The effect of sacroiliac joint manipulation on lumbar extensor muscle endurance in asymptomatic individuals

By

Kate Jones

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Durban University of Technology

I, Kate Jones, do declare that this dissertation is representative of my own work in both conception and execution.

K. Jones (20601351) Date

Approved for Final Submission

Dr L. O'Connor Date
M.Tech: Chiropractic

DEDICATION

It is with immense pleasure that I dedicate this dissertation to my parents, Nick and Jennifer, my brother John-Paul and my sister Caroline. This has been an incredibly long road, and I would never have been able to do this without your unwavering support, encouragement, positivity and love. Thank you for always believing in me.

To Ryan, for being so supportive and patient throughout my studies. You always give me a fresh perspective on life, and know the right things to say to motivate me. For that I am eternally grateful. Love you always.

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ABSTRACT

Background: Spinal manipulation has been shown to result in neurophysiological changes, most often noted in the paraspinal muscles. These effects have been associated with an increase in paraspinal muscle contractibility; it is unclear if this leads to an increase in paraspinal muscle endurance.

Objectives: To determine the effect of sacroiliac joint (SIJ) manipulation compared to a placebo treatment of the SIJ on lumbar extensor muscle endurance time.

Method: A randomised, placebo-controlled pre-test post-test experimental trial, involving 40 asymptomatic male participants divided into an intervention group receiving SIJ manipulation using an impulse adjusting instrument and a placebo group receiving a pre-load force without the delivery of an impulse thrust. Outcome measures were lumbar extensor muscle endurance time, surface electromyographic (SEMG) readings, lumbar spinal range of motion, paraspinal muscle length assessment and a subjective pain measurement.

Results: There was a significant difference between the groups ($p=0.004$) with the SIJ manipulation group showing an increase in endurance time compared to the placebo group which showed a decrease. SEMG readings increased for both groups with no statistically significant difference between the groups ($p>0.05$). Only extension lumbar spinal range of motion significantly improved in both groups ($p=<0.001$) with no significant differences between groups ($p=0.876$). Only one participant reported pain during the research procedure.

Conclusions: SIJ manipulation may enhance the endurance of the paraspinal muscles. This study should be conducted in a larger sample to validate the findings.

Keywords: *Spinal manipulation, extensor muscle endurance, surface electromyography.*

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LIST OF ABBREVIATIONS

ACh:	acetylcholine
AChE:	acetylcholinesterase
AP:	action potential
APB:	abductor pollicus brevis
ASIS:	anterior superior iliac spine
ATP:	adenosine triphosphate
BMI:	body mass index
B-S:	Biering-Sorensen
Ca^{2+} ions:	calcium ions
CI:	confidence interval
CLBP:	chronic low back pain
cm:	centimetres
CN:	cranial nerves
CNS:	central nervous system
CSPs:	cortical silent periods
DUT:	Durban University of Technology
EIP:	extensor indices proprios
EMG:	electromyography
ES:	erector spinae
GTO:	Golgi tendon organ
H-reflex:	Hoffman reflex
HVLA:	high-velocity low-amplitude
Hz:	Hertz
IO:	internal oblique
IVD:	intervertebral disc
IVF:	intervertebral foramen
kg:	kilograms
LBP:	low back pain
LM:	lumbar multifidus
m:	metres
mm:	millimetres

ms:	milliseconds
mVs:	microvolts
MEPs:	motor evoked potentials
MFMA:	manual force mechanically assisted
MLBP:	mechanical low back pain
MS:	muscle spindle
MVC:	maximum voluntary contraction
n:	sample number
N:	Newtons
Na^+ ions:	sodium ions
NMJ:	neuromuscular junction
p:	probability
PA:	posterioanterior
PBU:	Pressure Biofeedback Unit
PSIS:	posterior superior iliac spine
ROM:	range of motion
SC:	spinal cord
SD:	standard deviation
SEMG:	surface electromyography
SEPs:	somatosensory evoked potentials
SI:	sacroiliac
SICF:	short interval intracortical facilitation
SICI:	short interval intracortical inhibition
SIJ:	sacroiliac joint
SM:	spinal manipulation
SMT:	spinal manipulative therapy
SP:	spinous process
TA:	transversus abdominis
TLF:	thoracolumbar fascia
TMS:	transcranial magnetic stimulation
TVP:	transverse process
VB:	vertebral body
VC:	vertebral column

LIST OF DEFINITIONS

Afferent nerve:

A nerve conveying impulses from the periphery to the central nervous system (CNS) (Stedman's Medical Dictionary, 2005:38).

Asymptomatic:

Without symptoms, or producing no symptoms (Stedman's Medical Dictionary, 2005:129).

Body mass index (BMI):

BMI is an index of body weight in relation to height. It is calculated as follows: weight in kilograms (kg)/height in metres squared (m^2). A BMI between 18.5 kg/m^2 and 24.9 kg/m^2 is defined as a healthy body weight as individuals within this range have the lowest health risks. BMI correlates well with body fat, but it is not actually a measure of body fat (Smolin and Grosvenor, 2008:269-271).

Core strength:

The muscular control around the lumbar spine that is required to maintain functional stability (Akuthota and Nadler, 2004).

Cortical:

Relating to the cerebral cortex (Stedman's Medical Dictionary, 2005:342).

Diastasis:

The separation of parts which are normally joined (Stedman's Medical Dictionary, 2005:409).

Efferent nerve:

A nerve conveying impulses from the CNS towards the periphery (Stedman's Medical Dictionary, 2005:453).

Extensor muscles/paraspinal muscles/erector spinae muscles:

These three terms are used interchangeably throughout the text. These muscles originate from the sacrum, ilium and spinous processes of the lumbar vertebrae and form three columns, the iliocostalis, longissimus and spinalis, which insert onto the ribs and vertebrae at successively higher levels (Stedman's Medical Dictionary, 2005:495).

Facilitation:

The enhancement or reinforcement of a reflex or other nervous activity by the arrival of excitatory impulses at the reflex centre (Stedman's Medical Dictionary, 2005:525).

Inhibition:

The arrest or depression of a reflex or other nervous activity (Stedman's Medical Dictionary, 2005:747).

Isometric contraction:

When the ends of a contracting muscle are fixed so the muscle produces a force while at a constant length (Stedman's Medical Dictionary, 2005:778).

Joint fixation:

In Chiropractic it typically refers to a partial loss of joint movement (hypomobility), in one or more directions. It is the state in which an articulation has become temporarily immobilised in a position it may normally occupy during any phase of normal movement; the immobilisation of an articulation in a position of movement when the joint is at rest, or in a position of rest when the joint is in movement (Bergmann and Peterson, 2011:37).

Joint manipulation:

A manual procedure that involves a directed thrust to move a joint past normal physiological range of motion without exceeding the anatomical limit. It is commonly associated with an audible crack or cavitation (Bergmann and Peterson, 2011:85).

Motion palpation:

A procedure in which the hands are used to assess the active and passive segmental joint range of motion (Bergmann and Peterson, 2011:60-61).

Motor:

Neural structures that cause muscles to contract or glands to secrete by the impulses generated and transmitted by them (Stedman's Medical Dictionary, 2005:945).

Muscle endurance:

The ability of a muscle to sustain a force, or generate a force repeatedly over time (Stedman's Medical Dictionary, 2005:955).

Muscle inhibition:

The inability to fully activate a muscle (Suter and McMorland, 2002).

Nociceptive:

Capable of the appreciation or transmission of pain (Stedman's Medical Dictionary, 2005:1008).

Pathological:

The physical, functional, biochemical and immunological changes caused by illness or disease (Stedman's Medical Dictionary, 2005:1092).

Placebo:

Any treatment or intervention which has no intrinsic therapeutic value performed in order to achieve a placebo effect, which is an improvement in health not attributable to treatment (Stedman's Medical Dictionary, 2005:1140).

Proprioceptive:

Capable of receiving stimuli originating in the muscles, tendons and other internal tissues, indicating the movements and position of the body, especially its limbs (Stedman's Medical Dictionary, 2005:1198).

Sensory:

Neural structures capable of the appreciation or transmission of sensation (Stedman's Medical Dictionary, 2005:1328).

Somatic:

Relating to the wall of the body cavity, or the body in general, involves the skeleton and skeletal muscle (Stedman's Medical Dictionary, 2005:1356).

Visceral:

Relating to the viscera, such as the organs and glands (Stedman's Medical Dictionary, 2005:1564).

CHAPTER ONE

1.1 Introduction

Spinal manipulative therapy (SMT) is practiced by chiropractors and other manual therapists and has been shown to be effective in the conservative management of musculoskeletal disorders such as back and neck pain (Ferreira *et al*., 2003; Bronfort *et al*., 2004; Potter, McCarthy and Oldham, 2005; Dagenais *et al*., 2010; Goertz *et al*., 2012). It is a manual treatment that is directed at restrictions in joint movement, referred to as joint fixations, in order to restore joint range of motion and alignment. Joint fixations may result from segmental muscle spasm, joint and intradiscal derangements, intercapsular adhesions, soft-tissue fibrosis (Bergmann and Peterson, 2011:112) and psychological distress such as anxiety and depression (Muscolino, 2011:586). They are often associated with pain and paraspinal muscle hypertonicity (Leach, 2004:30).

The exact mechanism underlying the effectiveness of SMT is poorly understood (Herzog, Scheele and Conway, 1999; Colloca and Keller, 2001; Koppenhaver *et al*., 2011). However three main theories exist; biomechanical, neurophysiological and muscular reflexogenic (Potter, McCarthy and Oldham, 2005). Although they are described as separate components, they all appear to work on a neurophysiological basis (Bicalho *et al*., 2010), as the biomechanical changes caused by SMT are thought to have physiological consequences due to their effects on the inflow of sensory information to the central nervous system (CNS) (Pickar, 2002). When SMT is applied to a joint fixation, a vertebral movement is produced, altering the segmental biomechanics of the joint. This reduces strain on the paraspinal tissues and restores zygopophysial mobility and joint play (Pickar, 2002).

These biomechanical changes are associated with physiological changes. Persistent nociceptive and altered proprioceptive input results in a segmental cord response, leading to the development of pathological somatosomatic and

somatovisceral reflexes. If these reflexes persist, they may alter function in the segmentally supplied somatic or visceral structures (Bergmann and Peterson, 2011:45), resulting in pain, discomfort and altered muscle function (Pickar, 2002). When SMT is administered it stimulates tissue mechanoreceptors altering the inflow of sensory information to the CNS which changes reflex pathways and inhibits motor neuron pools leading to a reduction of muscle hypertonicity and pain (Katavich, 1998), and improves the functional ability of the muscles (Potter, McCarthy and Oldham, 2005).

When assessing the effects of lumbosacral SMT and/or mobilisation on paraspinal muscle function, studies have indicated either a transient decrease in surface electromyographic (SEMG) activity (Lehman, Vernon and McGill, 2001; DeVocht, Pickar and Wilder, 2005; Krekoukias *et al*., 2009; Lalanne, Lafond and Descarreaux, 2009) or alpha motor neuron inhibition (Murphy, Dawson and Slack, 1995; Dishman and Bulbulian, 2000; Dishman, Cunningham and Burke, 2002; Dishman and Burke, 2003; Dishman, Dougherty and Burke, 2005; Fryer and Pearce, 2012). This supports the hypotheses that SMT has an inhibitory effect on the alpha motor system, resulting in reduced muscle activity.

Experimental evidence has shown that the impulse load of a spinal manipulation (SM) impacts proprioceptive primary afferent neurons from paraspinal tissues (Pickar and Wheeler, 2001; Pickar and Kang, 2006; Pickar *et al.*, 2007; Cao *et al*., 2013). One study indicated that both the preload and the thrust components of a SM resulted in mechanoreceptor activity (Pickar and Wheeler, 2001).

The effects of SMT have been shown to be associated with significant increases in maximum voluntary contractions and therefore muscle strength at the same segmental level (Keller and Colloca, 2000). This indicates that SM causes a change in sensory input that may result in altered efferent pathways at that segmental level.

Paraspinal muscles provide functional stability and control movements of the spine (Moore and Dalley, 2006:534). Therefore, sufficient endurance is important for the good health of the spine (Moffroid, 1997). Reduced trunk extensor endurance has

been linked to mechanical low back pain (MLBP) in adults (Biering-Sorensen, 1984; Demoulin *et al*., 2006) and adolescents (Bernard *et al*., 2008). This occurs due to the reduced ability of the paraspinal muscles to support the spine, which may lead to overloading of the soft tissue and passive structures of the lumbar spine (Wilder *et al*., 1996) resulting in pain.

MLBP is one of the most common musculoskeletal conditions, with a lifetime prevalence of 60 to 85% (Krismer and van Tulder, 2007). It has thus become one of the most costly conditions to manage (Dagenais, Caro and Haldeman, 2008; Bell and Burnett, 2009). Therefore determining ways to improve trunk extensor muscle endurance and prevent its onset has become a focus of research.

Although studies have shown that SMT may improve the functional ability of muscles, there are no studies investigating whether this altered sensory input has an effect on the endurance of the lumbar extensor muscles. Therefore this study aims to determine if sacroiliac joint (SIJ) manipulation compared to placebo treatment of the SIJ affects lumbar extensor muscle endurance.

1.2 The aim

The aim of this study is to determine the effect of manipulation, using an impulse adjusting instrument applied to the SIJ, compared to a placebo treatment of the SIJ, in terms of lumbar extensor muscle endurance time, SEMG readings, lumbar spinal range of motion and paraspinal muscle length assessment outcomes in asymptomatic individuals with an identified SIJ restriction. A secondary aim of the study was to record pain experienced with the lumbar extensor muscle endurance test.

1.3 The objectives

The objectives of the study are:

1. To determine the effect of SIJ manipulation on lumbar extensor muscle endurance in terms of subjective and objective outcomes.

2. To determine the effect of a placebo treatment of the SIJ on lumbar extensor muscle endurance in terms of subjective and objective outcomes.
3. To compare the differences between the two groups in terms of subjective and objective outcomes.

1.4 The hypotheses

The null hypothesis states that:

1. There will be no significant difference in pre and post SIJ manipulation in terms of subjective and objective outcomes.
2. There will be no significant difference in pre and post placebo treatment of the SIJ in terms of subjective and objective outcomes.
3. There will be no significant difference between the groups in terms of subjective and objective outcomes.

1.5 Scope of the study

This study was a randomised, placebo-controlled pre-test post-test experimental trial. Forty asymptomatic participants were randomly allocated to either an intervention group receiving SIJ manipulation delivered by an impulse adjusting instrument or to the placebo group receiving a pre-load force without the delivery of an impulse thrust. The following measurements were taken: lumbar extensor muscle endurance time, SEMG readings, lumbar spinal range of motion, paraspinal muscle length assessment and a subjective pain measurement. Participants were not excluded if they had known about or been exposed to chiropractic care. The impulse adjusting instrument is a new manipulative device available in South Africa; therefore participants were less likely to have had exposure to it. Data was captured in an Excel spreadsheet and analysed using IBM* SPPS Statistics version 21 and SATA11. A p value <0.05 was considered as statistically significant.

1.6. Flow of dissertation

The following chapters will have the following information in them. Chapter two will outline the literature on the lumbar extensor muscles, SIJ dysfunction and the theories explaining the effects of SMT; chapter three describes in detail the methodology of this study; chapter four present the results; chapter five will discuss the results in terms of the literature and chapter six will provide the conclusions and recommendations of the study

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of the literature and describes the anatomy, neurology, physiology and biomechanics of the sacroiliac joints, lumbar spine and the lumbar extensor muscles, as well as creates an understanding of sacroiliac joint dysfunction and the theories explaining the effects of spinal manipulative therapy.

2.2. An overview of the vertebral column

The vertebral column (VC) forms part of the axial skeleton; it is made up of five distinct areas as depicted in Figure 1. It consists of four curves. Relative to the front of the body, they are the convex cervical and lumbar curves, and the concave thoracic and sacral curves (Tortora and Derrickson, 2006:214). There are 25 vertebrae making up the cervical, thoracic and lumbar regions which are movable and articulate at two synovial zygopophysial joints, which enhance and control the flexibility of the VC. The inferior nine vertebrae fuse to form the sacrum and coccyx (Moore and Dalley, 2006:478). The vertebral bodies (VBs) are joined by intervertebral discs (IVDs) which also add to the VC's flexibility (Moore and Dalley, 2006:478). The VC bears the weight of the head, neck and trunk (Martini, 1998) and transfers this weight to the pelvic girdle at the sacroiliac joints (SIJs) (Moore and Dalley, 2006: 478). It encloses and protects the spinal cord (SC) as well as providing attachments for the ribs, pelvic girdle and muscles of the back (Tortora and Derrickson, 2006:212).

The sacrum is a large triangular bone consisting of five fused sacral vertebrae, as depicted in Figure 1 (Moore and Dalley, 2006:490; Tortora and Derrickson, 2006:214). It provides stability to the pelvis, and transmits body weight to the pelvic girdle. It contains the sacral canal, a continuation of the vertebral canal through which the cauda equine, the spinal nerve roots arising inferior to the L1

vertebrae, passes to give rise to the sacral nerve roots, which traverse through the sacral foramina (Moore and Dalley, 2006:490).

The coccyx is a small triangular bone consisting of four fused coccygeal vertebrae. The coccyx is involved in slight weight bearing when sitting, and provides attachment for the gluteus maximus and coccygeus muscles (Moore and Dalley, 2006:494).

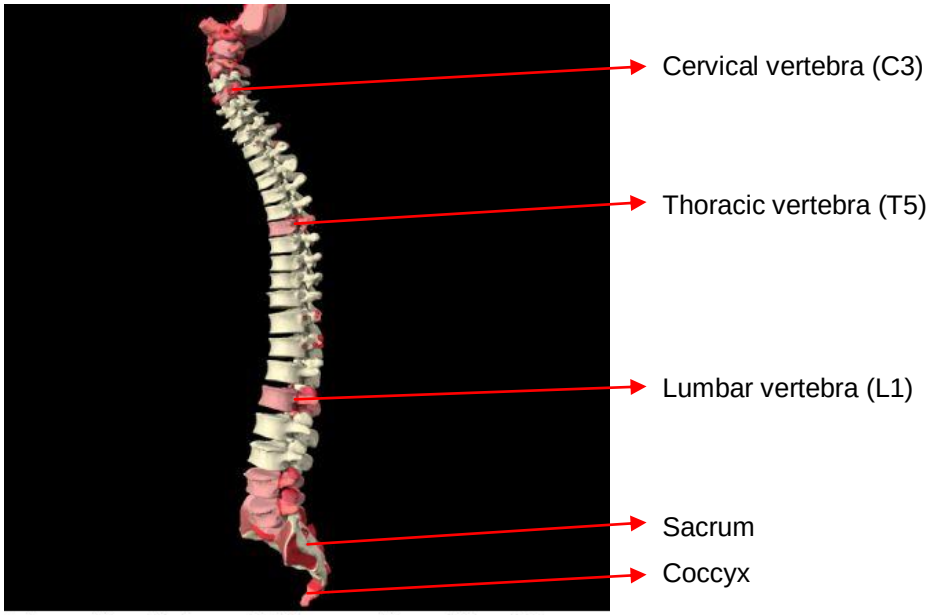


Figure 1: Vertebral column (Permission from Primal Pictures, 2001).

2.2.1 Anatomy of a typical vertebra

Vertebrae vary in size and characteristics in each region of the VC; however, their basic structure is the same. Each consists of a VB, a vertebral arch and seven processes (Moore and Dalley, 2006:482), as depicted in Figure 2.

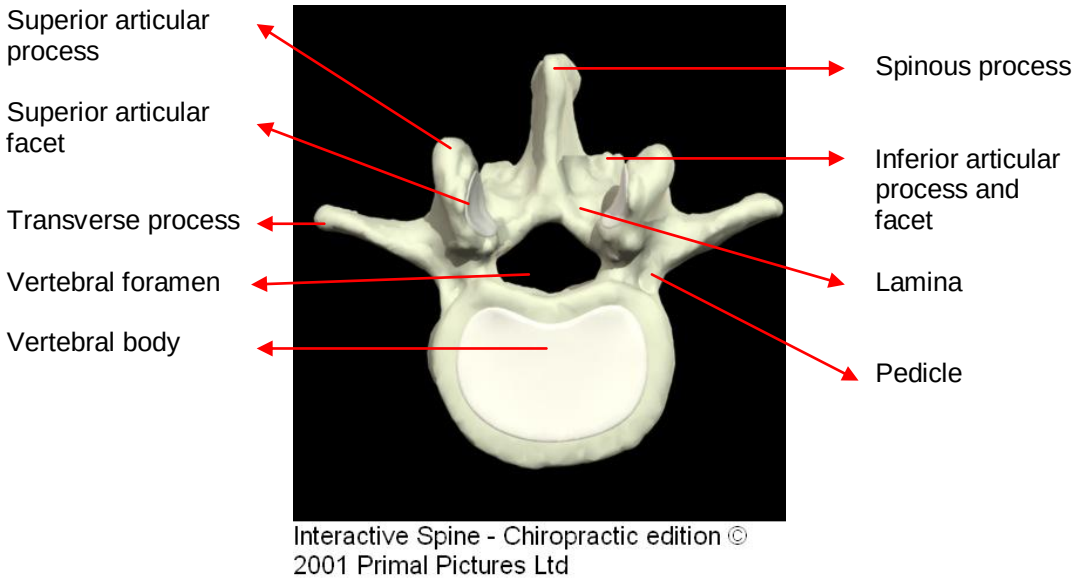


Figure 2: A typical vertebra (Permission from Primal Pictures, 2001).

2.2.2 Characteristics of vertebrae in the thoracic and lumbar regions

The vertebrae in each area of the spine have unique characteristics; those relative to the thoracic and lumbar vertebrae are shown in Table 1.

Table 1: Parts and distinctive characteristics of typical vertebrae.

Area	Part	Distinctive characteristics
Thoracic vertebrae	Vertebral body	Heart-shaped; with one or two costal facets for articulation with head of rib.
	Vertebral foramen	Smaller than cervical and lumbar vertebrae; circular.
	Transverse process	Long, strong, extends posterolaterally; length decreases from T1-T12 (T1-T10 has facets for articulation with tubercle of rib).
	Articular process	Superior facets face posteriorly and slightly laterally; inferior facets anteriorly and slightly medially.
	Spinous process	Long; slopes posteroinferiorly; tips extends to the level of the VB below.
Lumbar vertebrae	Vertebral body	Kidney-shaped; massive.
	Vertebral foramen	Triangular; larger than in thoracic vertebrae and smaller than in cervical vertebrae.
	Transverse process	Long and slender; on the posterior base each has an accessory process.
	Articular process	Superior facets face posteromedially; inferior facets face anterolaterally; on the posterior surface of each superior articular process is a mamillary process.
	Spinous process	Short and sturdy; thick, broad, and hatchet shaped.

(Adapted from Moore and Dalley, 2006:488-491).

2.2.3 Joints of the vertebral column

2.2.3.1 The intervertebral discs

Intervertebral discs (IVDs) are found between the bodies of adjacent vertebrae from C2 to the sacrum (Tortora and Derrickson, 2006:214). Each IVD has an outer fibrous ring, the annulus fibrosis and an inner semi-fluid elastic nucleus pulposis. The IVDs form strong joints, which permit movement between adjacent vertebrae, and function as shock absorbers (Moore and Dalley, 2006:499-500; Tortora and Derrickson, 2006:214). The IVD is innervated by the recurrent meningeal nerve arising from the spinal nerves (Moore and Dalley, 2006:519).

