Measurement of sacroiliac joint stiffness with Doppler imaging of vibrations – a reliability study

Scott Francis Pender

A thesis submitted in partial requirement for the degree of Master of Osteopathy, Unitec Institute of Technology, 2011
DECLARATION

Name of candidate: Scott Francis Pender

This Thesis/Dissertation/Research Project entitled Measurement of sacroiliac joint stiffness with Doppler imaging of vibrations – a reliability study is submitted in partial fulfillment for the requirements for the Unitec degree of Master of osteopathy.

Candidate’s declaration

I confirm that:

• This Thesis/Dissertation/Research Project represents my own work;
• Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee. Research Ethics Committee Approval Number: 2009-1023

Candidate Signature: .................................................Date: .................

Student number: 1260458
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ABSTRACT

Introduction: Sacroiliac joint (SIJ) motion dysfunction and its role in low back and pelvic pain remains an unresolved issue amongst the medical fraternity. Clinical objective SIJ motion and pain detection methods are both expensive and difficult to reproduce whilst most manual methods of SIJ motion assessment have been contentious with regard to their reliability. Doppler Imaging of Vibrations (DIV) has been advocated as one alternative adjunct method of evaluating SIJ dysfunction.

Purpose: The aim of this research was to test reliability of the DIV technique to assess SIJ stiffness within a normal population when using a custom built Vibration Generator (VG).

Methodology: Thirteen healthy participants with an age range of 23-50 years, 4 females (mean age 27 ± 5 years, height 167 ± 13cm, weight 65 ± 11 Kg) and 9 males (mean age 33 ± 9 years, height 176 ± 5cm, weight 76 ± 8 Kg) were assessed for SIJ stiffness using the DIV technique over two sessions. Participants were positioned in prone and vibration applied unilaterally to the anterior superior iliac spine. Vibrations were registered by a Colour Doppler Imaging (CDI) transducer over the ipsilateral SIJ. A Threshold Unit (TU) is the difference between ipsilateral sacral and ilial threshold level (TL) values and was accepted as the measured loss of vibrational power across the SIJ. A large difference between bilateral SIJ TU values in individuals is assumed to be indicative of SIJ stiffness asymmetry. Interclass correlation coefficients (ICC) with 95% confidence intervals (CI) were used to calculate intra and inter-session reliability. Standard error of the measurement (SEM) calculations were undertaken to assess difference between the actual measured score across trials and the smallest detectable difference (SDD) was calculated from the SEM to
indicate the degree of change that would exceed the expected trial to trial variability.

**Results:** All intra-session ICC reliability scores for DIV testing of SIJ stiffness were 'excellent' with 'substantial' to 'almost perfect' CIs. Inter-session ICC reliability scores for DIV testing of SIJ stiffness were 'excellent' with 'moderate' to 'almost perfect agreement' CIs for S1 means against only less than 'acceptable' to 'acceptable' ICC scores with 'poor' to 'fair agreement' CIs for S2 means. Only three participants were observed to have a consistent SIJ stiffness pattern over all intra-session measurements.

**Conclusion:** The DIV technique, when performed using a custom built VG to detect SIJ stiffness asymmetry in a normal population, showed a satisfactory level of intra-session reliability but a lower than satisfactory level of inter-session reliability. Further technical modifications are required to ensure the VG maintains robustness and signal consistency for future studies.

**Keywords:** Sacroiliac joint; Doppler Imaging of Vibrations; sacroiliac joint motion; reliability; sacroiliac joint dysfunction; sacroiliac joint asymmetry
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<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>ASIS</td>
<td>Anterior superior iliac spine</td>
</tr>
<tr>
<td>CDI</td>
<td>Colour Doppler imaging</td>
</tr>
<tr>
<td>DIV</td>
<td>Doppler Imaging of Vibrations</td>
</tr>
<tr>
<td>SIJ</td>
<td>Sacroiliac joint</td>
</tr>
<tr>
<td>STL</td>
<td>Sacrotuberous ligament</td>
</tr>
<tr>
<td>SSL</td>
<td>Sacrospinous ligament</td>
</tr>
<tr>
<td>ILL</td>
<td>Iliolumbar ligament</td>
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<tr>
<td>TA</td>
<td>Transversus abdominis</td>
</tr>
<tr>
<td>TL</td>
<td>Threshold level</td>
</tr>
<tr>
<td>TU</td>
<td>Threshold unit</td>
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<tr>
<td>US</td>
<td>Ultrasound</td>
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CHAPTER 1: INTRODUCTION

Low back pain (LBP) may affect up to 70-85% of the population at some stage of life (Andersson, 1999), with sacroiliac joint (SIJ) pain estimated to be between 13 and 30% of all LBP (Schwarzer, Aprill, Derby et al., 1995).

Due to challenges in diagnosing LBP radiographically, up to 85% of chronic low back pain cases have been termed ‘non-specific’ (O'Sullivan, 2005, p. 242) and may stem from various factors which include; patho-anatomical; neurophysiological; biomechanical and psychosocial. The biomechanical model of low back pain focuses on joint restriction as being influential in creating stress on low back and pelvic tissues which subsequently may lead to a diagnosis of ‘mechanical’ LBP (O'Sullivan, 2005, p. 244). SIJ related mechanical pain has often been confused with LBP due to overlapping sensory innervation of lumbo-sacral structures and similar pain referral patterns into the buttock and thigh (Van der Wurff, Buijs, & Groen, 2006).

Determining SIJ causative pain through manual SIJ palpatory, motion and pain provocation testing has proved largely unreliable (Riddle & Freburger, 2002; Stuber, 2007). Coupled with the absence of ‘gold standard’ SIJ motion and pain identification procedures, there is a clear need for more objective and reliable methods of identifying SIJ pain and dysfunction.

The sacroiliac joint (SIJ) typically consists of the first three cartilaginous sacral segments which ossify and fuse around the age of puberty (Belcastro, Rastelli, & Mariotti, 2008). The SIJ constantly remodels throughout and the skeletal maturation process to provide stability in response to the relentless and varied loads imposed upon it. Further remodeling and ossification of the intra-articular SIJ surfaces commencing in the fifth decade of life, coupled with extensive ligamentous support, enhance stability of the sacrum between the ilia whilst
reducing SIJ range of movement (Bellamy, Park, & Rooney, 1983; Forst, Wheeler, Fortin, & Vilensky, 2006). Ligamentous support, intra-articular ossification and muscular stabilization add to both ‘form’ and ‘force closure’ of the SIJ during static postural and dynamic movement tasks (A. Vleeming, Snijders, Stoeckart, & Mens, 1997). This inherent stability system limits potential movement to small rotational and translatory movements involved in both transmission and dissipation of gravitational and frictional forces.

‘Form closure’ has been described by Vleeming, Snijders, Stoeckart and Mens (1997) as a stable close fitting joint in which extra forces are not required to maintain congruency given the load situation. Force closure is achieved through myofascial components co-acting to tighten the fibrous fascial attachments during ipsilateral contraction and contralateral contraction within the “posterior oblique sling” (Pool-Goudzwaard, Vleeming, Stoeckart, Snijders, & Mens, 1998b, p. 16).

SIJ dysfunction, due to excessive or abnormal movement of the sacrum between the ilia, has been identified as one cause of pain originating from the SIJ, and probably due to irritation of SIJ capsular, ligamentous or intra-articular nociceptive nerve endings (Goode et al., 2008; Riddle & Freburger, 2002). Local anaesthetic blocks of the SIJ injections have been used in an attempt to confirm the experience of pain originating from the SIJ (Dreyfuss, Henning, Malladi, Goldstein, & Bogduk, 2009; Dreyfuss et al., 2008; Fortin, Aprill, Ponthieux, & Pier, 1994b; Fortin, Dwyer, West, & Pier, 1994a; Szadek, Hoogland, Zuurmond, de Lange, & Perez, 2008), however, attempts to map direct SIJ pain referral patterns have proved challenging due to the complex innervation of both SIJ and adjacent structures (Slipman et al., 2000; Van der Wurff et al., 2006).

Manual therapists, such as osteopaths, chiropractors and physiotherapists, have long advocated the use of manual palpatory, motion and pain provocation testing as a basis for diagnosing SIJ dysfunction (Cibulka, 2002). However, much debate has surfaced in the literature regarding both reliability and validity of clinical
palpatory diagnostic tests due to the small movements observed during objective roentgen stereophotogrammetric analysis (RSA) of SIJ motion (Van der Wurff, Hagmeijer, & Meyne, 2000a; Van der Wurff, Meyne, & Hagmeijer, 2000b).

Roentgen stereophotogrammetric analysis involves implantation of tantalum balls into bony pelvic and sacral bony landmarks. Using RSA, rotational movements of the SIJ have been recorded by Sturesson, Selvik & Uden (1989) who reported mean rotation of 2.5 degrees, and a mean of 0.7 millimeters translation with no difference detected between symptomatic and asymptomatic participants.

Roentgen stereophotogrammetric analysis is considered as the current gold standard test to identify SIJ motion (Sturesson, 1997), whilst anaesthetic blocks of the SIJ are seen as the gold standard technique to help identify pain originating from the SIJ (Laslett, Aprill, McDonald, & Young, 2005; Stuber, 2007). Both techniques are typically: (1) not reproducible for manual therapists due to lack of availability of specialized equipment, technical skill sets or associated cost; and (2) also considered as being a potential risk to patient’s health due to radiation exposure or risk of infection (Sturesson, 1997). The development of a reliable, non-invasive and accessible technology based criterion standard for assessing SIJ stiffness would be useful in supplementing the existing manual SIJ tests.

Doppler imaging of vibrations (DIV) across the SIJ has been suggested a non-invasive and quantifiable technique which carries a low risk of harm and has been successfully reproduced to determine SIJ stiffness (or laxity) in a number of previous studies (Buyruk, Snijders, Vleeming, Lameris et al., 1995b; Buyruk et al., 1999; Buyruk, Stam, Snijders, Vleeming, Lameris et al., 1995a; Damen, Stijnen, Roebroeck, Snijders, & Stam, 2002a).

The principle of the DIV technique is that vibrations are applied to a participant’s anterior superior iliac spine whilst lying in a prone position. The vibrations are registered using a Colour Doppler Imaging (CDI) transducer placed over the
ipsilateral SIJ and measured as a ‘threshold level’ (TL). A ‘Threshold Unit’ (TU) is calculated as the difference between ipsilateral sacral and ilial TL values and was accepted as the measured loss of vibrational power across the SIJ by the originators of the DIV technique (Buyruk, Stam, Snijders, Vleeming, Lameris et al., 1995a). A large difference between bilateral SIJ TU values in individuals is assumed to be indicative of SIJ asymmetrical stiffness and may therefore be diagnostic of SIJ dysfunction.

Buyruk and colleagues (1995a) successfully pioneered the DIV technique during an in-vitro study of 4 embalmed human specimens then applied DIV to 14 healthy, asymptomatic female volunteers, aged between 20 and 40 years of age in a follow up study (Buyruk, Snijders, Vleeming, Lameris et al., 1995b). A third study investigated a group of Peripartum Pelvic Pain patients, in which participants demonstrated significantly greater levels of absolute difference of left verses right SIJ stiffness (P<0.001) compared to a pain free control group (Buyruk et al., 1999).

Further studies utilizing DIV have included a reliability study to assess: (1) tarsometatarsal joint stiffness (Faber et al., 2000; Faber et al., 2001); (2) accuracy and reliability of SIJ stiffness measurement between an experienced sonographer and four inexperienced testers (Damen et al., 2002a); (3) an investigation into the effect of transversus abdominis on SIJ force closure (Richardson et al., 2002); (4) the effect of a pelvic belt on SIJ laxity in healthy women (Damen, Spoor, Snijders, & Stam, 2002c); and (5) asymmetrical SIJ laxity in peripartum females and its subsequent prognostic value (Damen et al., 2002b; Damen et al., 2001). De Groot, Spoor and Snijders (2004) evaluated the DIV technique and found that, although reliable, DIV still lacks validation through further research.

Drawbacks of the DIV technique are associated with issues of accessibility and expense of the associated Doppler ultrasound and vibration generation devices.
This current study attempted to address issues of DIV reproducibility by investigating the reliability of a custom built vibration generator (VG) prototype.

Clinical testing and reproducibility of results are reliant on minimisation of various types of measurement error including: instrument and technical error; biological and physiological stability of the characteristic or trait being tested; and operator skill, accuracy and judgment.

Intra and inter-session reliability depends on both accuracy and reproducibility of procedures, equipment (in this case DIV of SIJ stiffness using a custom built VG) and the skill of the operator in measurement and interpretation of test components. Inter-session reliability also relies upon biological factors pertaining to stability of the trait being tested such as SIJ motion (Domholdt, 2005). Therefore, the aim of this research project was to determine the intra- and inter-session reliability of DIV technique using a custom built vibration device to assess SIJ stiffness within a healthy asymptomatic population.

1.1 DEFINING LOW BACK AND SIJ PAIN

Low back pain (LBP) may affect up to 70-85% of the population at some stage of life (Andersson, 1999), with sacroiliac joint (SIJ) pain estimated to be between 13 and 30% of all diagnosed LBP (Schwarzer, Aprill, Derby et al., 1995).

Low back pain (LBP) is recognised as one of the most common, expensive and disabling musculoskeletal conditions (McBride, Begg, Herbison, & Buckingham, 2004). In New Zealand alone, between 2008/2009, both new and ongoing compensation claims for back pain cost the New Zealand government approximately NZD $355M (Accident Compensation Corporation, 2010).

Due to challenges in diagnosing LBP radiographically, up to 85% of chronic low back pain cases have been termed ‘non-specific’ (O’Sullivan, 2005, p. 242). Non-specific LBP aetiology may stem from various factors which include; patho-
anatomical; neurophysiological; biomechanical and psychosocial. The biomechanical model of low back pain focuses on joint restriction as being influential in creating stress on low back and pelvic tissues which subsequently may lead to a diagnosis of ‘mechanical’ LBP (O’Sullivan, 2005, p. 244).

The low back region has been defined by the International Association for the Study of Pain (IASP) as lying within the posterior boundaries of imaginary transverse lines between the 12th thoracic and 1st sacral vertebrae and lateral borders of the lumbar erector spinae muscles (Bogduk & McGuirk, 2002). The sensation of LBP, therefore, is pain perceived as arising from this defined region and may stem from any connective tissue relating to the lumbar spine which contains nociceptive nerve endings (Adams, 2006; Bogduk, 1992). Low back pain may also be a result of perceived pain which is referred from a region other than the low back such as the buttock, thigh or leg, by peripheral nerves separate to those irritated by pain causing stimuli (Bogduk, 1992; Van der Wurff et al., 2006). Other phenomena associated with LBP may include muscle weakness or sensations of numbness or tingling in the thigh or leg (Cheung & Al Ghazi, 2008).

The role of the SIJ and its contribution to LBP, together with the poor clinical diagnosis of SIJ pain have been debated for decades (Cibulka & Koldehoff, 1999; Freburger & Riddle, 2001; Horton & Franz, 2007; Levangie, 1999). Inter-examiner reliability for the identification of SIJ related pain appears to be poor and it has been proposed that this may be partly attributable to the complex anatomy and physiology of the area (Riddle & Freburger, 2002; Stuber, 2007).

The International Association for the Study of Pain (IASP) has stated three criteria that must be satisfied to confirm the SIJ as a source of the pain:

1. Pain has to be felt in the region of the SIJ(s),
2. Pain is reproducible by stressing the SIJ(s) and
3. Pain is relieved through local anaesthetic joint block injections (Szadek et al., 2008).

