASLR <10cm

Face and construct validity is provided by Teyhen *et al.* (2009) and Whittaker *et al.* (2013), who provided limited evidence that abdominal bracing occurs within the first 10cm of the ASLR. This is consistent with having to break inertia and lift the leg at its greatest mechanical disadvantage. The overloading of structures would induce pain when and alter MC strategies.

5.4.2 ASLR with a Lift Height of 10-30cm

5.4.2.1 Introduction

A total of 14 articles utilised a RoM of 10-30cm during the performance of the ASLR. The breakdown by pathologies was as follows: 10 LBP articles, 3 PGP/SIJP articles and 1 LPP articles. Sn, SP, reliability, motor control, pain, and pelvic symmetry were all examined. Articles included in this RoM as this range primarily loads the neural and SIJ structures during the lifting processes (Dutton 2020).

5.4.2.2 Sensitivity and Specificity

The four articles examined the Sn and Sp of the ASLR between 10- and 20-centimeter of height (Table 5.16 and Table 5.17). Three studies examined LBP and one for LPP. No studies have examined this RoM in PGP. The LPP article by Kwong *et al.* (2013) was evaluated as providing no evidence due to its poor appraisal. Therefore, there is limited conflicting evidence for Sn and limited evidence Sp of this RoM for LBP only. The Sn and Sp of the ASLR within range to assess motor control, ranges from 0.2 to

0.72 and 0.61 to 0.86 respectively. As this section would duplicate the LBP discussion, no further discussion will be undertaken apart from the validity section for this RoM.

Table 5.16: Sof of the sensitivity of ASLR with a lift height of 10-30cm

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Bruno, Millar and Goertzen	2014a	Cross-sectional	Functional Pain indices	Medium	Bad	Positive Sn						
Bruno, Millar and Goertzen	2014b	Cross-sectional	Functional Pain indices	Medium	Bad	Negative Sn						
Kwong *et al.*	2013	Cross-sectional	Disability and pain indices	Medium	Good	Positive Sn			**x**		x	
Nelson-Wong *et al.*	2016	Observational	Functional	Low	Bad	Positive Sn						

(Grey highlight = negative outcomes)

Table 5.17: Sof of the specificity of ASLR with a lift height of 10-30cm

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Bruno, Millar and Goertzen	2014a	Cross-sectional	Functional Pain indices	Medium	Bad	Positive Sp						
Bruno, Millar and Goertzen	2014b	Cross-sectional	Functional Pain indices	Medium	Bad	Positive Sp						
Kwong *et al.*	2013	Cross-sectional	Disability and pain indices	Medium	Good	Positive Sp			**x**			
Nelson-Wong *et al.*	2016	Observational	Functional	Low	Bad	Positive Sp						

5.2.2.3 Reliability

Three domains of inter-rater reliability were examined for this RoM: the ability to detect aberrant movement, the ability to assess respiratory mechanics, and test-retest reliability (Roussel et al. 2009; Roussel et al. 2007). Three articles examined LBP, while one studied LPP.

Table 5.17: Sof of the reliability of ASLR for 10-30cm

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Bruno, Millar and Goertzen	2014a	Cross-sectional	Functional Pain indices	Medium	Bad	Positive reliability						
Kwong *et al.*	2013	Cross-sectional	Disability and pain indices	Medium	Good	Positive reliability			**x**			

Nelson-Wong *et al.*	2016	Observational	Functional	Low	Bad	Positive reliability	

(Grey highlight = negative outcomes)

The test-rest reliability was examined by Roussel *et al.* (2007) in chronic nLBP, this article was found to provide moderate evidence to support the conclusion that the test-retest reliability was moderate (k=0.7). This article also examined inter-observer reliability for the assessment breathing patterns during the performance of the ASLR to be low (k=0.37).

In the article by Bruno, Millar and Goertzen (2014a), the article provided limited evidence that the ASLR for inter-rater reliability for the presence or absence of abnormal movement in LBP was high (K=0.76, 95% CI = 0.57-0.96, p < 0.001).

Kwong *et al.* (2013) examined the inter-rater reliability to determine if the ASLR was positive or negative in a wide spectrum of LPP subjects. This SR found that the provided moderate evidence to support the articles findings of high (K=0.87; 95% CI 0.77–1.00) inter-rater reliability.

5.2.2.4 Pain

Four studies examined the association between pain and the ASLR for 10-30cm lift height, two LBP, one each in PGP and LPP. The evidence between ASLR function and pain was conflicting. Two studies, Roussel *et al.* (2009) and Roussel *et al.* (2007) found no significant relationship between the breathing patterns and pain severity, and ASLR outcomes, and self-reported pain severity and disability. These studies were assessed as providing limited evidence and moderate evidence to support respectively. Vanti *et al.* (2016) in contrast provided limited evidence that there was a low relationship between pain, disability, and the ASLR. In addition, Bruno, Millar and Goertzen (2014b) found a positive relationship between pain and RPE of the ASLR. This study only provided limited evidence to support this finding.

Table 5.18: Sof of the relationship between pain and ASLR 10-30cm

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Bruno, Millar and Goertzen	2014b	Cross-sectional	Functional Pain indices	Medium	Bad	Positive association between ASLR performance and pain			x		x	

Roussel *et al.*	2007	Observational	Pain and disability indices	Medium	Good	Negative association between ASLR performance and pain	
Roussel *et al.*	2009	Case control	Pain and disability indices	Medium	Bad	Negative association between ASLR performance and pain	
Vanti *et al.*	2016	Observational	Functional	Low	Good	Positive association between ASLR performance and pain	

(Grey highlight = negative outcomes)

5.2.2.5 Motor Control

Eight articles (table 5.9) examined motor control for the range of 10-30cm. Three of the articles examined PGP, while the rest examined nLBP. Lewis and Olivier (2013) were an anomaly within the LBP articles, as the subject age range was between 12 and 18 YoA. This found no relationship between motor control of the ASLR and adolescent nLBP. They did find that there was a relationship between LPH complex stability during the ASLR and extensor muscle endurance. The appraisal of the was poor therefor the article was assessed as providing no evidence.

Roussel *et al.* (2009), reported altered breathing patterns during the performance of the ASLR (P=0.01) which were not related to pain severity (P = 0.01), but to motor control dysfunction (P = 0.01). It is unclear if this a result of or a contributing factor to poor performance of the ASLR.

Roussel *et al.* (2007), compared the ASLR to the single leg stand as a measure of sagittal plane stability. The evidence supports the assertion that the high internal consistency of the outcome for both assessors suggest the test assess the same dimension.