2.2.3.2. The zygopophysial joints

Zygopophysial joints are plane synovial joints surrounded by a thin articular capsule (Moore and Dalley, 2006:504). In the thoracic spine, the zygopophysial joints have a coronal orientation from the cervicothoracic junction to T10 (Yochum and Rowe, 2005:41) allowing rotation and some lateral flexion of the spine (Moore and Dalley, 2006:488). At T11/T12 they become more sagitally orientated. In the lumbar spine the zygopophysial joints have a sagittal orientation (Yochum and Rowe, 2005:51), allowing for flexion, extension, and some lateral flexion but prohibiting rotation of the spine (Moore and Dalley, 2006:489). The zygopophysial joints of two adjacent VBs, the IVD between them and their associated soft tissue structures form a vertebral motion segment or functional spinal unit (Herzog, 2000:98). The zygopophysial joints and their capsule are innervated by articular branches arising from medial branches of the posterior rami of the spinal nerves (Moore and Dalley:504, 2006; Peh, 2011).

2.2.4 Ligaments of the vertebral column

There are numerous ligaments that support the VC. Their attachments and functions are described in Table 2.

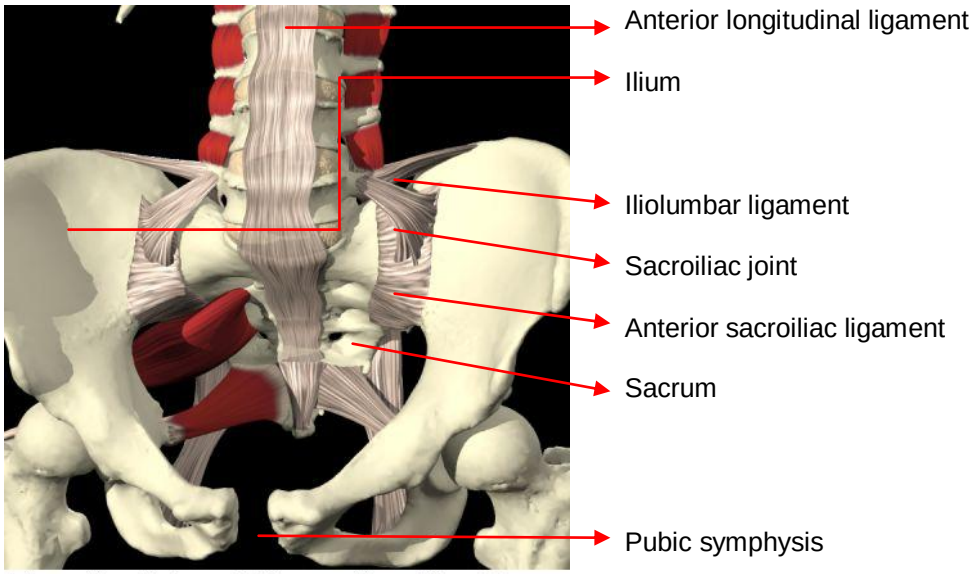
Table 2: Attachments and functions of the ligaments of the vertebral column.

Ligaments	Attachments	Function
Anterior longitudinal ligament	Long band which covers and connects anterior and lateral aspects of the VBs and IVDs. Extends from the pelvic surface of the sacrum to the anterior tubercle of C1 vertebra and the occipital bone anterior to foramen magnum.	Prevents hyperextension of the spine, therefore maintains stability of the joints between the VBs.
Posterior longitudinal ligament	Narrower, weaker band. Extends from C2 to the sacrum. Runs within the vertebral canal along posterior aspects of the VBs, and expands laterally to attach to the IVDs.	Weakly resists hyperflexion of the spine, and prevents or redirects posterior herniation of the nucleus pulposis.
Ligamentum flavum	Short, thick, strong elastic ligament which joins the laminae of consecutive vertebrae. Extends almost vertically from the lamina above to the lamina below, blending in the midline. It is a paired structure, represented symmetrically on the left and right sides at each segmental level.	Resists separation of the laminae by arresting sudden flexion of the spine, hence preventing injury to the IVDs. Helps to preserve normal curvatures of the spine, and assists in straightening the spine following flexion
Interspinous ligament	Weak, thin, membranous ligament, which attaches from the root to the apex of each spinous process (SP).	Connects adjacent SPs, and resists separation of the adjacent SPs during hyperflexion of the spine.
Supraspinous ligament	Cord-like ligament which lies in the midline and connects the tips of adjacent SPs, traversing the interspinous spaces.	Resists hyperflexion of the spine.
Intertransverse ligament	Thin and membranous. Connects tips of transverse processes (TVPs) of adjacent vertebra.	Connects adjacent TVPs.
Iliolumbar ligament	L5 TVP to the ilia.	Strengthens the lumbosacral joints.

(Adapted from Bogduk, 2005:44-49; Moore and Dalley, 2006:501-505).

2.3 An overview of the pelvis

The pelvis is the bony ring formed by the pelvic bones and sacrum, uniting posteriorly at the SIJs and anteriorly at the pubic symphysis (Moore and Dalley, 2006:358; Tortora and Derrickson, 2006:240) (Figure 3). It functions as a strong stable support for the VC and pelvic organs, as well as connecting the bones of the lower limbs to the axial skeleton (Tortora and Derrickson, 2006:240).



Interactive Spine - Chiropractic edition ©
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Figure 3: The pelvis (Permission from Primal Pictures, 2001).

2.3.1 Joints of the pelvis

2.3.1.1 The sacroiliac joint (SIJ)

The sacroiliac joints (SIJs) are formed by an articulation between the sacrum and its corresponding ilia on either side, as depicted in Figure 3 (Bogduk, 2005:177). The SIJs are true synovial joints, having a joint cavity containing synovial fluid and enclosed by a joint capsule (Bergmann and Peterson, 2011:263).

There is limited description of the joint capsule in the literature. Bogduk (2005:181) describes the posterior capsule as rudimentary or absent, and the anterior capsule as a thickening of the sacroiliac (SI) ligament. Microscopic examination of the joint reveals that the iliac surface is covered with fibrocartilage (Lee, 2004:10). This is the strongest type of cartilage, and adds strength and rigidity to the joint (Tortora and Derrickson, 2006:128). The sacral surface is covered with thicker hyaline cartilage (Lee, 2004:10), which gives flexibility and support to the joint, while reducing friction and acting as a shock absorber (Tortora and Derrickson, 2006:128.

The articular surface is described as auricular, and has different contours which develop into interlocking elevations and depressions (Moore and Dalley, 2006:365;

Bergmann and Peterson, 2011:263). This bony locking mechanism stabilises the joint, in order for it to be effective in transmitting and distributing axial compressive forces from the VC through the pelvic rim to the lower limbs when standing (Bogduk, 2005:177; Moore and Dalley, 2006:365), and to the ischial tuberosities when sitting (Moore and Dalley, 2006:365). It can also distribute forces from the lower extremities up towards the spine and anteriorly to the pubic symphysis (Bergmann and Peterson, 2011:263), functioning as a stress-relieving joint (Bogduk, 2005:178).

The SIJ has an anti-torsional function. During walking the pelvis is exposed to large twisting forces, due to alternating flexion and extension of the lower limbs. The range of motion of the SIJs is small in magnitude and irregular in direction (Bogduk, 2005:177). Sturesson, Uden, and Vleeming (2000a and 2000b) examined the movements of the SIJs in a variety of postures and movements, and determined that the range of movement of the SIJ is approximately one degree. This limited movement supports its function as a stress-relieving joint (Bogduk, 2005:178). Although it is widely accepted that the SIJ is a movable joint, there is still much controversy as to exactly how much it moves and where the axes of motion are located (Bergmann and Peterson, 2011:265).

During flexion of the hip, the ipsilateral ilium glides backwards and downwards across the sacrum and compresses against it, pivoting at the pubic symphysis. During extension of the hip, the ilium glides forwards and flares away from the sacrum. These movements are produced in the SIJ by the mass of the trunk acting on the sacrum, and tension from the muscles of the lower limbs pulling on the ilium (Bogduk, 2005:184).

Pure sagittal plane movements of the sacral base referred to as nutation (anterior and inferior) and counternutation (posterior and inferior) occur, but only during trunk flexion and extension, and when changing from the upright, seated and recumbent positions (Bergmann and Peterson, 2011:266).

Some of the strongest muscles in the body surround the SIJ; however none are intrinsic to it or act directly upon it to produce active movement. All the muscles

which cross the SIJ act directly on the hip or lumbar spine (Bogduk, 2005:183). However, they may influence the mechanical behaviour of the SIJ and respond to the stresses applied to it (Bergmann and Peterson, 2011:265).

The SIJs are supplied by articular branches from the superior gluteal nerves, the sacral plexus and the dorsal rami of the S1 and S2 nerves. The posterior aspect of the SIJ is innervated by both posterior rami of L5 to S2 spinal nerves, while the anterior aspect is innervated by both posterior branches from the L3 to S2 roots and superior gluteal nerve L5 to S2 (Moore and Dalley, 2006:379).

2.3.1.2 The pubic symphysis

The pubic symphysis is a fibrocartiginous joint, consisting of two pelvic bones which unite in the midline anteriorly as shown in Figure 3 (Moore and Dalley, 2006:358; Tortora and Derrickson, 2006:242). It is innervated by branches of the iliohypogastric, ilioinguinal and pudendal nerves (Becker *et al*., 2010).

2.3.2 Ligaments of the pelvis

There are many ligaments related to the pelvis. Only those relative to the SIJ will be discussed in the context of this research, as shown in Table 3.

Table 3: Attachments and functions of the ligaments of the sacroiliac joint.

Ligament	Attachments	Function
Interosseous sacroiliac ligament	Lies within the narrow recess between the sacrum and ilium. Deep layer attaches medially to the three fossae on the lateral aspect of the posterior sacral surface, and laterally to the iliac tuberosity. Superficial layer is a fibrous sheet which attaches to the lateral crest at S1 and S2 and the medial aspect of the iliac crest.	Strongest ligament in this group. Binds the ilium to the sacrum and secures the bony locking mechanism
Posterior sacroiliac ligament	Lies posterior to the interosseous ligament. Long posterior SI ligament consists of long fibres attaching medially to the lateral crest of S3 and S4, and laterally to the posterior superior iliac spine	Connects intermediate and lateral crests of the sacrum to the PSIS, and posterior aspect of the inner lip of the iliac crest. Tightens during counternutation of the sacrum preventing backward rocking movement

	(PSIS) and inner lip of the iliac crest.	of the sacral base. Short posterior longitudinal ligament and interosseous ligament prevent posterior diastasis of the SIJ.
Anterior sacroiliac ligament	Thickening of the anterior and inferior aspects of the joint capsule. Covers anterior aspect of the SIJ. Consists of numerous long, transversely orientated fibres extending from the ala and anterior surface of the sacrum to the anterior surface of the ilium.	Weakest ligament in this group. Its main function is to bind the ilium to the sacrum and prevent anterior diastasis of the SIJ.
Sacrospinous ligament	Triangular. Has a broad origin medially from the lower lateral edge of the sacrum below the SIJ, and on the upper edge of the coccyx. Laterally the apex of the triangular ligament attaches to the ischial spine. Proximally the fibres blend with the joint capsule of the SIJ.	Prevents upward tilting or nutation of the lower end of the sacrum, by anchoring it to the ischium.
Sacrotuberous ligament	Broad origin. Arises from the PSIS, and blends with the long posterior SI ligaments; from the transverse tubercles of the lower spinal segments and lateral margin of the sacrum; where it blends with the sacrospinous ligament. It then narrows and broadens again to attach to the medial margin of the ischial tuberosity. Composed of three large fibrous bands: Lateral band attaches to the PSIS and ischial tuberosity. Medial band attaches to S3, S4 and S5 transverse tubercles and the lateral margin of the lower sacrum and coccyx, and runs anteroinferolaterally to the ischial tuberosity. Superior band runs superficially to the interosseous ligament and attaches to the PSIS and coccyx.	Prevents upward tilting or nutation of the lower end of the sacrum, by anchoring it to the ischium.

(Adapted from Lee, 2004:21-23; Bogduk, 2005:180-181; Moore and Dalley, 2006:366; Bergmann and Peterson, 2011:264-265).

2.4 An overview of the musculature of the back

The muscles of the back can be divided into three groups: superficial, intermediate and intrinsic. The superficial and intermediate muscles are extrinsic back muscles and are responsible for movement of the limbs and respiration. The intrinsic back muscles function to maintain posture and control movements of the VC (Moore

and Dalley, 2006:534). For the purpose of this study only the intrinsic back muscles will be discussed.

2.4.1 The intrinsic muscles of the low back

The intrinsic muscles consist of three layers; the deep, intermediate and superficial layer (Moore and Dalley, 2006:534).

2.4.1.1 Deep layer of intrinsic back muscles

This layer is intimately related to the vertebrae and lies between the TVPs and SPs (Moore and Dalley, 2006:537). Table 4 highlights the attachments, innervations and actions of these muscles.

Table 4: Deep layer of intrinsic back muscles.

Muscle	Proximal attachment	Distal attachment	Innervation	Action
Multifidus	Posterior sacrum, PSIS, erector spinae (ES) aponeurosis, SI ligaments, mammillary processes of lumbar vertebrae, T1 to T3, and articular processes of C4 to C7.	Thickest in lumbar region; fibres pass obliquely superomedially to SPs of vertebrae, located 2 to 4 segments superior to proximal attachment.	Posterior rami of the spinal nerves.	Extension of the spine. Stabilises the vertebrae during local movements of the spine.
Rotatores	Arise from TVPs.	Fibres pass superomedially to attach to junction of lamina and TVP, or SP of vertebra immediately or 2 segments superior to vertebra of origin.	Posterior rami of the spinal nerves.	Stabilises the vertebrae and assist with local extension and rotation of the spine.
Interspinales	Superior surfaces of the SPs of the cervical and	Inferior surfaces of the SPs of vertebra superior to vertebra of	Posterior rami of the spinal nerves.	Assists in extension and rotation of the

	lumbar vertebrae.	origin.		spine.
Intertransversarii	TVPs of the cervical and the lumbar vertebrae.	TVPs of the adjacent vertebrae.	Posterior and anterior rami of the spinal nerves.	Assists in lateral flexion of the spine. Bilaterally: stabilises the spine.
Levatores costarum	Tips of TVPs of C7 and T1-T11 vertebrae.	Passes inferolaterally and inserts on rib between tubercle and angle.	Posterior rami of C8-T11 spinal nerves	Elevates ribs; assists in respiration; assists with lateral flexion of spine.

(Adapted from Moore and Dalley, 2006:539).

2.4.1.2 Intermediate layer of intrinsic back muscles

This layer consists of the main extensor muscles of the thoracolumbar spine, the erector spinae (ES) muscles commonly known as the paraspinal muscles. They consist of the longissimus and iliocostalis muscles (McGill, 2007:51). They lie in a groove on either side of the VC between the SPs centrally and the angle of the ribs laterally (Moore and Dalley, 2006:534) as seen in Figure 4.

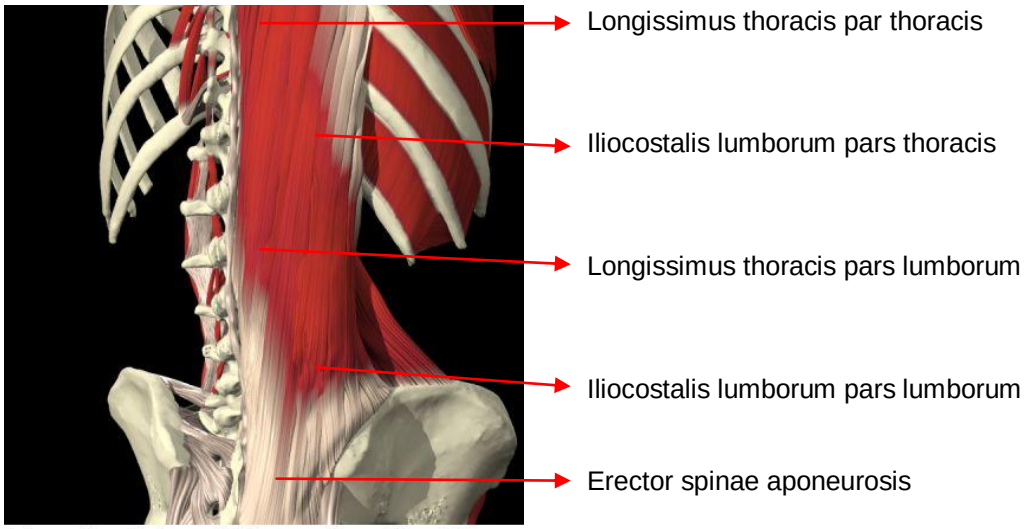


Figure 4: The intermediate layer of the intrinsic muscles (Permission from Primedia Pictures, 2001).

They form the prominent bilateral longitudinal bulges of the back muscles on either side of the spine (Bogduk, 2005:108). Each of these muscles has two

components: the pars lumborum, and the pars thoracis. The attachments, innervations and actions of these muscles are described in Table 5.

Table 5: Intermediate layer of intrinsic back muscles.

Muscle	Proximal attachment	Distal attachment	Innervation	Action
Longissimus thoracis pars lumborum	Five fascicles each arising from the accessory process and adjacent posteromedial surface of TVPs of L1 to L5 vertebrae.	L5 fascicle is the deepest and shortest, and attaches to the medial aspect of the PSIS. Each fascicle from L4 to L1 vertebrae lies more posteriorly, covering the previous fascicle. L4 to L1 fascicles form tendons at their inferior ends and attach to the ilium just lateral to the L5 fascicle.	Posterior rami of the spinal nerves.	Unilaterally: Lateral flexion of the lumbar spine. Bilaterally: Extension of the lumbar spine, (increases from L1 to L5). Posterior rotation of the lumbar spine (increases from L5 to L1).
Iliocostalis lumborum pars lumborum	Four fascicles arising from the tips of the TVPs of L1 to L4 vertebrae, and 2 to 3 cm laterally to the middle layer of the thoracolumbar fascia (TLF).	L4 fascicle is the deepest, and attaches to the iliac crest, just lateral to the PSIS. Each fascicle from L3 to L1 covers the previous one and attaches to the iliac crest, each progressively more posteriorly and laterally.	Posterior rami of the spinal nerves.	Unilaterally: Lateral flexion of the lumbar spine Bilaterally: Extension and posterior rotation of the lumbar spine.
Longissimus thoracis pars thoracis	11 to 12 pairs of fascicles that form two tendons. A medial one arises from the tips of TVPs of T1 or T2 to T12, and a lateral one arises from the rib.	Each tendon extends 3 to 4 cm and forms a muscle belly 7-8cm long. Muscle bellies from higher levels overlap those from lower levels; forming a tendon which inserts into the lumbosacral region such that: T2 fascicles attach to the L3 SP, and fascicles from lower levels insert into SPs at progressively lower levels. For example: T5 fascicles insert at the L5 SPs, T7 fascicles insert at S2 or S3 SP. T8 to T12 fascicles diverge from the midline and attach to the sacrum along a line extending from S3 SP to the caudal aspect of the PSIS. The caudal tendons form part of the ES	Posterior rami of the spinal nerves.	Acts on the thoracic vertebrae and the ribs. Unilaterally: Lateral flexion of the thoracic spine and indirectly lateral flexion of the lumbar spine Bilaterally: Extends the thoracic spine and indirectly extends the lumbar spine.

		aponeurosis.		
Iliocostalis lumborum pars thoracis	Consists of seven to eight fascicles which arise from the angle of the lower seven or eight ribs via a ribbon-like tendon, 9-10cm long.	Forms a muscle belly 8-10cm long. Each fascicle forms a tendon, which contributes to the ES aponeurosis and attaches to the PSIS. The most medial upper tendons attach more medially to the posterior surface of the sacrum. The fascicles have no attachment to the lumbar vertebrae; they span the lumbar region and attach to the iliac crest.	Posterior rami of the spinal nerves.	Unilaterally: Lateral flexion of the thoracic cage and indirectly lateral flexion of the lumbar spine. Bilaterally: exerts a 'bowstring' effect on the spine, causing direct extension of the thoracic spine and indirect extension of the lumbar spine.

(Adapted from Bogduk, 2005:108-114; Moore and Dalley, 2006:538).

2.4.1.3 Superficial layer of intrinsic back muscles

This layer consists of the splenius muscles on the posterior and lateral aspects of the neck, which cover and hold the deep neck muscles in position (Moore and Dalley, 2006:534). The attachments, innervations and actions of these muscles are described in Table 6.

Table 6: Superficial layer of intrinsic back muscles.

Muscle	Proximal attachment	Distal attachment	Innervation	Action
Splenius capitus	Nuchal ligament, and C7-T3/T4 SPs.	Runs superolaterally to the mastoid process and lateral third of superior nuchal line.	Posterior rami of spinal nerves.	Unilaterally: Laterally flexes neck and rotates head. Bilaterally: Extends head and neck
Splenius cervicus	Nuchal ligament and T3-T6 SPs.	Tubercles of TVPs of C1-C3 or C4.		

(Adapted from Moore and Dalley, 2006:537).

2.5 Fascia of the low back

2.5.1 Erector spinae aponeurosis

The ES aponeurosis is a broad sheet of tendinous fibres which attaches skeletal muscle to bone. It attaches to the ilium, sacrum, lumbar and sacral SPs, and forms a common origin for the lower part of the ES muscles. It is formed almost exclusively by the tendons of the longissimus thoracis pars thoracis, which forms the medial half, and the iliocostalis lumborum pars thoracis, which forms the lateral half as seen in Figure 4. The lumbar fibres of the longissimus and iliocostalis have no attachment to the ES aponeurosis, and therefore it moves freely over the surface of the underlying lumbar fibres, indicating that the lumbar fibres are able to move independently of the rest of the ES muscles. It is innervated by posterior rami of the spinal nerves (Bogduk, 2005:114).

Pickar and Wheeler (2001) observed increased Golgi tendon organ (GTO) activity during the impulse thrust of a spinal manipulation (SM). GTOs send impulses via Ia sensory neurons to the SC and central nervous system (CNS) resulting in inhibition of alpha motor neurons which decreases muscle contraction (Gatterman, 2005:400; Muscolino, 2011:588). This is what may occur during a SM.

2.5.2 Thoracolumbar fascia (TLF)

The TLF consists of three layers, the anterior, middle and posterior layer, which envelopes the muscles of the lumbar spine and effectively separates them into three compartments. The anterior layer is thin and covers the anterior aspect of the quadratus lumborum muscle, attaching medially to the anterior aspects of the lumbar TVPs. The middle layer lies posterior to the quadratus lumborum muscle, attaching medially to the tips of the lumbar TVPs, and laterally gives rise to the aponeurosis of the transverse abdominus (TA) muscle. The posterior layer attaches medially to the lumbar SPs, covering the back muscles and blends with the other layers of TLF along the lateral border of the iliocostalis lumborum (Bogduk, 2005:115).

The core muscles are categorised into global and local systems, depending on their mechanical role in stabilisation. The global stabilising system includes the internal and external obliques, rectus abdominus, gluteus maximus, lateral fibres of the quadrates lumborum and portions of the ES muscles. These muscles are larger, more superficial, torque producing muscles. They are responsible for maintaining the upright position, for movement, and balancing and controlling external loads applied to the trunk by reducing the resultant forces on the spine. The local system includes deep muscles, and portions of deep muscles which insert on the lumbar vertebrae, such as the multifidus muscle due to its vertebral attachments, and the TA muscle as it directly attaches to the lumbar vertebrae via the TLF (Richardson *et al*., 1999:14-15). The core muscles work together as a unit to stabilize the body and spine, serving as a corseted centre of the kinematic chain (Akuthota and Nadler, 2004).