Currently, manual therapists such as osteopaths, chiropractors and physiotherapists, are limited in their ability to fully investigate the IASP criteria due to scope of practice restraints in administering local anaesthetic. Once SIJ pain has been diagnosed by manual therapists, further testing to determine if the source of pain is due to SIJ dysfunction also remains controversial due to poor intra- and inter-reliability results surrounding manual sacral motion testing and bony landmark palpation (Walker, 1992). Central to the SIJ diagnostic challenges are the anatomical complexities, both structural and functional, pertaining to the SIJ and its contributing neural and myofascial elements. Improved reliability and validity of manual SIJ motion, positional assessment and pain provocation testing, remain as important aspects to successful diagnosis and treatment of this complex region.
CHAPTER 2: THE ANATOMY AND DEVELOPMENT OF THE SACRUM AND SIJ

2.1 Sacral anatomy

The anatomy and physiology of the sacrum has been well documented in previous studies. Whilst an exhaustive review of all anatomical aspects of the sacrum is beyond the scope of this review, an appreciation of sacrum and its relation to SIJ structure and function is useful in understanding the theoretical contribution SIJ motion and pain generation may make in predisposition to mechanical low back and SIJ pain.

The sacrum plays an important role within the pelvis due to its capability to withstand vertical shearing forces whilst simultaneously receiving, distributing and absorbing loads between axial and appendicular skeletons during upright postures and dynamic movement patterns (McGrath, 2004).

The sacrum is a large wedged shaped fusion of five vertebrae bordered superiorly by the bony articulations of the fifth lumber vertebra, laterally by both innominates and inferiorly by the coccyx. The adult sacrum bears a concave anterior surface, a convex posterior surface, an apex projecting postero-inferiorly and a sacral base which tilts antero-superiorly (Cheng & Song, 2003).

The sacrum contains eight sacral foramina on each surface, arranged in pairs resulting from developmental fusion of sacral vertebral bodies and transverse processes, the latter of which also unite to form the lateral masses. Posteriorly, the median crest is formed centrally by fusion of the spinous processes. Medial to the sacral foramina, fusion of laminae and transverse processes create the intermediate and lateral crests respectively. These crests provide strong attachment points for multifidi and erector spinae muscles and the myofascial elements pertaining to the thoracolumbar fascia which includes the large
latissimus dorsi and gluteus maximus muscles. Centrally, the sacral canal continues from the spinal canal, transmitting sacral and coccygeal branches of the cauda equina, the latter through the sacral hiatus inferiorly (Bogduk, 2005).

The sacrum is sometimes described as being ‘suspended’ between the two ilia and transmits vertical and translational shear forces through a combination of strong ligamentous support and evolving intra-articular ossification (A. Vleeming, Snijders, C.J., Stoeckart, R., Mens, J.M.A., 1997).

2.2 SACRAL DEVELOPMENT

Embryological development of the sacrum begins around the eighth intrauterine week of fetal life. Embryological development of the SIJ itself begins to occur in the tenth intrauterine week and does not reach complete cavitation until after the 34th week (Walker, 1986). The resultant structure is an auricular or bean shaped, articulation made up of a combination of horizontal and vertical limbs. The horizontal long limb of the articulation traverses antero-posteriorly, whilst the vertical short limb is aligned supero-inferiorly, somewhat perpendicularly to the long limb. The SIJ consists typically of the first three sacral segments, although L5, L4 and S4 may also be involved in some people (Bellamy et al., 1983; Willard, 1997).

Fusion and ossification of cartilaginous sacral segments begins during puberty, when rapid growth typically occurs, and reaches completion within the third to fourth decades of life (Belcastro et al., 2008; Foley & Buschbacher, 2006). Occasional sacral developmental anomalies, involving varying degrees of fusion pertaining to the 5th lumbar vertebra and 1st sacral vertebra, may occur. A fusion of the fifth lumbar and first sacral vertebra is referred to as ‘sacralization’, effectively shortening the lumbar spine. A fusion of the first and second sacral vertebrae results in a pseudo lengthening of the lumbar spine or ‘lumbarization’ (Konin & Walz, 2010).
Constant intra-articular osseous remodeling throughout life has made the SIJ a structure of curiosity amongst anatomists and clinicians. The joint is therefore a well researched articulation. Although typically considered as a diarthrodial joint due to the fibrous encapsulation of a synovial space, the opposing joint surfaces are lined with differing tissue types. The sacral joint surface is lined with hyaline cartilage, whilst the ilial surface is fibrocartilaginous making this part synovial, part syndesmotic joint unique within the body (Forst et al., 2006). As age advances, accumulative stresses transform the SIJ surface from a flattened appearance seen at birth to an irregular uneven one. Due largely to upright postures and axial loading associated with gravity, locomotion and other dynamic activities, remodeling of complementary ridges and corrugations occur within the SIJ, ensuring greater stabilization between each ilia (Bellamy et al., 1983; Forst et al., 2006; Mooney, 1997). According to Bowen and Cassidy (1981) such remodeling begins in the first decade, whilst early into the third decade of life an iliac tubercle, along with an analogous sacral indentation, develops within the SIJ itself, further restricting movement, increasing joint surface friction and thus joint stability.

After the fifth decade ossification and degeneration of the cartilaginous SIJ surface itself, particularly in males, begins to occur, further limiting range of motion and increasing risk of low back pain (Willard, 1997). In an in vitro study examining 55 Japanese adult and fetal SIJ surfaces, Ishimine (1989) noted a marked degeneration within adult cadavers over 30 years particularly on the ilial joint surface, leading to a conclusion of a decreased ability of the SIJ to withstand loads during aging. This finding may be explained by literature reviewed by Walker (1992) indicating a corresponding difference between sacral and iliac articular cartilage depths - the ratio lying between 1.5 to 1 and 3 to 1 respectively in both adult and fetal cadaveric studies. Walker (1992), therefore, suggests that the reduction in ilial articular cartilage depth in adults is likely to occur more
rapidly over time and may lead to joint degeneration and SIJ dysfunction in some people.

2.3 SIJ STABILITY AND LIGAMENTOUS SUPPORT

The capsule and ligamentous support of the SIJ are substantial and reflect the overall function of each joint during load bearing and locomotion and other dynamic motions.

Histologically the SIJ capsule consists of dense regular connective tissue and blends with the surrounding supporting ligaments – the anterior and posterior sacroiliac, interosseous, iliolumbar, sacrotuberous and sacrospinous ligaments. Typically separated for simplicity in anatomy texts and diagrams for teaching purposes, in reality these ligaments blend into a thick fibrous sleeve, providing rigidity yet allowing the small movements required to transition and disperse loads between the axial and appendicular skeletons during upright postures and locomotion (Willard, 1997).

2.3.1 The anterior and posterior sacroiliac ligaments

The anterior sacroiliac ligament (ASL) has a long thin attachment which blends with the anterior superior capsule and, according to Mooney (1997), the articular cavity itself. The posterior sacroiliac ligament (PSL) is the largest of the SIJ supporting structures and has been described by several authors as one of the strongest in the body (Slipman et al., 2001; Walker, 1992). Split into shorter superior and longer inferior fibers, the shorter fibers are arranged horizontally and attach between the first two transverse tubercles of the sacrum and the iliac tuberosity. The longer oblique fibers attach between the third sacral tubercle and posterior superior iliac spine (PSIS) (Gray, 1998).
The main role of the PSL is to limit sacral counter-nutation, or posterior tilting of the sacral base. The PSL is a continuation of the posterior fibrocartilaginous capsule and contains fibers which blend with the superior iliolumbar and inferior sacrotuberous ligaments. However, despite any anatomical connection, the PSL and the sacrotuberous ligament (STL) roles are generally opposed, with the exception of the inferior fibers of the STL which tension the PSL during counternutation as described by Vleeming et al., (1996).

2.3.2 The sacrotuberous and sacrospinous ligaments

The bilateral STLs attach firmly to the inferior angle of the sacrum and the ischial tuberosities, functioning to support pelvic stability and to limit sacral nutation, or anterior movement of the sacral base, posterior rotation of the ilium in relation to the sacrum, or rotational forces. Such restriction is assisted by attachment and contraction of the gluteus maximus and bicep femoris muscles, due to a blending of the myofascial tendinous and ligamentous tissues (McGrath, Nicholson, & Hurst, 2009; Mooney, 1997; A. Vleeming, Stoeckart, & Snijders, 1989a; A. Vleeming, Van Wingerden, Snijders, Stoeckart, & Stijnen, 1989b; Willard, 1997).

Further pelvic stability is maintained by the triangular shaped dual sacrospinous ligaments (SSL), which anchor the sacrum to each ischial spine via a broad lateral sacral attachment. The SSL acts in tandem with the STL to prevent rotational forces in a sagittal plane, whilst also restricting rotation within a horizontal plane – particularly sacral nutation or posterior rotation of the ilia as seen during actions such as rising from a chair. In biomechanical and histological tests, Varga et al. (2008) found there to be less ligamentous tensile strength than previously hypothesized, coupled with a significant finding of proprioceptive nerve endings, potentially indicating more of a primary proprioceptive role than stability. Due to the varied myofascial connections these ligaments interact with, this hypothesis appears to be theoretically plausible.
2.3.3 The iliolumbar ligament

Superior to the SIJs are the iliolumbar ligaments (ILL) which are broad strong connective tissue structures connecting the lumbar spine to the pelvis through attachments to the ilia. The ILL attachments are described by Willard (1997) as being complex and varied among individuals. The superior aspect of the ILL attaches to the transverse processes of the fifth lumbar vertebra, the fourth in some individuals, and intertransverse ligaments. Inferiorly the lower fibers are continuous with the ASL, whilst the upper fibers connect with the ilium anteriorly to the SIJ resulting in a restriction of sacral movement primarily within the sagittal plane (Pool-Goudzwaard et al., 2003).

The strong SIJ osseous structure, capsule and ligaments also provide attachment points for myofascial tissues which both support and influence locomotion. The most predominant include the thoracolumbar fascia, the gluteus maximus and piriformis muscles (Forst et al., 2006). The strength of the sacral ligaments, coupled with the shape and characteristics of the articular surfaces, dramatically restrict movement within the SIJs. However, during locomotive and weight bearing dynamics demanded by human upright posture, this minimal movement is integral to transmission and absorption of both gravitational and ground reaction forces (Hossain & Nokes, 2005).

2.4 Form and force closure

Anatomically the sacrum is often described as ‘hanging suspended between the two ilia’ (Gatterman, 2004), with only the previously mentioned articular and ligamentous structures to offset gravitational and frictional forces. Vleeming, Snijders, Stoeckart, & Mens (1997) propose two mechanisms of SIJ articular and ligamentous stability, these are: “Form closure” and “Force closure” (p. 55).
‘Form closure’ has been described by Vleeming, Snijders, Stoeckart and Mens (1997) as a stable close fitting joint in which extra forces are not required to maintain congruency given the load situation. Form closure of the SIJ is partially achieved due to joint surface structure, which resembles a “propeller-like” (A. Vleeming et al., 1997, p. 55) shape in adults, with the superior aspect of the joint facing posterolaterally, whilst the inferior joint surface tilts anteromedially. The multiple corresponding ridges and sulci, which appear developmentally within the SIJ, also contribute to form closure. However, the vertical orientation of the SIJ necessitates the need for further stabilizing forces, which are achieved by way of a ‘force closure’ or combinations of lateral force and friction. Force closure is achieved through a myriad of myofascial components co-acting to tighten the fibrous fascial attachments during ipsilateral contraction and contralateral contraction via the “posterior oblique sling” (Pool-Goudzwaard, Vleeming, Stoeckart, Snijders, & Mens, 1998a, p. 16). These muscles include the erector spinae, gluteus maximus, multifidi, piriformis, latissimus dorsi and biceps femoris muscles, which attach to the sacrum either directly or indirectly via the thoracolumbar fascia and, with respect to biceps femoris, the sacrotuberous ligament (Foley & Buschbacher, 2006; Forst et al., 2006; Franke & Bruce, 2003; Mooney, 1997; Wingerden, Vleeming, Buyrük, & Raissadat, 2004).

A dynamic combination of both form and force closure provides the SIJ with a balance between stability and mobility, in order to transition gravitational and frictional forces from above and below the pelvis during static upright postures or dynamic movements (Franke & Bruce, 2003; McGrath, 2004; Pel, Spoor, Pool-Goudzwaard, Hoek van Dijke, & Snijders, 2008). Theoretically, passive and dynamic self bracing should negate movement within the SIJ. Subsequently, there has much debate regarding whether movement exists at the SIJ and, if so, how much. Stone (2002) described the importance of a both stable yet mobile SIJ suggesting the sacrum needs to be level to allow for good spinal position in static postures and symmetrically mobile during locomotion to ensure smooth transference of cyclical/oscillatory forces.
2.5 SIJ innervation

Establishing the innervation of the SIJ has been the subject of many clinical *in vitro* and *in vivo* studies. Cadaveric dissections of the SIJ and surrounding structures have led to a wide variability among authors regarding nerve fiber origin relating to SIJ innervation. Variation may be largely due to small sample sizes, natural variation amongst subjects or the difficulties in the dissection of substantial dense connective tissues pertaining to the SIJ joint and surrounding structures. Consequently, nerve fibers from both ventral and dorsal rami of the sacral plexus; ventral and dorsal rami of the fifth lumbar nerve; and the superior gluteal and obturator nerves have been identified as contributing to innervation of the SIJ capsule and surrounding ligaments (Fortin et al., 1994a; Fortin, Kissling, O'Connor, & Vilensky, 1999; Grob, Neuhuber, & Kissling, 1995; Ikeda, 1991; Nakagawa, 1966; Solonen, 1957). In addition to peri-articular structures, more recently innervation of intra-articular joint structures have been identified (Sakamoto, Yamashita, Takebayashi, Sekine, & Ishii, 2001; Szadek, Hoogland, Zuurmond, De Lange, & Perez, 2010; Vilensky et al., 2002) which highlights the potential for the SIJ itself to be a pain generator.

2.5.1 Identification of innervation using anaesthetic block injections

Recent *in vivo* diagnostic studies involving local anaesthetic blocks of both ventral and dorsal nerve roots from levels L5 to S4 have added weight to arguments regarding variability among individuals of SIJ innervation. Dreyfuss et al. (2008) found a marked difference between 10 active and 5 control participants when using single site, single depth local anaesthetic blocks to decrease SIJ experimentally provoked pain versus normal saline for the control group. The authors concluded the local anaesthetic blocks were only effective at decreasing SIJ pain in 40% of active group participants.
Reporting a follow up study, Dreyfuss, Henning, Malladi, Goldstein, & Bogduk (2009) found that a multi-site, multi-depth approach to local anaesthetic blocks of spinal nerves L5 to S3 dorsal rami were 70% effective at eliminating SIJ pain among 10 active participants. However, because intra-articular structures of the SIJ were also stimulated during this study, the authors concluded the intra-articular portion of the SIJ was therefore innervated by both dorsal and ventral rami. This finding is contradictory to the earlier findings of Grob, Neuhuber, & Kissling (1995), which suggest the SIJ is supplied exclusively by the dorsal rami of the sacral plexus, however, it correlates with the findings from a recent study by Szadek, Hoogland, Zuurmond, De Lange, & Perez (2010) which found nociceptor nerve endings within intra-articular structures of the SIJ.

Variability involving SIJ innervation may also explain the clinical difficulty in accurately diagnosing SIJ and low back pain. Fortin, Vilensky, & Merkel (2003, p. 270) suggest SIJ dysfunction may even be causative of sciatic nerve pain stating;

“... in a traumatized and inflamed joint, extravasation of synovial fluid containing inflammatory mediators including Substance P, could traverse any of the three pathways described and irritate one or more of the neural elements that compose the sciatic nerve (L4-S2)”.

Other pain referral patterns from adjacent SIJ structures to the buttock and thigh, such as lumbar facet joints, have also served to create confusion when attempting to ascertain SIJ originating pain leading to various studies endeavoring to map pain referral patterns.