Table 5.19: Sof of the motor control of the ASLR 10-30cm

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Beales *et al.*	2009	Observational	EMG U/S	Low	Bad	Positive increased mm activation						

Lewis and Olivier (2023)	2013	Cohort	PBU Functional	Low	Bad	Negative between LBP and stability	x	**X**
Nelson-Wong *et al.*	2013	Observational	EMG	Poor	Poor	Positive Increased lag times Change recruitment patterns		
Nelson-Wong *et al.*	2016	Observational	Objective scoring	Poor	Poor	Positive For decrease pelvic stability		
Palsson *et al.*	2012	Experimental	EMG	High	Good	Positive bilateral increased mm activation		
Roussel *et al.*	2007	Observational	Functional	Good	Good	Positive of altered breathing patterns		
Roussel *et al.*	2009	Case control	Visual Borg score	Moderate	Bad	Positive association between ASLR performance and pain		
Shadmehr *et al.*	2012	Cross-sectional	EMG	Low	Bad	Positive increased latency and tonicity		
Vanti *et al.*	2016	Observational	Functional	Low	Good	Positive association between ASLR performance and pain		

(Grey highlight = negative outcomes)

Three studies examined planar stability during the performance of the ASLR. Nelson-Wong *et al.* (2013) examined muscle recruitment in the ASLR and AHAbd tests, and cross-correlated results. The study demonstrated that subjects with LBP utilized a variable muscle recruitment pattern in the frontal and coronal plans, while pain free subject consistently recruited muscles in a proximal to distal in both planes. Additionally, the LBP group was to have significantly shorter phase lag than controls ($p < 0.05$), showing a near co-activation of right RF and contralateral left GMx, while controls had a proximal to distal strategy with these muscle groups. In their follow up article, Nelson-Wong *et al.* (2016), which analysed the same data, 60% of subjects were found to have uniplanar instability while 40% had multiplanar instability. As both studies utilized the same data, their appraisals were the same. They were both found to provide no evidence, as both had poor internal and external validity. However, Vanti *et al*. (2016) reported variable motor control, distal to proximal patterns, in LBP subjects compared to control subjects who commonly used proximal to distal muscle

recruitment in frontal and sagittal planes. While the quality of Vanti et al. (2016) was not significantly better, it was appraised as providing limited evidence, which provides a degree of credibility to the Nelson-Wong *et al.* (2013) and Nelson-Wong *et al.* (2016) studies.

Palsson et al. (2012) found that experimentally induced PGP pain was found to cause bilateral increase in abdominal muscle firing. They concluded in their article that pain may be responsible for many but not all the motor control adaptations observed during the performance of the ASLR. This article demonstrates the need to consider the effects of pain and pain sensitization on the performance of the ASLR on the clinical setting. Palsson et al. (2012) article had good internal validity but poor external validity, therefore providing moderate evidence.

Beales *et al.* (2009) also reported when the ASLR was performed on the symptomatic side, the dominant MC pattern observed was bracing of the abdominal and chest walls with an associated increase in IAP and depression of the pelvic floor when compared to the non-symptomatic side. The quality of the article was assessed as being poor as both the internal and external validity was low therefore the article provides no evidence. In contrast to these studies, Shadmehr *et al.* (2012) observed a decrease in BF, GM, EO, IO and RA mm. activity during the performance of the ASLR in SIJP subjects. Additionally, they reported a significant increase of the latency of adductor longus compared to healthy controls. The quality of this study was also poor due to low internal and external validity therefore this study also provides no evidence.

5.2.2.6 Validity

The LPP and LBP both showed moderate to high Sp, but the Sn varied from moderate to low. If all three articles are examined together, there is moderate evidence that the 10-30cm ranges has moderate to low Sn and Sp was moderate to high. These findings reinforce the lack of information regarding to Sn and Sp to specific causes of LBP at this height. In contrast the motor control studies clearly demonstrated the ASLR has both face and construct value at this height for the saggital plane. Additional research is required to establish the validity and reliability of the ASLR as a tool to screen for coronal plane instability, as Nelson-Wong *et al.* (2013) and Nelson-Wong *et al.* (2016) were appraised as providing no evidence.

5.2.3 ASLR with a Lift Height of 30-60cm

5.2.3.1 Introduction

The articles were grouped within this range emphasise that as SIJ and neurological loading decrease, myofascial components begin to increase (Dutton 2020). Three articles examined ASLR in the 30-60cm RoM. Two articles focus on nLBP. The first article examined the effects of gynaecological surgery and brings into question where abnormal form closure is assessed by the ASLR. The second article examined LBP in young athletes with LBP. No articles examined the reliability, sensitivity, or specificity of the ASLR between 30-60cm lift height.

5.2.3.2 Motor control of the ASLR with a lift height of 30-60cm

Ericksen et al. (2010) provided limited evidence, via U/S analysis, that insignificant pelvic floor descent occurs from increased pressure on the PFM during the ASLR in elderly women with a history of genealogical surgery (P=0.4159).

Table 5.20: Sof of motor control with a lift height of 30-60cm

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Ericksen *et al.*	2010	Cohort	US	Moderate	Bad	Negative asymmetry			X			
Sasaki *et al.*	2011	Cohort	Walking capacity	Low	Bad	Positive muscle related to walking capacity					X	

(Grey highlight = negative outcomes)

In contrast, Sasaki *et al.* (2011) found that walking capacity was associated with muscle strength during the performance of the ASLR on the symptomatic side in intermittent claudication. However, the article had low internal validity and bad external validity and, therefore, provided no evidence.

5.2.3.3 Arthrokinematics

Two of the included articles (table 5.21) examined arthrokinematics in the 30-60cm RoM. Both found no correlation between the ASLR and altered joint mechanics for this RoM in females.

Table 5.21: Sof of pelvic symmetry with a lift height of 30-60cm

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Ericksen *et al.*	2010	Cohort	US	Poor	Bad	Negative asymmetry						×
Corkery *et al..*	2014	Cohort	PBU	Moderate	Bad	Negative no difference between control and pain groups						

(Grey highlight = negative outcomes)

Ericksen *et al.* (2012) examined SIJ compliance in elderly women with a history of genealogical surgery. They concluded that pain during the ASLR had no relationship to asymmetry of the SIJ in the older female population. However, the methodology used to reach this conclusion was problematic, as asymmetry of the SIJ was examined utilizing U/S in the prone position and not during the performance of the ASLR. As such the conclusions are based on a functionally different position (prone vs supine) and static versus dynamic. The appraisal of the article found the internal and external validity to be poor, which meant the article provided no evidence. Similarly, Corkery *et al.* (2014), found no correlation between AM and ASLR performance in female athletes. As this study had moderate internal validity and poor external validity, the article presence only limited evidence.

From the appraisal of these two articles, there is limited evidence that altered LPH mechanics are not associated with LBP in this RoM during the performance of the ASLR in females.

5.2.3.4 Validity

5.2.3.4.1 Face Validity

Due to the poor quality of the article by Sasaki *et al.* (2011) and no other article focusing specifically on neurogenic or neurodynamic causes of LBP been included in this article, no evidence was found to support the application of the ASLR in this RoM. However, the findings of Sasaki et al highlight the need for higher quality research additional study.

There is no evidence (i.e. the evidence is limited for negative outcomes) that this use of RoM provides any benefit to determine if asymmetry occurs in any of the LPH joints.

The use of the ASLR as a MC test was found to have limited evidence to support the findings. While there are articles that suggest that the ASLR is able to screen for multiplanar instability, the quality of these articles was poor.

5.2.3.4.1 Construct Validity

There is no evidence to support the theory of the ASLR testing neurological structures within this group. While Sasaki et al. (2011) has shown that the ASLR correlates to the walking capacity of subjects with intermittent neurogenic claudication L4/5 stenosis the appraisal of the article was deemed poor therefore the article provided no evidence. A significant limitation of this study was the article merely stated the spinal stenosis was present but fail to provide additional information.

Ericksen et al. (2010) provided limited evidence, via U/S analysis, that insignificant pelvic floor descent occurs from increased pressure on the PFM during the ASLR in elderly women with a history of genealogical surgery (P=0.4159). Significantly, no EMG analysis was conducted to determine the timing of PFM recruitment. This omission greatly undermined the value of the study as the timing of muscle contraction has been suggested to be the most significant determinant of pain. Significantly, thought this contradicts in which the pelvic floor was shown to descend. The main difference between the studies is that Beales *et al.* (2009) subjects were reported to all have urinary incontinence.