The posterior layer of the TLF has extensive muscular attachments to both the local and global systems, and is therefore ideally situated to regulate the tension of these muscles (Stevens *et al*., 2007). Therefore the TLF together with the core musculature, provides functional stability and support to the lumbar spine and core musculature, and may assist during movements such as extension during the Biering-Sorensen (B-S) extensor endurance test.

2.6 An overview of the nervous system

The nervous system consists of two parts; the CNS which includes the brain and SC, and the peripheral nervous system which is all nervous tissue outside of the CNS and is divided into the somatic nervous system, the autonomic nervous system, and the enteric nervous system (Tortora and Derrickson, 2006:405).

2.6.1 Peripheral nervous system

The peripheral nervous system consists of two types of nerves the cranial and spinal nerves. There are 12 pairs of cranial nerves (CNs) mostly responsible for the functions of the head with the exception of CN X which receives sensory information from the viscera of the thorax and abdomen, and CN XI which

innervates the sternocleidoidomastoid and trapezius muscles (Moore and Dalley, 2006:51,1127).

The spinal nerves are responsible for connecting the CNS to sensory receptors, muscles and glands within the body. There are 31 pairs which are named and numbered according to the region and level of the VC from which they emerge (Tortora and Derrickson, 2006:446). A typical spinal nerve as illustrated in Figure 5 consists of dorsal (sensory) and ventral (motor) nerve roots. The dorsal root carries afferent sensory axons whereas the ventral root carries efferent motor axons. The spinal nerve exits the spinal column through the intervertebral foramen (IVF) where it then divides into the dorsal and ventral rami (Moore and Dalley, 2006:51; Tortora and Derrickson, 2006:446).

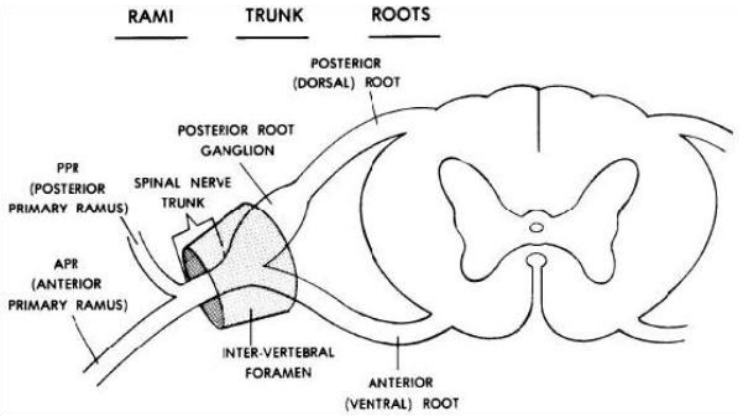


Figure 5: An illustration of a spinal nerve and the spinal cord (A 'typical' spinal nerve with a cross-section of the spinal cord, 2014).

The rami carry visceral and somatic motor and somatic sensory information to and from the SC, with the dorsal rami serving the skin and muscles of the back and the ventral rami serving the muscles and structures of the upper and lower limbs, and skin of the anterior and lateral aspects of the trunk. Adjacent ventral rami merge to form a nervous plexus e.g. lumbar plexus which carry nerves to the same target location (Moore and Dalley, 2006:52).

The spinal nerve also gives off a meningeal branch (recurrent meningeal/sinuvertebral nerve), which re-enters through the IVF to supply the vertebrae, IVD, zygopophysial joints, vertebral ligaments, meninges and blood

vessels of the SC (Moore and Dalley, 2006:519; Tortora and Derrickson, 2006:447).

2.6.2 Nerve types

Nerve fibres are divided into sensory, motor and interneurons. Sensory nerve fibres, as described in Table 7, are responsible for transmitting information from the sensory receptors to the CNS and are otherwise known as afferent neurons. Their cell bodies lie in the dorsal root ganglion. At the CNS they communicate with the interneuron which functions to distribute the sensory information and co-ordinate a motor response (Martini, 1998:374-375; Tortora and Derrickson, 2006:407).

Table 7: Classification of sensory nerve fibres.

Type	Size (µm) and conduction velocity (m/s)	Myelin	Characteristics	Associated receptor
Ia	12-20; 80-120	Yes	Responds to rate of length changes of a muscle	Muscle spindle
Ib	12-20; 80-120	Yes	Responds to tension changes of a muscle	Golgi tendon organ
II	5-15; 35-75	Yes	Stretch receptor, non adapting	Secondary receptors of muscle spindles, all cutaneous mechanoreceptors
III	1-5; 3-35	Thin	Responds to pain	Free nerve endings for touch and pressure, nociceptors of neospinothalamic tract and cold receptors
IV	0.2-1.5; 0.5-2	No	Responds to pain	Nociceptors of paleospinothalamic tract and warmth receptors

(Adapted from Hogervorst and Brand, 1998; Pickar, 2002; Leach, 2004:140).

The motor neurons are classified into three types (Table 8), and carry information from the CNS to the peripheral tissue, organ or organ systems. The cell body of the motor neuron lies inside the CNS (either in the grey matter of the SC or in the medulla oblongata), and its axon extends to the effector organ where it then forms

a neuromuscular junction (NMJ) with a muscle (Martini, 1998:375; Tortora and Derrickson, 2006:405).

Table 8: Classification of motor nerve fibres.

Type	Size and conduction velocity	Myelin	Function
Alpha	Largest (8-20 µm) and fastest (35-120 m/s)	Yes	Innervate the slow (for posture) and fast (for movement) twitch fibres of the extrafusal muscle fibres.
Beta	Medium size and velocity.	Yes	Innervate the slow (for posture) twitch fibres of the extrafusal muscle fibres, and intrafusal fibres of muscle spindles
Gamma	Smallest (2-8 µm) and slowest (10-50 m/s)	Yes	Innervate the intrafusal muscle fibres and together with the muscle spindles give proprioceptive feedback

(Adapted from Leach, 2004:140)

2.6.3. Sensory receptors

Sensory receptors are specialized cells which provide the CNS with information about the conditions of the body internally and externally (Martini, 1998:491). They are classified into mechanoreceptors, thermoreceptors, proprioceptors, pain receptors and chemoreceptors (Tortora and Derrickson, 2006:549). Those related to this study are discussed in Table 9.

Table 9: Summary of sensory receptors.

Receptor type		Location	Sensations	Adaption rate
Mechano-receptors	**Meissner corpuscles**	Hairless skin.	Fine touch, pressure & slow vibrations.	Rapid.
	Merkel discs	Epidermis.	Fine touch & pressure.	Slow.
	Type I: Ruffini corpuscles	Deep in the dermis, in ligaments & tendons, periosteum and superficial layer of the joint capsule.	Stretching of skin. Static joint position. Active and passive joint movements.	Static and dynamic, low threshold, slow adapting
	Type II: Pacinian corpuscles	Dermis, subcutaneous layer, submucosal tissues, joint capsule	Pressure, fast vibrations. Active and	Dynamic, low threshold, rapid adapting

		and articular fat pad, periosteum & some viscera.	passive joint movements.	
	Muscle spindles	Within most striated skeletal muscles.	Muscle length.	Slow.
	Type III: Golgi tendon organs	Ligaments and tendons	Muscle tension.	Dynamic, high threshold, slow adapting
Pain receptors:	**Type IV**	Joint capsule, joint fat pads and blood vessels walls. Free nerve endings – intrinsic and extrinsic ligaments.	Pain.	High threshold, non-adapting

(Adapted from Wyke, 1972; Hogervorst and Brand 1998; Martini, 1998:544; Leach, 2004:142-144; Tortora and Derrickson, 2006:555; Muscolino, 2011:583-584; Peterson and Bergmann, 2011:18-19).

2.7 The skeletal muscle fibre

Skeletal muscles attach to bones either directly or indirectly. Their main functions are to produce skeletal movement, maintain posture and body position, support soft tissues, guard openings of the digestive and urinary tracts and maintain body temperature (Martini, 1998:277; Tortora and Derrickson, 2006:291).

The skeletal muscle fibre as illustrated in Figure 6 consists of three layers separated by connective tissue. The connective tissue extends beyond the muscle fibres to form a tendon or aponeurosis, which attaches the skeletal muscle to bone. Therefore contraction of the muscle will exert a pull on its tendon and hence on the attached bone to produce movement (Martini, 1998:278; Tortora and Derrickson, 2006:292).

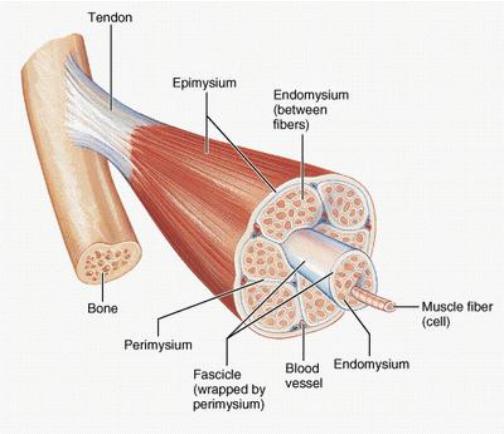


Figure 6: The skeletal muscle (Skeletal muscle fibre, 2014).

Each skeletal muscle fibre contains hundreds to thousands of myofibrils. Myofibrils consist of bundles of myofilaments which are arranged into individual contractile units, called sarcomeres as illustrated in Figure 7 (Martini, 1998:281; Tortora and Derrickson, 2006:292).

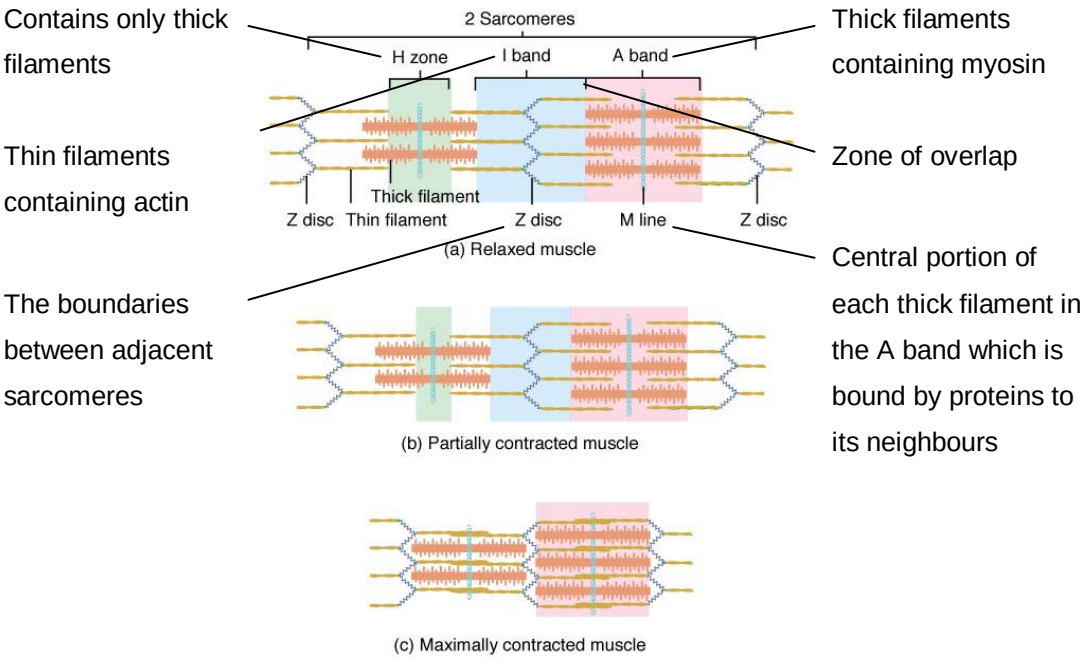


Figure 7: A sarcomere at rest, partially contracted and maximally contracted (The Muscular System, 2013).

2.7.1 Contraction of skeletal muscle

Skeletal muscle contraction is controlled by the CNS. Each skeletal muscle fibre is controlled by a motor neuron at a single NMJ midway along the fibre's length. As

shown in Figure 8, when a motor neuron stimulates a muscle fibre, an electrical impulse or action potential (AP) arrives at the synaptic terminal of the neuron, which stimulates the release of acetylcholine (ACh) into the synaptic cleft. ACh is a neurotransmitter, a chemical released by neurons to change the membrane properties of other cells. The vesicles containing ACh fuse with the membrane of the neuron, and release the ACh molecules.

The ACh molecules diffuse across the synaptic cleft and bind to ACh receptors on the motor end plate surface of the muscle fibre, which increases the membrane permeability to sodium ions (Na^+ ions). Na^+ ions then enter at an increased rate into the sarcoplasm (cytoplasm of the muscle fibre). This continues until the acetylcholinesterase (AChE), an enzyme, breaks down and removes the ACh from the receptors. This sudden inrush of Na^+ ions leads to the generation of an AP in the sarcolemma at the edges of the motor end plate.

The AP spreads across the cell membrane surface and down each of the transverse tubules, triggering the release of calcium ions (Ca^{2+} ions) at the terminal cistern of the sarcoplasmic reticulum. The change in permeability of the sarcoplasmic reticulum to Ca^{2+} ions is temporary, lasting about 0.03 milliseconds. The Ca^{2+} ions bind to the troponin, found in the thin filaments, which exposes the active sites along the thin filaments. The myosin from the thick filaments, binds to these active sites, and the subsequent pivoting of the myosin head shortens the sarcomeres. Each myosin head continues to attach, pivot, and detach as long as Ca^{2+} ions and adenosine triphosphate (ATP) are available, continually pulling the thin filaments closer to the thick filaments and shortening the muscle. ATP is provided by glycolysis of glycogen stores by mitochondria located in the myofibril.

As depicted in Figure 7, the thin filaments slide towards the centre of the sarcomere, alongside the thick filaments, hence the H zone and I bands get smaller, the zones of overlap become larger and the Z lines move closer together, whereas the length of the A bands remain constant. The contraction ends once the fibre has shortened by about 30 percent, with the elimination of the I bands. This is known as the sliding filament theory (Martini, 1998:284-287; Tortora and

Derrickson, 2006:299-300). Due to the myofibril attachments to the sacrolemma and connective tissue, when the myofibrils contract, the entire cell shortens and so pulls on the tendon.

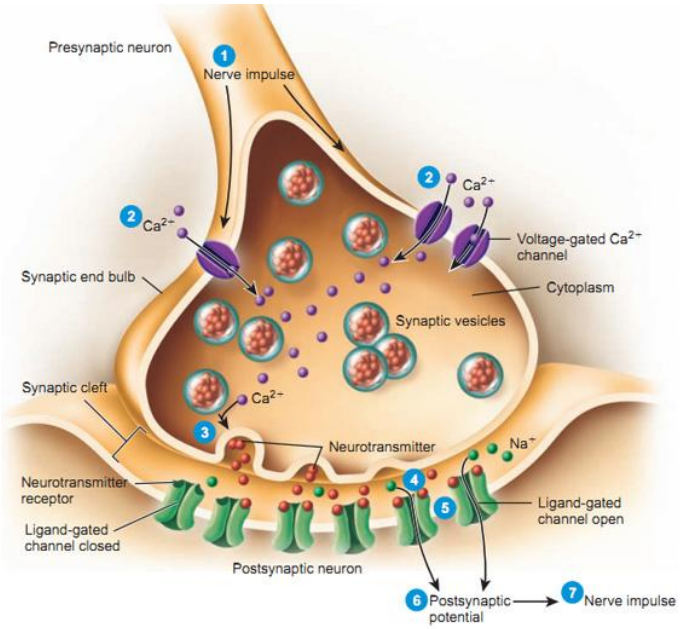


Figure 8: The neuromuscular junction (Neuromuscular junction, 2012).

2.7.2 The role of muscles spindles and Golgi tendon organs

2.7.2.1 Muscle spindles

Muscle spindles (MSs) are sensory receptors responsible for protecting muscles from being subjected to extreme lengthening or tension. They are stretch sensitive, fusiform in shape and are located within the belly of the muscle. They lie parallel to and attach to the surrounding extrafusal muscle fibres. Each spindle is encapsulated by a thin connective tissue capsule, within which are two to ten intrafusal muscle fibres. The central part of the fibre has no actin or myosin; therefore it does not contract, and is primarily for sensory perception. The sensory nerve endings are stimulated when the spindle is stretched. The end portions of the intrafusal muscle fibre are contractile in nature and are stimulated by gamma motor efferent fibres (Muscolino, 2011:584-586).

When a muscle is stretched, the intrafusal fibres of the MS are activated sending a message via Ia sensory neurons to the SC and CNS. This results in reflex contraction and shortening of the muscle, by transmitting the response via alpha motor efferents to the extrafusal muscle fibres. Also known as the stretch reflex, this reflex protects the muscle from being overstretched or torn.

Simultaneously, the gamma motor neurons fire causing the ends of the spindle to contract; this stretches the non-contractile central portion, making it taut and more sensitive to stretch and therefore more easily triggering the stretch reflex. This alpha gamma co-activation allows the MS to be taut within the contracting muscles so that it can accurately detect changes in stretch. The sensitivity of the MS to stretch is set by the gamma motor system (Tortora and Derrickson, 2006:554; Muscolino, 2011:585). The gamma loop consists of Ia sensory neurons transmitting a change in muscle length to the SC resulting in activation of the alpha motor neurons and a resultant change in muscle length.

Therefore the shorter the intrafusal fibres are, the more sensitive they are to muscle stretch. The gamma lower motor neurons are controlled by the gamma upper motor neurons. The degree of sensitivity is therefore based on subconscious processing of many factors such as: previous and present trauma to the region where the muscle is located, a need for stability in the area, and general emotional and physical stress levels. The areas of the brain which primarily influence the gamma upper motor neurons are the brainstem nuclei, hypothalamus and amygdala (limbic system structures) and the cerebellum (Muscolino, 2011:586).

In order for the stretch reflex to be effective, axon collaterals from the MS neurons produce excitation of the inhibitory interneurons, which have an inhibitory effect on the alpha motor neurons to the opposing muscle group, resulting in relaxation of the opposing muscle group, known as reciprocal inhibition (Muscolino, 2011:580).

2.7.2.2 Golgi tendon organs

Golgi tendon organs (GTOs) are encapsulated receptors located within the musculotendinous junction. They are stimulated when there is tension within the muscle. When the muscle contracts, tension in the tendon increases, this stretches and stimulates the GTO. The GTO sends impulses via Ib sensory neurons to the SC and CNS, resulting in excitation of inhibitory neurons, which inhibit alpha motor neurons and therefore decreases muscle contraction. When the tension is extreme, the inhibition reflex causes sudden relaxation of the muscle. This is called the lengthening reaction or tendon reflex and is a protective mechanism which prevents tearing of the muscle, muscle tendon interface, tendon or avulsion of bone (Gatterman, 2005:400; Muscolino, 2011:588).

2.7.3 Factors affecting muscle contractibility

Several factors affect the ability of a muscle to contract, including length-tension relationships, limbic system dysfunction and low levels of vitamins and minerals.

2.7.3.1 Length-tension relationships

During a muscle contraction the amount of tension generated depends on the number of cross-bridge interactions that occur in the sarcomeres. This is determined by the amount of overlap between the thick and thin filaments. When muscle fibres contract, only the myosin heads that are within the zone of overlap can bind to active sites and produce tension in the muscle (Martini, 1998:287).

When a sarcomere is at or close to resting length, the zone of overlap is optimal (extending from the edge of the H zone to one end of the thick filament) and the muscle fibre can produce maximum tension. When a sarcomere is stretched to a longer length, the zone of overlap shortens, and fewer myosin heads can make contact with thin filaments. Hence, the tension the fibre is able to produce decreases. Therefore the length-tension relationship of the skeletal muscle indicates the forcefulness of the muscle contraction (Tortora and Derrickson, 2006:302).

When a sarcomere length becomes increasingly shorter than the optimum, the thick filaments crumple as they are compressed by the Z discs and fewer myosin heads make contact with thin filaments, so the tension that may develop decreases. This reduced ability to contract efficiently may occur in muscle hypertonicity, or muscle strains involving a partial or complete muscle tear. Normally, resting fibre length is kept close to the optimum by the firm attachments of skeletal muscles to bones via their tendons, and to other inelastic tissues (Tortora and Derrickson, 2006:302).

2.7.3.2 Limbic system dysfunction

The limbic system is one of the areas of the brain which influences gamma upper motor neurons, which are responsible for setting the sensitivity of the MSs to stretch. Limbic system dysfunction is associated with depression and anxiety, as well as emotional and physical stress (Muscolino, 2011:586), which may cause prolonged muscle contraction and muscular tension, resulting in reduced ability of the muscles to contract effectively.

2.7.3.3 Low levels of vitamins and minerals

Minerals such as sodium, calcium, magnesium and potassium, and vitamins such as vitamins B1 (thiamine), B2 (riboflavin), B3 (niacin), B6 (pyridoxine), B12 and folic acid are all involved in the different processes related to muscle contraction, nervous tissue function and energy expenditure. Hence low levels of any of these vitamins or minerals due to dehydration, over hydration or inadequate dietary intake, can contribute to the development of muscle tiredness, weakness and cramps (Clark, 2008:186-187; Burke and Deakin, 2010:274-278).

2.7.4 Muscle endurance

Muscle endurance refers to the ability of a muscle to maintain a contraction till either isometric (when a single contraction can no longer be sustained at a

particular level), or dynamic fatigue (when repetitive contractions can no longer be sustained at a particular level) occurs (Moffroid, 1997).

Muscle endurance is a favourable characteristic of muscle especially those that have a postural function e.g. Multifidus/extensor muscles (Richardson *et al*., 1999:25). In order for a muscle to have endurance there must be a predominance of fatigue resistant type I muscle fibres (Kankaanpaä *et al*., 1998).

2.8 Paraspinal muscles and endurance

The primary function of the paraspinal muscles is to provide stability and control movements of the spine (Moore and Dalley, 2006:534). Sufficient endurance of these muscles is important for good health, and is often taken for granted (Moffroid, 1997). Reduced trunk extensor endurance has been linked to mechanical low back pain (MLBP) in adults (Biering-Sorensen, 1984; Demoulin *et al*., 2006) and adolescents (Bernard *et al*., 2008).

The reduced ability of the paraspinal muscles to support the spine may lead to overloading of the soft tissue and passive structures of the lumbar spine (Wilder *et al*., 1996) resulting in pain. MLBP is one of the most common musculoskeletal disorders with a lifetime prevalence of 60 to 85% (Krismer and van Tulder, 2007). It has become a major economic burden on society (Dagenais, Caro and Haldeman, 2008; Bell and Burnett, 2009). Therefore determining ways to prevent its onset has become a focus of research.

Other factors could influence the ability of the paraspinal muscles to function such as pain and core strength. The core refers to the ability of the body to have healthy force couple relationships in the lumbo-pelvic-hip complex (Liebenson, 2007:713). According to Richardson (1999:111) in Therapeutic exercise for spinal segmental stabilization in low back pain - Scientific basis and clinical approach, the TA muscle is considered important in aiding lumbar spine stability and can be clinically assessed by using a Pressure Biofeedback Unit (PBU). This unit consists of an inelastic, three-section air-filled bag and a pressure cell to monitor pressure in the bag for feedback on the movement. A drop in pressure of between 6-10

mmHg indicates an ability to contract the TA muscle effectively, whereas a change of 2 mmHg or less is a negative result and movement of the pelvis could result in a false positive (Richardson *et al*., 1999:114).