2.5.2 Pain referral zone mapping of the SIJ

Pain provoking injections, usually of normal saline, into the SIJ have been used in an attempt to map various pain referral distribution zones created by SIJ irritation (Fortin et al., 1994a). Such mapping has been considered as clinically
viable diagnostically regarding SIJ pain by Fortin, Aprill, Ponthieux and Pier (1994b). However, Slipman et al.'s (2000) finding of variable patterns of SIJ pain based upon “…the joint’s complex innervation, sclerotomal pain referral, irritation of adjacent structures, and varying locations of injury with the sacroiliac joint”, subsequently nullified any diagnostic usefulness. Van der Wurff, Buijs, & Groen (2006) also dispute the validity of such mapping in distinguishing between SIJ or low back pain, after identifying similarities in pain distribution between affected SIJ and lumbar spine structures.

2.6 SIJ Dysfunction

Walker (1992) suggests SIJ motion must occur both to create SIJ dysfunction and to validate manual therapy procedures designed to restore SIJ function and relieve SIJ related symptoms. Stone (2002) reports that early ideology existing within orthodox medicine suggested the SIJ were incapable of movement, however clinically quantifiable in vitro and in vivo studies within the last three decades have confirmed the existence of, albeit small, rotational and translational SIJ movements (Goode et al., 2008). Theoretically this may suggest, based upon earlier discoveries of nociceptor nerve endings within the SIJ capsule, ligaments and intra-articular structures, that excess or asymmetrical movement patterns which stress SIJ structures may therefore cause SIJ pain. Earlier findings by Sturesson, Selvik & Uden (1989), when objectively testing unilateral and bilateral SIJ motion in both symptomatic and asymptomatic participants, challenge this hypothesis by suggesting pain can be associated with the SIJ when no discernible movement can be quantified.

2.6.1 Manual therapy considerations

Manual therapists have long considered SIJ dysfunction to be related to pain experienced in or around the SIJ region due to asymmetry or abnormal motion within the joint (Riddle & Freburger, 2002).
Pain generated by the SIJ may be due to a variety of causative factors such as direct trauma, repetitive asymmetrical shearing or torsional forces, inflammatory, or be of idiopathic origin (Hansen et al., 2007; McKenzie-Brown, Shah, Sehgal, & Everett, 2005).

Manual therapists, such as osteopaths (McGrath, 2004), chiropractors (Mitchell, Urli, Breitenbach, & Yelverton, 2007) and physiotherapists (Egan, Cole, & Twomey, 1996), suggest SIJ dysfunction may stem from asymmetrical forces leading to a change in sacral or ilial position in relation to each other. For example; movements of the ilium on the sacrum may involve an ‘upslip’, ‘downslip’ or an anterior or posterior rotation (Walker, 1992, p. 903). Sacral initiated dysfunctional movements within the ilia may result in a nutation, counter nutation, torsion, side bending or combination of these movements (Cibulka, 2002). Subsequently manual therapy clinical diagnostic, treatment and management options addressing SIJ dysfunction are predicated on the assumption the SIJ moves (Cibulka, 2002; Kapandji, 1974; Walker, 1992). However, much debate has surfaced regarding the reliability and validity of SIJ clinical palpatory based motion screening, due to small movements quantified during objective clinical in vitro and in vivo testing (Van der Wurff et al., 2000a; Van der Wurff et al., 2000b).

2.6.2 Pregnancy related pelvic pain

Pregnancy related pelvic pain (PRPP) has been linked to ligament laxity of the SIJ and pubic symphysis due to hormonal fluctuations during the gestation period resulting in SIJ dysfunction (Kristiansson, 1997). Two abundant hormones during pregnancy, relaxin and estrogen, have been linked to the softening of collagen and subsequent increase in laxity of ligaments throughout the body resulting in joint hypermobility. Whilst relaxin has long been considered instrumental in increasing pelvic mobility (Östgaard, 1997), estrogen has also recently been
linked to anterior cruciate ligament laxity in both menstruating and pregnant women (Charlton, Coslett-Charlton, & Ciccotti, 2001; Heitz, Eisenman, Beck, & Walker, 1999)

The destabilisation of load bearing joints such as the SIJs and particularly the pubic symphysis, which further increases SIJ strain due to the circular design of the pelvic bony ring, has been linked to dysfunction of gait, SIJ tenderness and lumbosacral pain (Walker, 1992). During upright postures and gait, the added weight associated with pregnancy is thought to cause pelvic and abdominal compression leading to a flattening of the lumbar spine. The resultant decrease in lumbar lordosis may cause the gluteal muscles to lose some hip abductor function resulting in an altered gait pattern which may predispose the hypermobile SIJs to pain and dysfunction (Kristiansson, 1997).

There has yet been no positive correlation made between the degree of pubic symphysis widening and pelvic pain during pregnancy, nor has pelvic pain been related to any radiographic finding (J. Mens, Pool-Goudzwaard, & Stam, 2009). A lack of radiographic evidence may largely be a result of limited research due to potential fetal exposure to radiation. However, there has been evidence correlating levels of pregnancy related hormones with pelvic pain (Charlton et al., 2001; Kristiansson, 1997) and radiological evidence supporting the presence of increased peri and post partum SIJ hypermobility (Walker, 1992). Whilst there is no recognized link between SIJ hypermobility and PRPP, an association between asymmetric SIJ laxity and PRPP has been established (Buyruk et al., 1999; Damen et al., 2001) indicating SIJ motion dysfunction may be causative of PRPP. Research investigating the relationship between asymmetrical SIJ laxity and PRPP demonstrated a decrease in PRPP in 25 postpartum females when using a pelvic belt to reduce SIJ movement (J. M. A. Mens, Damen, Snijders, & Stam, 2006).
2.6.3 Asymmetrical weight bearing

Asymmetrical weight bearing has been proposed as one possible cause of SIJ dysfunction relating to SIJ pain, due to asymmetrical loads placed on the SIJs (Al-Eisa, Egan, & Wassersug, 2004; Childs, Piva, Erhard, & Hicks, 2003; Hungerford, Gilleard, & Lee, 2004). Asymmetrical weight bearing may originate from, for example, the alteration of SIJ stiffness during and after pregnancy (Buyruk et al., 1999), a structural or functional leg length discrepancy, a resultant pain behaviour pattern designed to decrease load on a painful joint, or a change in postural pattern (A. Vleeming, Mooney, & Stoeckart, 2007).

Normal weight bearing is controlled by both passive and active stabilisation systems, influencing form or force closures, which rely upon optimal functioning of bone, joint and supporting ligaments, myofascial and neural elements (Hungerford et al., 2004; A. Vleeming et al., 2007). Any dysfunction within these systems may result in an imbalance of biomechanical loading during weight bearing, predisposing the person to injury and potential pelvic, SIJ or low back pain (Al-Eisa et al., 2004).

To date few studies appear to have been conducted which address the direct correlation between asymmetrical weight bearing and sacroiliac, pelvic or LBP, or the usefulness of weight bearing as a diagnostic tool. In one study conducted by Childs, Piva, Erhard, & Hicks (2003), changes in side to side weight bearing asymmetry were found to be significantly greater in 35 subjects symptomatic of LBP, compared to 31 healthy control subjects (8.8% of total body weight (kgs) vs. 3.6%, respectively, P<.001). A follow up intervention study tested both side to side weight bearing and iliac crest height improvements in subjects with LBP after spinal thrust manipulation. The results showed an improvement in both iliac crest and side to side weight bearing symmetry after manipulation (P<.001). Weight bearing symmetry improvement was also correlated to a decrease in LBP (Childs, Piva, & Erhard, 2004). These studies suggest that an improvement in
weight bearing asymmetry, theoretically due in part to a normalization of bilateral SIJ loading, may correlate with a decrease in LBP.
CHAPTER 3: A BACKGROUND UNDERSTANDING INTO RELIABILITY AND ACCURACY

The following section attempts to; (1) introduce the reader to the concepts of reliability, validity, sensitivity and specificity in relation to quantitative research; (2) review current literature regarding both manual and objective clinical measures of SIJ motion and pain provocation including current ‘gold standard’ protocols and (3) introduce the Doppler imaging of vibrations technique which serves as a basis for section two of this study.

3.1 Statistical measures of diagnostic utility

In clinical terms, diagnostic procedures are evaluated based on indices of reliability, validity, sensitivity and specificity. Clinical testing of the SIJ, whether it be manual pain provocation testing, positional assessment, motion palpation or objective clinical computer motion analysis, need to be considered in light of these indices.

3.1.1 Reliability

Reliability has been defined as:

“The extent to which a test measurement or device produces the same results with different investigators, observers, or administration of the test over time. If repeated use of the same measurement tool on the same sample produces the same consistent results, the measurement is considered reliable.” (Mosby, 2002, p. 78).

Hopkins (2000) describes reliability as pertaining to the reproducibility of output based upon a test, assay or other measurement repeated by the same examiners. In this sense, Hopkins explains that ‘good’ reliability is an indication of
single measurement accuracy that in turn leads to improved scrutinisation of inter or intra-session changes.

There are various influencing components within experimentation which may impact upon reliability strength, namely; instrumental reliability, intra-session, inter-session, intra-rater, inter-rater, and inter-subject reliability (Domholdt, 2005). Whilst instrumental reliability may relate to the test-retest accuracy and consistency of relevant measuring apparatuses, intra-session reliability is the immediate test and re-test reliability relating to random variability of a measurement, whilst inter-session reliability pertains to reliability between measures over a set time frame (days, weeks, months). Intra and inter-rater reliability indicates either multiple tests by the same individual or individual examiners and their respective data collection idiosyncrasies (Bauer, Gröger, Rupprecht, & Gabmann, 2008). Hopkins (2000) maintains that intra-subject variation is the most important type of reliability for research, due to its effect on precision of estimate values caused by such factors as learning, motivation or fatigue.

3.1.2 Validity

Reliability alone is not sufficient to support the quality of a diagnostic test (Robinson et al., 2007). Reliability is a necessary, but not entirely sufficient, condition for validity. It pertains to the strength of our conclusions, inferences or propositions (Domholdt, 2005). Whilst reliability in alone is considered insufficient to sustain the quality of a diagnostic test, the strength of reliability increases when measured alongside validity. Validity can be interpreted as: (1) the strength of conclusions, inferences or propositions (Domholdt, 2005); (2) indicating the extent of an individual’s experimental results to reflect a “true or criterion performance” and, (3) only being measured against tests which show high reliability (Hopkins, Schabort, & Hawley, 2001, p. 212).
Reliability and validity are both important elements required for accuracy and consistency during measurement taking. Sensitivity and specificity are inherent in validity and thus are important in evaluating the clinical usefulness of any diagnostic test.

3.1.3 Sensitivity and specificity

Chibulka & Koldehoff (1999, p. 84) describe sensitivity as the proportion of subjects who have a disease and test “true-positive”, whilst specificity pertains to a proportion of subjects without the disease who test “true-negative”. Combined, these elements are used to determine the “positive predictive value” of a test, i.e. how frequently those who have a positive test will actually have the condition, or the “negative predictive value” which indicates how frequently those with a negative test do not have the condition (Stuber, 2007). These values can be used to help establish a prognosis or treatment guide by adding to an ability of a test to gauge “clinical usefulness”.

Clinically, diagnostic tests usually contain either a high sensitivity or a high specificity. Therefore appropriate levels of sensitivity and specificity are essential elements of screening or diagnostic testing and are key statistical tools used to: (1) Measure diagnostic precision and, (2) “calculate likelihood ratios of a positive or negative test” (Laslett et al., 2005, p. 143).

When aiming to make a diagnosis of SIJ dysfunction for example, clinical tests should optimally possess high specificity and low sensitivity scores for the dysfunction, preferably determined by a controlled comparison against an acceptable reference standard, in order to rule in the possibility of the dysfunction. A test indicating high sensitivity and low specificity scores, alternatively, may assist to rule out the dysfunction.

Practical implications contributing to clinical usefulness of a diagnostic test also include; availability of equipment and resources, budget, the invasiveness of the
procedure, undesirable consequences of the test such as potential for side-effects and other harms. All of these factors need to be considered when performing clinical tests.
CHAPTER 4: CLINICAL OBJECTIVE PAIN PROVOCATION TESTING OF THE SACROILIAC JOINT

4.1 Gold Standard versus Manual Sacroiliac Clinical Testing

Gold standard quantitative clinical tests, such as roentgen stereophotogrammetric analysis (RSA) to detect SIJ motion (Sturesson, 1997) or fluoroscopically guided, contrast enhanced intra-articular anaesthetic block injections to help identify SIJ pain (Laslett, 2008; Laslett et al., 2005; Stuber, 2007), are typically not appropriate or widely available for routine clinical practice. This is especially true for practitioners of manual therapy such as osteopaths and physical therapists, due largely to an unavailability of specialized equipment, technical skills and scope of practice constraints. Consequently manual therapies such as osteopathy, chiropractic and physiotherapy commonly use palpatory cues, passive and active ranges of movement and pain provocation tests to diagnose SIJ dysfunction (Horton & Franz, 2007). As a result the SIJ has naturally become a target for quantitative researchers due to the subsequent conjecture surrounding 1) the extent of SIJ motion; 2) relative lumbar spine and lower extremity associated movements; and 3) similarity of pain distribution patterns between these regions (Laslett, Young, Aprill, & McDonald, 2003; Robinson et al., 2007).

Clinical quantification of small SIJ motions and unpredictable articular movement patterns has led to some scepticism among various commentators regarding the usefulness of manual SIJ testing. Walker (1992), in a critical review of the literature of the SIJ, has raised doubts about the abilities of manual therapists to detect minute SIJ movements ranging from 1±3 degrees or 1±3 mm, whilst McGrath (2004) similarly questions whether SIJ movement is manually detectable due to poor intra- and inter-measurement reliability study results.
Manual therapy SIJ positional assessment, motion palpation and pain provocation tests have been mostly criticised as lacking both reliability and validity in relation to clinical diagnosis.

In a series of reviews, Van der Wurff and colleagues (2000a; 2000b) assessed the literature regarding reliability and validity of previous manual SIJ motion and pain provocation studies. These included either inter or intra-examiner reliability studies published prior to February 1999. Of the 11 clinical tests meeting inclusion criteria the authors concluded that nine lacked both reliability, with kappa scores ranging from 0.02 to 0.42, and validity where sensitivity ranged from 0.41 – 0.43 and specificity between 0.68 – 0.83. The exception were the Gaenslen and Thigh thrust SIJ pain provocation tests, originally described by Laslett & Williams (1994) and later Dreyfuss, Michaelsen, Pauza, McLarty, & Bogduk (1996), which Van der Wurff and colleagues deemed to be reliable based upon the original researchers findings (82-86% agreement) coupled with their own methodological scoring system (56-63 out of 100). Van der Wurff et al. concluded that sensitivity, specificity, confidence intervals and likelihood ratios need to improve in order to consider these tests both reliable and valid.

4.2 **Fluoroscopically guided, contrast enhanced intra-articular anaesthetic block injections**

Manual therapy practitioners have traditionally approached the diagnosis of SIJ related pain by careful consideration of case history and physical examination findings. However, at present there have been no “…absolute historical, physical, or radiological features to provide definitive diagnosis of sacroiliac joint pain” (Hansen et al., 2007, p. 166). Consequently, due to the rich innervation of the SIJ and its demonstrated role in pain referral and LBP, fluoroscopically guided, contrast enhanced intra-articular anaesthetic block injections have been adopted as the currently accepted reference standard for diagnosing clinical SIJ pain (Fortin, Pier, & Falco, 1997; Hansen et al., 2007; Laslett et al., 2005; McKenzie-Brown et al., 2005; Stuber, 2007). By anaesthetising the intra-articular
nociceptive nerve endings in this way, it has been hypothesised that pain perceived as originating within the SIJ diminishes, thus providing evidence of the SIJ as a source of nociception through a diagnosis of exclusion.