5.2.4 Full Available Range of Motion

5.2.4.1 Introduction

The articles included in this RoM as this range primarily test the myofascial components (Dutton 2020). Two articles examined the ASLR in full available range of motion. One article focused on nLBP while the other was sLBP. These articles only examined motor control and pelvic symmetry and, therefore, only these domains and the validity are discussed.

5.2.4.2 Motor Control Full Available Range of Motion

KreKeljas and Kovac (2018) was the only article that examined the motor control through this RoM. The article used athletic population who were suffering from nLBP. The reviewer appraisal led to the assessment that there was moderate evidence support the use of the ASLR through this RoM.

Table 5.22: Sof of motor control through full available RoM

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
KrKeljas and Kovac	2018	Observational	Functional	Medium	Good	Positive reduced muscle activation	X					

5.2.4.3 Pelvic Symmetry Full Available Range of Motion

Two articles included in this SR studied pelvic symmetry through full available RoM (see table 5.18), one examined sLBP and the other nLBP. Both articles reported pelvic asymmetry during the ASLR, with increased posterior pelvic tilt.

The article by KreKeljas and Kovac (2018) who examined nLBP in marathon runners was found to have moderate internal validity and good external mobility. They examined the correlation between flexibility and mobility tests, and the ASLR. They found that limitations in these tests correlated with a Cooks level 1 ASLR.

Table 5.23: Sof of pelvic symmetry through full available RoM

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
KrKeljas and Kovac	2018	Observational	Functional	Medium	Good	Positive asymmetry	X					
Sadghisani *et al.*	2017	Observational	3D Motion capture	Low	Bad	Positive asymmetry						

The second article by Sadghisani *et al.* (2017) examined the speed and timing of pelvic rotation in LBP with a flexion + rotation pattern. They reported an increased speed of pelvic movement on the symptomatic side throughout range but especially in the first half of range. Additionally, they noted that movement patterns were more synchronised and were associated with increased posterior pelvic tilt. However, due to poor the internal validity and bad external validity of article, the quality of the article was deemed to provide no evidence.

The outcomes of the studies were consistent, with both articles noting an increase in posterior pelvic tilt and the pelvic biomechanics been influenced early in RoM.

5.2.4.4 Validity

Validity in this section will only be discussed as face and construct validities as the inclusion of load transfer and motor control test limits rather than improves discussion

5.2.4.4.1 Face validity

The findings of KreKeljas and Kovac (2018) clearly show that the ASLR is a complex multifaceted motor control test which tests different neuromuscular facet at different degrees of hip flexion. The findings of this article also show that if RoM is restricted that additional testing is required to fully appreciate the clinical findings of the test and implement the best intervention.

The outcomes of this study indicate that tightness in the anterior hip muscles, namely the iliopsoas, increases resting anterior pelvic tilt. This places the gluteal muscles which are the primary hip extensors during the last 10 degrees hip extension at mechanical disadvantage, as demonstrated by reduced gluteal activity and reduced hip internal rotation. This has the dual effect of placing the hamstrings on stretch, and thus increasing eccentric loading and increasing the dependency on the hamstrings during hip extension. This increased loading leads to changes in the muscles architecture and reduces the muscles extensibility of the hamstrings. Subsequently, the pelvic stability needs to reduce to enhance compensatory biomechanics which leads to increased loading of joint structures as well as increased posterior pelvic tilt early in hip flexion.

As a result of these biomechanical considerations limited hip flexion early in RoM is therefore likely a test of anterior chain flexibility and/or a function of motor control while limitations in late RoM is due to flexibility.

5.2.4.4. Construct validity

The findings support the construct validity of the Cooks ASLR scoring system while highlighting the need for additional research to adequately interpret what dimensions are been assessed in each value and whether these scores correlate to loading/overloading of structures.

5.2.5 No Specified Lift Height

One article, Castro *et al.* (2018), failed to provide a specified height in text (Table 5.19). This article provided a picture which suggests that the lift height is between 10 and 60cm height, most likely 10-30cm. This article focused on sLBP (spondyloartophy), and due to poor internal validity and external validity, it provided no evidence that the ASLR had moderate sensitivity and low specificity to detect inflammation in

spondylopathy. The article, therefore, concluded that the ASLR is not suitable for this function in the clinical setting and pain provocation tests should rather be used.

Table 5.24: No Specified Lift Height of ASLR

Author(s)	Year	Study type	Test type	Internal Validity	External Validity	Outcomes	Strong	Moderate	Limited	Consensus	Conflicting	No evidence
Castro *et al.*	2018	Observational	MRI	Bad	Bad	Positive sensitivity Negative specificity			x			

(Grey highlight = negative outcomes)

5.5 LIMITATIONS OF SYSTEMATIC REVIEW

This systematic review had a few limitations. The first was the quality of evidence was limited by the study design of the articles included, as they were all observational. As a result, the internal validity of the articles was inherently lowered as subjects were not randomised (Meinert and Piantadosi 2022). The included articles represent a diverse type of LBP, thereby introducing uncontrolled variables into the review (Ahlawat 2020). This occurred due to many articles including a variety chronicity's, severities and pathological mechanisms. While this allows for greater external validity of the ASLR, it fundamentally reduces the ability to ascertain the best way apply the ASLR in the clinical setting.

The second most significant limitation of this study was the exclusion of non-English studies. There appears to be a great body of literature written in Japanese and Korean languages that were not included in this review. The ASLR research trends in Japan are significantly more diverse than Australia and Europe with less does not appear to focus on pregnancy and post-partum PGP (Takasaki *et al.* 2020).

5.6 STRENGTHS OF THIS SYSTEMATIC REVIEW

The type of studies, observational, which were analysed in this SR are both a limitation and a strength of this review, as the external validity of recommendations is greatly enhanced. This SR therefore gain significance as it highlights many confounding variables that were not considered or were not known at the time of undertaking the studies that the articles were derived from.

The study addresses the pain syndromes which fall under the greater label of LBP, i.e. nLBP and sLBP, PGP and LPP. The population i.e. non-pregnant or post-partum is also a group that has not previously undergone SR.

5.7 CONCLUSION

This chapter complied and reviewed the findings of chapter 4 to determine the level of evidence to support the application of the ASLR in lower back pain. Due to the study designs, the level of evidence does not exceed level 3 in chapter 4. When the data was synthesised and analysed in the totality by pathology and height it was found that only limited evidence exists in the application and interpretation of the ASLR in various sub-groupings of LBP.

CHAPTER SIX STUDY, SUMMARY, RECOMMENDATIONS AND CONCLUSION

6.1 INTRODUCTION

This chapter represents the conclusion of this dissertation. The chapter will include a summary, recommendations, and conclusion.

6.2 STUDY SUMMARY

The aim of this study was to determine the sensitivity, reliability, and validity of the ASLR by analysing muscular recruitment and biomechanics for optimal application and interpretation of the ASLR in the clinical setting. This was achieved by systematically reviewing 25 articles according to the GRADE principles and ranking the evidence in terms of “no evidence”, “limited evidence”, “moderate evidence” and “strong evidence” (Guyatt *et al.* 2011b). For all subtypes of LBP, limited evidence was found due to study design. Apart from 30-60cm lift height, the ASLR has good face validity however construct validity is problematic. This systematic found no evidence to support the assertion that neurological tissue is preferentially load within this RoM. The construct validity of force transfer i.e. the self-bracing theory is also open to challenge, as the PSJ is well proven to be the centre the axis of rotation during the ASLR and can have a radiographical observable slippage. The evidence pertaining to the recruitment of abdominal muscles is conflicting due to lack of sub-typing of low back pain often contradictory.