2.8.1 Measures of paraspinal muscle endurance

2.8.1.1 The Biering-Sorensen extensor endurance test

The B-S extensor endurance test has been described as the gold standard for assessing the isometric endurance of the trunk extensor muscles (Moreau *et al*., 2001; Demoulin *et al*., 2006). It is a common valid and reliable test, used to measure trunk extensor muscle endurance (Latimer *et al*., 1999; Demoulin *et al*., 2006), and has also been found to be less costly for use in a clinical setting than other fatigue inducing tests (da Silva *et al*., 2005). It is generally considered a safe test for both healthy individuals and research participants (Pitcher, Behm and MacKinnon, 2007), with no reports of persistent adverse effects such as pain exacerbation (Demoulin *et al*., 2006).

Demoulin *et al*. (2006) recommended the following procedure to follow when utilising the B-S extensor endurance test:

- The participant should lie prone on an examination table with the upper edges of the iliac crests aligned with the edge of the table, with their upper body extended beyond the edge of the examination table.
- Their lower body must be supported by strapping their pelvis, knees and ankles to the table, with their arms folded across the chest.
- Whilst the participant is not performing the test, their upper body is kept in a neutral position by the use of a support.
- When testing the participant must hold their upper body in a horizontal position, parallel with the floor. Their head should be maintained in a neutral position by looking down at a visual point.

The use of tactile feedback by placing a rope hung between two vertical stands, which is perpendicular to the T7 vertebra can be used to improve the accuracy of the test (Coorevits *et al*., 2008a; Coorevits *et al*., 2008b; Koumantakis *et al*.,

2001). The endurance time is determined as the time instant when the participant can no longer hold the horizontal position, and the contact between the T7 vertebra and the rope is lost.

If participants experience no pain or discomfort while performing the test and can keep the horizontal position for longer than 240 seconds they have good extensor muscle endurance. A failure to maintain the contraction for at least 176 seconds demonstrates decreased extensor muscle endurance (Kankaanpää *et al*., 1998; Demoulin *et al*., 2006).

Differences between males and females have been observed when performing the B-S extensor endurance test. Women have been shown to perform the test for a longer period of time, with less progressive decreases in the median frequency slope on surface electromyography (SEMG), suggesting women are more fatigue resistant than men (Mannion *et al*., 1997; Kankaanpää *et al*., 1998). Therefore it is recommended to use a homogenous sample (Kankaanpää *et al*., 1998).

2.8.1.2 Ito test

The Ito test is an alternative test developed by Ito *et al*. (1996) to assess isometric endurance of the trunk extensor muscles. The subject lies prone with a pad placed under the abdomen and the arms to their sides. The subject then lifts their sternum off the examination table, whilst flexing the neck maximally and contracting the gluteus maximus muscles in order to stabilize the pelvis. This is purported to be an optimal position for reducing lumbar lordosis, therefore it is hypothesised to result in less spinal loading than the B-S test, and due to the lack of need for strapping, there is supposedly less activation of the hamstrings (Demoulin *et al*., 2006).

It is an easy test to perform and does not require expensive equipment, and its test-retest reliability is high without inducing any pain (Ito *et al*., 1996). Müller, Strässle and Wirth (2010) found that the Ito test showed good criterion validity and indicated that it may assess back muscle endurance more specifically than the B-S test, however, this must be verified in further studies as there have been

insufficient studies conducted using the Ito test (Demoulin *et al*., 2006; Müller, Strässle and Wirth, 2010).

2.8.2 Measures of paraspinal muscle activity

2.8.2.1 Electromyography

Electromyography is used to measure muscle activity (Kent, 1997). There are two types, namely, surface electromyography (SEMG) and needle electromyography (EMG).

2.8.2.1.1 Surface electromyography (SEMG)

SEMG is a non-invasive technique used to record electrical potentials that are produced when a muscle contracts (Kent, 1997). It has been used extensively to monitor the development of localised muscle fatigue (Kent, 1997; Moffroid, 1997; Dolan and Adams, 1998; Kankaanpää *et al*., 1998; Mohseni-Bandpei and Watson, 2001; Coorevits *et al*., 2008b). Muscle fatigue is measured by the rate of decline in the median frequency slope; the more progressive the decline, the greater the fatigability of the muscle (Mannion *et al*., 1997; Roy *et al*., 1997). SEMG has been shown as a valid indicator of fatigue and correlates well with endurance time of the trunk extensor endurance muscles in healthy individuals during the B-S test (Mannion *et al*., 1997).

SEMG is commonly used in kinesiological studies when assessing the global function of groups of muscles working together, and for abnormal muscle activity. Due to its non-invasive nature, there is no tissue damage. It is also easy to replicate the location of application of the surface electrodes in research studies (Kent, 1997). Kent (1997) found it to be a reliable method for quantitatively assessing paraspinal muscle activity in healthy subjects during an unsupported trunk holding test such as the B-S test, and is especially useful in assessing altered paraspinal muscle activity in response to a chiropractic manipulation. When using SEMG it is important to consider body mass index (BMI) as

subcutaneous fatty tissue (Baars *et al*., 2006) and whether the individual is right or left handed (Mannion *et al*., 1997) as these factors may influence the results.

2.8.2.1.2 Needle electromyography (EMG)

Needle EMG is also used to measure muscle activity and electrical potentials. It is a more invasive approach as wire or needle electrodes are inserted into the specific muscle being assessed and may result in tissue damage which may lead to injury electrical potentials (Kent, 1997). The needle electrodes monitor a much smaller field of muscle activity and are therefore more appropriate for the analysis of specific muscles, myopathies and denervation potentials. It is also more difficult to replicate the exact depth and location of the needle's area of insertion, therefore resulting in inferior reliability to SEMG (Kent, 1997).

2.9 Spinal manipulative therapy (SMT)

Spinal manipulative therapy (SMT) is practiced by chiropractors and other manual therapists in the conservative management of back and neck pain (Ferreira *et al*., 2003; Bronfort *et al*., 2004; Potter, McCarthy and Oldham, 2005; Dagenais *et al*., 2010; Goertz *et al*., 2012). It is a manual treatment that is directed at restrictions in joint movement or hypomobility, referred to as a joint fixation (Bergmann and Peterson, 2011:37).

A joint fixation results in motion segment dysfunction, which incorporates the interaction of pathological changes within the connective tissue, nerves, muscles and ligaments. Resulting in abnormal joint motion, lack of joint play and end feel, and the presence of palpable soft tissue changes such as; muscle hypertonicity and the presence of pain (Gatterman, 2005:136).

Joint fixations may result from posterior joint derangement, intercapsular adhesions, intradiscal derangements, segmental muscle spasm, soft tissue fibrosis (Bergmann and Peterson, 2011:112) and psychological distress such as anxiety and depression (Muscolino, 2011:586). A synovial joint may also become dysfunctional due to entrapment of a synovial fold. A manipulative thrust which

separates the joint surfaces may release the entrapped synovial fold (Hyde and Gengenbach, 2007:229). A vertebral motion segment has three zones in which movement can take place (see Figure 9):

- Physiological – normal active and passive range of motion (ROM).
- Paraphysiological – joint play can be felt. A high-velocity low amplitude SMT separates the articular surfaces, overcoming the elastic barrier of resistance and producing an audible release (the 'cracking' or 'popping' sound) known as cavitation.
- Pathological – movement beyond the barrier of normal anatomical integrity in a joint will result in a sprain or dislocation, ranging from a simple elongation to complete rupture of the joint capsule (Leach, 2004:158).

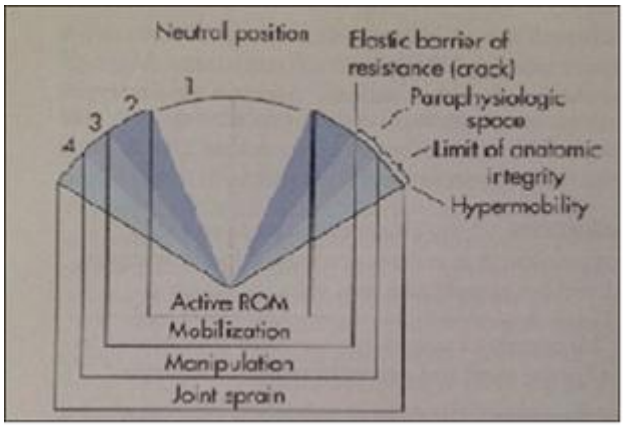


Figure 9: Physiological, paraphysiological and pathological zones of motion of a synovial joint (Permission from Gatterman, 2005).

2.9.1 Methods of delivering SMT

Manipulation is a term broadly used to define the therapeutic application of a manual force (Hyde and Gengenbach, 2007:231). Manipulation aims to restore the lost joint motion and there are many different methods used to apply SMT to a motion segment.

2.9.1.1 High-velocity low-amplitude (HVLA) thrusts

This specific manipulative thrust as used by Chiropractors is commonly known as the chiropractic adjustment (Hyde and Gengenbach, 2007:231). A HVLA thrust is

delivered with controlled speed, depth and magnitude through a specific contact on a particular structure such as the TVP or SP of a vertebra. This type of manipulation is often associated with joint gapping and a cavitation (cracking or popping noise) (Potter, McCarthy and Oldham, 2005; Hyde and Gengenbach, 2007:231).

There is variability in the impulse durations, preload and peak forces in HVLA SMT performed manually. Impulse durations can range from 200 to 420 milliseconds (ms) (Pickar and Kang, 2006), preload forces can range between 20 Newtons (N) and 180 N, and peak forces can range between 50 N and 550 N (Keller, Colloca and Fuhr, 1999). The preload and peak forces during SMT depend on the patient, the chiropractor, the location of treatment, the problem being treated and the manipulative technique utilised (Herzog, 2000:172-173).

2.9.1.2 Instrument adjusting (activator & impulse adjusting instruments)

The two types of instruments used by manual therapists for SMT are the handheld spring-loaded activator device, and the handheld electromechanical activator device (Colloca *et al*., 2005). Activator devices deliver precise, targeted adjustments to joints of the spine and extremities in order to relieve pain and restore motion (Introducing Impulse, 2009).

In spring-loaded activator devices, the spring is pulled back and released which creates the force imparted into the joint. Electromechanical activator devices have an electronic trigger which allows the delivery of the force through a stylus, which contacts the joint (Colloca and Keller, Impulse Adjusting Instrument Operations manual, 2009). Colloca *et al*. (2005) compared these two types of adjusting instruments, and found that electromechanical instruments produced larger peak forces, had a greater range of forces, were faster and had a more uniform frequency distribution compared to spring activated instruments.

The electromechanical activator adjusting instrument imparts a pre-selected force for each area of the spine. For the SIJs, using the Impulse Adjusting Instrument, the setting allows for a force delivery of 400N with a rapid pulse mode, where 12

consecutive thrusts are delivered (6Hz for 2 seconds) (Colloca and Keller, Impulse Adjusting Instrument Operations manual, 2009). The repeated thrusts are used for inducing further joint motion and resetting neuromuscular reflexes (Introducing Impulse, 2009).

The benefit of using an electromechanical activator device especially for research purposes is that each participant receives a standardised force and impulse duration (Colloca *et al*., 2005), however the force with which the practitioner applies the instrument to the person's skin may vary.

2.9.1.3 Mobilisation

Mobilisation is a manual therapy applied within the physiological passive range of joint motion. It is a technique characterised by a non-thrust, passive joint movement. During mobilisation the joint is taken to its barrier and is repetitively moved along or beside it, this encourages the barrier to recede and break down. It can be applied through grade I to IV moving from small rhythmic amplitudes early in ROM to end ROM. Mobilisation techniques help to loosen and break adhesions and fixations (Hyde and Gengenbach, 2007:232).

The administration of mobilisation is practitioner based and is therefore hard to standardise.

2.9.2 Effects of manipulation

The exact mechanism explaining the effectiveness of SMT is poorly understood (Herzog, Scheele and Conway, 1999; Colloca and Keller, 2001; Koppenhaver *et al*., 2011). However three main theories exist: biomechanical, neurophysiological and muscular reflexogenic (Potter, McCarthy and Oldham, 2005). The effects of manipulation do not occur singularly because there is an intimate reaction between the biomechanics, biochemistry and neurophysiology of the joint and supporting tissues. Therefore although the initial insult may be mechanical, its actions provoke a cascade of biochemical and physiological events (Pickar, 2002; Hyde and Gengenbach, 2007:230). Gillette (1987) suggested that there could be

40 types of mechanoreceptor nerve endings in the superficial and deep tissues of the paraspinal area that have thresholds below the level of mechanical forces applied during SMT that could be activated during a SM.

When SMT is applied to a joint fixation, a vertebral movement is produced, altering the segmental biomechanics of a joint. This reduces strain on the paraspinal tissues and restores zygopophysial joint mobility and joint play (Pickar, 2002), allowing restoration of ROM and alignment (Potter, McCarthy and Oldham, 2005; Hyde and Gengenbach, 2007:228). Changes in spinal ROM have been found following SMT (Suter and McMorland, 2002). A measuring device like the Saunders Digital Inclinometer, which has been shown to be valid and reliable is often used to measure these changes (Newton and Waddell, 1991; Witvrouw *et al*., 2001).

When SMT is applied it activates the tissue mechanoreceptors altering the inflow of sensory information to the CNS which changes reflex pathways and inhibits motor neuron pools leading to a reduction of muscle hypertonicity and pain (Katavich, 1998) and improves the functional ability of the muscles (Potter, McCarthy and Oldham, 2005).

Persistent nociceptive and altered proprioceptive input results in a segmental cord response, leading to the development of pathological somatosomatic and somatovisceral reflexes. If these reflexes persist, they may alter function in the segmentally supplied somatic or visceral structures (Bergmann and Peterson, 2011:45), resulting in pain, discomfort and altered muscle function (Pickar, 2002).

This study used asymptomatic participants, therefore the theories related to pain, such as Melzack and Wall (1965) will not be discussed, but it is acknowledged that the pain spasm pain cycle can persist and result in joint dysfunction.

2.9.2.1 Gamma gain – Korr's theory

According to Korr, when there is a joint fixation the segmental muscles of the spine have an increased gamma gain to restore spindle afferent discharge. This

increased gamma gain increases the alpha motor neuron activity resulting in excessive contraction and restriction of the involved motion segment. When SMT is applied there is a rapid stretch of the extrafusal and intrafusal muscle fibres affecting the MSs producing a bombardment of afferent impulses from group Ia and possibly II afferents to the CNS, which responds appropriately by 'turning down' the gamma efferents, therefore re-establishing normal gamma gain and muscle tone (Korr, 1975; Leach, 2004:151-153; Gatterman, 2005:270-271; Potter, McCarthy and Oldham, 2005).

According to Dishman and Bulbulian (2000), the paraspinal muscles have a relatively high density of MSs, therefore the muscle stretch induced by SMT may alter the mechanical state of the MSs leading to reflex inhibition of the motor neurons and hence reduction of hypertonic musculature.

2.9.2.2 Arthrokinetic reflexes

Sandoz theorises that SMT causes reflex inhibition of hypertonic spinal muscles due to the intense activation of mechanoreceptors induced by the sudden stretch of the spinal joint capsules, ligaments and muscle tendons. This leads to inhibition of motor unit activity in the muscles operating over the adjusted joint, thereby re-establishing normal muscle tone and normalising the dysfunctional arthrokinetic reflex which is the major regulator of muscle tone (Leach, 2004:154). This is supported by the findings of Indahl *et al*. (1997) who investigated the effect of porcine zygopophysial joint injections on needle EMG readings, and demonstrated that stretching of the facet joint led to excitation of the inhibitory interneurons and inhibition of the alpha motor neuron activation, therefore decreasing muscle activation of the paraspinal muscles. This is a theory for what may happen if the facet joint is stretched during HVLA SMT.

Arthrokinetic reflexes are important for manual therapists, as they play a major role in initiating and changing the activity of muscle groups associated with active and passive movements of joints. Afferent discharges from joint receptors exert reflex influences on the activity of limb and paravertebral muscles at spinal and brainstem levels. Arthrokinetic reflexes are coordinated in terms of reciprocal

inhibition and facilitation between different muscle groups over a joint. Mechanoreceptor reflex effects on muscle tone are exerted by afferent impulses from type I and II receptors (see Table 9). Type III receptors are only activated at extremes of joint displacement, causing reflex inhibition of muscles acting over the joint. Loss of normal arthrokinetic reflexes from joint mechanoreceptors due to trauma of a joint leads to abnormalities of limb and spinal posture and movement (Wyke, 1972).

2.9.2.3 Pain-spasm-pain model

The pain-spasm-pain model of musculoskeletal dysfunction indicates that pain leads to muscle hypertonicity (spasm), which in turn causes pain. A hyperactive spinal stretch reflex forms the basis of this cycle. Nociceptive group III and IV afferents excite the gamma motor neuron pool in the SC; this increases the sensitivity of the MSs to stretch, resulting in excitatory input to the alpha motor neurons, which increases muscle activation. This leads to increased muscle stiffness thus completing the pain-spasm-pain cycle (Potter, McCarthy and Oldham, 2005; Clark, 2011; Lehman, 2012).

This is supported by Patterson and Steinmetz (Leach, 2004:154) who determined that a joint fixation can be produced by central or peripheral inputs to segmental circuits, and if there is sufficient stimulus an abnormal reflex can be created in a short time span. According to this, an adjustment breaks the cycle, especially soon after the start of an initiating stimulus. The pain may resolve with time, however, there may still be residual joint dysfunction and muscle spasm following the initial trauma (Haavik-Taylor and Murphy, 2010b).

2.9.2.4 Placebo effect

When one assesses the effects of SMT these can be divided into specific and non-specific. Specific effects include restoring joint motion, reducing muscle hypertonicity and altering neurophysiological effects. Non-specific effects are benefits felt by the patient due to the nature of the healing encounter, such as the

reassurance of laying on of the hands, the 'click' of SMT and the presence of a confident health practitioner (Dugmore, 2006:26).

The physiological effect of the laying on of hands cannot be overlooked. In combination with a skilled evaluation involving palpation for soft tissue changes and altered joint mechanics, the patient becomes convinced of the manual skills of the practitioner. Following examination, if a manipulation is performed resulting in an audible pop, the placebo effect is undeniably high (Hyde and Gengenbach, 2007:230).

2.9.2.5 Research on the neurophysiological effects of SMT

According to Pickar (2002) the biomechanical effects from SMT have the ability to alter the afferent flow of sensory information to the CNS from the spine and its related structures. Reflex responses (as represented in Table 10) to SMT in asymptomatic participants were studied by Herzog *et al*. (1999) using HVLA SM and Symons *et al*. (2000) using activator instrument SM. Both studies found changes in SEMG readings in the limb and back muscles.

Colloca and Keller (2001) (see Table 10) utilised an activator adjusting instrument with a preload controlled frame and an impedance head to deliver SMT to participants with low back pain (LBP). SEMG readings were taken and neuromuscular reflex responses were observed where the thrusts were delivered over the SPs or over bony landmarks beneath the ES muscles. Paraspinal EMG responses were greatest the closer the manipulation was delivered to the electrode site and this was more pronounced in those with chronic low back pain (CLBP) although not statistically significant (p=0.12). These studies failed to use a control group but similar reflex responses were found in symptomatic and asymptomatic populations.

Table 10: Studies assessing reflex responses following SMT.

Reference	Sample size	Design	Intervention	Outcome measures	Results
Colloca and Keller, 2001	20 LBP 1 group	Pre -test post-test experiment	Mechanical force manually assisted (MFMA) SMT of	SEMG readings over the ES muscles bilaterally at L3 & L5	Consistent, relatively localised reflex responses occurred

		al	thoracic, lumbar spine & SIJs.	levels.	in response to localised, brief duration MFMA SMT to the thoracolumbar spine & SIJs.
Symons *et al*., 2000.	9 asympto matic 1 group	Pre -test post-test experiment al.	Activator mediated SMT to the cervical, thoracic, lumbar spine & SIJs.	SEMG readings with 16 bilateral electrodes over the paraspinal & proximal limb musculature before, during & after SMT.	68% of thrusts resulted in a detectable reflex response, occurring close to treatment site ipsilaterally & was detected in muscles which had an origin or insertion at the adjusted level.
Herzog, Scheele and Conway, 1999.	10 asympto matic 1 group	Pre -test post -test experiment al.	Diversified manual SMT to the cervical, thoracic, lumbar spine & SIJs.	SEMG readings with 16 bilateral electrodes over the back & proximal limb musculature.	SMT produced consistent reflex responses in target specific areas.

Pickar and Wheeler (2001) (see Table 11) investigated muscle proprioceptive responses to SM using an electronic feedback control system applied to the spine of an anesthetised cat (feline). The SM load was applied in four phases with durations of 1.0-3.0 seconds for the control phase, 3.0 seconds for the preload phase, 3.0 seconds with a force of 25% body weight for the plateau phase and a duration of 200 ms with a peak force of 100% body weight for the impulse phase. The SM-like load was applied in long axis distraction and compression. During long axis the MSs discharged at rest, preload and during the manipulation, with greater magnitude of discharge frequency during the impulse than the preload. During distraction of the L6-7 facet the MSs fired more frequently than during compression. After the impulse there was a pause in the MSs activity of up to 4 seconds. The GTOs were silent during the rest phase and showed no response to the preload, however during the impulse the GTO afferent activity increased irrespective of distraction or compression of the facet joint. This study indicated that both the preload and the thrust components of a SM result in mechanoreceptor activity. These findings support Korrs theory that an afferent barrage to the CNS could be responsible for the changes induced by SMT.

Pickar *et al*. (2007) investigated the effect of SM amplitude and duration on lumbar paraspinal MSs (see Table 11). SM thrusts (using the same device as above) delivered to an anesthetised cat (feline) of short duration (≤200 ms), similar to a

HVLA manipulation (Pickar and Kang, 2006), were associated with increased MS discharge from the ES muscles as compared to longer thrust durations. In terms of amplitude the spindle afferents were more sensitive to smaller amplitudes (1 mm compared to 2 mm), indicating that the HVLA characteristics of SM affects MS sensitivity (Pickar *et al*., 2007). The findings of Pickar and Kang (2006) supported these findings.

In a similar study Cao *et al*. (2013) further assessed the lumbar MS response to HVLA SM amplitude and duration during vertebral position and movement (see Table 11). Thrust duration did not significantly affect the way the spindles responded but amplitude did (as previously found by Pickar *et al*., 2007). It was suggested that the spindles did not return to their original position after SM but remained slightly stretched which in turn affected the resting spindle discharge, altering sensory input into the CNS. The authors suggested that mechanoreceptors other than MSs may influence the sustained effects of SM.

Table 11: Studies measuring paraspinal muscle spindle activity.