Schwarzer et al. (1995) added weight to this hypothesis by utilising local anaesthetic blocks to distinguish ‘SIJ pain’ from LBP in a study of 43 patients symptomatic of LBP below the L5/S1 spinal level. The authors reported a decrease in SIJ pain in 30% of participants, concluding that SIJ pain is, indeed, a significant source of LBP that warrants further investigation.

Fortin, Pier & Falco (1997, p. 272) describe four foundations on which to base a successful diagnosis by block injections:

1. “determining a pain referral pattern of an anatomic structure by provoking that structure in asymptomatic individuals
2. utilizing known pain referral patterns to selectively inject anatomic structure in symptomatic patients
3. provoking a pain response concordant with a patient’s typical pain pattern
4. eliminating pain with anaesthetic injection.”

One of the criticisms of this technique has been the technical difficulty in its administration. Failure to affect all innervated structures within the joint may result in false-negative findings; conversely extravasation of anaesthetic to extra-articular structures, such as the interosseus ligaments or peri-articular myofascial tissues, may lead to false-positive findings (Hansen et al., 2007).

Except for small numbers of medical practitioners with specialist training, this technique remains unfeasible due to its invasiveness, technical reproducibility and accuracy. Without use of fluoroscopy the success rate for accurately administering an injection within the SIJ is as little as 12% by experienced
clinicians (Hansen et al., 2007). Subsequently, alternate measures have been utilized by manual therapists which include: (1) pain provocation tests; (2) motion palpation testing; and (3) pelvic landmark position testing (Van der Wurff et al., 2000a).

### 4.3 Manual pain provocation testing

Manual SIJ pain provocation tests use mechanical procedures aimed at stressing intra and peri-articular SIJ structures, as opposed to distinguishing range of motion or positional characteristics. Such tests are considered as potentially useful diagnostic tools to ascertain sensitivity and specificity of identifying the SIJ as a source of pain (Laslett, 1997).

Maigne, Aivaliklis & Pfefer (1996) researched the efficacy of a group of individual SIJ pain provocation tests, versus a local SIJ anaesthetic block injection within a population of 54 patients with unilateral low back pain. Surmising that peri-articular muscles and ligaments of the SIJ and hips could potentially lead to false positive findings, the authors found no single provocation test had any useful predictive value and there was no significant difference detected between the response to any single test and an anaesthetic block.

Reseaching the benefit of using individual or, alternatively, a cluster of SIJ pain provocation tests to identify SIJ pain against the use of a local SIJ anaesthetic block injection, Dreyfuss, Michaelsen, Paulza, McLarty, & Bogduk (1996) found there to be no single test or group of tests which exceeded a $+LR = 1.0$, when used on 85 patients positive for low back pain below the level of L5. The authors concluded that the physical examination tests selected for the study were ineffective at diagnosing SIJ related pain.

However, Laslett, Young, April, & McDonald (2003) conducted a similar experiment to Dreyfuss et al but included (1) ‘McKenzie motion testing’ to rule out false positives for lumbar disc pain; and (2) a test for the phenomena of pain
centralisation and peripheralisation. The tests were deemed 91% sensitive within a range of 62 to 98%; 83% specific (range 68 to 96%) and had a +LR = 6.97 (95% CI 2.70 to 20.27), indicating that use of a cluster of pain provocation tests were a viable clinical alternative to local SIJ anaesthetic block injections.

Further research by Laslett, April, McDonald, & Young (2005), into the validity of using a cluster of SIJ pain provocation tests, was conducted on 48 patients positive for SIJ pain when compared against a positive intra-articular local anaesthetic block. Results suggested that use of 3 or more of 6 positive tests (distraction bilaterally, compression, thigh thrust bilaterally or sacral thrust) selected for the study showed 94% sensitivity and 78% specificity and produced +LR = 4.29. The authors concluded that should any of the 6 provocation tests not reproduce the patients’ familiar pain, the SIJ could, therefore, be “ruled out” as a source of LBP.

To determine the presence of SIJ pain and/or dysfunction, Stuber (2007) reviewed the literature to identify examination tests returning the highest sensitivity, specificity and predictive values when measured against a gold standard SIJ local anaesthetic block injection. Stuber, similarly to Laslett et al (2005), found singular tests to be comparably poor in effect to each other. However, the use of a cluster of higher sensitivity and specificity scoring tests was more accurate. These tests were: (1) The distraction test; (2) compression test; (3) thigh thrust/posterior shear test; (4) sacral thrust test; and (5) resisted hip abduction. These 5 tests were the only ones that scored in excess of 60% sensitivity and specificity when measured against a local SIJ anaesthetic block injection.

Laslett (2008) has since questioned the use of a cluster of SIJ tests to determine SIJ dysfunction by suggesting that although utilising a group of individually unreliable tests improves reliability, using a ‘cluster’ doesn’t directly address validity, as a reliable test is not necessarily valid (Robinson et al., 2007).
4.4 Objective Motion Testing of the Sacroiliac Joint

Various \textit{in vivo} and \textit{in vitro} measurement modalities have been employed by researchers attempting to establish: (1) the extent of SIJ movement; and (2) the relative axes of motion in which movement may occur. Various \textit{in vivo} techniques have been pioneered to measure SIJ motion. Such techniques include: physical examination with or without bony landmark measurements or manual pressure; roentgenography; tomography; use of kinematic systems such as the Waterloo Spatial Motion Analysis Recording Technique; Roentgen Stereophotogrammetric Analysis (RSA); stress radiology; use of Kirschner wires; and computer generated biomechanical model simulations (Walker, 1992). Of the techniques listed, use of RSA has shown both high accuracy and specificity (Sturesson, 1997) and remains the current gold standard procedure for measuring SIJ motion.

4.4.1 Roentgen Stereophotogrammetric Analysis

Egun, Olssen, Schmid & Selvik (1978) was amongst the earliest to report data for SIJ movements using RSA technology. To facilitate sacral motion, the authors used changes in body position and a manual pressure test on the sacrum. Findings indicated there to be a mean of 0.2 degrees of rotation about a sagittal, or a frontal or transverse plane with the greatest range of motion in the transverse plane measured at 2.0 degrees.

Sturesson, Selvik & Uden (1989) pioneered their own RSA technique to measure SIJ movement, which involved the implantation of tantalum balls (0.8 mm in diameter) into bony pelvic and sacral bony landmarks. These markers were highlighted by dual x-ray imaging using a reference grid during set movements or static positions. Reference points were captured on camera and subsequently calculated using mathematical equations. SIJ rotational movements using RSA were measured as a mean of 2.5 degrees of rotation and a mean of 0.7 millimetres translation with no difference detected between 25 symptomatic and
asymptomatic participants. Although considered to be an accurate measurement technique, Sturesson acknowledges that RSA techniques can be difficult to reproduce due to: (1) time required; (2) requirement of a technical skill for each step; and (3) it involves exposure to ionising radiation (Sturesson, 1997).

4.4.2 Kirschner wires and stereophotogrammetry

Another *in vivo* study involving the use of Kirschner wires to detect SIJ motion by stereophotogrammetry was pioneered by Jacob and Kissling in 1995. The technique utilized transcutaneous implantation of wires into pelvic and sacral bony landmarks of participants under local anaesthetic. Use of cross wires with attached beads measured using stereophotogrammetry produced a three dimensional depiction of SIJ motion during upright postural changes. In Jacob and Kissling’s 1995 study (Jacob & Kissling, 1995) the mean rotation and translational values were determined; for 7 females 1.9 degrees and 0.9mm respectively; and for 14 males 1.8 degrees and 0.7mm respectively. The authors hypothesized that the potential may exist for SIJ dysfunction when rotation is greater than 6 degrees and translation more than 2mm. There were no statistical differences in movement associated with age or sex.

As with RSA, reproducibility of using Kirschner wires remains challenging due to technical requirements and health risks associated with implantation of the wires, which limits its usefulness for routine clinical practice. Such challenges have resulted in only small sample sizes for RSA SIJ motion studies to date potentially reducing the statistical power of these studies.

4.4.3 Review of RSA and stereophotogrammetric techniques

Goode et al. (2008) conducted a critical review of the literature regarding three dimensional analysis of SIJ movement. This study included both *in vivo* and *in vitro* stereophotogrammetric and RSA techniques. Studies were included if motion output was greater than the standard error of measurement (SEM) for the
applicable technique. Excluded were studies involving “mathematical modeling, computerized modeling, and/or skin markers was not included because of concerns of transferability and validity”. Studies not following a “Cartesian coordinate system for each specimen or for a mean or median of all specimens” were also excluded (p. 26). Seven studies were selected in which the authors found SIJ rotational ranges to be between:

-1.1 to 2.2 degrees along a transverse axis,
-0.8 to 4.0 degrees along a longitudinal axis,
-0.5 to 8.0 degrees along a sagittal axis.

SIJ translation was noted as ranging between:

-0.3 to 8.0 mm along a transverse axis,
-0.2 to 7.0 mm along a longitudinal axis,
-0.3 to 6.0 mm along a sagittal axis.

The authors concluded that SIJ motion is limited to minute rotational and translational movements and questioned the reliability and validity of clinical methods utilising palpation for diagnosing SIJ pathology.

The small objective rotational and translational SIJ measurements, produced by the aforementioned gold standard techniques, may cast doubt on the accuracy, reliability and validity of manual clinical palpatory and motion testing. However, manual therapists appear to remain confident that SIJ dysfunction and pain is associated with positional asymmetries of the sacrum within the pelvis, and, that these dysfunctions can be detected using palpation. Therefore there is a need to bridge the gap between difficult techniques to reproduce, such as RSA, and clinical manual palpatory based SIJ testing, in order to satisfy the need for objective identification of SIJ dysfunction in clinical practice.
CHAPTER 5: DOPPLER ULTRASOUND IMAGING OF VIBRATIONS

Questioning the subjectivity and reliability of non-invasive manual clinical tests to accurately assess SIJ dysfunction, whilst seeking an alternative to bridge the gap between objective and subjective testing of SIJ dysfunction, Buyruk et al. (1995a) experimented with using Doppler ultrasound technology to detect vibrations applied to the ilium and received at the both ilium and sacrum.

5.1 History of Doppler Imaging of Vibrations

Parker, Lerner and colleagues (1990; 1990; 1992) were among the first to combine the use of vibration and Doppler colour ultrasound as a clinical diagnostic tool. Pioneered as “Sonoelasticity Imaging” (SI) the authors used Doppler ultrasound imaging to detect low vibration frequencies (0-1000Hz) in order to identify human soft tissue tumours within prostate, liver and kidney tissue.

Buyruk et al. (1995b; 1999; 1995a), using sonoelasticity imaging, began a series of studies to attempt to bridge a gap between the apparent subjectivity and non-reliability of non-invasive manual clinical SIJ testing and the objective, but technically challenging gold standard tests (RSA and anaesthetic blocks) which were deemed to be difficult to reproduce clinically. The authors, in a series of in vitro and in vivo studies, experimented further with SI theory by applying the technique to the anterior ilium and measuring the vibrational signal at both posterior ilium and sacrum in an attempt to assess for asymmetrical SIJ stiffness. The authors named their version of the SI technique “Doppler Imaging of Vibrations” (DIV).

5.2 DIV Procedures
Initial DIV procedures involved participants lying in a relaxed neutral prone position on a treatment table to exclude unnecessary myofascial tension transmitted to the SIJ via gluteal, hamstring and erector spinae muscles (Buyruk, Stam, Snijders, Vleeming, Laméris et al., 1995a). Sinusoidal signals were produced by a signal generator, amplified and transformed into vertical vibrations by a vibration generator (VG) that were received by a Colour Doppler Imaging (CDI) transducer. Buyruk et al. (1999, p. 162) explain that positioning of the VG is not critical because “…vibrations are spherically distributed in the pelvic bones”. Secondly, positioning of the CDI transducer is also not critical because “…only the difference in vibration intensity between the left and right side of the SI joint is of interest”.

In Buyruk et al’s set up, a rod with attached metal plate was connected to the VG which was positioned adjacent to the table. The participant’s unilateral anterior superior iliac spine (ASIS) was contacted by the plate, whereby a vibration frequency of 200 Hz, at ‘low amplitude’, could be applied. The vibrational amplitude used by Buyruk et al. was not specified.

A conventional grey-scale B-mode image of the sacrum and ilium is displayed on a CDI monitor overlaid with simultaneous colour pixilation produced by vibration and detected at an applicable threshold level by the CDI transducer. The threshold level is indicative of the signal power necessary to be displayed as motion by the CDI and may be altered by the sonographer. “Threshold level” (TL) values were assigned to both sacrum and ilia once vibrations (displayed as red and blue pixels) disappeared and the image returned to grey-scale (Buyruk et al., 1999, p. 161). The authors argued that TL values were directly related to the vibrational energy transmitted from the bone. Therefore by calculating the difference between ipsilateral iliac and sacral TL values, a “threshold unit” (TU) value could be ascertained. The authors postulated that a large TU would suggest a substantive energy loss through the SIJ, thereby indicating a ‘hypermobile’ or ‘lax’ joint. Conversely a small difference could be perceived as a
'stiff' or 'hypomobile' joint. When bilateral joint TU values were compared an indication of SIJ asymmetry could be ascertained and therefore, potentially, may be associated with SIJ dysfunction.

5.3 Early DIV research

Early experimentation of DIV by Buyruk and colleagues involved a series of studies (1995b; 1999; 1995a) designed to assess the validity and reproducibility of the technique when assessing the SIJ. An initial study involved 4 human cadavers ranging in age between 92 and 97 years. To ascertain if there was a proportional relationship between SIJ stiffness the cadaveric SIJs were fixated with screws to increase stiffness. Conversely, supporting ligaments were transected to decrease SIJ joint stiffness. The authors surmised there to be both intra- and inter-individual visible objective and reproducible differences in SIJ stiffness (Buyruk, Stam, Snijders, Vleeming, Laméris et al., 1995a). Whilst this study appeared to be quantifiable in terms of objective comparative results of SIJ stiffness with and without supporting ligaments, an obvious limitation of this study was the assumption made in which vibrations would propagate similarly via living tissue, and tissue would behave predictably in vivo. Secondly, the sample size was small thereby limiting statistical power of the study. All cadavers were female and at least 92 years old which is not typical of participants who potentially would be receiving the measurement technique in research or practice.

A second study, which attempted to answer the above question, applied DIV to 14 healthy, asymptomatic female participants aged between 20 and 40 years (Buyruk, Snijders, Vleeming, Laméris et al., 1995b). Results showed that DIV could successfully distinguish between inter-individual differences in SIJ stiffness with a reliability coefficient of 0.97 for all left SIJ and 0.94 for all right SIJ. No significant intra-individual differences between left and right sides were noted using t-tests (p=0.44). Although the effect size for this study was 'small', the researchers found there to be a wide variation in SIJ stiffness within their sample of healthy people. Due to the small sample size, it is difficult to make any
inferences about pathological and non-pathological SIJ stiffness ranges without further research involving larger sample sizes, including both asymptomatic and symptomatic participants (for LBP and pelvic pain).

A follow up study by Buyruk et al. (1999) addressed SIJ stiffness, using DIV in 56 females with peri-partum pelvic pain (PPPP) aged between 24-54 years, compared to a control group of 45 healthy female participants aged between 24-42 years. The authors selected the active group based upon their predilection for SIJ ligament laxity due to potential effects of pregnancy hormones, muscle weakness and weight of the foetus within the pelvis. The active group were included if they complained of pelvic and/or back pain for at least 3 months post delivery. Participants in both the active and control groups displayed both high SIJ stiffness as well low stiffness, and there were no significant differences in stiffness separating the two groups. The authors did, however, note a significant difference with regards to the left and right SIJ mean between each group (P<0.001). Active PPPP participants showed a greater level of SIJ asymmetry when compared to the control group, indicating SIJ asymmetry may be more related to PPPP than the stiffness level of a single SIJ (Buyruk et al., 1999).