6.3. RECOMMENDATIONS FOR RESEARCH

Research recommendations consist of general and pathology specific. General recommendations were identified from the descriptions of the methodology used to perform the ASLR in the various studies and the samples used. Specific recommendations were developed from dearth’s within the literature.

6.3.1 General Recommendations

- Researchers need to highlight variations in the performance of the ASLR in comparison to the studies that they cite to validate the use of the ASLR in their study. Some studies utilise RoM greater based on angles, while others utilise heights greater than 20cm. These studies usually cite Mens *et al.* (1999) and Mens *et al.* (2002) in their methodology to support the study of the ASLR. Mens *et al.* (1999) utilises a lift hight of 5cm, while Mens *et al.* (2002) utilises a lift height of 20cm. While both the 5cm and 20cm techniques have been studied with sufficient subjects to determine validity, reliability and sensitivity in pregnancy related PGP, these variations have not. Subsequently, it is important that researchers follow the technique that they are citing, or clearly state what and why modifications are being made. Additional pilot studies should also be performed to determine the reliability and validity of the adaptations prior to the main study.
- Researchers need to be clear on foot positioning during their studies. Except for two studies utilising the Mens ASLR, the foot position is either not stated/reported or not controlled for, which leads to the potential introduction of variable through altered length tension relationships during the performances of the ASLR, as per the theory of regional interdependence (Sueki *et al.* 2013). Additionally, a study comparing whether foot positioning has any meaningful effect on proximal muscle recruitment is required or associated with the development of pain via long-leg, short-leg syndrome, which is associated with asymmetrical loading of the SIJ and the development of pain in the SIJ region and lumbar spine (Azizan *et al.* 2018). There also is a need to adequately screen the gastrocnemius muscle in studies examining the SIJ, as myofascial trigger points located in this region have the potential to refer pain to this region (Donnelly 2018; Simmons and Travell 1999). At present, no study has screen for potential referral from the soleus muscle to the SIJ. This may influence the outcomes of validity, sensitivity, specificity, and reliability of ASLR correlations, as false positive subjects would be reduced from studies.
- Manual compression of the iliac crest and bracing have been shown to improve the performance of the ASLR (Beales *et al.* 2010). While these two techniques (manual compression and bracing) were not the focus of this study, it is apparent that manual compression techniques used in clinical practice to facilitate certain

muscles have not been adequately researched (e.g. compression to simulate latissimus dorsi contraction). It is, therefore, necessary to empirically analyse these techniques to see if they produce the theorised muscular recruitment or a different effect.

- During the reporting phase, a researcher should clarify both the dominate leg and side with pain. Most studies do not state whether the left or right side are affected or report the dominate leg. This introduces confounding variables into these studies, reducing the studys' internal validity. Additionally, researchers should perform bilateral analysis rather than just unilateral to allow for contralateral muscle recruitment comparison, dominant and non-dominate legs have different neuromuscular recruitment (Ball and Scurr 2011).
- This study found a dearth in the peer review literature for the application of the Postural Restoration Institute biomechanical theory of lumbo-pelvic-hip dysfunction in relation to the performance of the ASLR in adult LBP subjects (Norasteh 2012). Therefore, research is required to determine if this is a valid paradigm and/or the presence or absence of left anterior interior chain dysfunction influences sensitivity and specificity of the ASLR. This is necessary as there is a growing population of health professional utilizing this approach to determine exercise and manual therapy requirements.

6.3.2 Pelvic Girdle Pain

- Subjects recruited to PGP studies are primarily female which is likely due the long-term effects of pregnancy. More studies are required to determine how PGP influences the performance, validity, sensitivity, and reliability of the ASLR in male population.
- There is a need for further research into the motion of the SIJ in all forms of LBP (Hu 2017). At present, the invasive but more accurate forms of analysis provide different reports of movement during the ASLR in serve PGP compared to the standard theory (Kibsgård *et al.* 2017; Mens *et al.* 1999). Even these more accurate forms of motion analysis are limited by the degree of accuracy (Kibsgård 2017). Additionally, study is needed to correlate PSJ and SIJ movement in PGP.

6.3.3 Low Back Pain

- At present there is no research that has analysed the dimensions of the Cook ASLR (i.e. level 1 vs level 2 vs level 3). A score of 1 is likely to be assessing different dimensions compared to a score of level 3 (Takasaki *et al.* 2020). It is, therefore, necessary to determine whether any empirical difference exists as well as whether Cook level 1 is interchangeable with Mens ASLR research.
- More detailed subgrouping of sample populations is required for LBP. Researchers need to more adequately clarify whether their subjects are acute, subacute, or chronic, and whether pain is constant, intermittent, or episodic, as this may cause different muscular adaptations. Therefore, more detailed subgrouping would potentially allow for the recognition of muscular recruitments as well as determining the specificity, sensitivity, and validity in the different subgroups of LBP. This would also reduce variables and enhance internal validity of research.

6.3.4 Lumbopelvic Pain

- Researchers should only use the term when both pelvic girdle and low back pain are present. This would improve homogeneity of the study sample and reduce possible variables in the findings.

6.4 RECOMMENDATIONS FOR CLINICAL PRACTISE

There were four key findings to the application and interpretation of the ASLR for biomechanical assessment in LBP. The primary finding was many aspects of the ASLR still have limited evidence outside of pregnancy related PGP and long-lasting pregnancy related PGP. Even within the more studied PGP populations, the evidence to explain the theories is conflicting and there is recognition that there is a need to enhance application and interpret, subgroup analysis is required to understand the pathology more fully.

- The evidence within the literature regarding pelvic girdle during movement during the performance of the ASLR is ambiguous. Kibsgård *et al.* (2017) raise questions over the direction and side of instability of the SIJ in severe unilateral pain with those of Mens *et al.* (1999). It is, therefore, essential for practitioners to screen both the SIJ and PSJ in the presence of a positive ASLR for instability and restricted

movement. This would allow for the correct selection of manual therapy and corrective exercise prescription.

- There is a growing body of evidence that dysfunctional movement may occur in one or more planes of motion during ASLR (Nelson-wong *et al.* 2016; Fitzgerald *et al.* 2022). A recently published study by Fitzgerald *et al.* 2022 found that LPP also has increase movement in the transverse plane. It is, therefore, necessary to do multiplanar movement assessment.
- Although limited, the evidence on the hamstring length in relation to the performance of the ASLR suggests that if RoM is limited, assessment of the gluteal muscle recruitment is required. This is to determine whether hamstring extensibility is reduced or if the hamstrings have shortened to enhance their biomechanical efficiency at the LPH-complex. (Cook 2012)
- The use of muscle contraction to assess muscle function is problematic. At present there is no objective data to affirm the use of compression to simulate muscle function other than compression of the iliac crests (Lee 2004). The use of palpation to determine muscle contraction is problematic as EMG analysis is only weakly correlated that of U/S. This implies that attempting to palpate the contraction does not provide adequate information on the co-ordination.

6.5 CONCLUSION

The ASLR has face construct validity as a test in LBP, PGP and LPP as a load transfer test. However, the construct validity in the non-pregnant population questionable. Due to its moderate sensitivity, it needs to be used in conjunction with other tests to increase to improve assessments (Castro *et al.* 2018). The ASLR is not an adequate test to discern impaired motor control strategies, as dysfunction appears to be related to poor intermuscular coordination rather than weakness (KreKeljas and Kovac 2018; Sadghisani *et al.* 2017). This is best analysed with EMG. Further research is required to ascertain the significance of the PSJ in this test and clarify the underlying paradigm of form closure in a positive ASLR test (Kibsgård *et al.* 2017).