Reference	Sample size	Design	Intervention	Outcome measures	Results
Cao *et al*., 2013.	112 deeply anesthetized cats. 5 cohorts of 20 cats. 1 cohort of 12 cats.	Randomised complete block design.	HVLA SMs delivered by feedback controlled motor to the L6 SP. With the motor in displacement control, a cohort received 1 of 3 displacement amplitudes (1 mm, 2 mm or 3 mm) or with the motor in force control a cohort received 1 of 3 force amplitudes (25%, 55% or 85% of cats body weight). Each cohort received all 8 thrust durations (0/no thrust, 25, 50, 75, 100, 150, 200, 250 ms) each separated by 5 minutes. Before & after each thrust, the motor applied a ramp & hold	Recorded afferent discharge from 112 lumbar paraspinal MSs. Changes in the mean instantaneous frequency were measured at rest, during vertebral movement & in vertebra's new position.	Relatively low-amplitude thrust displacements applied during HVLA SM produced increases in the resting discharge of paraspinal MSs, regardless of the thrust duration applied. Regardless of the HVLA SMs thrust amplitude or duration, the responsiveness of the paraspinal MSs to vertebral movement & to a new vertebral position was not affected.

			displacement to L6, 1.5 mm ventrally for displacement control experiments & 2 mm for force control experiments, & held at new position for 4 seconds.		
Pickar *et al*., 2007.	54 deeply anesthetized cats. 1 group	Randomised block design	Feedback controlled motor delivered impulse thrusts of 12.5, 25, 50, 100, 200 & 400 ms) to L6 SP, & displacing L6 1 mm & 2 mm posteroanteriorly.	Recorded single motor unit activity from dorsal root filaments of MS afferents innervating lumbar paraspinal muscles.	Lumbar paraspinal MS discharge increased as impulse duration decreased. Spindle afferents were almost twice as sensitive to a 1 mm than a 2 mm displacement amplitude.
Pickar and Kang, 2006.	46 deeply anesthetized cats. 1 group	Randomised block design.	SM loads to L6 with impulse durations of 25, 50, 100, 400 & 800 ms, delivered at constant magnitudes of 33%, 66% & 100% body weight.	Neural activity recorded from individual MSs located in multifidus & longissimus.	MS discharge increased as impulse duration decreased. After HVLA SMT spindles often became silent.
Pickar and Wheeler, 2001.	10 deeply anesthetized cats. 1 group	Pre-test post-test experimental	Loads were applied at L6 SP with an electronic feedback control system.	Single unit recordings from MSs & GTOs with receptive fields in paraspinal muscles.	A 200 ms duration HVLA SMT increased discharge frequency of afferent neurons from MSs and GTOS.

Clark *et al*., (2011) (see Table 12), in a case controlled study on symptomatic (LBP) and asymptomatic participants following one lumbar spine HVLA manipulation, found that manipulation did not alter the ES motor evoked potential amplitude or the ES stretch reflex amplitude in either group when assessed 10 minutes after the SM. However, after further analysis of results from participants in whom the SM resulted in an audible release, it was found that there was a 20% decrease in the stretch reflex, indicating that the Ia stretch reflex was activated thus “down regulating the gain of the MSs or other segmental sites for the Ia reflex”. Interestingly this study may show that in order for the stretch reflex to be sufficiently activated there needs to be increased mechanoreceptor firing from more than just the MSs.

Indahl *et al*., (1997) (see Table 12), showed in adolescent pigs that when saline was injected into the zygopophysial joints there was a reduction in the motor unit AP (measured with needle EMG) in the paraspinal muscles within 5 minutes. With the stretch in the facet joint capsule there was decreased paraspinal muscle activity. This suggests that stretching the facet joint capsule initiates afferent impulses from cutaneous receptors, MSs, mechanoreceptors and free nerve endings in the facet joint capsule and spinal ligaments, causing excitation of inhibitory interneurons, which inhibits alpha motor neurons to the paraspinal muscles. The findings of Clark *et al*., (2011) and Cao *et al*., (2013) could support the observation made by Indahl *et al*., (1997) that besides MS activity, the mechanoreceptors of the facet joints need to be activated to allow for the effects of SMT.

Krekoukias *et al*., (2009) (see Table 12) observed statistically significant reductions in the average SEMG activity of the ES muscles in asymptomatic individuals following central posteroanterior (PA) L3 mobilisations with a maximum force of 103 N, compared with control and placebo groups. The greatest decrease in SEMG activity was at L3, then L5, then T10, indicating the effect of PA mobilisation is greatest nearest to where the force is applied. PA mobilisation at L3 with a force of 100 N has been shown to cause segmental movement of the lumbar spine (Keller, Colloca and Beliveau, 2002). It has been suggested that if higher forces were used in this study, a greater difference in SEMG may have been found between the mobilisation group and the placebo and control groups. If segmental movement does occur with 100 N of force with PA mobilisation, this may be responsible for the reduction in SEMG activity, indicating that segmental movement may increase joint afferent activity leading to a reduction in muscle activity.

Table 12: Studies measuring sEMG of paraspinal muscles.

Reference	Sample size	Design	Intervention	Outcome measures	Results
Clark *et al*., 2011.	20 2 groups 10 CLBP 10 asympto	Case-control study.	A single manual HVLA SMT to lumbar spine.	Transcranial magnetic stimulation (TMS) to elicit motor evoked potential (MEPs). Electromechanical	No change in ES MEP & reflex amplitude in CLBP & controls. Those with audible response had a 20%

	matic controls			tapping to elicit short-latency stretch reflexes in ES.	decrease in stretch reflex.
Bicalho *et al*., 2010.	40 2 groups 20 CLBP 20 controls	Random, placebo-, controlled repeated measures	Manipulation group- HVLA SMT to L4-L5 level. Control group- lay in same position.	SEMG activity from left & right ES muscles (L5-S1 level) during flexion-extension cycles.	EMG activity decreased during full flexion static relaxation phase & extension phase in intervention but not control group. No change in either group for flexion phase.
Krekoukias *et al*., 2009.	36 asymptomatic 3 groups	Random, placebo-controlled, repeated measures.	Placebo: lay prone. Control: lay prone with finger on L3 for 2 minutes. Mobilisation group: Central PA mobilisation to L3 for 2 minutes.	SEMG resting levels were taken while subject stood erect before & after intervention over the ES muscles at T10, L3 & L5	Central PA mobilisation of L3 results in a statistically significant decrease in SEMG of ES muscles.
Lehman and McGill, 2001.	14 LBP	Analytic cohort, with a convenience sample	Manual side posture lumbar SM.	Lumbar spinal curvature before & after lumbar SM. SEMG over rectus abdominus, external oblique & ES whilst performing 3 tasks: flexion-extension, lateral bend & axial twist immediately before & after lumbar SM.	No consistent kinematic or electromyographic changes occurred following SM.
Indahl *et al*., 1997.	23 adolescent pigs. 1 group	Pre -test post-test experimental.	Injected physiological saline into the zygopophysial joint.	Measured muscle activity using needle EMG into the mulitifidus & longissimus bilaterally at L4-L5 before & after saline injection.	EMG activity decreased in the paraspinal muscles. This may be due to stretching of the zygopophysial joint.

Several studies, as shown in Table 13, (Murphy, Dawson and Slack, 1995; Dishman and Bulbulian, 2000; Dishman, Cunningham and Burke, 2002; Dishman and Burke, 2003; Dishman, Dougherty and Burke, 2005; Fryer and Pearce, 2012) have assessed tibial nerve Hoffman-reflexes (H-reflexes) in asymptomatic participants following SMT and/or mobilisation of the lumbosacral spine and demonstrated significant but transient attenuation of the lumbar region alpha motoneuronal excitability resulting in short-term motor neuron inhibition. These results indicate that SMT may lead to short-term inhibitory effects on the motor system (Dishman and Bulbulian, 2000).

The tibial nerve H-reflex response is a neurophysiological indicator of the alpha motoneuron pool excitability as a result of lumbosacral SMT. Ia afferents from the triceps surae muscle activate the alpha motoneuron pool of the lumbosacral spine. Thus, the amplitude of the tibial nerve H-reflex response is reduced or enhanced if the activation of proprioceptive afferents following lumbosacral SMT inhibits or excites the alpha motoneuron pool, thus indicating the neurophysiological response of SMT and/or mobilisation. In these studies there is a reduction in alpha motoneuron excitability, suggesting that lumbosacral SMT stimulates sensory receptors in the lumbosacral segmental region, affecting their sensory input and resulting in a change in the motor output, namely, inhibition at the same segmental level.

Table 13: Studies assessing tibial nerve H-reflexes following SMT or mobilisation of the lumbosacral spine in asymptomatic participants.

Reference	Sample size	Design	Intervention	Outcome measures	Results
Fryer & Pearce, 2012.	14 asymto-matic 2 groups	Randomised controlled crossover design.	SMT group: Manual HVLA SMT L5-S1. Control group: lateral recumbent position for 45 seconds, no SMT. One week later subjects received opposite interventions.	TMS to elicit MEPs & H-reflexes to measure spinal reflex excitability immediately before & after intervention.	HVLA SMT applied to L5-S1 joint produced a significant decrease in corticospinal and spinal reflex excitability. No significant change occurred after the control.
Dishman, Dougherty and Burke, 2005.	Exp 1: 34 (17 in each group). Exp 2: 20 (10 in each group). Asympt-omatic	Pre-test post-test experimental repeated measures and between subjects.	Experiment 1: Group 1: Joint preload & SMT with pelvic assist. Group 2: Joint preload & SMT without pelvic assist. Experiment 2: Group 1: L5-S1 side-posture SMT Group 2: side posture.	Tibial nerve H-reflexes before & after prone HVLA SMT. Tibial nerve H-reflexes before & after side posture HVLA SMT & side posture positioning.	H-reflex decreased 18.2% in assisted SMT & 9.5% in unassisted SMT. Smaller decreases were observed in joint preloading. Decreases were greater after L5-S1 SMT than side-posture positioning.
Dishman and Burke, 2003.	9 asympt-omatic 1 group	Repeated measures, experimental	Manual HVLA cervical (C5-C6) & lumbar (L5-S1) SMT on different days with 48 hours between	Measured motoneuron pool excitability using H-reflex of the median & tibial nerve	Significant transient decrease in motoneuron excitability. Lumbar SMT had greater

			each.	respectively.	suppression.
Dishman, Cunningham and Burke 2002.	36 asympt-omatic 3 groups Each group n= 12	Random, pre-test post-test experimental, comparative study.	Group 1: lumbar spine SMT (L5-S1). Group 2: cervical spine SMT (C5-C6). Group 3: lumbar & cervical SMT (All manual SMT).	H-reflex technique of the tibial nerve, which measures motoneuron pool excitability by peripheral nerve Ia afferent fibre stimulation.	Lumbar SMT had a transient but significant decrease in the lumbar region motoneuron pool. Cervical SMT had an insignificant effect on lumbar motoneruon pool.
Dishman & Bulbulian, 2000.	17 asympt-omatic Group 1 (10) Group 2 (7)	Pre-test post-test repeated measures experimental	Group 1: Bilateral manual L5-S1 HVLA SM. Group 2: Lumbar spinal mobilisation without thrust, then within 1 hour lumbar SM with thrust	Tibial nerve H-reflex technique to assess alpha motoneuron activity of the lumbosacral spine, before & immediately after intervention, then at 5, 10, 15 & 20 minutes.	SM with a thrust & mobilisation without thrust resulted in a significant, transient decrease in alpha motoneuronal excitability.
Murphy, Dawson and Slack, 1995.	34 asympt-omatic Manip-ulation group (n=18) Sham group (n=16)	Pre-test post-test experimental repeated measures.	Manipulation group- SIJ manipulation. Sham group- Sham SIJ manipulation. Repeated measures after applying a local anesthetic cream over SIJ.	Measured motoneuron pool excitability using H-reflex of the tibial nerve.	H-reflex significantly decreased in ipsilateral leg following SIJ manipulation. No change after sham. Same results with anesthetic cream.

In other investigations into the effect of SM in the cervical spine in participants with neck pain and stiffness (Haavik-Taylor and Murphy, 2007, 2008, 2010a and 2010b) (see Table 14), SM has been shown to modify transmission in neural circuits at a cortical level by improving the ability of the CNS to filter somatosensory information in sensorimotor integration circuits. The results indicate that cervical SMT affects central neural processing and thereby improves motor control. Somatosensory information is extremely important for motor control; the various sensorimotor processing circuits that make up the sensorimotor integration system continuously monitor and respond to peripheral sensory input by altering connectivity and strength of synaptic connections. Joint dysfunction due to an injury may be a cause of pain and loss of function, and can have an effect on central neural processing, as abnormally functioning spinal segments can lead to altered afferent input to the CNS, and may lead to maladaptive central plastic changes (Haavik-Taylor and Murphy, 2007). These changes may result in

abnormal responses, such as the way the CNS receives and processes sensory input, and hence may affect motor control. These studies suggest that if the reduced sensorimotor filtering after motor training represents a process that could lead to maladaptive plastic changes in the CNS, and spinal dysfunction is a component that enables this dysfunction to develop, then this process may be avoided by treating the dysfunctional joint using SMT. In the study by Haavik-Taylor and Murphy (2010a) this was found to be possible, as an improved ability to filter somatosensory information in sensorimotor integration circuits was observed after the same 20 minute motor training task, when this was preceded with SM of the subjects' dysfunctional cervical joints. Haavik-Taylor and Murphy (2008) observed muscle specific changes after SMT of dysfunctional cervical joints, which indicates that spinal dysfunctions may lead to muscle-specific alterations in intracortical inhibitory and facilitatory processing and motor control. Thus, SMT may reverse these maladaptions in sensorimotor integration and thereby improve motor control.

Table 14: Studies investigating effects of SMT on central sensorimotor integration.

Reference	Sample size	Design	Intervention	Outcome measures	Results
Haavik-Taylor and Murphy, 2010a.	11 Recurrent neck pain &/stiffness. Pain free at time of study. 1 group	Randomised crossover study design.	Motor training (thumb abductions). Motor training & cervical HVLA SMT to dysfunctional segments.	Recorded 3 somatosensory evoked potentials (SEPs) (stimulation of median, ulnar & both nerves simultaneously) before & immediately after motor training or SMT & motor training.	Motor training- decreased suppression of dual input at cortical level for at least 20 minutes after stopping typing task. SMT & motor training- significantly increased suppression of dual input at cortical level.
Haavik-Taylor and Murphy, 2010b.	13 Recurrent neck pain &/stiffness. Pain free at time of study. 1 group	Randomised crossover study design.	Cervical HVLA SMT to dysfunctional segments. Control-passive head movement which occurs when setting up a patient for cervical SMT.	Recorded 3 SEPs (stimulation of median, ulnar & both nerves simultaneously) before & immediately after SMT or control intervention.	Single cervical SMT session led to improved suppression of SEPs, evoked by dual upper limb nerve stimulation. No changes in control intervention.
Haavik-Taylor and Murphy, 2008.	12 Recurrent neck pain &/stiffness. Pain	Randomised crossover study design.	Cervical HVLA SMT to dysfunctional segments. Control-passive head movement	Short interval intracortical inhibition (SICI), short interval intracortical facilitation (SICF), MEPs & cortical silent	Cervical SMT- increase in SICF, decrease in SICI & shortening of CSP in APB. Decrease in SICF& lengthening of CSP in EIP. No

	free at time of study. 1 group		which occurs when setting up a patient for cervical SMT.	periods (CSPs) recorded from abductor pollicus brevis (APB) & extensor indices proprios (EIP) after single & paired pulse TMS of contralateral motor cortex.	changes in control intervention.
Haavik-Taylor and Murphy, 2007.	24 Recurrent neck pain &/stiffness. Pain free at time of study. SMT group (12). Control group (12).	Pseudo-randomised study design.	SMT group: Cervical HVLA SMT to dysfunctional segments. Control group- passive head movement (setting up a patient for cervical SMT).	Spinal, brainstem and cortical SEPs to median nerve stimulation were recorded before & for 30 minutes after a single session of cervical spine manipulation or passive head movement.	Single session of cervical SMT led to attenuated cortical SEPs lasting 20minutes after SMT. No changes in control group.

When assessing the effect of SMT on muscle function, many studies have found a transient decrease in SEMG activity or motor neuron inhibition immediately following SMT. Keller and Colloca, (2000) (see Table 15) found that SMT to the thoracolumbar spine, SIJ and sacrum resulted in statistically significant ($p < 0.001$) increases in SEMG ES output during maximum voluntary contractions (MVCs) post-SM when compared to a placebo and a control group in LBP subjects, indicating that SMT altered muscle function. The participants were required to perform three consecutive MVC isometric trunk extensions of three to five seconds duration, with three to five seconds rest in between each one, while simultaneously recording SEMG output of the ES muscles. The SMT group received a short duration (<5 ms) SM with a peak force of 150 N to the thoracolumbar spine, SIJs and sacrum using an activator. The sham SMT group received a sham SMT thrust with the activator set on zero force, and the control group lay prone for 20 minutes. Each group repeated the three consecutive MVC isometric trunk extensions immediately following their interventions. These increases in SEMG output after SMT, and increased strength of the ES muscles, suggest that a potential benefit of SMT may be an improvement in the muscles' functional ability.

Harvey and Descarreaux (2013) (see Table 15) assessed the effect of SM on ES SEMG and lumbopelvic kinematics and found that the control group had significant increases of SEMG during the 30 minute post-test of flexion-extension movements compared to the SM group. The significance of this study is that it may indicate that SM alters the recruitment ability of the ES muscles. The clinical implication of this is that repeated movements result in fatigue so if SM can improve the ability of a muscle to resist fatigue the implications are significant.

Bicalho *et al*., (2010) (see Table 12) investigated the effect of SM on ES activity during a set of trunk flexion-extension cycles. The SM group showed significant decreases in the static relaxation phase and the extension phase showing that SM was able to reduce abnormal EMG activity. This is contrary to the results of Lehman and McGill (2001) (see Table 12) in a similar study who found no immediate effect on dynamic flexion or extension. Bicalho *et al*., (2010) proposed the mechanism was decreased alpha motor unit activity such as occurs in postural maintenance or increased alpha motor unit inhibition as reported post SM. The participants were LBP sufferers for whom higher resting ES activity levels had been reported. Therefore, according to Dishman, Dougherty and Burke (2005), SM results in motor neuron inhibition related to the muscles supplied by that segment.

Suter *et al*., (2000) (see Table 15) investigated the effect of SM in knee extensor muscle inhibition in participants with anterior knee pain. It was observed that there was a significant decrease in presenting muscle inhibition of the knee-extensor muscles following SIJ manipulation of the ipsilateral leg. This was associated with increases in knee-extensor force during maximal knee extensor contractions but this was not significant. Similarly, Suter and McMorland (2002) (see Table 15) found that muscle inhibition found in participants with chronic neck pain decreased after SM with an associated short term increase in elbow flexor strength. These studies reported that by manipulating the spine there was a change in sensory input that may have resulted in a changed efferent pathways at that segmental level. This may affect body parts distal to the spine.

Koppenhaver *et al*., (2011) (see Table 15) observed an increase in lumbar multifidus (LM) muscle thickness using ultrasound, and increased ability of this muscle to contract following two sessions of lumbosacral SMT applied over a week in participants with LBP. These studies show the potential for SM to alter the function of muscles either directly related to the spine or within the extremities (i.e. motor neural pool).

Table 15: Studies measuring muscle function following SMT.

Reference	Sample size	Design	Intervention	Outcome measures	Results
Harvey and Descarreaux, 2013.	60 LBP 2 groups Experimental group (30) Control group (30)	Control group study	Experimental group: L3 SMT. Control group: same position, no SMT.	SEMG of ES at L2 & L5. Kinematic data to evaluate lumbo-pelvic kinematics during 5 flexion-extension movements before, immediately after, as well as 5 minutes & 30 minutes after SMT.	Control group showed a significant increase in EMG activity during the last block (30 minutes) of flexion-extension movements at flexion & full-flexion at L2. Did not observe a decrease in EMG activity following SMT.
Koppenhaver *et al*., 2011.	78 LBP 1 group	Prospective cohort.	3 sessions in 1 week: Session 1: Ultrasound imaging of muscles & lumbosacral SMT. Session 2: repeat of session 1. Session 3: Ultrasound measurements.	Measured thickness of the transverse abdominus (TA), internal oblique (IO) & LM muscles using ultrasound imaging during the 3 sessions, during rest & 2 different submaximal contractions at L4-L5 & L5-S1 levels.	Increases in thickness of contracted LM muscles after 1 week associated with large improvements in LBP-related disability. Significant decreases in TA & IO thickness immediately after SMT, but transient & unrelated to clinical improvements.
Suter and McMorland, 2002.	16 Chronic neck pain 1 group	Pre-test post-test experimental	SMT at C5/C6 & C6/C7 levels.	Biceps activation during 3 elbow flexor MVCs assessed using interpolated twitch technique, EMG, cervical ROM & pressure pain thresholds using goniometer before & after SMT.	Significant reduction in biceps inhibition on both sides & an increase in biceps force. Cervical ROM & pain pressure thresholds increased significantly.
Suter *et al*., 2000.	28 Anterior	Randomised controlled,	Treatment group: SIJ	Knee extensor strength measured	Significant decrease in muscle inhibition

	knee pain (unilateral or bilateral) 14 treatment group 14 control group	double-blinded.	manipulation on ipsilateral side to injured knee. Control group: No SIJ manipulation.	by a dynamometer, muscle inhibition using interpolated twitch technique & muscle activation using SEMG was measured during 3 maximal-effort isometric knee-extensor contractions, before & after SIJ manipulation or control.	of 7.5% in involved legs & no change in contralateral legs of treatment group. No change in muscle inhibition of control group in both legs. No statistically significant changes in knee-extensor moments or muscle activation in either group.
Keller and Colloca, 2000.	40 LBP SMT group (20) Sham-SMT group (10) Control group (10)	Prospective clinical trial.	SMT group: MFMA SMT to thoracolumbar & SIJs. Sham SMT group: sham SMT thrust with the setting on zero. Control group: lie quiet for 20mins, no SMT.	SEMG readings of ES muscles at L3 & L5 levels during MVC trunk extension tasks before & immediately after the intervention.	MFMA SMT results in a significant increase in SEMG ES isometric MVC muscle output compared to pre-SMT MVCs. No change for sham SMT & control groups.

The studies presented show that there are neurophysiological changes following spinal manipulation with some studies showing how this could affect muscle function. This study aims to add to the literature by determining if there is a change in lumbar extensor muscle endurance following SIJ manipulation.

CHAPTER THREE: METHODOLOGY

3.1. Introduction

This chapter outlines the study design, participant recruitment, interventions, data collection and analysis procedures employed in this study.

3.2. Study design

The study was designed as a randomised, placebo-controlled pre-test post-test experimental trial.

The study was approved by the Institutional Research Ethics Committee (IREC 066/13) of the Durban University of Technology (DUT) (Appendix I) and was registered on the South African Clinical Trials register (registration number: DOH-27-0114-4604) (Appendix K). The study was conducted at the DUT Chiropractic Day Clinic, after permission was obtained from the Clinic director (Appendix H).

3.3 Study population

Participants were recruited from the Greater Durban area for this research project.

3.4 Sampling procedure

3.4.1 Sample size

A sample size of 40 participants was selected for this study based on similar studies in the literature (Keller and Colloca, 2000; Colloca and Keller, 2001; Krekoukias *et al*., 2009; Bicalho *et al*., 2010) and a power analysis which was performed on changes in the Biering-Sorensen (B-S) test for extensor muscle endurance which indicated a sample size of 11 per group.

3.4.2 Sample allocation

Participants were randomly allocated to one of two groups by using a random allocation chart (Brink, 2006:128; Esterhuizen, 2013):

- Group 1 - Intervention group (n=20)
- Group 2 - Placebo group (n=20)

If a participant/s dropped out of the study or were excluded a new participant/s were recruited in their place. The original randomisation table was used to allocate the six extra participants into the intervention and placebo groups, using the same numbers (i.e.: Group 1 and Group 2) that were allocated to the excluded participants in a consecutive order.

Six participants were excluded from the study as during the B-S extensor endurance test one participant experienced calf cramp, one participant experienced pain in their foot due to the ankle strap, and four participants lost concentration. These incidents could have skewed the results therefore they were excluded. Six more participants were recruited in their place as displayed in Figure 10.