These findings lead the authors Buyruk et al. (1999) to question previous claims regarding the increased risk of SIJ strain, due to stiffness asymmetry, during shock absorbing activities such as walking. The authors make an argument that typically, most low back, pelvic or SIJ pain sufferers complain of symptoms not only during walking but when sitting or standing as well, therefore questioning the effect of asymmetrical shock absorption and low back and pelvic pain. However, what is possibly not taken into consideration is the extra strain placed upon the hyper-mobile or less stiff intra-articular structures and supporting SIJ ligaments during static postures. Such asymmetrical loading may potentially be causative of, or aggravate already sensitized tissues thereby provoking low back or pelvic pain during sitting or standing. However, there is yet still no clear relationship
between perceived SIJ motion or positional abnormalities leading to SIJ dysfunction (Laslett, 2008).

5.4 Further research utilizing DIV

Subsequent studies utilising the DIV technique have been conducted since its initial development. These studies have included: (1) SIJ biomechanical testing pertaining to SIJ stiffness including use of muscular contractions or pelvic belts to induce SIJ force closure; (2) first tarsometatarsal (TMT) joint stiffness; and (3) DIV measurement reliability studies based upon the original measurement techniques described by Buyruk and colleagues.

5.4.1 Tarsometatarsal joint stiffness

Faber and colleagues (2000) tested the comparable stiffness of 46 first tarsometatarsal (TMT) joints in the feet of 23 healthy subjects. In a connected pilot study of 3 participants with known first TMT hypermobility, all three showed DIV TU values to be in excess of 5 units – indicating likely joint hypermobility. The authors concluded the technique was objective, and demonstrated good repeatability and was noninvasive.

In a follow up study by Faber et al. (2001), 32 first TMT joints of 20 hallux valgus patients were tested to compare joint stiffness determined by an independent examiner. Results indicated a statistical relationship existed between a clinical mobility test of the first TMT and DIV measurement of stiffness of the first TMT joint (p=0.008). High DIV stiffness values correlated with hypermobile first TMT joints and low DIV values with non-hypermobile joints. The authors concluded that, coupled with manual clinical testing, DIV data provided sufficient supporting evidence to help rationalize the choice surrounding a specific hallux valgus surgical procedure.
5.4.2 Measuring SIJ stiffness asymmetry in relation to pregnancy related pelvic pain

Damen et al. (2001) used DIV as one of a group of techniques to test pregnancy-related pelvic pain (PRPP) in 163, 36 month pregnant females, 73 of which were noted to have ‘moderate to severe’ PRPP, and the remaining 90 ‘mild to no’ PRPP. The authors also used a visual analog scale, posterior pelvic pain provocation test, active straight leg raise test, and Quebec back pain disability scale to assess for PRPP. Damen and colleagues, whilst conversely using SIJ ‘laxity’ instead of stiffness as a measure, noted that while there was no difference in SIJ laxity between the groups (3.0 versus 3.4 TU), there was a noteworthy difference in asymmetrical SIJ laxity within the ‘moderate to severe’ PRPP group (37%) against the ‘mild to no pain’ PRPP group (4%). The authors concluded that these findings may add weight to the argument that SIJ asymmetry is an important factor in SIJ pain and dysfunction. However, cross sectional studies such as this do not explain whether asymmetry is a cause or an effect of SIJ pain only that asymmetry is associated with SIJ pain.

A follow up study by Damen et al. (2002b) was conducted involving 123 women at 36 weeks gestation and at 8 weeks postpartum, using only DIV to assess SIJ asymmetry. The authors defined SIJ asymmetry to be a difference of ≥3 TU between left and right sides. For the postpartum group, the sensitivity, specificity, and positive predictive values of SIJ asymmetric laxity were 65%, 83%, and 77%, respectively. The pregnant group was 77% predictive of ‘moderate to severe’ pelvic pain persisting postpartum due to SIJ asymmetric laxity and were deemed three times more likely to develop postpartum pain than participants with symmetrical SIJ laxity. Therefore Damen and colleagues postulated that asymmetric SIJ laxity during pregnancy is a predictor of PRPP persisting postpartum.
5.4.3 DIV technique reliability when measuring SIJ laxity

In between the two studies on PRPP, Damen, Stijnen, Roebroeck, Snijders, & Stam (2002a) recognized a gap in the existing literature with regards to tester reliability when performing the DIV technique. The authors conducted an experiment assessing both intra- and inter-tester reliability of SIJ laxity measurement, involving 10 healthy females utilising five inexperienced testers and one experienced tester. Intra-class correlation coefficients (ICC) ranging between 0.53 to 0.80 and 0.75 to 0.89 were reported for the inexperienced and experienced tester(s) respectively. The authors concluded both experienced and inexperienced testers could reliably assess SIJ laxity utilising DIV, but particularly if performed by an experienced tester.

In a recent investigation, run parallel to the current study, Crossley (2011) examined the reliability of inexperienced observers to identify sacral and ilial bony landmarks to assess SIJ stiffness ‘Threshold Levels’ from pre-recorded video clips of DIV. Intra-observer reliability ranged from ‘moderate’ (ICC 0.48, 95% CI = -0.04 to 0.81) to ‘very high’ (ICC = 0.99, 95% CI = 0.99 to 1.0) whilst inter-observer reliability was ‘very high’ (ICC = 0.99, 95% CI = 0.99 to 1.0). Crossley concluded that inexperienced observers can make reliable judgements about threshold levels when assessing SIJ stiffness from video recording of DIV, therefore identifying that much of the error associated with measurement is probably attributable to factors other than rater error.

5.4.4 Transversus Abdominis effect on SIJ force closure

Richardson and colleagues (2002) tested the effect of transverse abdominis (TA) contraction versus lateral abdominal muscles on force closure of the SIJ, and used DIV to assess SIJ laxity values in 13 healthy participants. The researchers found TA contraction increased SIJ stiffness when compared to the other abdominal contractions (p=0.03), and concluded TA plays an important role in stabilization of the pelvic ring by increasing SIJ stiffness during contraction.
5.4.5 The effect of a pelvic belt on SIJ laxity

Damen, Spoor, Snijders and Stam (2002c) used DIV to measure SIJ stiffness both before, and after, the effect of SIJ force closure, using a pelvic belt in 10 healthy female subjects. The authors found that although changes in tension did not significantly influence SIJ laxity, efficacy of SIJ force closure, measured as SIJ stiffness, was improved with different positional modifications of the belt, particularly when positioned high on the pelvis just below the anterior superior iliac spines.

Mens, Damen, Snijders & Stam (2006) applied their pelvic belt to 25 subjects with PRPP. The group were able to report that SIJ stiffness increased significantly during two different applications of a pelvic belt in ‘high’ position or just below the ASIS (p < 0.001). However, in summarizing, Mens et al. questioned the validity of DIV to measure SIJ laxity based upon the findings of de Groot, Spoor & Snijders (2004), stating: “It is still unproven that DIV measures SIJ laxity” and after acknowledging the plausibility of DIV in terms of previous research continued “…there is serious doubt that the primary concept of Buyruk et al. (1995a,b) is true” (p. 126).

5.5 Critique of the DIV technique

The apparent success of the DIV technique to assess SIJ laxity encouraged Groot, Spoor & Snijders (2004) to conduct a review of both reliability and validity of the DIV technique. De Groot and colleagues identified the need for further investigation into the following claims with regards to their accuracy or need for further investigation:

1. “Energy loss in propagation ensures vibration intensity reduction across a joint.
2. Joint stiffness is proportional to the conducted vibration intensity.
3. Vibration intensity changes during one measurement session are negligible.
4. Vibration phase differences across a joint can be ignored.
5. Threshold units are a measure for the velocity (squared) of the vibrating bone.” (p.366)

The authors concluded that although the reliability and clinical relevance of DIV has been established and remains a promising technique with regards to SIJ stiffness/laxity measurement, the technique has yet to be thoroughly validated by fundamental research.

5.5.1 Alternative hypothesis for DIV
Mens, Damen, Snijders & Stam (2006) offer an alternative hypothesis to the suggestion of de Groot et al. (2004), in which observed vibrations may not necessarily be conducted through bone. The authors proposed that vibrations may be transmitted instead through surrounding muscle and ligamentous tissues and concluded that SIJ stiffness may also be reliant upon ‘tone’ of these tissues. Therefore DIV may offer an indirect elucidation of SIJ stiffness.

5.6 Review of conclusive remarks made by the DIV originators
Following the originating series of DIV studies, Buyruk et al. (1997) concluded DIV to be: (1) safe; (2) easy to apply due to not requiring intensive training; (3) the measurements were reproducible; (4) stiffness measurements were quantifiable between intra- and inter-individuals; and (5) sacroiliac joint stiffness asymmetry could be correlated to low back and SIJ pain although one sided SIJ stiffness could not. The authors also claimed there was no inconvenience to healthy patients, however, due to the type of vibration generator used in all studies utilising DIV found in the literature to date, participants have been
restricted to lying in a prone position. People with LBP, pelvic or neck pain, may not be able to assume a prone position for the duration required to be measured by DIV. Secondly, aggravation of a person’s pain due to prone positioning, may potentially impact upon force closure of the SIJ due to altered muscle tension and therefore may have an immediate affect on SIJ stiffness levels thereby confounding measurements. The authors also conceded that the DIV technique is limited by the expense of the CDI and vibration generator and suggest “…a less expensive apparatus, especially designed to assess SI joint stiffness, could be developed for this type of measurement in the future” (Buyruk, Snijders, Vleeming, Laméris et al., 1995b, p. 120).

Further studies incorporating: (1) low back and pelvic symptomatic and asymptomatic patient’s; (2) patient’s assuming different postures which both load and unload the SIJ; and (3) static and dynamic movement patterns pertaining to the SIJ, need to be undertaken to advance DIV technique’s clinical viability.

5.7 Justification for DIV Technique Selection

The DIV technique was selected for the current study as it may provide a conduit to bridge the gap between objective quantifiable SIJ pain provocation and movement techniques such as anaesthetic block injections RSA, and manual therapy pain provocation, palpatory and range of motion based examinations. The DIV technique is both a non-invasive and quantifiable technique which appears to be safe and has been successfully and reliably used to determine SIJ stiffness or laxity in a number of previous studies (Buyruk, Snijders, Vleeming, Laméris et al., 1995b; Buyruk et al., 1999; Buyruk, Stam, Snijders, Vleeming, Laméris et al., 1995a; Damen et al., 2002a).

5.8 Indications for Further Study
With newer technologies offering portable hand held Doppler colour ultrasound functionality and the use of a more portable vibration generator the DIV technique may become more reproducible and accessible for use within a clinical or research environment. This may allow for a greater range of studies involving different biomechanical studies of the SIJ or other joints, the effect of a treatment intervention or the use of DIV to assess other soft tissue structures within the body.
CHAPTER 6: CONCLUSION

Sacroiliac joint (SIJ) motion dysfunction and its role in low back and SIJ pain remains an unresolved issue amongst the medical fraternity. Sacroiliac joint pain and its relationship to low back pain, has proven notoriously difficult to diagnose clinically, due to complex anatomical variations and pain referral patterns. Manual therapists rely upon palpatory, motion and pain provocation testing to diagnose SIJ pain and dysfunction. However, limitations exist around both reliability and validity of clinical manual therapy screening of the SIJ, coupled with reproducibility and health risk issues associated with the invasive, but gold standard SIJ motion procedures. Based on the literature, it appears that pain provocation testing is of questionable utility.

The development of a reliable, non-invasive and accessible technology based criterion standard for assessing SIJ stiffness is required, to supplement existing clinical SIJ tests. Therefore, the research question addressed in the following experimental investigation was to ascertain whether DIV, when utilising a custom built VG, was deemed to be a reliable technique when measuring SIJ stiffness within a normal population.
SECTION II: EXPERIMENTAL INVESTIGATION
CHAPTER 7: METHODS

An imbalance between right and left sacroiliac joint (SIJ) stiffness may lead to possible sacroiliac pain and dysfunction. In order to study SIJ dysfunction it would be useful to first understand the frequency and severity of SIJ stiffness asymmetry within a normal population.

7.1 Aims/Objectives

The aim of the current study was to estimate inter and intra-session reliability of a custom built vibration generator (VG) when using Doppler Ultrasound Imaging of Vibrations (DIV) technique to measure SIJ stiffness within a normal population.

7.2 Study design

The study was a test-retest intra and inter-session reliability study. The first session comprised of two bilateral sacral and ilial measurements followed by a brief ambulation, repositioning and repeat of initial measurements (Figure 1.). A follow up session within 7 to 14 days involved two successive bilateral measurements of sacrum and ilia without ambulation (Figure 2.). All participants read an information sheet (Appendix C.) and were given the opportunity to ask questions before signing a consent form (Appendix D.). Participants were given the option to withdraw from the study up to two weeks post data collection with no consequences. The study was approved by the Unitec Research Ethics Committee.

7.3 Participants

Participants were not considered for this study if they had undergone surgery to the spine or buttock region or were peripartum or postpartum. No further restrictions were placed on participation criteria as the sample was intended to be a sample from a normal population. Participants were recruited at either Unitec or
Auckland University of Technology (AUT) through use of word of mouth and email.
Figure 1. Flowchart showing study design for Session one.
Figure 2. Flowchart showing study design for Session two.
7.4 Procedures

7.4.1 Equipment set up

Two clinical treatment tables were oriented perpendicularly to each other so that the ‘face hole’ of one of the tables could be used to project the vibration generator (VG) applicator (Figure 3.). The VG (Figure 4.) was set up and positioned on top of a height adjustable static table beneath the head hole of the inferior treatment table (see Figures 5 & 6.). The signal generator and power amplifier (Figure 7.) were positioned statically to one side of the treatment tables, the ultrasound equipment and sonographer were positioned on the opposite side. Both treatment tables were raised or lowered as needed to appropriately position the VG applicator.
Figure 3. Patient and procedure setup showing perpendicular positioning of examination tables. This allows the face hole of the longitudinal table to project the VG applicator to contact participant’s anterior superior iliac spine.
Figure 4. Unitec designed, Phillip Harris manufactured Vibration Generator. Maximum peak to peak displacement: 12mm. Total frequency range: D.C. to 12Khz.
Figure 5. Vibration generator in situ. The VG sits on top of static table beneath examination table. A foot pedal controls height adjustment of the VG applicator by raising or lowering the examination table accordingly.
Figure 6. Close up view of VG showing position of applicator which is controlled by the table height adjustment pedal so that a comfortable contact to the participant’s ASIS is achieved and maintained throughout the measurement procedure.
Figure 7. Dick Smith Electronics™ Signal Generator (3Mhz maximum frequency output) controlling vibration frequency and amplitude (top) with Custom built Power Amplifier circuit fed by -30V, 0, 30V from power supply and signal feed from signal generator (below).
Power supply 230VAC input from mains and -30V, 0, +30V output which is sent to the power amplifier

Dicksmith Electronics™ Signal Generator 3Mhz maximum frequency output

Power amplifier circuit fed by -30V, 0, 30V from power supply, and signal feed from signal generator

Power signal from amplifier

Vibration Generator, Phillip Harris manufactured, Maximum peak to peak displacement: 12mm. Total frequency range: d.c. to 10kHz.

Figure 8. Schematic of Vibration Generator, power amplifier and signal generator.
7.4.2 Participant set up

Participant height and weight were measured and recorded before each participant was requested to lie prone over two treatment tables with their arms at their sides and their head turned opposite to the targeted ASIS (Figure 1.). This position was chosen to achieve a neutral, unloaded posture by reducing the influence the thoracolumbar fascia may have upon force closure of the SIJ by way of the broad latissimus dorsi, erector spinae and gluteus maximus muscles (A. Vleeming et al., 1997). Each participant was positioned and checked by a researcher, using the electronic treatment table height adjustment pedals, so that a light but consistent contact was made to the target ASIS by the VG applicator.