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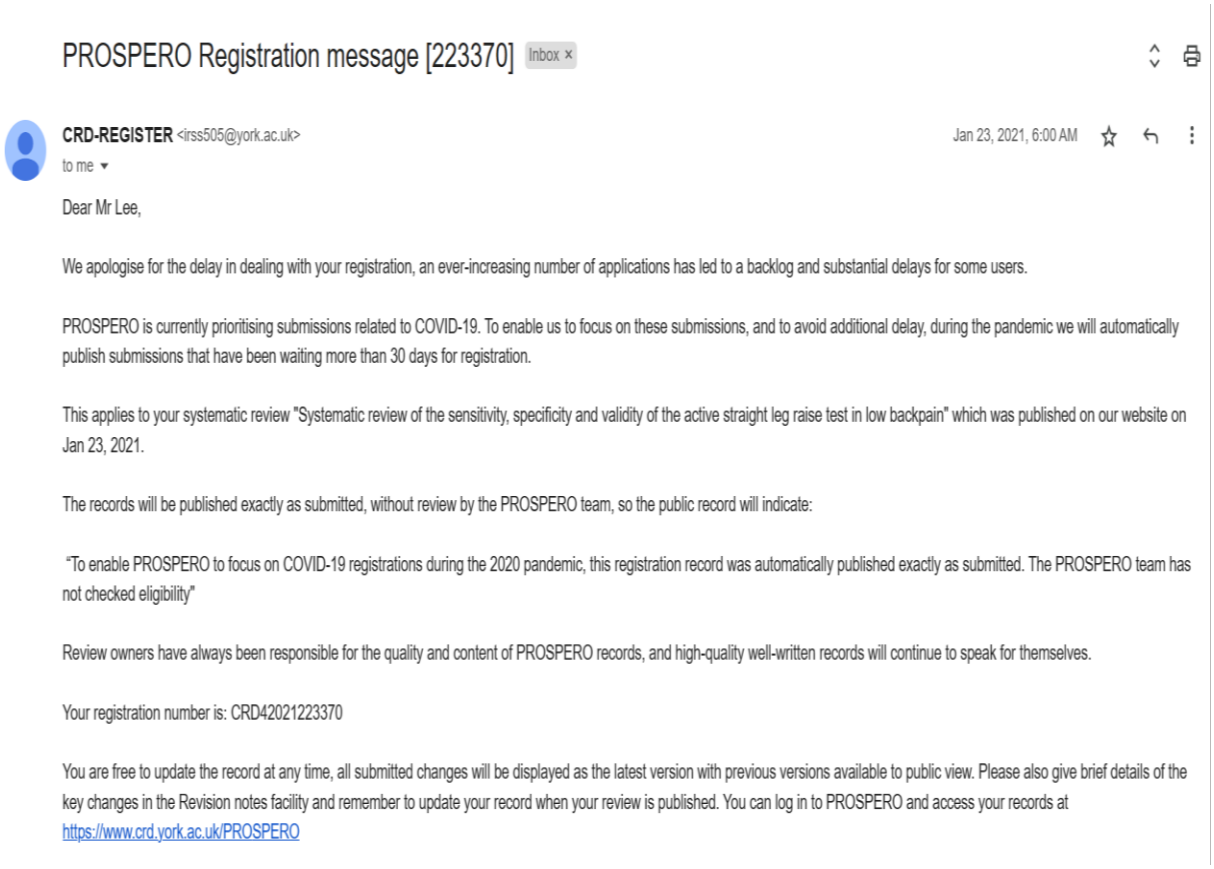
APPENDICES

APPENDIX A PROPERO REGISTRATION



PROSPERO Registration message [223370] Inbox ×

CRD-REGISTER <irss505@york.ac.uk> Jan 23, 2021, 6:00 AM

to me

Dear Mr Lee,

We apologise for the delay in dealing with your registration, an ever-increasing number of applications has led to a backlog and substantial delays for some users.

PROSPERO is currently prioritising submissions related to COVID-19. To enable us to focus on these submissions, and to avoid additional delay, during the pandemic we will automatically publish submissions that have been waiting more than 30 days for registration.

This applies to your systematic review "Systematic review of the sensitivity, specificity and validity of the active straight leg raise test in low backpain" which was published on our website on Jan 23, 2021.

The records will be published exactly as submitted, without review by the PROSPERO team, so the public record will indicate:

"To enable PROSPERO to focus on COVID-19 registrations during the 2020 pandemic, this registration record was automatically published exactly as submitted. The PROSPERO team has not checked eligibility"

Review owners have always been responsible for the quality and content of PROSPERO records, and high-quality well-written records will continue to speak for themselves.

Your registration number is: CRD42021223370

You are free to update the record at any time, all submitted changes will be displayed as the latest version with previous versions available to public view. Please also give brief details of the key changes in the Revision notes facility and remember to update your record when your review is published. You can log in to PROSPERO and access your records at https://www.crd.york.ac.uk/PROSPERO

APPENDIX B: FACULTY OF RESEARCH APPROVAL LETTER

26 November, 2020

Mr AC Lee
Student No: 213557701

8 Glen Cairn Close
Westville
3629

Dear Mr Lee

MASTER OF TECHNOLOGY: CHIROPRACTIC

I am pleased to advise that:

1. The Faculty Research Committee approved the following:

    (i) Your research proposal and dissertation title, being:

Systematic review of the sensitivity, specificity and validity of the active straight leg raise test in low back pain.

Please note: ANY PROPOSED CHANGES in the DISSERTATION TITLE require the approval of your supervisor and the Faculty Research Committee.

(ii) Supervisor – **Dr C Korporaal**
Co-supervisor – **Dr D Jack**

2. Your request for funding totalling **R 8 000.00** subject to any literature referred to in Section A of the PG 4a form being accessioned by this University, and any equipment purchased shall become the property of the department.

NOTE: - This funding is not paid directly to you but is controlled by the Faculty Office. Any proposed changes to this funding allocation needs the approval of your supervisor, and Faculty Research Committee

The University Research Committee has stipulated that:

(a) Ownership of any patent registered in respect of the results of your Master's studies is retained by you as the initiator of the project;

(b) Should you make any drift from the results of your Master's studies, you will be required to repay pro rata, the **R 8 000.00** investment which the University Research Committee has made in approving your request for funding;

(c) If the Durban University of Technology provided the equipment/materials for the creation of artefacts, this cost would be refunded to the University if such artefacts were sold and

(d) Durban University of Technology is given first refusal in respect of any possible future sale by you of any patent that may be registered in respect of your said project.

(e) All journal articles, referenced in your dissertation, are to accompany your ring-bound copies when submitting for examination purposes.

Should you experience any problems relating to your research studies, your supervisor must be informed as soon as possible. If the difficulty persists, you must then approach your Head of Department and thereafter the Executive Dean of the Faculty.

Yours sincerely

Ms S Perumal
FACULTY RESEARCH OFFICER

APPENDIX C: MEMORANDUM OF AGREEMENT

Title of Research Study: **A systematic review**

Principle investigators: **Andrew Lee (Researcher)**

Co-investigators: **Dr C. Korporaal (Supervisor)**

Dr D. Jack (Co-supervisor)

Introduction and Purpose of the Study:

The study is a systematic review of the literature pertaining to the validity, sensitivity and reliability active straight leg raise in pelvic girdle, lower back and groin pain populations. Articles have been collected electronically via databases by the researcher and categorised into different types of designs: randomised controlled clinical trials/clinical trials, case reports/series and observational studies.