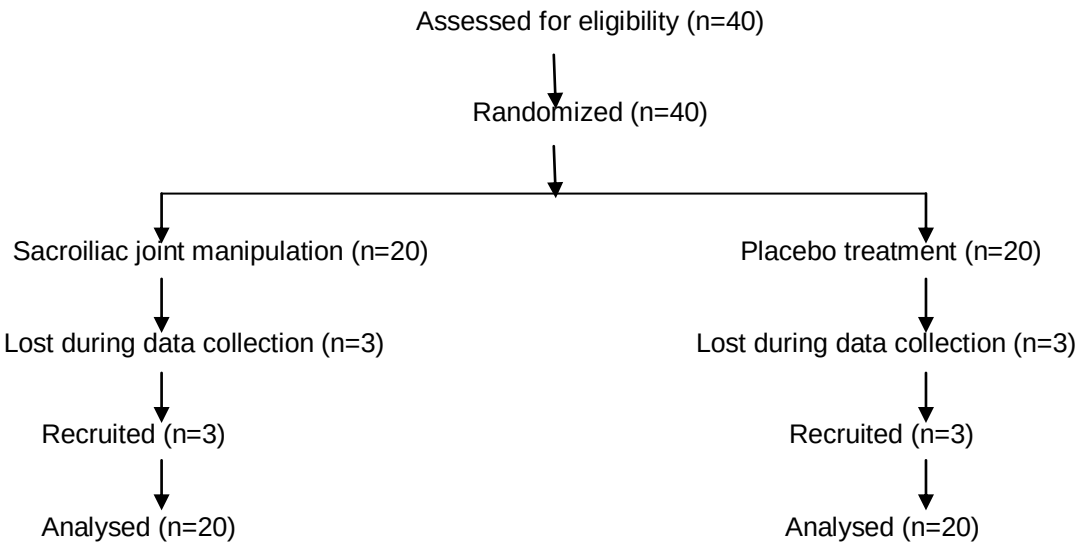


Figure 10: CONSORT flow diagram of participation in the research study (CONSORT flow diagram, 2010).

3.4.3 Sample recruitment

Advertisements (Appendix A) were placed in and around the DUT campus, the Chiropractic Day Clinic at the DUT, local sports clubs and places of communal gathering and through word of mouth. Permission was obtained to place advertisements prior to them being displayed (Appendix G).

Respondents to the advertisements contacted the researcher telephonically and were asked a series of qualifying questions to determine their eligibility to partake in the research (Table 16).

Table 16: Qualifying questions regarding eligibility.

Questions asked of respondents	Expected answers from the respondents to qualify to participate in the study.
Would you be willing to answer a few questions in order to determine your eligibility into the study?	Yes
Are you currently healthy?	Yes
Are you male?	Yes
Are you between the ages of 20 and 40 years old?	Yes
Are you right handed?	Yes
Have you experienced any low back pain in the last three months?	No
Do you know your weight and height in order for me to calculate your body mass index (BMI)?	Participant was to be between 18.5 and 24.9 kg/m^2.
Have you had any major spinal traumas, spinal surgeries, or suffer from any chronic illnesses?	No

If the respondent did not meet the above criteria they were thanked for their time, and if necessary referred to an appropriate facility for further investigation or treatment. If the respondent fulfilled the criteria and was interested in being involved in the research, an appointment was scheduled at the DUT Chiropractic Day Clinic. The participant was informed that they needed to be available for two and a half hours for the initial consultation.

At the initial consultation the respondent was given a Letter of Information and Informed Consent (Appendix B) along with a verbal explanation of the research and what was expected of the participant. The participant was informed that they

were free to withdraw from the study at any time, and that this would not jeopardise any future treatments at the Chiropractic Day Clinic. If the participant wished to withdraw from the study, they were thanked for their time and were allowed to leave.

The participants were given the opportunity to ask any questions regarding the study, which were then answered by the researcher. When all questions were answered, the participant was required to complete and sign the Letter of Information and Informed Consent.

Those agreeing to participate underwent a case history (Appendix C), physical examination (Appendix D), lumbar and pelvic regional examination (Appendix E).

3.4.4 Sample characteristics

Participants had to have the following characteristics in order to be included in the research:

3.4.4.1 Inclusion criteria

1. Participants read, agreed to and signed the Letter of Information and Informed Consent (Appendix B).
2. Participants were all male for homogeneity of the sample, as differences between males and females have been shown when performing the B-S extensor endurance test.
3. Participants were between the ages of 20 and 40 years old (Jette *et al*., 1994). This age range excludes the need for parental consent (MRC of SA, 2002-2004) and was selected to reduce the likelihood of the participants having degenerative changes (Beers *et al*., 2006:295).
4. Participants had to be right handed for homogeneity.
5. Participants had to have a BMI between 18.5 kg/m² and 24.9 kg/m² to ensure accurate readings from the surface electromyograpic (SEMG) unit.
6. Participants had to have held the B-S extensor muscle endurance test for less than 176 seconds, as a failure to maintain the contraction for at least

176 seconds demonstrates decreased extensor muscle endurance (Kankaanpää et al., 1998; Demoulin et al., 2006).

7. Participants had to be free of low back pain (LBP) for a duration of at least three months.
8. Participants had a sacroiliac joint (SIJ) restriction determined by motion palpation, performed according to Chiropractic technique: Principles and procedures (Bergman and Peterson, 2011:271-272). A research assistant verified the SIJ restriction to ensure reliability.
9. Participants had to have hypertonicity of the paraspinal muscles, verified by paraspinal muscle length assessment in Functional soft tissue examination and treatment by manual methods (Hammer, 2007:527).

3.4.4.2 Exclusion criteria

1. Medical conditions which could make physical activity unsafe for the participant, including but not limited to hypertension, cardiac or respiratory disease, musculoskeletal disorders and neurological symptoms (Champagne, Descarreaux and Lafond, 2009).
2. Significant trauma affecting the low back, or if the clinical assessment warranted that the participant needed radiographic analysis.
3. Previous spinal surgery.
4. On-going treatment for LBP by other health care providers.
5. Any mechanical or manual intervention to the thoracic or lumbar spine three weeks prior to the study.
6. The use of any muscle relaxants for any reason within 72 hours (three day) wash out period before commencement of the study (Seth, 1999:9).
7. Contraindications to SIJ manipulation (as was determined by the case history, physical and regional examination) including, but not limited to:
    - Metabolic disorders (osteoporosis, osteomalacia, clotting disorders);
    - Abdominal aortic aneurysm;
    - Tumours (thyroid, lung, breast and bone);
    - Bone infections (osteomyelitis, tuberculosis);

- Arthritis (rheumatoid arthritis, psoriatic arthritis);
- Traumatic injuries (fractures, instability, severe sprains and strains);
- Neurological complications (Gatterman, 1990:67-68; Bergmann and Peterson, 2011:93).

8. Contraindications to surface electromyography (SEMG) including, but not limited to:
    - Skin irritation, which does not occur from the hypoallergenic self-adhesive electrodes which were used in this study;
    - Open wounds, rashes, psorasis or skin conditions of any kind in the region of electrode placement.

3.5 Measurement tools

3.5.1 Subjective data

Subjective data was obtained pre-intervention and post-intervention whilst the participant performed the B-S extensor endurance test, by asking the participant to verbally communicate if there was any discomfort or pain whilst performing the test. The time at which this was felt was recorded.

3.5.2 Objective data

Objective data was obtained using the B-S extensor endurance test, SEMG, the digital inclinometer and paraspinal muscle length assessment pre-intervention and post-intervention, and the Pressure Biofeedback Unit (PBU) pre-intervention.

3.5.2.1 Biering-Sorensen extensor endurance test

This test was performed as outlined in Chapter Two, with the use of a tactile feedback method. The endurance time was determined as the time instant when the participant could no longer hold the horizontal position, and the contact between the T7 vertebra and the rope was lost (Demoulin *et al*., 2006) (Figure 11).

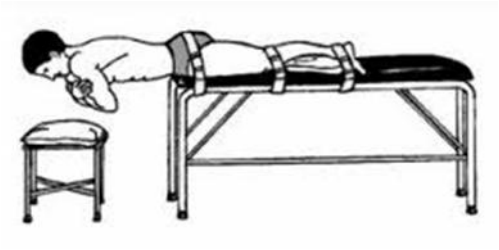


Figure 11: Biering-Sorensen extensor endurance test (Biering-Sorensen test, 2013).

3.5.2.2 Surface electromyography (SEMG)

The Neuro Trac^{TM} ETS® unit (Verity Medical LTD, Uplands Place, Drove Road, Chilbolton, England, ISO9001:2000, MDD93/42/EEC) was utilised to obtain the data using the EMG mode. It was used to determine the endurance time and fatigability of the extensor muscles. The Neuro Trac^{TM} ETS® unit was linked up to a PC using the training template mode, which was set for 5 minutes, and recorded the endurance time and the mean microvolts (mVs) (Neuro TracTM ETS®: Operators manual, 2007:15). Self-adhesive hypo-allergenic surface electrodes (VS.30 30 mm diameter round) were used (Neuro Trac^{TM} ETS®: Operators manual, 2007:23).

The pairs of electrodes were placed bilaterally at the level of T10 and L3 (Dolan and Adams, 1993; Mannion *et al*., 1997; Dolan and Adams, 1998) with an inter-electrode distance of approximately 3.5 cm (Krekoukias *et al*., 2009) in the midline of the muscle belly (De Luca, 1997). The electrode Channel A and Channel B was always used on the left and right side respectively. The black and red surface electrodes were placed bilaterally on either side of T10 and L3 respectively.

The lights were turned off, and there was no conversing during the test to reduce any affects this may have on the SEMG readings. The Neuro Trac^{TM} ETS® may be affected by electrical interference while using the EMG mode. The power supplies of some notebook computers can give off substantial amounts of interference. To reduce the probability of interference, the power cable from the notebook was run as far away as possible from the subject's connection wires of the Neuro Trac^{TM} ETS®. The Neuro Trac^{TM} ETS® was kept as close to the subject's body as possible (alongside the participant on the examination table).

The electrode wires were run along the surface of the subject's body, in order to keep them as close to the surface of the subjects body as possible all the way from the electrodes to the Neuro Trac^{TM} ETS®, and not dangling free in the space away from the subject as indicated by the Neuro Trac^{TM} ETS®: Operators manual (2007:27).

3.5.2.3 Digital Inclinometer

Prior to these measurements being taken, the researcher explained the use of the digital inclinometer, and the participant was shown the spinal movements required namely flexion and extension. The measurements were taken on a flat, firm surface. The spinal movements occurred from a neutral position according to the methods outlined in the Saunders Digital Inclinometer User's Guide (1998:6). Each measurement was taken three times and the average of these was calculated.

3.5.2.4 Pressure Biofeedback Unit (PBU)

Participants were taught to recruit the transversus abdominis (TA) muscle using the four point kneeling procedure according to Therapeutic exercise for spinal segmental stabilization in low back pain - Scientific basis and clinical approach (Richardson *et al*, 1999:110). In this procedure the participant's hips were over the knees, the shoulders directly over the hands and the elbows relaxed. Participants were instructed to avoid deep inspiration, in order to minimise movement of the abdominal wall. Participants were then instructed to take a relaxed breath in and out, and without breathing in, draw the abdomen up and in towards the spine, whilst maintaining a neutral steady position of the spine. Participants resumed normal breathing once the contraction had been elicited, and this was sustained for 10 seconds. This allowed the participants to gain an increased awareness of the abdominal wall, and as such, the contraction being performed.

The abdominal draw in test also outlined in Therapeutic exercise for spinal segmental stabilization in low back pain - Scientific basis and clinical approach (Richardson *et al*, 1999:111), was performed with the participant in the prone position. The PBU was placed under the abdomen of the participant, with the

umbilicus in the centre of the bag, and the inferior distal margins of the bag in line with the right and left anterior superior iliac spines. The pressure bag was inflated to 70 mmHg, and allowed to stabilise, allowing for detection of fluctuations of approximately 2 mmHg for each inhalation and exhalation, as a result of normal breathing (Richardson *et al*, 1999:113).

Participants were instructed to perform a contraction. A drop of 6-10 mmHg with contraction is considered normal, indicating that the participant was able to contract the TA muscle independently of the global abdominal muscles. Failure to create a sufficient drop in pressure may be due to an inability to activate the TA muscle, or recruitment of the global abdominal muscles. In this study if the participant was able to perform the TA muscle contraction effectively with a drop of 6-10 mmHg it was graded as 'good', all other readings were considered 'poor' (Richardson *et al*, 1999:114).

3.5.2.5 Paraspinal muscle length assessment

This measurement was taken pre-intervention to determine whether the participant had hypertonicity of the paraspinal muscles in order to be included in the study, and was then repeated post-intervention to determine whether there was any change.

The paraspinal muscle length assessment was performed according to Functional soft tissue examination and treatment by manual methods (Hammer, 2007:527), in which the participant was seated with legs fully flexed off the edge of the table. The researcher stood behind the participant and palpated the anterior superior iliac spine (ASIS) bilaterally. The participant was instructed to tilt their pelvis posteriorly, flattening the lumbar lordosis and creating lumbar flexion. They were told to flex forward and attempt to bring their forehead to their knees, and form a 'C' shaped curve, not simply flex from the hips. The researcher felt when the ASISs began to move, indicating the end of thoracolumbar flexion. The participant had paraspinal hypertonicity if they were unable to bring their forehead within 10 inches (25.4 cm) of the knees, measured using a measuring tape. The researcher

made certain no knee flexion occurred and movement originated from the thoracolumbar spine only.

3.6 Intervention

In the intervention group (Group 1) and the placebo group (Group 2), the side to be manipulated was determined by motion palpation with the sacral push and standing upper SIJ mobility tests as outlined in Chiropractic technique: Principles and procedures (Bergmann and Peterson, 2011:271-272); the research assistant verified the SIJ restriction to ensure reliability.

3.6.1 Sacral push

The participant was asked to sit with their arms crossed over the front of their chest contacting the shoulders. The researcher stood behind the patient and established bilateral thumb contacts across the patient's SIJs and sacral ala. The participant was then asked to extend back and rotate to the right and then the left around the researcher's thumbs. With normal motion of the SIJs and lumbosacral base the researcher's thumbs should move forward symmetrically. Restricted anterior gliding of the sacral base may indicate an SIJ restriction (Bergmann and Peterson, 2011:271).

3.6.2 Upper sacroiliac joint mobility

The participant was asked to stand and support himself by contacting the wall with both hands. The researcher kneeled behind the participant and established thumb contacts on the participant's posterior superior iliac spine (PSIS) and second sacral tubercle. The participant was then instructed to flex the ipsilateral hip to approximately 90 degrees, keeping his knee bent, which induces flexion of the hip and SIJ. With normal movement, the researcher's thumbs should approximate as the PSIS moves posteriorly and inferiorly towards the relatively stationary second sacral tubercle. An SIJ flexion restriction was suspected when the thumbs did not approximate and the pelvis rotated obliquely around the opposite hip. The participant was then instructed to flex the contralateral hip to approximately 90

degrees, keeping his knee bent, which induces extension of the ipsilateral hip and SIJ. With normal movement, the researcher's thumbs move apart as the PSIS moves anteriorly and superiorly away from the second sacral tubercle. An SIJ extension restriction was suspected when the researcher's thumbs did not move apart. This procedure was then repeated on the opposite side to establish if there was an SIJ restriction on the opposite side (Bergmann and Peterson, 2011:272).

3.6.3 Group 1: Sacroiliac joint manipulation

Group 1 received a SIJ manipulation administered by the research assistant utilising the Impulse Adjusting Instrument (Colloca and Keller, 2009) as outlined in the Impulse Adjusting Instrument Operations manual (Colloca and Keller, 2009:1). The Force Adjustment Switch was placed in position 3, this activated the high force setting which administers 400 Newtons and is appropriate for the SIJs. With the participant in the prone position, the Impulse Adjusting Instrument was placed in contact with the PSIS, using an anterosuperior and medial to lateral line of drive (The Neuromechanical System, 2008). Preload was applied prior to the application of the thrust. The Preload Control Nosepiece was pressed down until the spring was fully compressed. The LED light adjacent to the Force Adjustment Switch turned from amber to green when the preload spring was maximally compressed providing visual feedback to the research assistant that tissue compression, commonly known as a tissue pull in chiropractic techniques, had been achieved. The research assistant held down the Electronic Trigger, which initiated the rapid pulse mode where 12 consecutive thrusts were delivered into the SIJ (6 Hz, 2 seconds). Repeated thrusts are used for inducing further joint motion and for resetting neuromuscular reflexes (Introducing Impulse, 2009).

3.6.4 Group 2: Placebo treatment

Group 2 received a placebo treatment performed by the research assistant using the Impulse Adjusting Instrument, with the participant in the prone position. The Impulse Adjusting Instrument was placed in contact with the PSIS. The Preload Control Nosepiece was pressed down until the spring was fully compressed. The LED light adjacent to the Force Adjustment Switch turned from amber to green. In

order for the participant to hear the clicking noise a second Impulse Adjusting Instrument was activated that had no contact with the participant therefore allowing for the participant to hear the noise but not receive the treatment.

3.7 Blinding

Blinding is used in research to minimise bias and to increase the validity of the results (Dugmore, 2006:33). In this study double blinding was utilised, as both the researcher and the participant were unaware of which group the participant was allocated to. One research assistant who is a chiropractic student registered for their M.Tech Chiropractic, and who is doing a similar study, allocated the participants to one of two groups using a computer generated random allocation chart (Brink, 2006:128; Esterhuizen, 2013) that was provided by the statistician. They were responsible for administering the interventions while the researcher stepped out of the room.

3.8 Research procedure

Once the participant had met all the requirements and was included in the study, measurements of TA contractibility was assessed using the PBU, and lumbar active ranges of motion in flexion and extension was taken using the digital inclinometer and the paraspinal muscle length assessment was taken, and recorded on the data collection sheet (Appendix F). The participant was taught how to perform the B-S extensor endurance test correctly by the researcher. The skin where the surface electrodes were placed was cleaned with alcohol, and when necessary any participants with hairy skin were shaved using a disposable razor (DeVocht, Pickar and Wilder, 2005; Bicalho et al, 2010). Each participant had their seventh and tenth thoracic vertebrae (T7 and T10) and third lumbar vertebrae (L3) marked using a water soluble marker with an ‘X’ over the spinous process (DeVocht, Pickar and Wilder, 2005). The pairs of SEMG electrodes were placed as explained above.

The Neuro Trac^{TM} ETS® unit was switched on, selecting the EMG mode. The EMG Threshold Level was then set up. This is a target at which the participant

strives to achieve when performing the muscle contraction. To set up the Threshold Level (THRS) the participant was asked to perform the B-S test in order to contract the extensor muscles, hold this position for approximately 5 seconds, then relax between 5 to 10 seconds before repeating the same extensor muscle contraction. This microvolt reading was displayed on Channel A. The researcher then calculated the average of the two peak readings, and 40% of this reading was the threshold level. The researcher adjusted the threshold setting to this value (at the top of the LCD screen) by pressing either the B-THRS+ or the B-THRS- buttons according to the Neuro Trac™ ETS: Operators manual (2007:15).

The correct EMG parameters for the Neuro Trac™ ETS® had to be set, by pressing the SET button until the researcher got to WDE FLTR or NRW FLTR on the LCD screen, and by pressing the B+ or B- button in order to select the narrow filter (NRW FLTR) which is appropriate for use over the back in order to eliminate interference from the heart as shown in the Neuro Trac™ ETS: Operators manual (2007:17).

The Neuro Trac™ ETS® PC program was set on the training template mode, which was set for 5 minutes. The participant was instructed to perform the B-S extensor endurance test, and timed using the Neuro Trac™ ETS® PC program, to determine how long they were able to hold this position for, using the tactile feedback method. The Neuro Trac™ ETS® PC program was only activated by the researcher once the participant had made contact with the rope; a break in contact with the rope indicated the end of the test, and the Neuro Trac™ ETS® PC program was stopped immediately. The Neuro Trac™ ETS® PC program simultaneously recorded the mean microvolts (mVs) in order to determine the fatigability of the paraspinal muscles.

The participant was then given 15 minutes to recover from the B-S extensor endurance test, as this was determined as the amount of time taken for muscles to fully recover from fatigue (Larivière *et al*., 2003). The participant continued to lie in the prone position during this recovery time.

The participant was given the intervention, either the SIJ manipulation or the placebo treatment of the SIJ according to which group they were randomly allocated to.

Immediately post-intervention (not more than one minute) the participants in both groups re-performed the B-S extensor endurance test monitored by the Neuro Trac^{TM} ETS® unit and program to determine the endurance time and mean microvolts (mVs). Measurements of lumbar active ranges of motion in flexion and extension and the paraspinal muscle length assessment were taken (Appendix F).

The research assistant was used in this study to verify SIJ restriction and to verbalise to the researcher the exact moment when the participant broke contact with the rope in order for the researcher to stop the recordings on the PC program.

Flow diagram of research procedure:

Participant responds to the advertisement.
Inclusion or exclusion of the respondent telephonically and appointment scheduled.
↓
Participant arrives at the Chiropractic Day Clinic.
↓
Research procedure explained to the participant.
↓
Letter of Information and Informed Consent read and signed by the participant (Appendix B).
↓
Case history (Appendix C), physical examination (Appendix D) and lumbar and pelvic regional examination (Appendix E) are completed including a BMI calculation for each participant and recorded on the data collection sheet (Appendix F).
↓
SIJ restriction was identified and verified by the research assistant.
↓

Measurements of TA contractibility were assessed using the PBU, lumbar active ranges of motion in flexion and extension were taken using the digital inclinometer, and the paraspinal muscle length assessment was taken, all of which were recorded on the data collection sheet (Appendix F).

↓

Participants were taught how to perform the B-S extensor endurance test correctly by the researcher.

↓

Electrodes were placed as explained above.

↓

The threshold level and the correct EMG parameters were set.

↓

Participant was instructed to perform the B-S extensor endurance test, and was timed using the Neuro Trac^{TM} ETS® unit and program, to determine how long the participant was able to hold the position (endurance time) using the tactile feedback mechanism, while simultaneously recording the mean microvolts (mVs) to determine the fatigability of the paraspinal muscles.

↓

The participant remained prone and was given 15 minutes to recover from the B-S extensor endurance test.

↓

The participant was given the intervention; according to which group they were allocated to. They received either the SIJ manipulation or the placebo treatment of the SIJ, performed by the research assistant.

↓

Immediately post-intervention, not more than one minute, the participants in both groups re-performed the B-S extensor endurance test monitored by the Neuro Trac^{TM} ETS® unit and program to determine the endurance time and mean microvolts (mVs). Measurements of lumbar active ranges of motion in flexion and extension and the paraspinal muscle length assessment were taken (Appendix F).

3.9 Ethical considerations

Participants signed a letter of information and informed consent (Appendix B) at the initial consultation.

Participants were asymptomatic. However, if any illness or pathology was diagnosed at the initial consultation or during the research process, the participant would be suitably referred.

The testing of extensor muscle endurance via the B-S extensor endurance test and measurement of muscle fatigue by SEMG has no known risk factors, and was done under the supervision of the researcher. If the participant developed pain, stiffness or discomfort in the lower back region during or within 24 hours after the study, they were examined and treated by the researcher using conventional chiropractic treatment such as spinal manipulative therapy, mobilisation, dry needling, soft-tissue therapies and electrical modalities (Dagenais *et al*., 2010) as deemed appropriate by the researcher, or they were referred appropriately if needed.

The participant had a 50% chance of being placed in the placebo group, but they were all asymptomatic and therefore treatment was not being withheld.

If the participant wished to withdraw from the study, they were free to do so at any point, with no adverse consequences.