7.4.3 Procedure

The sonographer introduced himself to the subject, explained the ultrasound procedure and gained verbal consent. The participant was asked to adjust their clothing to expose their lower back and superior gluteal region as explained in the information sheet. The participants were instructed to relax and breathe normally. Pre-warmed Aquaflex® Ultrasound Gel (Fairfield, USA) was applied to the SIJ region, to allow efficient ultrasound transmission from the 12.5 MHz, 55mm, linear array transducer device to the SIJ.

The transducer was applied in transverse section (Figure 9.) approximate to the medial aspect of the posterior superior iliac spine (PSIS) and spanning the SIJ to contact the ipsilateral posterior superior aspect of the sacrum. The fifth lumbar spinous process was located and visualized in normal grey scale as an initial focal landmark. The scan plane was adjusted until appropriate sacral and ilial bony landmarks were identified for orientation and exact landmark selection. Depth and focus were optimized to improve image quality.
A VG test was conducted to make sure the participant was (1) positioned correctly and (2) the amplitude and frequency of vibrations were not uncomfortable for the participant. Vibrations were applied (Figure 9.) directly to the ileum, through the anterior superior iliac spine (ASIS). The VG was controlled using a Dick Smith Electronics™ Signal Generator (3Mhz). In this study a frequency of 150 Hz with a low amplitude not exceeding 0.1 mm was used for all measurements. VG output signals were received and recorded using an iU22 Doppler Ultrasound machine (Philips IU22, Medical Systems Company, Eindhoven, The Netherlands).

Using Doppler mode the sonographer increased the signal power by adjusting the gain dial to increase power signal percentage (in decibels) at a rate of approximately 3 dB/s until:

- Doppler signals were received back from vibrating elements of the sacrum and ileum and displayed as red or blue pixels on a CDI monitor (Figures 9. & 10.).
• A threshold level (TL) was established by recording the percentage gain noted when the Doppler colour image of either the sacral or ilial landmark was observed receiving vibration (Figure 10.).
• A further TL was established when the Doppler colour image of the alternate vibrating bone was observed, either the sacrum or the ilium, across the target joint line.
• Subtracting the sacral TL from the ilial TL indicated the apparent power decrease of vibration across the scanned SIJ.
Figure 10. Doppler imaging of vibrations screenshot showing the right sacral threshold level (in percentage Gain). Both right sacral and ilial bony landmarks can be seen receiving vibrations as coloured pixelations.

7.4.4 First session recordings

In the first session TL recordings were taken twice for each unilateral sacral and ilial landmark, beginning with the right SIJ, to obtain two individual sets of measurements (Session 1, Measure 1; and Session 1, Measure 2). Between measures the patient was repositioned so that the contralateral left ASIS was positioned appropriately and the participant’s posture adjusted to conform to the original position and the measurements repeated.

The participant was then requested to walk the length of a corridor equating to a distance of approximately 100 meters. The act of the participant standing up, ambulating and repositioning themselves on the table was performed to (1) test the intra-session reliability of the measurement process and (2) test for individual TL measurement consistency. Upon repositioning of the participant, two further
measures (Session 1, Measure 3; and Session 1, Measure 4) were recorded for each SIJ (left and right) without an additional ambulation.

7.4.5 Second session recordings

Participants were requested to return for a second session of measurement within a period of 7 to 14 days whereby two further measurements were recorded (Session 2, Measure 5; and Session 2, Measure 6).
7.5 Data analysis

The baseline descriptive information obtained from each participant was tabulated for statistical analysis.

Analyses of statistical comparisons, of intra- and inter-session reliability were calculated using a one-way ANOVA using a statistical package (SPSS, v17.0, Chicago, IL).

An intraclass correlation coefficient (ICC) of 1 indicates ‘perfect’ reliability with no measurement error, whilst 0 indicates no reliability (Rankin & Stokes, 1998). The ICC is a type of relative reliability index containing a unit less number which may be used to compare inter-test reliability (Chen, Chen, Hseuh, Huang, & Hsieh, 2009). Reliability coefficients are determined as the ratio of variance between participants, to the sum of error variance and participant variance. There is currently no definitive acceptable level of reliability using the ICC, or other reliability coefficients, however, for any reliability measure to be useful it should have a minimum ICC ≥ 0.6 (Bruton, Conway, & Holgate, 2000). Vincent (2005) previously described ICC values as: ICC > 0.90 = ‘excellent’, > 0.80-0.89 = ‘high’, and >0.70-0.80 = ‘acceptable’.

For the judgment of identifying TLs using DIV to measure SIJ laxity, test-retest reliability was conducted using ICCs along with 95% confidence intervals (CI), using the agreement levels rating suggested by Landis and Koch (1977) to interpret the results (where: <0 = ‘Poor agreement’; 0.01-0.20 = ‘Slight agreement’; 0.21-0.40 = ‘Fair agreement’; 0.41-0.60 = ‘Moderate agreement’; 0.61-0.80 = ‘Substantial agreement’ and 0.81-1.00 = ‘Almost perfect agreement’). The descriptor was used only when the lower boundary of the CI was equal to or greater than the minimum threshold for the descriptor.
Intra-session reliability analyses involved separately comparing the mean of ICC measurements of left and right sacral and ilial TL values. A one-way mixed model ANOVA for absolute agreement (ICC$_{1,4}$, the average of four measures for S1 and ICC$_{1,2}$, the average of two measures for S2) was used.

An inter-session reliability analysis was conducted by comparing the intra-session ICC means of S1 (M1-4) versus S2 (M5-6) for left and right sacral and ilial TL values using a one-way mixed model ANOVA for absolute agreement (ICC$_{1,2}$, the average of 2 measures). Standard error of the measurement (SEM) calculations were undertaken (where SEM = $\sqrt{1-\text{ICC}}$) to indicate the extent of measurement error caused by chance variation in measurement (Chen et al., 2009). The smallest detectable difference (SDD) was also calculated, indicating the degree of change that would exceed the expected trial to trial variability. The SDD was calculated using the following formula: SDD = SEM * $\sqrt{2} \times 2.179$ (where 2.179 represents the $t$-value of distribution for a 95% Confidence Interval with 12 degrees of freedom; where df = n-1). During evaluation of a therapeutic intervention, an improvement in an outcome variable has to be equal to or exceed the SDD for a 95% confidence level of an effect of the intervention (Damen et al., 2002a). The SDD should be low together with high ICC and CI scores when a test is considered to be highly reliable (Chen et al., 2009).

Bland-Altman plots were produced as a supplement to ICC scores to provide a graphical representation of key reliability findings. The Bland-Altman method determines a range within which the variation between two occasions will lie with a probability of 95% (Bland & Altman, 2003; Mantha, Roizen, Fleisher, Thisted, & Foss, 2000). It is worth noting that Bland-Altman plots have been criticized by Hopkins (2004, p. 45) for creating an “artifactual bias” in a Bland-Altman plot containing measures with substantial random error, however, due to the small
sample size used in the current study it was assumed artifactual bias was less likely to have a pronounced effect on overall graphical representation of the data. A three by three contingency table was constructed to visually inspect the pattern of SIJ stiffness between participant inter-session measurements. Further statistical analysis of the contingency table was invalidated since the individual cell size was less than n=5 (Field, 2009), however, visual inspection of the table was undertaken.

To determine if a relationship between same side SIJ inter-session TU measurements existed, a \textit{t}-test for paired samples was performed to detect statistical differences between the two groups.
CHAPTER 8: RESULTS

Thirteen healthy participants with an age range of 23-50 years, 4 females (mean age 27 ± 5 years, height 167 ± 13cm, weight 65 ± 11 Kg) and 9 males (mean age 33 ± 9 years, height 176 ± 5cm, weight 76 ± 8 Kg) completed the study. All participants met recruitment requirements for the study and were able to lie prone unassisted for at least 20 minutes.

8.1 Intra- and intersession Reliability

Session one (M1 & 2, M3 & 4, M5 & 6) intra-session ICC scores and confidence intervals are presented in Table 1.

Inter-session S1 (means of M1,M2,M3,M4) versus S2 (means of M5,M6) ICC scores and confidence intervals are presented in Table 2.

8.2 Individual SIJ stiffness

Individual threshold unit (TU) scores depicting unilateral SIJ stiffness levels are presented in Table 3. Threshold unit values ranged between 0.0 and 24.5 for all participants. Three of 13 participants showed a consistent SIJ stiffness pattern over two sessions (P3, P5 and P8).
Table 1. Intra-session reliability indices based upon threshold level (TL) outputs per bony landmark.

<table>
<thead>
<tr>
<th>Session</th>
<th>Bony Landmark</th>
<th>ICC(^a)</th>
<th>CI(^b) (lower)</th>
<th>CI(^b) (Upper)</th>
<th>SEM(^c)(TL)</th>
<th>SDD(^d)(TL)</th>
<th>ICC Descriptor(^e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 (M1&amp;2)</td>
<td>Right Ilium</td>
<td>0.95</td>
<td>0.85</td>
<td>0.99</td>
<td>0.21</td>
<td>0.66</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Left Ilium</td>
<td>0.98</td>
<td>0.94</td>
<td>0.99</td>
<td>0.13</td>
<td>0.41</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Right Sacrum</td>
<td>0.94</td>
<td>0.79</td>
<td>0.98</td>
<td>0.25</td>
<td>0.77</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Left Sacrum</td>
<td>0.97</td>
<td>0.91</td>
<td>0.99</td>
<td>0.16</td>
<td>0.51</td>
<td>Excellent</td>
</tr>
<tr>
<td>S1 (M3&amp;4)</td>
<td>Right Ilium</td>
<td>0.99</td>
<td>0.96</td>
<td>1.00</td>
<td>0.12</td>
<td>0.36</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Left Ilium</td>
<td>0.98</td>
<td>0.94</td>
<td>1.00</td>
<td>0.13</td>
<td>0.41</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Right Sacrum</td>
<td>0.99</td>
<td>0.96</td>
<td>1.00</td>
<td>0.11</td>
<td>0.35</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Left Sacrum</td>
<td>0.96</td>
<td>0.89</td>
<td>0.99</td>
<td>0.19</td>
<td>0.58</td>
<td>Excellent</td>
</tr>
<tr>
<td>S2 (M5&amp;6)</td>
<td>Right Ilium</td>
<td>0.96</td>
<td>0.78</td>
<td>0.99</td>
<td>0.19</td>
<td>0.59</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Left Ilium</td>
<td>0.97</td>
<td>0.89</td>
<td>0.99</td>
<td>0.18</td>
<td>0.57</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Right Sacrum</td>
<td>0.99</td>
<td>0.98</td>
<td>1.00</td>
<td>0.09</td>
<td>0.28</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Left Sacrum</td>
<td>0.97</td>
<td>0.90</td>
<td>0.99</td>
<td>0.17</td>
<td>0.53</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

Note:
1. Intraclass correlation coefficient
2. Confidence Intervals
3. Standard error of the measurement based on threshold level values.
4. Smallest detectable difference based on threshold level values.
5. ICC descriptors are based on Vincent (2005) suggestions where: > 0.90 = ‘excellent’, > 0.80-0.89 = ‘high’, and >0.70-0.80 = ‘acceptable’.
Table 2. Inter-session reliability indices based upon threshold level (TL) outputs per bony landmark.

<table>
<thead>
<tr>
<th>Session</th>
<th>Bony Landmark</th>
<th>ICC$^1$</th>
<th>CF$^2$ (lower)</th>
<th>CF$^2$ (Upper)</th>
<th>SEM$^3$ (TL)</th>
<th>SDD$^4$(TL)</th>
<th>ICC Descriptor$^5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Right Ilium</td>
<td>0.90</td>
<td>0.70</td>
<td>0.97</td>
<td>0.31</td>
<td>0.95</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Left Ilium</td>
<td>0.94</td>
<td>0.82</td>
<td>0.98</td>
<td>0.24</td>
<td>0.73</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Right Sacrum</td>
<td>0.93</td>
<td>0.59</td>
<td>0.98</td>
<td>0.27</td>
<td>0.83</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Left Sacrum</td>
<td>0.96</td>
<td>0.86</td>
<td>0.99</td>
<td>0.21</td>
<td>0.64</td>
<td>Excellent</td>
</tr>
<tr>
<td>S2</td>
<td>Right Ilium</td>
<td>0.71</td>
<td>0.12</td>
<td>0.91</td>
<td>0.54</td>
<td>1.65</td>
<td>Acceptable</td>
</tr>
<tr>
<td></td>
<td>Left Ilium</td>
<td>0.70</td>
<td>0.09</td>
<td>0.90</td>
<td>0.55</td>
<td>1.70</td>
<td>Acceptable</td>
</tr>
<tr>
<td></td>
<td>Right Sacrum</td>
<td>0.51</td>
<td>-0.38</td>
<td>0.84</td>
<td>0.70</td>
<td>2.17</td>
<td>&lt; Acceptable</td>
</tr>
<tr>
<td></td>
<td>Left Sacrum</td>
<td>0.74</td>
<td>0.21</td>
<td>0.92</td>
<td>0.51</td>
<td>1.56</td>
<td>Acceptable</td>
</tr>
</tbody>
</table>

Note:
1. Intraclass correlation coefficient
2. Confidence Intervals
3. Standard error of the measurement based on threshold level values.
4. Smallest detectable difference based on threshold level values.
5. ICC descriptors are based on Vincent (2005) suggestions where: ICC > 0.90 = 'excellent', > 0.80-0.89 = 'high', and >0.70-0.80 = 'acceptable'.
Table 3. Intra-session SIJ threshold unit (TU) measurements per participant with inter-session participant TU means indicating individual SIJ stiffness symmetry.

<table>
<thead>
<tr>
<th>Session (Measurement)</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>P7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>L</td>
<td>R</td>
</tr>
<tr>
<td>S1(M1)</td>
<td>9</td>
<td>4</td>
<td>8</td>
<td>0</td>
<td>9</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>S1(M2)</td>
<td>3</td>
<td>7</td>
<td>15</td>
<td>4</td>
<td>9</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>S1(M3)</td>
<td>18</td>
<td>3</td>
<td>8</td>
<td>5</td>
<td>0</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>S1(M4)</td>
<td>16</td>
<td>12</td>
<td>8</td>
<td>5</td>
<td>0</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>S2(M5)</td>
<td>8</td>
<td>11</td>
<td>15</td>
<td>8</td>
<td>3</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>S2(M6)</td>
<td>12</td>
<td>11</td>
<td>6</td>
<td>12</td>
<td>6</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td><strong>S1 Mean (M1-4)</strong></td>
<td><strong>11.5</strong></td>
<td><strong>6.5</strong></td>
<td><strong>9.8</strong></td>
<td><strong>3.5</strong></td>
<td><strong>4.5</strong></td>
<td><strong>7.0</strong></td>
<td><strong>3.0</strong></td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td><strong>6.9</strong></td>
<td><strong>4.0</strong></td>
<td><strong>3.5</strong></td>
<td><strong>2.4</strong></td>
<td><strong>5.2</strong></td>
<td><strong>0.8</strong></td>
<td><strong>1.6</strong></td>
</tr>
<tr>
<td><strong>S2 Mean (M5-6)</strong></td>
<td><strong>10.0</strong></td>
<td><strong>11.0</strong></td>
<td><strong>10.5</strong></td>
<td><strong>10.0</strong></td>
<td><strong>4.5</strong></td>
<td><strong>6.5</strong></td>
<td><strong>12.5</strong></td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td><strong>2.8</strong></td>
<td><strong>0.0</strong></td>
<td><strong>6.4</strong></td>
<td><strong>2.8</strong></td>
<td><strong>2.1</strong></td>
<td><strong>2.1</strong></td>
<td><strong>2.1</strong></td>
</tr>
</tbody>
</table>

Abbreviations: P1-P13 = participants; S1-S2 = sessions one & two; R = right; L = left; M1-6 = Measurements; Avg = Average; SD = standard deviation.