Ten reviewers have been recruited to assess the quality of the studies, using rating scales design for the type of study design. Your analysis and feedback of the studies assigned to you will be collated and presented in a master's dissertation.

Procedure Outline:

You will receive articles which have been grouped according to study type (RCCT's, case report/series and observational studies) with corresponding scales (RCCT's – PEDro scale, Case report/series and observational studies - Newcastle-Ottawa scale, Non-randomised clinical trials – Liddle scale). An advisory sheet on how to apply the applicable scales to rate the studies will also be provided. A follow-up email will be sent within a week to confirm receipt of all relevant materials and answer any pertinent questions.

Each reviewer will be expected to review between 20 publications within a 6-week period. You are requested to individually read and rate each article according to its respective scale. To ensure blinding and anonymity and to avoid biasing personal reviews, your analysis will be forwarded to Dr Korporaal (charmak@dut.ac.za) who will hold this data until such time as my own gradings are complete. At this time, the all data will be collated for analysis. A reminder email will be sent 4 weeks into allotted time regarding the deadline at the end of 6 weeks.

Confidentiality:

You as reviewers are request not to disclose or discuss the review or any of its constituents with any peers during the review process to prevent contamination of outcomes results via peer influence.

Remuneration and Recognition:

Should the study be published, all participants in the study will receive acknowledgement unless you request to be excluded. Should you as a reviewer wish to be excluded from this, please write exclude and initial alongside this paragraph.

An honorarium of R1, 000.00 will awarded to each reviewer in appreciation of their time and dedication to this study.

Please do not hesitate to contact me and/or research supervisor regarding any questions via the following details:

Andrew Lee

Telephone: N/A

Cell no.: +2773 467 1359

E-mail: aclee.chiro@gmail.com

Dr. Charmaine Korporaal (Supervisor):

charmak@dut.ac.za

Statement of Agreement to Participate in the Research Study:

I ……..... (reviewer's full name), ……(Nationality) ……(Identity number/passport number – this is only required for the purposes of audits, should this study be audited, the committee will use these details to verify your participation), have read this document in its entirety and understand its contents and voluntarily consent to participate in the study.

Should any questions, uncertainties or queries arise, I will email the researcher (Andrew Lee) and have these explained and resolved to me to my satisfaction.

Reviewer's full name and surname:……..

Reviewer's signature:…….. Date:……

Supervisor name:……

Supervisor signature:…….. Date:……

Researcher name:……..

Researcher signature:…….. Date:……..

APPENDIX D: LIDDLE SCALE

Reviewer:		
Article Title:		
EVALUATION CRITERIA FOR THE STUDY:	Comments:	Code Option: A, B1, B2, C, or I
1. Are the study participants well-defined in terms of time, place and person?		
2. What percentage of individuals refused to participate?		
3. Are outcomes measured in a standard, valid and reliable way?		
4. Are outcomes measured in the same way for both intervention and control groups?		
5. Are factors other than the intervention e.g. confounding factors, comparable between intervention and control groups and if not comparable, are they adjusted for in the analysis?		
6. What percentage of individuals recruited into the study are not included in the analysis? (loss to follow-up).		
7. Is the analysis by intention to intervene (treat)?		
8. Are results homogeneous between sites? (multicentre/multisite studies only).		
OVERALL ASSESSMENT OF THE STUDY:		
1. How well was the study done to minimise bias? IF coded as B1, B2 or C, what is the likely direction in which bias might affect the study results?		
2. Is the overall effect of the study due to the study intervention?		
3. Explain if there is any practical/ethical reason why an RCT cannot be done.		
4. Include any other comments		

APPENDIX E: LIDDLE SCALE EXPLANATION

Case Reports/Series and Observational Studies

Codes for evaluation criteria:

Evaluation criteria are coded according to the extent to which the criteria are fulfilled	**Code**
Criterion entirely fulfilled	A
Criterion mostly fulfilled	B1
Criterion mostly not fulfilled	B2
Criterion not at all fulfilled	C
Criterion not described adequately to classify as a,b1,b2 or c I	I
Criterion not applicable	n/a

Codes for overall assessment of quality of study checklists:

Low risk of bias	A	All or most evaluation criteria from the checklist are fulfilled. Where evaluation criteria are not fulfilled, the conclusions of the study are thought very unlikely to alter.
Low-moderate risk of bias	B1	Some evaluation criteria from the checklist are fulfilled. Where evaluation criteria are not fulfilled or are not adequately described, the conclusions of the study are thought unlikely to alter.
Moderate to high risk of bias	B2	Some evaluation criteria from the checklist are fulfilled. Where evaluation criteria are not fulfilled or are not adequately described, the conclusions of the study are thought likely to alter
High risk of bias	C	Few or no evaluation criteria fulfilled. Where evaluation criteria are not fulfilled or are not

		adequately described, the conclusions of the study are thought very likely to alter.

APPENDIX F: PEDRO SCALE: RATING SHEET

The PEDro scale is used for rating the methodological quality of randomised controlled trials. Accessed from http://www.pedro.org.au.

For all criteria: Points are only awarded when a criterion is clearly satisfied and reported. Scoring guidelines can be found below.

1. Eligibility criteria were specified	Yes	No
2. Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received)	Yes	No
3. Allocation was concealed	Yes	No
4. The groups were similar at baseline regarding the most important prognostic indicators	Yes	No
5. There was blinding of all subjects	Yes	No
6. There was blinding of all therapists who administered the therapy	Yes	No
7. There was blinding of all assessors who measured at least one key outcome	Yes	No
8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups	Yes	No
9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by “intention to treat”	Yes	No
10. The results of between-group statistical comparisons are reported for at least one key outcome	Yes	No
11. The study provides both point measures and measures of variability for at least one key outcome	Yes	No

APPENDIX G: PEDRO SCALE EXPLANATION

Randomised Controlled Clinical Trial Rating

The PEDro scale is based upon the Delphi list (Delphi list: a criteria list for quality assessment of RCTs for conducting systematic reviews developed by the Delphi consensus. Journal of Clinical Epidemiology, 51(12): 1235-1241). The purpose of the PEDro scale is to determine internal validity of RCTs, reflected by criteria 2 – 9. Criterion 1 reflects external validity of the RCT, or simply the applicability of the trial. Criteria 10 – 11 represents whether the RCT statistical information is interpretable.

The following is an explanation for each individual criterion:

When completing the scale a total of 11 criteria are available. 1 point is awarded for each criterion if the respective criterion is clearly satisfied. When answering yes to a criterion, 1 point is awarded.