All participant information was kept confidential and will be stored securely in the Department of Chiropractic and Somatology for 15 years, after which it will be shredded. All data was collected in a manner that ensured participant information was kept confidential.

The research study was conducted at the Chiropractic Day Clinic under permission from the clinic director, and was under the indemnity cover relating to the Chiropractic Day Clinic.

3.10 Data storage and analysis

Data recorded from the participants for the duration of the study was stored on the Neuro Trac^{TM} ETS® software system, which was password protected. All the names of the participants were coded to ensure confidentiality. The data was collected and transferred onto a data collection sheet (Appendix F). Once the study was completed the data was transferred onto a hard drive, which was also password protected, and deleted off the software system. All participant information and research data will be kept securely for 15 years in the Department of Chiropractic and Somatology and will be disposed of after this time.

The data was analysed using IBM* SPPS Statistics version 21 and SATA11. A p value <0.05 was considered as statistically significant. Quantitative outcome data was tested using Q-Q plots and formal quantitative normality tests (Kolmogorov-Smirnov test). The majority of the variables were acceptably normally distributed and met the assumptions to perform parametric tests. Paired t-tests were used to compare pre and post measurements within a group and independent t-tests were used to assess between group differences. The repeated measures ANOVA was used to compare the change in the two time points between the two treatment groups (intervention and placebo) (McCaul, 2014).

CHAPTER FOUR: RESULTS

4.1 Participant characteristics

4.1.1 Age

The age range for the combined study sample was 20 to 40 years. The mean age for the intervention group was 26.95 (±4.63) years and the placebo group was 27.8 (±3.96) years, resulting in a mean age difference of 0.85 years. There were no statistically significant differences between the groups in terms of age (p = 0.537, t-test).

4.1.2 Height, weight and body mass index (BMI)

There were no statistically significant differences between the groups for height, weight and body mass index (BMI) as displayed in Table 17.

Table 17: Height (m), weight (kg) and body mass index (BMI) (kg/m²) per group.

Category	Group	n	Mean	SD	CI	*p*- Value
Height (m)	Intervention	20	1,78	0,05	1,75 - 1,81	0,709
	Placebo	20	1,77	0,06	1,74 - 1,80	
Weight (kg)	Intervention	20	72,77	9,33	68,51 - 76,99	0,725
	Placebo	20	73,78	8,58	69,89 - 77,66	
BMI (kg/m²)	Intervention	20	22,78	2,36	21,72 - 23,85	0,466
	Placebo	20	23,27	1,80	22,46 - 24,09	

(paired two tailed t-test)

4.1.3 Transversus abdominis contractibility

Participants were graded as having either ‘good’ or ‘poor’ transversus abdominis (TA) contractibility. The ability of the participant to reduce the pressure by 6-10

mmHg was considered a ‘good’ test, all other readings were considered ‘poor’. There were no statistically significant (p = 0.197; t-test) differences between the groups in terms of TA contractibility, with 60% of the population having a good core rating (Table 18).

Table 18: Transversus abdominis contractibility grading per group.

Core assessment	Intervention		Placebo	
	N	%	n	%
Good	10	50	14	70
Poor	10	50	6	30

4.2 Subjective pain measurement

Only one participant, who was in the control group, experienced pain during the baseline assessment of the Biering-Sorensen (B-S) extensor endurance test, following the intervention this same participant reported pain on the post- B-S extensor endurance test. Indicating no change in the subjective pain measure.

4.3 Paraspinal muscle length assessment (cm)

Both groups showed a decrease in the measurement which indicates an improvement in the paraspinal muscle length following the intervention as seen in Table 19.

Table 19: Paraspinal muscle length assessment results (cm).

Group	Pre-intervention			Post-intervention			p-value
	Mean	SD	CI	Mean	SD	CI	
Intervention	30,75	3,99	28,88 - 32,61	27,62	3,48	25,99 - 29,25	<0,001**
Placebo	30,89	3,69	29,17 - 32,61	28,43	4,43	26,36 - 30,50	0,005**
p-value	0,909*			0,527*			
	0,539***						

*independent two tailed t-test
**paired two tailed t-test
***Repeated measure ANOVA

4.4 Lumbar extensor muscle endurance (seconds)

The groups were comparable at baseline, with the intervention group showing improved endurance time compared to the placebo group which showed a decrease in endurance time as represented in Table 20.

Table 20: Lumbar extensor muscle endurance results (seconds).

Group	**Pre-intervention**			**Post-intervention**			**p-value**
	Mean	**SD**	**CI**	**Mean**	**SD**	**CI**	
Intervention	60,25	20,28	50,76 - 69,74	69,6	19,60	60,43 - 78,78	0,027**
Placebo	58,75	26,94	46,14 - 71,36	53,8	23,78	42,67 - 64,93	0,081**
p-value	0,843*			0,276*			
	0,004***						

*independent two tailed t-test
**paired two tailed t-test
***Repeated measures ANOVA

4.5 Electromyographic readings (mVs)

The mean electromyographic readings for channel A and channel B increased for both groups post-intervention as seen in Table 21.

Table 21: Electromyographic readings results (mVs).

Group		Pre-intervention			Post-intervention			p-value
		Mean	SD	CI	Mean	SD	CI	
CH A	Intervention	148,48	42,28	128,69 - 168,27	154,14	46,90	132,19 - 176,09	0,054**
	Placebo	140,22	41,70	120,71 - 159,74	153,33	47,16	131,26 - 175,40	0,002**
	p-value	0,538*			0,956*			
		0,112***						
CH B	Intervention	136,61	42,15	116,90 - 156,33	142,27	42,89	122,20 - 162,34	0,035**
	Placebo	144,84	68,58	112,74 - 176,94	152,76	67,53	121,16 - 185,36	0,021**
	p-value	0,065*			0,56*			
		0,575***						

*independent two tailed t-test
**paired two tailed t-test
*** Repeated measures ANOVA

4.6 Active lumbar spinal range of motion (degrees)

Extension range of motion increased for both groups, flexion increased for both groups but this was not statistically significant, as seen in Table 22.

Table 22: Active lumbar spinal range of motion results (degrees).

Range of motion (degrees)	Group	Pre-intervention			Post-intervention			p-value
		Mean	SD	CI	Mean	SD	CI	
Flexion	**Intervention**	28,50	7,06	25,20 - 31,80	29,20	6,92	26,00 - 32,44	0,069**
	Placebo	28,55	5,66	25,90 - 31,20	29,20	5,71	26,53 - 31,87	0,061**
	p-value	0,980*			1*			
		0,919						
Extension	**Intervention**	46,85	6,69	43,72 - 49,98	51,5	6,83	25,96 - 32,44	<0,001**
	Placebo	46,25	7,07	42,94 - 49,56	51,1	8,19	47,27 - 54,94	<0,001**
	p-value	0,784*			0,868*			
		0,876***						

*independent two tailed t-test
**paired two tailed t-test
***Repeated measure ANOVA

CHAPTER FIVE: DISCUSSION

5.1 Participant characteristics

This study controlled the following variables: sex, age, height, weight, body mass index (BMI) and paraspinal muscle length to attempt to limit their impact on the independent variable. Age was limited to 20 and 40 years as people older than 40 years of age have been documented to have a higher risk of degenerative changes (Beers *et al*., 2006:295), which may have influenced their lumbar range of motion scores and their ability to perform the Biering-Sorenson (B-S) extensor endurance test (Champagne, Descarreaux and Lafond, 2009). Participants recruited for this study were only included if they had a BMI of between 18.5 kg/m² and 24.9 kg/m², which is considered normal (Smolin and Grosvenor, 2008:270) as surface electromyographic (SEMG) readings have been shown to be affected by larger BMIs (Baars *et al.*, 2006). By controlling for these variables it decreases the external validity of the results as the results are only able to be generalised to populations meeting these criteria. There were no differences between the groups in terms of the participant characteristics therefore making the groups comparable.

Transversus abdominis (TA) contractibility was not a controlled variable in this study, but it was measured. The core musculature is important in controlling functional stability around the trunk and spine (Akuthota and Nadler, 2004). The TA muscle is considered an important core muscle. A 'poor' abdominal draw-in test measured using the Pressure Biofeedback Unit (PBU) denotes the inability to contract the TA muscle (Richardson *et al.*, 1999:114). Therefore a 'poor' test may indicate that the spine may have less functional stability whilst performing the B-S extensor endurance test. This in turn may overload the paraspinal muscles resulting in fatigue and reduced ability of the extensor muscles to maintain an isometric extension contraction. Indicating TA contractibility may have affected the results of the study. In this study there were no differences between the groups in terms of their ability to contract the TA muscle, indicating that this was not a factor in the results obtained, however it is possible that there may have been other core

muscles which were not functioning properly which may have influenced the results.

5.2 Discussion of the results

5.2.1 Subjective pain measurement

All of the participants involved in this study were asymptomatic in terms of pain; however they were required to have a sacroiliac joint (SIJ) restriction and paraspinal muscle hypertonicity. The B-S extensor endurance test is generally considered a safe test for both healthy individuals and research participants (Pitcher, Behm and MacKinnon, 2007), with no reports of persistent adverse effects such as pain exacerbation (Demoulin *et al.*, 2006). Two participants experienced adverse reactions to performing the test, and were excluded from the study, one participant developed calf cramp and the other developed foot pain from the ankle strap during the test. The adverse reactions were transient and did not result in long term problems, indicating that the B-S extensor endurance test is safe to perform as the literature suggests (Demoulin *et al,* 2006; Pitcher, Behm and MacKinnon, 2007).

This outcome was included as it was hypothesised that since the participants had joint dysfunction that it was likely that on an exertion test, like the B-S test, they may experience pain. The researcher then wanted to determine if the participant experienced pain if it changed post-manipulation. Only one person experienced pain, which occurred in the low back on the pre- B-S test however the same pain was present on the post B-S test, indicating that no change in pain occurred. This indicated that although the participants had joint dysfunction of the SIJs it did not affect their ability to perform in a pain-free manner the B-S test.

5.2.2 Paraspinal muscle length assessment

The length-tension relationship of a muscle has been shown to affect its ability to perform. When muscles contract only the myosin heads that are within the zone of

overlap in the sarcomere can bind to active sites and produce tension. In hypertonic muscles the sarcomere is in a shortened state; the thick filaments crumple as they are compressed by the Z discs, fewer myosin heads of the thick filaments are able to bind with the active sites on the thin filaments, and the tension the muscle may produce decreases (Tortora and Derrickson, 2006:302). All the participants in this study had paraspinal hypertonicity and therefore limited flexibility. The results showed no significant difference between the groups in terms of this measure at baseline or following the interventions. However both groups showed a decreased in the paraspinal muscle length assessment which means an increase in paraspinal muscle flexibility and reduced hypertonicity. If this measurement is accurate and muscle length did improve then this proves that hypertonicity decreases post-SMT. This is supported by Katavich (1998) as when SMT is applied it activates tissue mechanoreceptors, such as muscle spindles (MSs), of which the paraspinal muscles have a relatively high density (Dishman and Bulbulian, 2000). The muscle stretch induced by spinal manipulative therapy (SMT) may alter the mechanical state of the MSs (Dishman and Bulbulian, 2000), which alters the inflow of sensory information to the central nervous system (CNS) and changes reflex pathways leading to reflex motor neuron inhibition and reduced muscle hypertonicity (Katavich, 1998). This is supporting by other studies which have demonstrated short-term motor neuron inhibition following SMT related to the muscles supplied by that segment (Murphy, Dawson and Slack, 1995; Dishman and Bulbulian, 2000; Dishman, Cunningham and Burke, 2002; Dishman and Burke, 2003; Dishman, Dougherty and Burke, 2005; Fryer and Pearce, 2012).

However some problems were encountered when implementing this assessment. Firstly, the participants were instructed to tilt their pelvis posteriorly, flattening the lumbar lordosis. The researcher then instructed the participant to stop flexing when through manual palpation the anterior superior iliac spines (ASISs) bilaterally began to move, indicating the end of thoracolumbar flexion. This made the measure subjective which may have influenced the accuracy of the results. Secondly, this measurement was taken using a tape measure from the forehead to the knees; the positions from which the measurements were taken may have not been exact in each and every participant, and this may have resulted in less accurate results.

5.2.3 Lumbar extensor muscle endurance and electromyography

The B-S test is frequently used in the clinical setting to determine isometric extensor muscle endurance (Moreau *et al*., 2001; Demoulin *et al*., 2006). In this study the mean endurance times of the participants were found to be 60.25 seconds (s) and 58.75s pre-intervention and 69.6s and 53.8s post-intervention for the intervention and placebo groups respectively. These scores are much lower when compared to other studies of asymptomatic participants which range from 132.6s to 198s (Biering-Sorensen, 1984; Mannion *et al*, 1997; Latimer *et al*., 1999).Women have been shown to perform the test for longer periods of time, with less progressive decreases in the median frequency slope on SEMG, suggesting women are more fatigue resistant than men (Mannion *et al*., 1997; Kankaanpää *et al*., 1998). Only males were used in this study in order to have a homogenous sample, this may account for reduced endurance time when compared to other studies involving females only (Mannion et al., 1997) or a mixed group of males and females (Latimer et al., 1999).

Methodological variations may have contributed to reduced endurance time. Many studies use motivation and verbal encouragement during the B-S test (Mannion et al., 1997; Kankaanpää et al., 1998; Coorevits et al, 2008; Mannion et al., 2011). Strong verbal encouragement to continue throughout the extensor endurance test has been shown to be a contributing factor towards an increased endurance time (Kankaanpää et al., 1998). Other studies have also used a once off notification during the test if the test position was not maintained. If the subject was unable to regain this position following the notification, the test was ended (Kankaanpää et al., 1998; Latimer et al., 1999). In this study the participant was told before commencement of the B-S test, to hold the horizontal position for as long as possible until fatigue. No verbal encouragement or notifications were used if this position was not maintained and as a result may have resulted in the low score obtained by the participants in this study. Some participants also had difficulty in distinguishing the tactile feedback used during the B-S test. Therefore they may have been able to hold the endurance test for a longer period of time, but did not realise that they were not making contact with the rope. A break in contact with the rope indicated the end of the test.

Inactive participants have also demonstrated statistically significant lower endurance times than active subjects (Moffroid et al., 1994). Since fitness levels were not taken into account, this may have produced highly variable results, and perhaps decreased the mean endurance times overall.

The shorter endurance times may have affected the results of the study; however, the B-S tests pre- and post-intervention were conducted in an identical way and therefore should not have affected the difference in mean endurance times between the B-S test pre-intervention and post-intervention.

Endurance is a favourable characteristic for the paraspinal muscles to possess due to their postural role (Richardson *et al*., 1999:25). SMT has been associated with a neuromuscular reflex, which leads to the reduction of muscle hypertonicity and pain, as well as increasing the functional capacity of muscles (Symons *et al.*, 2000). Studies have demonstrated the existence of this reflex following manual and activator assisted SMT in asymptomatic and low back pain (LBP) individuals (Herzog *et al*., 1999; Symons *et al.*, 2000; Colloca and Keller, 2001).

In this study the participants had paraspinal muscle hypertonicity and following SIJ manipulation the paraspinal muscle endurance time improved significantly, compared to the placebo group whose endurance time decreased (although not significantly from baseline measurement). This indicates that the SMT may have played a role in increasing the endurance capabilities of the paraspinal muscles, compared to the placebo group who only received the preload force. SMT may have altered the recruitment ability of the paraspinal muscles making them more resistant to fatigue. The decreased endurance time in the placebo group may simply be an artefact of muscle fatigue, which further strengthens the results of the intervention group, as SMT may have allowed them to overcome the fatigue. However, it was not possible to assess motor unit recruitment, therefore it cannot be established whether more motor units were recruited or if the motor units that were active you able to fire more effectively. This was demonstrated in a study by Harvey and Descarreaux (2013) in which the control group showed significantly higher SEMG activity during a 30 minute post-test of flexion-extension movements

when compared to the SMT group. According to the authors SMT had appeared to have altered the recruitment ability of the paraspinal muscles making them more fatigue resistant.

The increased endurance capacity of the paraspinal muscles may also be due to SMT altering the sensory input, leading to motor neuron inhibiton and decreased hypertonicity in the muscle supplied by that same segmental level. If this does occur following SMT, the paraspinal muscles will be in a more relaxed and lengthened state and closer to resting length. The sarcomere will be closer to its resting length and the zone of overlap will be closer to optimal, more myosin heads would be able to bind to active sites on the thin filaments, and the paraspinal muscle fibres would be able to produce greater tension and contract more efficiently (Tortora and Derrickson, 2006:302) resulting in better muscle performance. Several studies have shown a significant short-term inhibition of alpha motoneuronal excitability in the lumbar region following SMT and/or mobilisation of the lumbosacral spine in asymptomatic individuals measuring the tibial nerve Hoffman-reflex (H-reflex) (Dishman and Bulbulian, 2000; Dishman, Cunningham and Burke, 2002; Dishman and Burke, 2003; Dishman, Dougherty and Burke, 2005; Fryer and Pearce, 2012). Murphy, Dawson and Slack (1995) reported motoneuron inhibition of up to 15 minutes following SIJ manipulation, attributed to the discharge properties, quantity and distribution of the mechanoreceptors in this larger less mobile joint, compared with those of the smaller more mobile zygopophysial joints. This suggests that SMT stimulates mechanoreceptors in the lumbosacral region, affecting sensory input which alters motor output at the same segmental level, causing motoneuron inhibition and a reduction of paraspinal muscle hypertonicity at that segmental level. This supports Korr's theory in which a bombardment of afferent impulses to the CNS, leads to the reflex inhibition of the alpha motoneurons and reduction of hypertonicity (Leach, 2004:151-153; Gatterman, 2005:270-271).

It has been indicated that the effect of SMT on motoneuron activity is more likely caused by joint and muscle mechanoreceptors rather than cutaneous receptors which are stimulated by manual contact. When comparing SIJ manipulation during two experimental trials, one using a local anesthetic cream over the SIJ and one

without, it was found that similar changes in the H-reflex were observed in both groups, indicating that cutaneous receptors are not likely to be involved in the changes mediated by SMT (Murphy, Dawson and Slack, 1995). In a study comparing massage therapy of the paraspinal muscles to SMT, massage therapy did not lead to a decrease in motoneuron activity (Dishman and Bulbulian, 2001). Pickar and Wheeler (2001) showed that during a spinal manipulation (SM) the Golgi tendon organs (GTOs) were generally silent during rest and preload, and their afferent activity increases during the impulse thrust, whereas the muscle spindles (MSs) had a resting discharge which increased 30% during preload and 200% during the impulse thrust. This indicates that mechanoreceptor afferent activity is much greater during the impulse thrust than during the preload phase.

The placebo in this study utilised the Impulse Adjusting Instrument which was placed in contact with the skin over the SIJ with slight tissue tension. This contact with the skin would have increased the afferent activity of the cutaneous receptors, and the MSs may also show increased afferent activity (Pickar and Wheeler, 2001). However, as the afferent activity of the MSs increase to a much smaller degree in the preload phase and the GTOs show no increased activity during preload, this most likely led to less of an effect on alpha motoneuron activity and therefore less effect on paraspinal muscle functionality, possibly leading to greater paraspinal muscle fatigue and decreased extensor muscle endurance.

The effect observed in the placebo group may also be explained by the development of muscle fatigue from performing the B-S test, where the endurance score would have decreased on the second test. This supports the muscle fatigue resistant effects observed by Harvey and Descarreaux (2013) post SMT.

In terms of electromyography, no statistically significant difference was found between the groups, but in both groups the mean channel A and B SEMG readings increased. The increase in SEMG readings observed in the intervention group may have been attributed to either increased or more efficient motor recruitment, which enabled the muscles to endure the isometric contraction for longer periods of time compared to the placebo group, hence the intervention group had improved strength and functionality of the paraspinal muscles.

However, the placebo group's mean sEMG readings in channel A and B also increased. This may have been due to paraspinal muscle fatigue during the second B-S test, leading to an increased need for the recruitment of additional motor units in order to maintain the holding position.

The SEMG readings were only taken once the patient had made contact with the rope i.e. when the muscle was contracted. As a result changes to the resting SEMG readings were not available. Increased EMG activity has been observed in the paraspinal muscles in LBP patients (Fryer, Morris and Gibbons, 2004), and several studies show a reduction in SEMG readings of the paraspinal muscles in LBP patients following SMT (Lehman, Vernon and McGill, 2001; DeVocht, Pickar and Wilder, 2005; Lalanne, Lafond and Descarreaux, 2009). However, these studies assessed the SEMG changes immediately post SMT or mobilisation in LBP patients and asymptomatic individuals, while the participant was at rest or standing. As readings for the present study were taken once the isometric contraction was initiated, comparison with these studies is difficult.

The effects of SM on paraspinal SEMG activity may be associated with increases in muscle strength. Suter *et al.*, (2000) investigated patients with symptomatic SIJ dysfunction, anterior knee pain and signs of muscle inhibition of the knee-extensor muscles. SIJ manipulation of the ipsilateral leg resulted in a significant decrease in the knee-extensor muscle inhibition. Similarly, Suter and McMorland (2002) found a decrease in muscle inhibition and a short term increase in elbow flexor strength following SM in patients with chronic neck pain. A study by Keller and Colloca, (2000) found that manually assisted SMT to the thoracolumbar spine, SIJ and sacrum resulted in statistically significant ($p < .001$) increases in SEMG readings during isometric trunk extension maximum voluntary contractions of the paraspinal muscles when compared to a placebo and control group, indicating that SMT improved strength of the paraspinal muscles.

These studies indicate that SM of the spine may lead to a change in sensory input, resulting in a changed motor output at that segmental level. This changed motor output was observed as increased muscle strength and hence improved

functionality of these muscles. These studies support the findings of the current study, as an increase in SEMG readings was observed in the intervention group.

5.2.4 Active lumbar spinal range of motion

Changes in range of motion (ROM) after manipulation and/or mobilisation are controversial. Goodsell, Lee and Latimer (2000) observed that ROM of the lumbar spine did not improve following posteroanterior (PA) mobilisation in LBP patients, whereas Konstantinou *et al.* (2007) showed that lumbar mobilisations produced immediate statistically significant increases in lumbar ROM in LBP subjects compared to the placebo. Stamos-Papstamos, Petty and Williams (2011) investigated lumbar rotational manipulation and PA mobilisations on flexion and extension ROM, however no significant difference was found.

In the current study, although not significant when compared to each other the extension lumbar spinal ROM measure for both the intervention and the placebo group increased. This result was surprising because as the paraspinal muscle length increased post-intervention, one would have expected the flexion ROM to increase to the same extent. This improved extension may be due to the performance of the isometric extension contraction during the B-S extensor endurance test for the second time, as the muscles and joints had sufficiently warmed up, and therefore the extension movement may have been easier to perform.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Sacroiliac joint manipulation was effective in increasing immediate post-intervention lumbar extensor muscle endurance. This finding supports previous research that spinal manipulation may result in neurophysiological changes that may be responsible for altering muscle function. The results should be viewed with caution due to the small sample size however future research should be conducted to verify these findings in a larger sample.

6.2 Limitations

The following limitations were identified:

1. The small sample size (n=40) in this study may have limited the ability to obtain surface electromyographic (SEMG) readings. .
2. The SEMG unit used in this study was only able to determine the mean readings whereas the literature most commonly refers to the median SEMG frequency to measure fatigability of the paraspinal muscles (Farina and Merletti, 2000). However, the mean frequency has similar properties to the median frequency (Farina and Merletti, 2000) this may have had an impact on the study.
3. This study was conducted on asymptomatic participants; it is acknowledged that the results may not apply to symptomatic individuals.
4. Only the immediate effect of the intervention was assessed, therefore whether the effect was sustained over a period of time is unknown.