* A threshold unit (TU) equals the difference between ipsilateral ilial & sacral threshold levels (TL).
Table 4. Intra-session SIJ threshold unit (TU) measurements per participant with inter-session participant TU means indicating individual SIJ stiffness symmetry (continued).

<table>
<thead>
<tr>
<th>Session (Measurement)</th>
<th>P8</th>
<th>P9</th>
<th>P10</th>
<th>P11</th>
<th>P12</th>
<th>P13</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>L</td>
</tr>
<tr>
<td>S1(M1)</td>
<td>9</td>
<td>17</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>S1(M2)</td>
<td>8</td>
<td>9</td>
<td>17</td>
<td>6</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>S1(M3)</td>
<td>6</td>
<td>9</td>
<td>16</td>
<td>11</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>S1(M4)</td>
<td>9</td>
<td>3</td>
<td>14</td>
<td>11</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>S2(M5)</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>S2(M6)</td>
<td>4</td>
<td>12</td>
<td>12</td>
<td>6</td>
<td>9</td>
<td>0</td>
</tr>
</tbody>
</table>

S1 Mean (M1-4) 8.0 9.5 14.0 9.8 10.0 10.3 10.3 5.3 19.8 9.8 10.5 11.8
SD 1.4 5.7 3.6 6.2 1.2 3.9 4.0 2.9 19.6 2.1 3.1 5.0

S2 Mean (M5-6) 6.0 9.5 8.0 7.0 9.0 13.0 2.0 5.0 3.0 10.5 6.5 11.0
SD 2.8 3.5 5.7 7.1 4.2 5.7 2.8 0.0 4.2 6.4 3.5 5.7

Abbreviations: P1-P13 = participants; S1-S2 = sessions one & two; R = right; L = left; M1-6 = Measurements; Avg = Average; SD = standard deviation.

* A threshold unit (TU) equals the difference between ipsilateral ilial & sacral threshold levels (TL).
8.3 Inter-session Participant SIJ Stiffness

The threshold unit (TU) averages (Table 3.) representing unilateral SIJ stiffness between participants ranged from 3.0 to 19.8 in S1 (mean = 8.8 TU) and 0.0 to 24.5 in S2 (mean = 8.5 TU). There is a large variation between individual SIJ stiffness patterns. As an example: participant 7 had a low TU difference (right TU–left TU) between both left and right SIJ during both session measurements of 2.0 TU (S1 SDD = 0.79) for S1 and 1.5 TU for S2 (S2 SDD = 1.77) indicating a high level of stiffness, or hypo-mobility, for both right and left sacroiliac joints. Participant 6 shows a large right SIJ S2 TU average of 24.5 indicating a potentially hyper-mobile SIJ. Participant 3 exhibited an asymmetrical right SIJ stiffness pattern when the means of S1 and S2 TU are examined.

8.4 Individual SIJ Stiffness Pattern

The pattern of consistency of TU measurements for individual participants between S1 & S2 was variable (Table 4.). Only three participants (P3, P8 & P13) exhibited a consistent ipsilateral SIJ stiffness finding over S1 and S2. Participants four, six, 11 and 12 displayed a change in SIJ stiffness side over S1 and S2. Participants; one, two, five, seven, nine & 10 were noted as having a stiff SIJ during one session and parity when compared to the other session.

Table 5. Contingency table showing inter-session participant SIJ stiffness pattern as measured by threshold units.
8.5 Inter-session Participant Comparison for the Right SIJ

Graphs portraying individual participant inter-session differences in TUs for right and left SIJs are displayed in Figures 10 & 11 respectively. A horizontal line indicates little or no TU difference between sessions whereas a diagonal line indicates an inter-session TU variance, the greater the gradient, the greater the variance. As an example of participant variance for the right SIJ, participant six is noted as having the largest variance between sessions of 17.8 TU (6.8 TU S1 – 24.5 TU S2). Participant 12 has a variance of 16.8 TU (19.8 TU S1 – 3 TU S2). There was no difference in inter-session TU noted for participant three (4.5 TU S1 & S2) and little or no difference noted for participant 10 (1.0 TU).

8.6 Inter-session Participant Comparison for the Left SIJ

TU inter-session variation for the left SIJ per participant was less pronounced than the right SIJ. As an example of participant variation for the left SIJ, participant 7 showed the largest variance with 7.5 TU (9 TU S1 – 1.5 TU S2). Participant 8 showed no difference (9.5 TU S1 & S2) whilst participants 3, 11 & 13 showed little or no difference of 0.25 TU (SDD 1.63 TL) between sessions.
Figure 11. Individual inter-session variance of TU for the right SIJ.
Figure 12. Individual Inter-session variance of TU for the left SIJ.
8.7 Paired t-test results for inter-session SIJ TU values

To ascertain whether a relationship between inter-session ipsilateral SIJ stiffness was evident, paired t-tests were calculated (Tables 5. and 6.). There was no notable difference in right SIJ TU values between sessions S1 and S2 (mean 0.62 TU SEM = 2.5). There was also no notable difference in left SIJ TU values between sessions S1 and S2 (mean -0.08 TU SEM = 1.0).

Table 6. Paired t-test results for mean inter-session TU values for the right SIJ.

<table>
<thead>
<tr>
<th></th>
<th>Participants*</th>
<th>SD</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right S1 (TU)</td>
<td>9.27</td>
<td>4.38</td>
<td>1.2</td>
</tr>
<tr>
<td>Right S2 (TU)</td>
<td>8.65</td>
<td>6.49</td>
<td>1.8</td>
</tr>
<tr>
<td>Mean Difference</td>
<td>0.62</td>
<td>8.98</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Abbreviations: SD = Standard deviation; SEM = Standard error of the mean; TU = Threshold level. * = number of participants measured per session.

Table 7. Paired t-test results for mean inter-session TU values for the left SIJ.

<table>
<thead>
<tr>
<th></th>
<th>Participants*</th>
<th>SD</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left S1 (TU)</td>
<td>8.23</td>
<td>3.02</td>
<td>0.84</td>
</tr>
<tr>
<td>Left S2 (TU)</td>
<td>8.30</td>
<td>3.29</td>
<td>0.91</td>
</tr>
<tr>
<td>Mean Difference</td>
<td>-0.08</td>
<td>3.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Abbreviations: SD = Standard deviation; SEM = Standard error of the mean; TU = Threshold level. * = number of participants measured per session.

8.8 Bland-Altman plots

Figure 13. illustrates the Bland-Altman plot for S1 (M1 & 2) intra-session results for all TL values, within 95% limits of agreement, bias of -0.7 ± 6.7 SD (lower limit -13.7, upper limit 12.4).
Figure 13. Bland-Altman plot for S1 (M1 & 2) intra-session results for all TL values.

Figure 14 illustrates the Bland-Altman plot for intra-session S1 (M3 & 4) results for all TL values, with a 95% limits of agreement, bias of -1.4 ± 5.3 SD (lower limit -11.9, upper limit 9.0).

Figure 14. Bland-Altman plot for intra-session S1 (M3 & 4) results for all TL values.
Figure 15. illustrates the Bland-Altman plot for S2 (M5 & 6) intra-session results for all TL values, with a 95% limits of agreement, bias of $-1.8 \pm 6.1$ SD (lower limit -13.7, upper limit 10.1).

Figure 16. illustrates the Bland-Altman plot for S1 mean (M1-4) versus S2 mean (M5-6) inter-session results for all TL values, with a 95% limits of agreement, bias of $8.6 \pm 18.0$ SD (lower limit -26.0, upper limit 43.0).
Figure 16. Bland-Altman plot for S1 mean (M1-4) versus S2 mean (M5-6) inter-session results for all TL values.
CHAPTER 9: DISCUSSION

9.1 INTRODUCTION

The aim of the current study was to estimate inter and intra-session reliability of a custom built vibration generator (VG) when using the Doppler Ultrasound Imaging of Vibrations (DIV) technique to measure SIJ stiffness within a normal population. The DIV technique was adapted from the “sonoelasticity imaging” technique pioneered by Gao and associates (Parker et al., 1990, p. 241) which combined the application of vibrations with Doppler ultrasound technology to detect hard tumours within human soft tissues.

DIV was first described and applied to embalmed human pelvises to measure SIJ stiffness by Buyruk et al. (1995a; Parker et al., 1990, p. 241). In vivo studies followed using both healthy participants (Buyruk, Snijders, Vleeming, Lameris et al., 1995b) and a controlled experiment using peripartum pelvic pain patients (Buyruk et al., 1999). In the in vivo studies the authors demonstrated the DIV technique could reliably discriminate intra-participant variations in SIJ stiffness. Further studies utilizing DIV technique to measure SIJ stiffness (or laxity) or tarsometatarsal joint stiffness have been performed (Damen et al., 2002b; Damen et al., 2001; Damen et al., 2002c; J. M. A. Mens et al., 2006; Richardson et al., 2002). Damen et al. (2002a) examined both Intra and inter-tester measurement reliability involving DIV of SIJ laxity levels in 10 healthy women.

9.2 SUMMARY OF FINDINGS

All intra-session ICC reliability scores for DIV testing of SIJ stiffness were ‘excellent’ with ‘substantial’ to ‘almost perfect’ CIs. Inter-session ICC reliability scores for DIV testing of SIJ stiffness were ‘excellent’ with ‘moderate’ to ‘almost perfect agreement’ CIs for S1 means against only less than ‘acceptable’ to ‘acceptable’ ICC scores with ‘poor’ to ‘fair agreement’ CIs for S2 means. The
results of the current study displayed a satisfactory level of intra-session reliability, however, inter-session results indicate a less than satisfactory level of reliability when using DIV with the custom built VG prototype used in this study to measure SIJ stiffness within a healthy population. Only three participants were observed to have a consistent SIJ stiffness pattern over all intra-session measurements.

There was a wide range of SIJ stiffness TU values recorded between all healthy participants over two sessions (0-49 TU)(mean 8.8 TU S1 and 8.5 TU S2). This finding was similar to those obtained by Buyruk et al. (1995b) suggesting a normal population demonstrates a range of SIJ stiffness. Variations of hyper-mobility or hypo-mobility may not, therefore, necessarily be a primary indicator of SIJ dysfunction leading to low back and pelvic pain. Variations in between-session individual SIJ stiffness pattern may suggest possible dynamic biological variability in both form and force closure of the SIJs.

9.3 Limitations of this study

9.3.1 Population considerations

This scope of this research project was constrained to reliability and reproducibility of the DIV technique utilizing a custom built VG prototype to measure SIJ stiffness within a normal population.

The inclusion criteria selected for this study was designed to create a sample of participants from a healthy, asymptomatic, population so that future studies may assess populations with, for example, low back or pelvic pain relating to SIJ dysfunction. Volunteers with a previous low back or pelvis surgery, peri or postpartum females were excluded. Although normative data was obtained including age, weight, height, this information was not investigated statistically to produce a hypothesis based upon SIJ stiffness as the sample size was deemed too small to be indicative of a wider population.
9.3.2 Measurement error

The current study was designed the following controls in an attempt to minimise bias: (1) The VG was set to operate at the same frequency and amplitude for all measurements; (2) Each participant was positioned as accurately as possible prior to each measurement; (3) The recording process was repeated consistently with each measurement. The sonographer alerted the examiner as to when the first consistent pixel was observed at the applicable bony landmark on the ultrasound screen and the percentage gain reading was recorded by the examiner and standard procedures and settings were strictly adhered to.

Measurement error may be caused by many variables such as instrument error, intra-rater, inter-rater, and inter-subject reliability (Domholdt, 2005). When utilizing DIV, factors which may contribute to measurement error include:

- Changes in SIJ biology of participants between measurements and/or measurement sessions leading to SIJ stiffness variation.
- The effect of DIV application testing itself (e.g. potential influence of vibration upon the SIJ).
- Changes in instrumentation (e.g. faults or changes with vibration generation); alterations in application of measurement (e.g. changes in applied force or amplitude of the vibration piston; or varied contact points and subsequent effect on vibration transmission and/or translation).
- Changes in the operator, (e.g. the effect of learning, including kinaesthetic ‘memory’ of the operator for bony landmarks; subtle changes in interpretation of criteria, and potential impact of cognitive fatigue sustained during multiple experimental measurements over time).

9.3.3 Biological factors for consideration
Uncontrolled biological factors may have led to an alteration in force closure of the sacroiliac joints in between session measurements. A change in room temperature, stress levels, or immediate activities preceding each measurement session such as; walking, running, jumping or prolonged driving may have influenced participant muscular tension of myofascial tissues which contribute to force closure of the SIJ. These myofascial components include the myofascial tissues associated with the following named structures: gluteus maximus, piriformis, multifidi, latissimus dorsi and the thoracolumbar fascia and collectively produce ipsilateral and contralateral forces pertaining to force closure of the SIJs (Pool-Goudzwaard et al., 1998b).

Altered SIJ force closure, due to participant familiarisation of the measurement protocol in S2, may have been a consequence of either muscle relaxation or increased muscular tension and may have impacted inter-session TL values. Similarly, participant reaction to the effect of vibration applied to their ilium coupled with a period of static prone lying may also have altered muscle tension and SIJ force closure.

Future studies may consider whether participants can comfortably lie in a prone position for periods of approximately 20 minutes or alternatively, adjust the measurement protocol to limit potential stress positions.

9.3.4 Methodological factors for consideration

Some technical limitations may have contributed to less than perfect reliability in the present study. Physical changes during breathing (e.g. abdominal distension; chest expansion/contraction) was found to be an influencing factor on contact loading of the VG piston and was visualised as increased signal generation on the ultrasound monitor. Participants also reported subtle changes in VG contact during the phases of breathing. Changes in Threshold Value induced with breathing may negatively influence the reliability of measures. Future protocols
may consider controlling respiratory cycles, for example breath holding, or alternatively, consider a different ilial application point that does not impact on the VG in load bearing postures. Vibration propagation throughout the ilium is spherical in nature (Buyruk, Snijders, Vleeming, Lameris et al., 1995b), therefore a contact point closer to the SIJ may be appropriate such as the iliac tubercle on the supero-lateral surface of the ilium. A load free application point may also allow for additional postures and weight bearing studies in the future, such as sitting and standing postures which may contribute to an understanding of the influence of passive structures (ligaments) under load and of muscle activity on SI joint stiffness. The compact design of the custom built VG also proffers this opportunity for future investigation.

In some participants vibration was not observed in target areas identified as bony landmarks, therefore the sonographer was forced to make an assumption that the vibration was still occurring within the sacrum or ilium. Whether vibration was detected within bony landmarks as expected or whether correct landmarks were identified remains uncertain and needs clarification. Secondly, whilst the expectation was that vibration would be detected initially on the ilium due to direct application and resultant spherical nature of vibration transmission (Buyruk, Snijders, Vleeming, Lameris et al., 1995b), in some cases, signals were observed to appear first on the sacrum. De Groot, Spoor & Snijders (2004) criticised the assumption made by Buyruk and colleagues that vibrations were received through the bone during administration of the DIV technique, by implying that adjacent soft tissues may more likely be the transmitting medium. However, Mens, Damen, Snijders & Stam (2006) suggest SIJ joint stiffness may also be reliant upon tone of adjacent contractile myofascial tissues, therefore, regardless of the tissue type emitting signals, DIV may still offer an indirect elucidation of a SIJ stiffness level. To address issues of validity, further investigation into the tissue types involved in signal conduction and transmission of vibrations is required.
The current study did not aim to classify SIJ stiffness for a clinical purpose. In this study, the term ‘SIJ stiffness’ is used to indicate the calculated difference in threshold units (TU). In previous studies, differences in TU values between left and right joints in the same participant have been thought to be associated with signs of joint dysfunction (Buyruk, Snijders, Vleeming, Lameris et al., 1995b; Buyruk et al., 1999), however, in the current study the participants were all healthy and asymptomatic for low back or pelvic pain and the clinical relevance of any asymmetry is unclear. Future studies will be required to determine the relationship between joint stiffness and joint dysfunction.