Criterion 1	This criterion is satisfied if the report describes the source of subjects and a list of criteria used to determine who was eligible to participate in the study.
Criterion 2	A study is considered to have used random allocation if the report states that allocation was random. The precise method of randomisation need not be specified. Procedures such as coin-tossing and dice-rolling should be considered random. Quasi-randomisation allocation procedures such as allocation by hospital record number or birth date, or alternation, do not satisfy this criterion.
Criterion 3	Concealed allocation means that the person who determined if a subject was eligible for inclusion in the trial was unaware, when this decision was made, of which group the subject would be allocated to. A point is awarded for this criteria, even if it is not stated that allocation was concealed, when the report states that allocation was by sealed opaque envelopes or that allocation involved contacting the holder of the allocation schedule who was “off-site”
Criterion 4	At a minimum, in studies of therapeutic interventions, the report must describe at least one measure of the severity of the condition being treated and at least one (different) key outcome measure at baseline. The rater must be satisfied that the groups’ outcomes would not be expected to differ, on the basis of baseline differences in prognostic variables alone, by a clinically significant amount. This criterion is satisfied even if only baseline data of study completers are presented. 7-11 Key outcomes are those outcomes which provide the primary measure of the effectiveness (or lack of effectiveness) of the therapy. In most studies, more than one variable is used as an outcome measure.
Criterion 5	Blinding means the person in question (subject, therapist or assessor) did not know which group the subject had been allocated to. In addition, subjects and therapists are only considered to be “blind” if it could be expected that they would have been unable to distinguish between the

	treatments applied to different groups. In trials in which key outcomes are self-reported (e.g., visual analogue scale, pain diary), the assessor is considered to be blind if the subject was blind.
Criterion 4, 7-11	Key outcomes are those outcomes which provide the primary measure of the effectiveness (or lack of effectiveness) of the therapy. In most studies, more than one variable is used as an outcome measure.
Criterion 8	This criterion is only satisfied if the report explicitly states both the number of subjects initially allocated to groups and the number of subjects from whom key outcome measures were obtained. In trials in which outcomes are measured at several points in time, a key outcome must have been measured in more than 85% of subjects at one of those points in time
Criterion 9	An intention to treat analysis means that, where subjects did not receive treatment (or the control condition) as allocated, and where measures of outcomes were available, the analysis was performed as if subjects received the treatment (or control condition) they were allocated to. This criterion is satisfied, even if there is no mention of analysis by intention to treat, if the report explicitly states that all subjects received treatment or control conditions as allocated
Criterion 10	A between-group statistical comparison involves statistical comparison of one group with another. Depending on the design of the study, this may involve comparison of two or more treatments, or comparison of treatment with a control condition. The analysis may be a simple comparison of outcomes measured after the treatment was administered, or a comparison of the change in one group with the change in another (when a factorial analysis of variance has been used to analyse the data, the latter is often reported as a group × time interaction). The comparison may be in the form hypothesis testing (which provides a "p" value, describing the probability that the groups differed only by chance) or in the form of an estimate (for example, the mean or median difference, or a difference in proportions, or number needed to treat, or a relative risk or hazard ratio) and its confidence interval.
Criterion 11	A point measure is a measure of the size of the treatment effect. The treatment effect may be described as a difference in group outcomes, or as the outcome in (each of) all groups. Measures of variability include standard deviations, standard errors, confidence intervals, interquartile ranges (or other quantile ranges), and ranges. Point measures and/or measures of variability may be provided graphically (for example, SDs may be given as error bars in a figure) as long as it is clear what is being graphed (for example, as long as it is clear whether error bars represent SDs or SEs). Where outcomes are categorical, this criterion is considered to have been met if the number of subjects in each category is given for each group

Adapted from: PEDro scale (online) 1999.

Definition of Intention to treat: Fisher *et al*., (1990) describes intention to treat as an approach for the analysis of RCTs. This strategy associate's patients in the groups they were originally randomly assigned to. Generally, this is interpreted as including all patients, regardless of whether:

a) They fulfilled the inclusion criteria

- Treatment was received
- Withdrawal from the trial

Derivation from the protocol Clinical effectiveness of an RCT can be overestimated if the intention to treat analysis is not done. References:

PEDro scale (online). 2011. Available at: www.pedro.org.au (Accessed 1 August 2020).

APPENDIX H: PEDRO SCALE

Reviewer:	
Article Title:	

Please cross out YES or NO for each criterion:

CRITERION:				REFERENCE PAGE:
1	Eligibility criteria were specified	YES	NO	
2	Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received)	YES	NO	
3	Allocation was concealed	YES	NO	
4	The groups were similar at baseline regarding the most important prognostic indicators	YES	NO	
5	There was blinding of all subjects	YES	NO	
6	There was blinding of all therapists who administered the therapy	YES	NO	
7	There was blinding of all assessors who measured at least one key outcome	YES	NO	
8	Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups	YES	NO	
9	All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by “intention to treat”	YES	NO	
10	The results of between-group statistical comparisons are reported for at least one key outcome	YES	NO	
11	The study provides both point measures and measures of variability for at least one key outcome	YES	NO	

APPENDIX I: NEWCASTLE-OTTAWA SCALE EXPLANATION

The Newcastle-Ottawa scale is divided into 8 items, that are subdivided into 3 categories; selection, comparability and exposure.

For each of the 8 items, there is a variety of response options; one response (a, b, or c, etc.) is to be chosen, with the exception of the comparability section, where one, two or no response can be chosen.

One star is available to be awarded for each item, excepting comparability, which allows for two stars to beawarded. The maximum amount of stars that a study can be awarded is nine stars.

In the event that a study only contains one group of subjects, comparability cannot be completed, and should be omitted from the scale.

APPENDIX J: NEWCASTLE-OTTAWA QUALITY ASSESSMENT SCALE (CASE CONTROL STUDIES)

Reviewer	
Article title	

Note: A study can be awarded a maximum of one asterixis for each of the numbered item within the

Selection and Exposure categories. A maximum of two asterixis may be awarded for Comparability.

Selection

1) Is the case definition adequate?
   b) Yes, with independent validation *
   c) Yes, e.g. record linkage or based on self-reports
   d) No description
2) Representativeness of the cases
   a) Consecutive or obviously representative series of cases *
   b) Potential for selection biases or not stated
3) Selection of Controls
   a) Community controls *
   b) Hospital controls
   c) No description
4) Definition of Controls
   a) No history of disease (endpoint) *
   b) No description of source

Comparability

1) Comparability of cases and controls on the basis of the design or analysis
   a) Study controls for _____ (Select the most important factor.) *
   b) Study controls for any additional factor *(This criteria could be modified to indicate specific
      control for a second important factor.)

Exposure

1) Ascertainment of exposure
   a) Secure record (e.g. surgical records) *
   b) Structured interview where blind to case/control status *
   c) Interview not blinded to case/control status
   d) Written self-report or medical record only
   e) No description
2) Same method of ascertainment for cases and controls
   a) Yes*

b) No

3) Non-Response rate

a) Same rate for both groups *
b) Non respondents described
c) Rate different and no designation

APPENDIX K: NEWCASTLE-OTTAWA QUALITY ASSESSMENT SCALE-COHORT STUDIES

Reviewer	
Article title	

Note: A study can be awarded a maximum of one star for each numbered item within the selection and outcome categories. A maximum of two stars can be given for comparability selection.

1) Representativeness of the exposed cohort

a) truly representative of the average _____ (describe) in the community *

b) somewhat representative of the average _____ in the community *

c) selected group of users

d) no description of the derivation of the cohort

2) Selection of the non -exposed cohort

a) drawn from the same community as the exposed cohort *

b) drawn from a different source

c) no description of the derivation of the non-exposed cohort

3) Ascertainment of exposure

a) secure record*

b) structured interview*

c) written self-report

d) no description

4) Demonstration that outcome of interest was not present at start of study

a) yes*

b) no

Comparability

1) Comparability of cohorts on the basis of the design or analysis

a) study controls for _____ (select the most important factor)*

b) study controls for any additional factor (This criteria could be modified to indicate specific

control for a second important factor.)*

Outcome

1) Assessment of outcome

a) independent blind assessment *

b) record linkage*

c) self-report

d) no description

2) Was follow-up long enough for outcomes to occur

a) yes (select an adequate follow up period for outcome of interest)*

b) no

3) Adequacy of follow up of cohorts

a) complete follow up - all subjects accounted for*

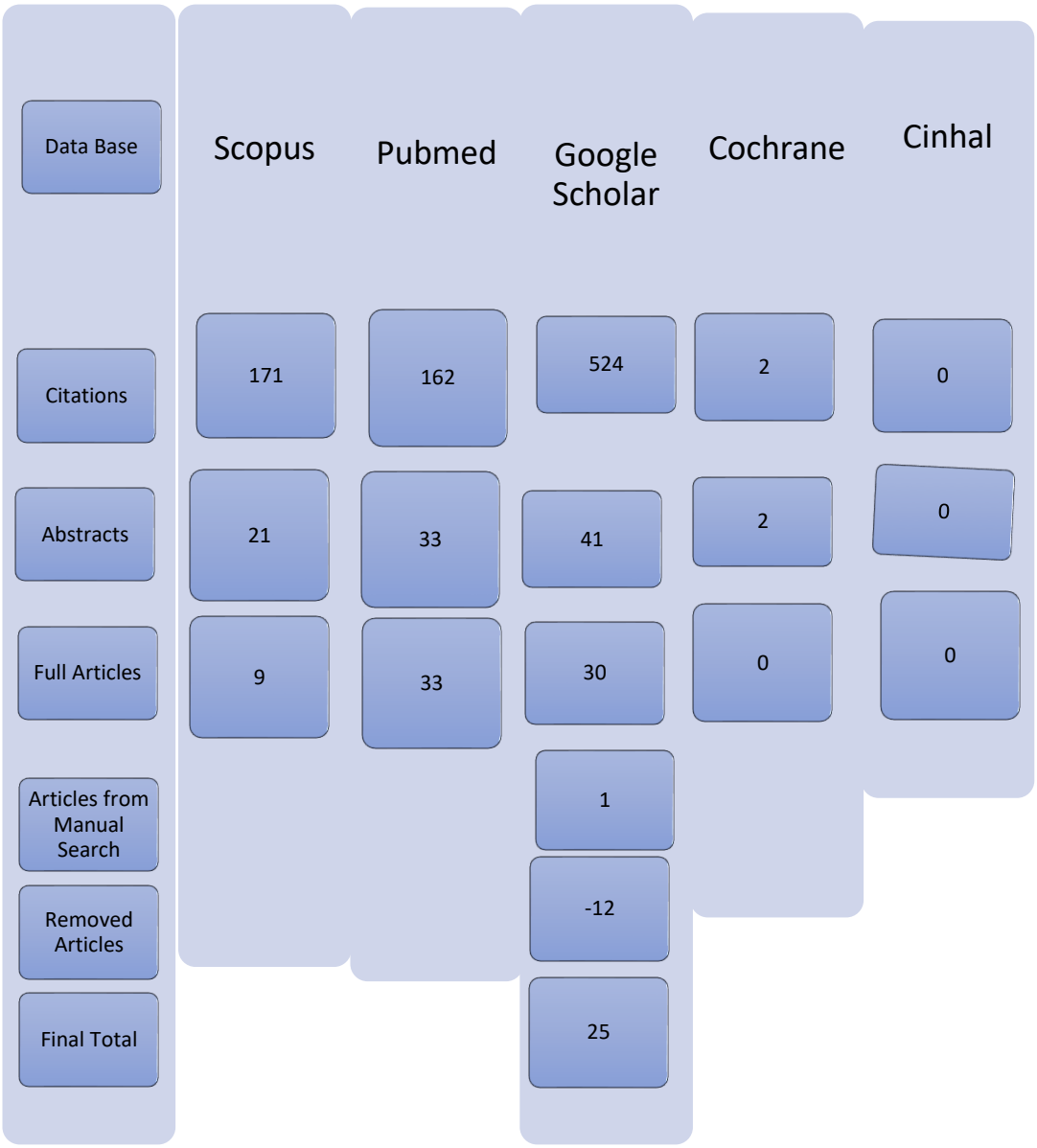
b) subjects lost to follow up unlikely to introduce bias - small number lost - > ____ % (select an

adequate %) follow up, or description provided of those lost)

c) follow up rate < ____% (select an adequate %) and no description of those lost

d) no statement

APPENDIX L: PRISMA FLOW CHART



APPENDIX M: SYSTEMATIC REVIEW CHECK LIST

Topic		Section	Page
Title			
Abstract			
Rationale			
Objectives			
Eligibility criteria	Inclusion and exclusion criteria.		
Information sources	Databases, registers, websites, organisations, reference lists and other sources searched to identify studies	3.4.1.1	68 Appendix
Search strategy		3.4.1.1	68
Selection process		3.4.1.2-3.4.3.3 3.5.1	68-70 71
Data collection process	Methods used to collect data from articles, number of reviewers collecting data per article, independent / collaboration when reviewing, processes for obtaining or confirming data by study researchers.	3.4	70-71
Data items	List and define all outcomes for which data were sought. List and define all other variables for which data were sought. Describe any assumptions made about any missing or unclear information.	Chapter 1, Chapter 3, Chapter 4	
Study risk of bias assessment	Specific methods used to assess risk of bias in the included articles: tool(s) details, number of reviewers assessing each study	3.9	77-79
Synthesis methods	Processes used to decide eligible data for each synthesis. Methods used to prepare the data for presentation / synthesis, Methods used to tabulate results of individual studies and syntheses. Methods used to synthesize results and provide a rationale for the choices. Methods to explore possible causes of heterogeneity among study results.	3.9	77-79
Reporting bias assessment	Methods used to assess risk of bias due to missing results in a synthesis		
Certainty assessment	Methods used to assess confidence in the body of evidence for an outcome		
Study selection	The results of the search and selection process - number of records identified in the search, number of studies and use of a flow diagram. Explain why studies were excluded.		Appendix
Study characteristics	Cite each included study and present its characteristics.	Chapter 4	81-155
Synthesis methods	Processes used to decide which studies were eligible for each synthesis. Methods used to prepare the data for presentation or synthesis – i.e. handling of missing summary statistics, or data conversions. Methods used to tabulate results of individual studies and syntheses. Methods used to synthesize results and provide a rationale for the choice(s). Methods used to explore possible causes of heterogeneity among study results	Chapter 3 Chapter 3 Chapter 4	81-155
Risk of bias in studies	Present assessments of risk of bias for each included study	Chapter 4	81-155
Results of individual studies	For all outcomes, present, for each study: a summary of statistics for each group Provide an effect estimate and its precision	Chapter 4	81-155
Results of syntheses	Brief summarisation of the characteristics and risk of bias among contributing articles for each synthesis. Results of all statistical syntheses presented.	Chapter 4 Chapter 4, Chapter 5	81-155 81-155, 156-182

	For group comparison the direction of the effect is presented.	Chapter 5	156-182
	Results of all investigations of possible causes of heterogeneity among study results presented,	Chapter 4, Chapter 5	81-155, 156-182
	Results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Chapter 4, Chapter 5	81-155, 156-182
Reporting biases	Methods used to assess risk of bias due to missing results in a synthesis	Chapter 2	81-155
Certainty of evidence	Methods used to assess confidence in the body of evidence for an outcome.	Chapter 4, Chapter 5	81-155, 156-182
Discussion	General interpretation of the results in the context of other evidence.	Chapter 4, Chapter 5	81-155, 156-182
	Discuss any limitations of the evidence included in the review.	Chapter 4, Chapter 5	81-155, 156-182
	Discuss any limitations of the review processes used.	5.5-5.6	179-180
	Discuss implications of the results for practice, policy, and future research.	Chapter 6	
Registration and protocol		3.8	76-77

APPENDIX N: MASTER LIST

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