### 9.3.5 Technological factors for consideration

Previous studies utilizing the DIV technique used earlier ultrasound technologies and less sophisticated imaging software coupled with an industrially designed vibration generator that is both expensive and difficult to obtain. This study used contemporary Doppler measurement technologies with that of a custom built, affordable and easy to operate VG. Recent ultrasound portable handheld Doppler machines have also been produced which, coupled with a purpose built portable VG may increase the reproducibility of the DIV technique making it more affordable and accessible. Smaller more portable imaging devices may have more practical application for clinical use.

The protocol for the current study was based on those from previous studies that utilized the DIV technique and demonstrated its safety and applicability to human participants (Buyruk, Snijders, Vleeming, Lameris et al., 1995b; Buyruk et al., 1999; Buyruk, Stam, Snijders, Vleeming, Lameris et al., 1995a; Damen et al., 2002a). However, the following assumptions were made based upon technological differences in ultrasound and VG equipment used:

Earlier Quantum Angiograph ultrasound machines used to replicate the DIV technique contained a “rotating threshold button” (Buyruk, Stam, Snijders,
Vleeming, Lameris et al., 1995a, p. 114) which was used to increase or decrease the Doppler signal image generated by vibration. The higher end iU22 Doppler Ultrasound machine used in this study did not have a threshold button utilized by the previous researchers that published relating to DIV, therefore the assumed equivalent control was identified as the “Gain dial”, which, similarly to the threshold button, controls Doppler output power in decibels (dB). Gain is displayed as a percentage and, similar to previous DIV studies, the displayed percentage equates to a threshold value and was recorded as a TL when observed vibrations were identified at the relevant bony landmark. Making direct correlations to SIJ stiffness TLs from previous studies was difficult due to the difference in reported measurement ranges. Buyruk et al. (1999) reported a range of 0-27 threshold values available through use of the threshold button whilst the use of the gain dial used in the current study allowed for a range of 0-100 threshold values. However, because the independent variable of SIJ stiffness is derived from the difference between both SIJ TU values, it was assumed as long as the measurement protocol was consistent, output values would also be consistent.

Earlier studies had used a vibration frequency of 200Hz with a ‘low amplitude’ (Buyruk, Snijders, Vleeming, Lameris et al., 1995b; Buyruk, Stam, Snijders, Vleeming, Lameris et al., 1995a) whilst Damen et al. (2002a) used an amplitude not exceeding 0.1mm. The current study used a slightly lesser frequency of 150Hz (with amplitude not exceeding 0.1mm). The 150Hz frequency was selected because higher frequencies resulted in an intermittent pulsing effect received from the VG prototype. This pulsatile effect was observed to increase in regularity when vibrational frequency was increased at the signal generator. Due to the advanced Doppler ultrasound technology used in this study an assumption was made that a decrease in vibrational frequency was mitigated by an increase in signal detection capability of the later model equipment coupled with a greater range of power output control available through application of the gain functionality.
Vibration generator amplitude was observed to decline throughout the measurement period. The researchers hypothesize this decline may possibly be due to material creep in the diaphragm of the vibrating device over time due to excessive loading. The amplitude decline resulted in a decreased signal being observed over bony landmarks. To accommodate for any signal deterioration the Doppler US gain was increased until vibration was detected at the targeted bony landmark. In some instances the signal could not be detected on the bony landmark due to excessive pixilation, or “noise”, therefore the TL value was registered and recorded as the closest adjacent soft tissue signal. This may have had a definitive effect upon inter-session outcome variables by decreasing ICC reliability levels and increasing CI ranges due to the potential for recording of different tissue type TL values which could contaminate relevant data.

Redevelopment and recalibration of the VG prototype is needed for future studies to; (1) eliminate the pulsatile effect and (2) improve material strength to maintain a consistent frequency and amplitude output.

9.3.6 Operational factors for consideration

Discrepancies between measurements may be partly attributed to identification challenges of bony landmarks within some participants. Recording and measurement of participants with substantial adipose tissue around pelvic and gluteal regions were observed as being more difficult when identifying bony landmarks with US. Thus, participant morphology and somatotype may potentially influence accuracy of measurement. There was insufficient data to draw clear statistical conclusions regarding the influence of subject morphology on reliability in the current study, therefore subject morphology should be further considered in future reliability studies utilising the DIV technique.
Operator bony landmark identification may also have been improved through short term kinaesthetic ‘muscle memory’ or “controlled processing” which relates to the way in which consistently applied tasks may develop into automatic subconscious motor responses (Schneider & Chein, 2003, p. 527). Controlled processing may have influenced operator identification of intra-participant bony landmarks potentially leading to improved intra-session reliability of results.

Reproducibility of the DIV technique is a critical component to reliability and validity. Damen et al. (2002a) researched the reliability of both intra and inter-tester abilities between an experienced sonographer and four inexperienced testers to ascertain whether sonographic experience is an essential element for DIV measurement. The authors found reliability ICC scores ranged from ‘moderate’ to ‘high’ (0.53 to 0.80 for all five testers with the experienced sonographer ranging between 0.75 to 0.89) and concluded that regardless of the testers previous experience, DIV is a reliable technique for assessing SIJ laxity measurement in healthy participants, although results were higher when performed by an experienced sonographer. No CI were recorded during this study therefore no CI correlation could be made to the current study. In a recent unpublished study run parallel to the current one, Crossley (2011) also tested intra-tester reliability of identifying TLs of DIV of the SIJ and found that 12 observers could make reliable judgments when using video clips to identify DIV signals on target bony landmarks.

9.3.7 Generalisability and validity

Due to a lack of power it is difficult to draw any meaningful conclusions regarding SIJ stiffness within the sample. Although increasing the sample size in future studies may enhance generalisability and reduce risk of a random error rendering results invalid. The current study did not consider variables which may have had an effect on SIJ stiffness and generalisability such as; (1) the potential inapplicability of prolonged prone positioning applied to a clinical group suffering
low back or pelvic pain and (2) the ability of patients suffering from neck pain or dysfunction to lie prone with head and neck rotated to one side. Further studies may address this issue by designing a customised examination table complete with face hole and a space for the VG.

Findings of this study may contribute towards an improved understanding of validity because reliability is an essential component of validity (W. H. Hopkins, 2000). Initial investigation into the validity of DIV to assess SIJ stiffness asymmetry was conducted by Buyruk et al. (1995a) using embalmed pelvises. Later studies demonstrated construct validity of DIV by exhibiting asymmetry of SIJ laxity within pregnancy related pelvic pain participants against a normal control group (Buyruk et al., 1997; Damen et al., 2002b; Damen et al., 2001).

The DIV technique and subsequent assumptions made by the originators and other proponents of the technique have been questioned by De Groot et al. (2004). Assumptions include: loss of vibration across the SIJ is represented by differences in threshold values and, vibration is occurring within the bone rather than adjacent soft tissue. Further research is needed to investigate these assumptions, however, investigating and quantifying DIV reliability remains a prerequisite to future use of the technique as a diagnostic technique or as an outcome measure for intervention studies.

9.4 INDICATIONS FOR FUTURE STUDY

Although inter-session reliability of DIV using a prototype VG to measure SIJ stiffness was deemed to be less than satisfactory in the current study, intra-session reliability scores were consistently high and the DIV technique has been demonstrated to be a reliable technique in previous studies. Whilst the custom built VG prototype showed potential as an approach for objectively evaluating SIJ stiffness, further design is necessary to improve performance, consistency and accuracy by eliminating the intermittent pulse effect and making the VG more
robust in order to withstand prolonged loading without affecting performance. If achieved, future studies may focus on other possibilities pertaining to the DIV technique such as; the effect of load bearing on form and force closure of the SIJ utilising the portability of the custom built VG to allow for different static and dynamic postures; the effect of an manual therapy intervention on SIJ stiffness within various asymptomatic and symptomatic populations. Further studies aimed at different soft tissues within the body may also make use of the equipment using the original sonoelasticity imaging technique which was designed to test for hard tumours in soft tissue (Gao, Parker, Alam, & Lerner, 1995).
9.5 Conclusion

Doppler imaging of vibration technique is a potential adjunct to clinical diagnostic testing pertaining to SIJ dysfunction. DIV remains impractical for most clinical practitioners due to current cost and reproducibility factors. This current study involving the use of DIV, with a custom built VG, to measure SIJ stiffness within an asymptomatic population showed satisfactory intra-session reliability results but poor inter-session results. Technical and material issues involving the VG have been identified as possible causative factors pertaining to poor inter-session results. Further modifications to the VG are required to improve consistency and robustness for future studies.
REFERENCES


### Session 1 Raw data - Measurements 1 & 2 in Threshold level (TL) values.

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Table 8. Session 1 Raw Data for measurements 1 & 2.
Session 1 Raw data - Measurements 3 & 4 in Threshold level (TL) values.

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Table 9. Session 1 Raw Data for measurements 3 & 4.
Session 2 – Raw data. Measurements 5 & 6 in Threshold level (TL) values.

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Table 10. Session 1 Raw Data for measurements 5 & 6.
APPENDIX B: ETHICS APPROVAL

Scott Pender
3/2 Mt Royal Avenue
Mt Albert
Auckland

25 March 2010

Dear Scott

Your file number for this application: 2009-1023.
Title: Weight bearing asymmetry and sacroiliac stiffness in a normal population

Your application for ethics approval has been reviewed by the Unitec Research Ethics Committee (UREC) and has been approved for the following period:

Start date: 25 February 2010
Finish date: 25 February 2011

Please note that:
1. the above dates must be referred to on the information AND consent forms given to all participants
2. you must inform UREC, in advance, of any ethically-relevant deviation in the project. This may require additional approval.

You may now commence your research according to the protocols approved by UREC. We wish you every success with your project.

Yours sincerely

[Signature]

Ref: Lyndon Walker
Deputy Chair, UREC

cc: Craig Hilton
    Cynthia Almeida
APPENDIX C: PARTICIPANT INFORMATION SHEET

Participation Information Sheet - for research on:
Measurement of sacroiliac joint stiffness with Doppler imaging of vibrations – a reliability study

Who are we
James Crossley and Scott Pender are senior students of Osteopathy undertaking post graduate research. We are interested in researching the potential relationship between pelvic biomechanics and low back pain.

What we are doing
You are invited to participate in a study investigating the relationship between sacroiliac joint stiffness within a normal population.

This research study aims to investigate the use of Colour Doppler imaging of Vibration to measure relative stiffness of the sacroiliac joints (left compared to right) and any potential relationship between asymmetry in stiffness.

By taking part in this research you will be helping to contribute to research in the field of diagnosis and potential treatment of low back pain, and the development of a new technique in measuring joint function.

Taking part in the study
We require male and female participants between 18-65 years of age, both with or without low back pain. Females must not have been pregnant or given birth.

After you have read and understood the information sheet, and if you are interested in participating, please contact either principle researchers (James Crossley or Scott Pender) via email, phone or in person. Upon receipt of your interest, we will contact you to address any concerns or queries you may have and determine if you are available to participate on one of the data collection session dates. If you are willing and available to participate, you will be invited to the Unitec osteopathic clinic for two measurement sessions, at least one week apart, of approximately thirty minutes each.

Upon arrival you will be asked to sign a consent form. This does not stop you from changing your mind if you wish to withdraw from the study. You can withdraw from this study at any stage up until 1 week after the data collection session.

The next stage of the process involves a measurement of sacroiliac joint (found near the lower back) stiffness using Doppler ultrasound measurement of levels of vibration across the joint. This technique involves a maximum of 200hz and 1.0 amplitude vibration applied across the Joint which has been shown to be both non-harmful and painless to humans – similar to the vibration from a mobile phone, however, should any discomfort be felt by the participant then the process will be stopped immediately upon request. A trained ultra-sonographer using a Colour Doppler ultrasound machine (also harmless to humans) will calculate joint stiffness. This may involve removing or movement of outer garments of clothing to gain access to the joint (located at the small of the back) so that an ultrasound transducer may be applied to bare skin. Modesty will be ensured by the use of a drape when necessary. This measurement will be repeated twice on each side the body (left and right sacroiliac joints) followed by a short walk then the process
repeated for both sides. Each measurement should take approximately 20 minutes. During the procedures you will be asked to report on the presence of discomfort and measurement will be stopped with any reproduction of low back pain.

An anonymised ultrasound recording may be taken of your measurements which may be used to further test the reliability of the measurement process by multiple participants.

**Confidentiality**

Your name and information that may identify you will be kept completely confidential. All information collected from you will be stored in a lockable cabinet at either the researcher’s home office or in one of the supervisors’ office. Electronic data derived from the study will be stored on a password protected file and only the researcher and supervisors will have access to this information. Information will be stored for a minimum of five years. All data derived from the research will be anonymous. Anonymised data derived from the study may also be used for future study. A copy of the final report will be available in the Unitec library. All participants will be welcome to view this. Summaries and recommendations may be published in research journals.

**Registration**

If you would like to participate in this study please contact James Crossley or Scott Pender. Your participation is greatly appreciated.

**Information and concerns**

Please contact us if you would like further information or have any concerns about the research study. You can contact James Crossley or Scott Pender or relevant supervisors:

**Primary Researchers:**

**James Crossley**  
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**Scott Pender**  
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**Supervisors:**

**Rob Moran**  
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Phone: 09 815 4321 ext 8642

**Dr Wayne Hing**  
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Thank you for reading the information sheet – please keep it for your records

**UREC REGISTRATION NUMBER: 2009-1023**

This study has been approved by the UNITEC Research Ethics Committee from 26/02/2010 to 25/02/2011. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 7248). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
APPENDIX D: PARTICIPANT CONSENT FORM

Participation Consent Form - for research on: Sacroiliac joint stiffness

I have seen the Information Sheet about this study. I have read and understand the information sheet given to me. I have had the opportunity to discuss any queries or concerns regarding this study with Scott Pender and/or James Crossley or their supervisors and am satisfied with explanations given.

I understand that that taking part in this study is my choice. I don't have to be part of this if I don't want to and I understand that I may withdraw from this study at any stage up until 1 week after the data collection session. I also understand that withdrawing will not affect my access to any services provided by Unitec, New Zealand.

I have been informed that the ultrasound measurement of joint vibration will take place and that the examination will be directed at the sacroiliac joints. For this assessment I am aware that I may be asked to remove outer layers of clothing below my waist.

I have been informed that the measurements taken may be recorded, anonymously, and used in a further study to evaluate the reliability of the equipment and technique being tested.

I understand that all the information that I give will be stored securely on a computer for a period of 5 years and that any information reported will not identify me in any way. I give permission for the data from this study to be retained and combined with other future studies provided that my identity remains anonymous.

- I understand that I can see the finished research document.
- I have had time to consider everything and I give my consent to be a part of this study.
- I know whom to contact if I have any questions or concerns about this study.

The principal researchers are:

James Crossley
Email: jcrossley@hotmail.com
Phone: 0210-234-2869

Scott Pender
Email: Scottiepender@yahoo.co.nz
Phone: 028-850-72688

Participant Name: .................................
Participant Signature: ...............................  Date: .................................
Study explained by: ..........................

Signature: .......................... Date: ..........................

Thank you for participating in this research

UREC REGISTRATION NUMBER: 2009-1023
This study has been approved by the UNITEC Research Ethics Committee from 26/02/2010 to 25/02/2011. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 7248). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.