6.3 Recommendations

The recommendations arising from this study are:

1. Use a larger sample size to increase the validity of the SEMG results.

2. Include a follow up measurement to determine the short and long term effect.
3. Compare different types of spinal manipulative therapies and symptomatic to asymptomatic participants to determine if the effect is different.
4. Measure the SEMG of the paraspinal muscles throughout the research protocol, from before the first Biering-Sorensen (B-S) test to the end of the second B-S test in order to capture the SEMG readings at rest, during the isometric contraction to determine the effect of the sacroiliac joint (SIJ) manipulation on the muscles, and then through the isometric contraction again. This will provide a more comprehensive picture of the electrical activity of the muscles throughout the research activity.
5. Use a more sophisticated SEMG unit.
6. Some participants had difficulty in distinguishing the tactile feedback used during the B-S test. Future studies should modify this technique.
7. Future studies should include a mechanism, such as motion palpation following the manipulation, to reassess whether joint manipulation has occurred.
8. A cross-over design in which the 20 participants that received the SIJ manipulation, received the placebo treatment of SIJ after an appropriate wash out period. For the participants originally assigned to the placebo group vice versa. This would have given substantial credibility to the study design and strength of the results.
9. Future studies should include a longer recovery time following the endurance test, as 15 minutes may not be sufficient for the muscle to fully recover from fatigue.

REFERENCES

Akuthota, V., Nadler, SF. 2004. Core strengthening. *Archive of Physical Medicine and Rehabilitation*, 85(1): S86-92.

A 'typical' spinal nerve with a cross-section of the spinal cord (image). 2014. Available: http://operationalmedicine.org/blog3/study-guides/guide-11a-nervous-system/ (Accessed 31 January 2014).

Baars, H., Jollenbeck, T., Humberg, H., Schroder, J. 2006. Surface-electromyography: Skin and subcutaneous fatty tissue attenuate amplitude and frequency parameters. *Proceedings of the XXIV International Symposium on Biomechanics in Sports* (Salzburg, Austria).

Becker, I., Woodley, S.J., Stringer, M.D. 2010. The adult human pubic symphysis: A systematic review. *Journal of Anatomy*, 217(5): 475–487.

Beers, M.H., Porter, R.S., Jones, T.V., Kaplan, J.L., Berkwits, M. 2006. *The Merck manual of diagnosis and therapy.* 18th ed. White House Station NJ: Merck and Co., Inc.

Bell, J.A., Burnett, A. 2009. Exercise for the primary, secondary and tertiary prevention of low back pain in the workplace: A systematic review. *Journal of Occupational Rehabilitation,* 19(1): 8-24.

Bergmann, T.F and Peterson, D.H. 2011. *Chiropractic technique: Principles and procedures*. 3rd ed. St Louis MO: Mosby Elsevier.

Bernard, J-C., Bard, R., Pujol, A., Combey, D., Boussard, C., Begue, C., Salghetti, A.M. 2008. Muscle assessment in healthy teenagers: Comparison with teenagers with low back pain. *Annales de réadaptation et de medécine physique,* 51(4): 274-283.

Bicalho, E., Setti, J.A.P., Macagnan, J., Cano, J.L.R., Manffra, E.F. 2010. Immediate effects of high velocity spine manipulation in paraspinal muscle activity of nonspecific chronic low-back pain patients. *Manual Therapy*, 15(5): 469-475.

Biering-Sorensen, F. 1984. Physical measurements as risk factors for low back trouble over a one year period. *Spine*, 9(2): 106-119.

Biering-Sorensen test (image). 2013. Available: http://www.docstoc/Biering-sorensen. (Accessed 15 April 2013).

Bogduk, N. 2005. *Clinical anatomy of the lumbar spine and sacrum.* 4th ed. Philadelphia: Elsevier.

Brink, H. 2006. *Fundamentals of research methodology for health care professionals. 2nd* ed. Cape Town: Juta and Co.

Bronfort, G., Haas, M., Evans, R.L., Bouter, L.M. 2004. Efficacy of spinal manipulation and mobilization for low back pain and neck pain: A systematic review and best evidence synthesis. *The Spine Journal*, 4(3): 335-356.

Burke, L., Deakin, V. 2010. *Clinical sports nutrition.* 4th ed. Sydney: McGraw Hill Medical.

Cao, D., Reed, W.R., Long, C.R., Kawchuk, G.N., Pickar, J.G. 2013. Effects of thrust amplitude and duration of high-velocity, low-amplitude spinal manipulation on lumbar muscle spindle responses to vertebral position and movement. *Journal of Manipulative and Physiological Therapeutics,* 36(2): 68-77.

Champagne, A., Descarreaux, M., Lafond, D. 2009. Comparison between elderly and young males' lumbopelvic extensor muscle endurance assessed during a clinical isometric back extension test. *Journal of Manipulative and Physiological Therapeutics,* 32(7): 521-526.

Clark, N. 2008. *Sports nutrition guidebook.* Champagne IL: Human Kinetics.

Clark, B.C., Goss Jr, D.A., Walkowski, S., Hoffman, R.L., Ross, A., Thomas, J.S. 2011. Neurophysiologic effects of spinal manipulation in patients with chronic low back pain. *BMC Musculoskeletal Disorders*, 12: 170.

Colloca, C.J., Keller, T.S. 2001. Electromyographic reflex responses to mechanical force, manually assisted spinal manipulative therapy. *Spine*, 26(10): 1117-1124.

Colloca, C.J., Keller, T.S. 2009. Impulse Adjusting Instrument operations manual. Arizona: Neuromechanical Innovations.

Colloca, C.J., Keller, T.S. 2009. *Impulse Adjusting Instrument*. US patents: 7,144,417 and 8,083,699.

Colloca, C.J., Keller, T.S., Black, P., Normand, M.C., Harrison, D.E., Harrison, D.D. 2005. Comparison of mechanical force of manually assisted chiropractic adjusting instruments. *Journal of Manipulative and Physiological Therapeutics*, 28(6): 414-422.

CONSORT flow diagram (online). 2010. Available: http://www.consort-statement.org/ (Accessed 15 May 2014).

Coorevits, P., Danneels, L., Cambier, D., Ramon, H., Druyts, H., Karlsson, J.S., De Moor, G., Vanderstraeten, G. 2008a. Test-retest reliability of wavelet and Fourier based EMG (instantaneous) median frequencies in the evaluation of back and hip muscle fatigue during isometric back extensions. *Journal of Electromyography and Kinesiology,* 18(5): 798-806.

Coorevits, P., Danneels, L., Cambier, D., Ramon, H., Vanderstraeten, G. 2008b. Assessment of the validity of the Biering-Sorensen test for measuring back muscle fatigue based on EMG median frequency characteristics of back and hips muscles. *Journal of Electromyography and Kinesiology,* 18(6): 997-1005.

da Silva, R.A., Arsenault, A.B., Gravel, D., Laviriere, C., de Oliviera, E. 2005. Back muscle strength and fatigue in healthy and chronic low back pain subjects: A comparative study of three assessment protocols. *Archives of Physical Medicine and Rehabilitation,* 86(4): 722-729.

Dagenais, S., Caro, J., Haldeman, S. 2008. A systematic review of low back pain cost of illness studies in the United States and internationally. *The Spine Journal*, 8(1): 8-20.

Dagenais, S., Gay, R.E., Tricco, A.C., Freeman, M.D., Mayer, J.M. 2010. NASS contemporary concepts in spinal care: Spinal manipulation therapy for acute low back pain. *The Spine Journal*, 10(10): 918-940.

De Luca, C.J. 1997. The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics,* 13(2): 135-163.

Demoulin, C., Vanderthommen, M., Duysens, C., Crielaard, J.M. 2006. Spinal muscle evaluation using the Sorensen test: A critical appraisal of the literature. *Joint Bone Spine,* 73(1): 43-50.

DeVocht, J.W., Pickar, J.G., Wilder, D.G. 2005. Spinal manipulation alters electromyographic activity of paraspinal muscles: A descriptive comparison. *Journal of Manipulative and Physiological Therapeutics*, 28(7): 465-471.

Dishman, J.D., Bulbulian, R. 2000. Spinal reflex attenuation associated with spinal manipulation. *Spine*, 25(19): 2519-2525.

Dishman, J.D., Bulbulian, R. 2001. Comparison of effects of spinal manipulation and massage *on motoneuron excitability. Electromyography and Clinical Neurophysiology,* 41(2): 97-106.

Dishman, J.D., Burke, J. 2003. Spinal reflex excitability changes after cervical and lumbar spine manipulation: a comparative study. *The Spine Journal*, 3(3):204-212.

Dishman,J.D., Cunningham, B.M., Burke, J. 2002. Comparison of tibial nerve H-reflex excitability after cervical and lumbar spine manipulation. *Journal of Manipulative and Physiological Therapeutics*, 25(5): 318-325.

Dishman, J.D., Dougherty, P.E., Burke, J.R. 2005. Evaluation of the effect of posterior perturbation on motorneuronal activity following various methods of lumbar spine manipulation. *The Spine Journal*, 5(6): 650-659.

Dolan, P., Adams, M.A. 1993. The relationship between EMG activity and extensor moment generation in the erector spinae muscles during bending and lifting activities. *Journal of Biomechanics,* 26(4-5): 513-522.

Dolan, P., Adams, M.A. 1998. Repetitive lifting tasks fatigue the back muscles and increase the bending moment acting on the lumbar spine. *Journal of Biomechanics,* 31(8): 713-721.

Dugmore, B.R. 2006. A double-blinded, placebo controlled study to determine the influence of the clinical ritual in instrument assisted adjusting during the management of mechanical low back pain. M.Tech: Chiro dissertation, Durban University of Technology.

Farina, D., Merletti, R. 2000. Comparison of algorithms for estimation of EMG variables during voluntary isometric contractions. *Journal of Electromyography and Kinesiology,* 10(5): 337- 349.

Ferreira, M.L., Ferreira, P.H., Latimer, J., Herbert, R., Maher, C.G. 2003. Efficacy of spinal manipulative therapy for low back pain of less than 3 months duration. *Journal of Manipulative and Physiological Therapeutics*, 26(9): 593-601.

Fryer, G., Morris, T., Gibbons, P. 2004. Paraspinal muscles and intervertebral dysfunction: Part two. *Journal of Manipulative and Physiological Therapeutics,* 27(5): 348-357.

Fryer, G., Pearce, A.J. 2012. The effect of lumbosacral manipulation on corticospinal and spinal reflex excitability on asymptomatic participants. *Journal of Manipulative and Physiological Therapeutics,* 35(2): 86-93.

Gatterman, M.I. 1990. *Chiropractic management of spine related disorders*. Philadelphia PA: Lippincott, Williams & Wilkins.

Gatterman, M.I. 2005. *Foundations of chiropractic subluxation*. 2nd ed. St Louis MO: Elsevier Mosby.

Gillette, R.G. 1987. A speculative argument for the coactivation of diverse somatic receptor populations by forceful chiropractic adjustments. *Manual Medicine,* 3:1-14.

Goertz, C.M., Pohlman, K.A., Vining, R.D., Brantingham, J.W., Long, C.R. 2012. Patient-centered outcomes of high-velocity, low-amplitude spinal manipulation for low back pain: A systematic review. *Journal of Electromyography and Kinesiology,* 22(5): 670-691.

Goodsell, M., Lee, M., Latimer, J. 2000. Short-term effects of lumbar posteroanterior mobilization in individuals with low-back pain. *Journal of Manipulative and Physiological Therapeutics*, 23(5): 332-342.

Haavik-Taylor, H., Murphy, B. 2007. Cervical spine manipulation alters sensorimotor integration: A somatosensory evoked potential study. *Clinical Neurophysiology,* 118(2): 391-402.

Haavik-Taylor, H., Murphy, B. 2008. Altered sensorimotor integration with cervical spine manipulation. *Journal of Manipulative and Physiological Therapeutics,* 31(2): 115-126.

Haavik-Taylor, H., Murphy, B. 2010a. The effects of spinal manipulation on central integration of dual somatosensory input observed after motor training: A crossover study. *Journal of Manipulative and Physiological Therapeutics*, 33(4): 261-272.

Haavik-Taylor, H., Murphy, B. 2010b. Altered central integration of dual somatosensory input after cervical spine manipulation. *Journal of Manipulative and Physiological Therapeutics*, 33(3): 178-188.

Hammer, W. 2007. *Functional soft tissue examination and treatment by manual methods*. 3rd ed. Sudbury MASS: Jones and Bartlett Publishers.

Harvey, M-P., Descarraeux, M. 2013. Short term modulation of trunk neuromuscular responses following spinal manipulation: A control group study. *BMC Musculoskeletal Disorders,* 14: 92.

Herzog, W. 2000. *Clinical biomechanics of spinal manipulation*. Philadelphia: Churchill Livingston.

Herzog, W., Scheele, D., Conway, P.J. 1999. Electromyographic responses of back and limb muscles associated with spinal manipulative therapy. *Spine*, 24(2): 146-152.

Hogervorst, T., Brand, R.A. 1998. Current concepts review: Mechanoreceptors in Joint Function. *The Journal of Bone and Joint Surgery*, 80(9):1365-1378.

Hyde, T.E., Gengenbach, M.S. 2007. *Conservative Management of Sports Injuries*. 2nd ed. Sudbury MASS: Jones and Bartlett Publishers.

Indahl, A., Kaigal, A.M., Reikeras, O., Holm, S.H. 1997. Interaction between the porcine lumbar intervertebral disc, zygopophyseal joints and paraspinal muscles. *Spine*, 22(24): 2834-2840.

Interactive Spine - Chiropractic Edition (DVD). 2001. Primal Pictures Ltd.

Introducing Impulse (DVD). 2009. Arizona: Neuromechanical Innovations.

Ito, T., Shirado, O., Suzuki, H., Takahashi, M., Kaneda, K., Strax, T.E. 1996. Lumbar trunk muscle endurance testing: An expensive alternative to a machine for examination. *Archives of Physical Medicine and Rehabilitation,* 77(1): 75-79.

Jette, A.M, Smith, K., Haley, S.M., Davis, K.D. 1994. Physical therapy episodes of care for patients with low back pain. *Journal of the American Physical Therapy Association,* 74(2): 101-110.

Kankaanpää, M., Laaksonen, D., Taimela, S., Kokko, S-M., Airaksinen, O., Hänninen, O. 1998. Age, sex and body mass index as determinants of back and hip extensor fatigue in the isometric Sorensen back endurance test. *Archives of Physical Medicine and Rehabilitation*, 79(9): 1069-1075.

Katavich, L. 1998. Differential effects of spinal manipulative therapy on acute and chronic muscle spasm: A proposal for mechanisms and efficacy. *Manual Therapy,* 3(3): 132-139.

Keller, T.S., Colloca, C.J. 2000. Mechanical force spinal manipulation increases trunk muscle strength assessed by electromyography: A comparative clinical trial. *Journal of Manipulative and Physiological Therapeutics*, 23(9): 585-595.

Keller, T.S., Colloca, C.J., Beliveau, J.G. 2002. Force deformation response of the lumbar spine: a sagittal plane model of posteroanterior manipulation and mobilisation. *Clinical Biomechanics*, 17(3): 185-196.

Keller, T.S., Colloca, C.J., Fuhr, A.W. 1999. Validation of the force and frequency characteristics of the Activator Adjusting Instrument: Effectiveness as a mechanical impedance measurement tool. *Journal of Manipulative and Physiological Therapeutics*, 22(2): 75-86.

Kent, C. 1997. Surface electromyography in the assessment of changes in paraspinal muscle activity associated with vertebral subluxation: A review. *Journal of Vertebral Subluxation Research*, 1(3): 1-8.

Konstantinou, K., Foster, N., Rushton, A., Baxter, D., Wright, C., Breen, A. 2007. Flexion mobilizations with movement techniques: The immediate effects on range of movement and pain in subjects with low back pain. *Journal of Manipulative and Physiological Therapeutics*, 30(3): 178-185.

Koppenhaver, S.L., Fritz, J.M., Hebert, J.J., Kawchuk, G.N., Childs, J.D., Parent, E.C., Gill, N.W., Teyhen, D.S. 2011. Association between changes in abdominal and lumbar multifidus muscle thickness and clinical improvement after spinal manipulation. *Journal of Orthopaedic & Sports Physical Therapy*, 41(6): 389-399.

Korr, I.M. 1975. Proprioceptors and the behaviour of lesioned segments. In: Stark E.H. ed. *Osteopathic Medicine*. Action MASS: Publication Sciences group. 183-199.

Koumantakis, G.A., Arnall, F., Cooper, R.G., Oldham, J.A. 2001. Paraspinal muscle EMG fatigue testing with two methods in healthy volunteers. Reliability in the context of clinical applications. *Clinical Biomechanics*, 16(3): 263- 266.

Krekoukias, G., Petty, N.J., Cheek, L. 2009. Comparison of surface electromyographic activity of erector spinae before and after the application of central posteroanterior mobilization on the lumbar spine. *Journal of Electromyography and Kinesiology,* 19(1): 39-45.

Krismer, M., van Tulder, M. 2007. Low back pain (non-specific). *Best Practice & Research Clinical Rheumatology*, 21(1): 77-91.

Lalanne, K., Lafond, D., Descarreaux, M. 2009. Modulation of the flexion-relaxation response by spinal manipulative therapy: A control group study. *Journal of Manipulative and Physiological Therapeutics*, 32(3): 203-209.

Larivière, C, Gravel, D., Arsenault, A.B., Gagnon, D., Loisel, P. 2003. Muscle recovery from a short fatigue test and consequence on the reliability of EMG indices of fatigue. *European Journal of Applied Physiology*, 89(2): 171-176.

Latimer, J., Maher, C.G., Refshange, K., Colaco, I. 1999. The reliability and validity of the Beiring-Sorensen test in asymptomatic subjects and subjects reporting current or previous non-specific low back pain. *Spine*, 24(20): 2085-2090.

Leach, R.A. 2004. *The chiropractic theories: A textbook of scientific research*. 4th ed. Philadelphia PA: Lippincott Williams & Wilkins.

Lee, D. 2004. *The pelvic girdle. An approach to the examination and treatment of the lumbopelvic-hip region. 3rd ed*. Philadelphia: Elsevier.

Lehman, G. 2012. Kinesiological research: The use of surface electromyography for assessing the effects of spinal manipulation. *Journal of Electromyography and Kinesiology,* 22(5): 692-696.

Lehman, G.J., McGill, S.M. 2001. Spinal manipulation causes variable spine kinematic and trunk muscle electromyographic responses. *Clinical Biomechanics*. 16(4): 293-299.

Lehman, G.J., Vernon, H., McGill, S.M. 2001. Effects of a mechanical pain stimulus on erector spinae activity before and after a spinal manipulation in patients with back pain: A preliminary investigation. *Journal of Manipulative and Physiological Therapeutics,* 24(6): 402-406.

Leibenson,C. 2007. *Rehabilitation of the Spine. A Practitioners Manual.* 2nd ed. Philadelphia: Lippincott Williams and Wilkins.

Mannion, A.F., Connolly, B., Wood, K., Dolan, P. 1997. The use of surface EMG power spectral analysis in the evaluation of back muscle function. *Journal of Rehabilitative Research and Development*, 34(4): 427-439.

Mannion, A.F., O'Riordan, D., Dvorak, J., Masharawi, Y. 2011. The relationship between psychological factors and performance on the Biering-Sorensen back muscle endurance test. *The Spinal Journal*, 11(9): 849-857.

Martini, F.H. 1998. *Fundamentals of anatomy and physiology*. 4th ed. Upper Saddle River NJ: Prentice Hall Inc.

McGill, S. 2007. *Low back disorders: Evidence-based prevention and rehabilitation*. 2nd ed. Champagne IL: Human Kinetics.

Medical Research Council of South Africa. 2002-2004. Guidelines on ethics for medical research: General Principles. 4th ed. Available: http://www.mrc.ac.za/ethics/ethics.htm (Accessed 26 May 2014).

Melzack, R., Wall, P.D. 1965. Pain mechanisms: A new theory. *Science.* 150(3699): 971-979.

Moffroid, M.T. 1997. Endurance of trunk muscles in persons with chronic low back pain: assessment, performance, training. *Journal of Rehabilitative Research and Development*, 34(4): 440-447.

Moffroid, M., Reid, S., Henry, S.M., Haugh, L.D., Ricamata, A. 1994. Some endurance measures in persons with chronic low back pain. *The Journal of orthopaedic and sports physical therapy*, 20(2): 81-87.

Mohseni-Bandpei, M.A., Watson, M.J. 2001. Electromyographic power spectral analysis of the paraspinal muscles. Reliability study. *Physiotherapy,* 87(9): 470-478.

Moore, K.L., Dalley, A.F. 2006. *Clinically orientated anatomy*. 5th ed. Philadelphia PA: Lippincott Williams & Wilkins.

Moreau, C.E., Green, B.N., Johnson, C.D., Moreau, S.R. 2001. Isometric back extension endurance tests: A review of the literature. *Journal of Manipulative and Physiological Therapeutics,* 24(2): 110-122.

Müller, R., Strässle, K., Wirth, B. 2010. Isometric back muscle endurance: An EMG study on the criterion validity of the Ito test. *Journal of Electromyography and Kinesiology,* 20(5): 845-850.

Murphy, B.A., Dawson, N.J., Slack, J.R. 1995. Sacroiliac joint manipulation decreases the H-reflex. *Electromyography and Clinical Neurophysiology*, 35(2): 87-94.

Muscolino, J.E. 2011. *Kinesiology. The skeletal muscle system and muscle function.* 2nd ed. St Louis MO: Elsevier Mosby.

Neuromuscular junction (image). 2012. Available: http://antranik.org/synaptic-transmission-by-somatic-motorneurons/ (Accessed 31 January 2014).

Neuro Trac™ ETS: Operators manual. 2007. Document number: VM-ETS100-OM001-8.

Newton, M., Waddell, G. 1991. Reliability and validity of clinical measurement of the lumbar spine in patients with chronic low back pain. *Physiotherapy,* 77(12): 796-800.

Peh, W.C.G. 2011. Image-guided facet joint injection. *Biomedical Imaging and Intervention Journal,* 7(1): 1-10.

Pickar, J.G. 2002. Neurophysiological effects of spinal manipulation. *The Spine Journal*, 2(5): 357-371.

Pickar, J.G., Kang, Y. 2006. Paraspinal muscle spindle responses to the duration of a spinal manipulation under force control. *Journal of Manipulative and Physiological Therapeutics,* 29(1): 22-31

Pickar, J.G., Sung, P.S., Kang, Y., Ge, W. 2007. Response of lumbar paraspinal muscles spindles is greater to spinal manipulative loading compared with slower loading under length control. *The Spine Journal*, 7(5): 583-595.

Pickar, J.G., Wheeler, J.D. 2001. Response of muscle proprioceptors to spinal manipulative-like loads in the anesthetized cat. *Journal of Manipulative and Physiological Therapeutics*, 24(1): 2-11.

Pitcher, M.J., Behm, D.G., MacKinnon, S.N. 2007. Neuromuscular fatigue during a modified Biering-Sorensen test in subjects with and without low back pain. *Journal of Sports Science and Medicine*, 6(4): 549-559.

Potter, L., McCarthy, D., Oldham, J. 2005. Physiological effects of spinal manipulation: A review of proposed theories. *Physical Therapy Reviews*, 10:163-170.

Richardson, C., Jull, G., Hodges, P., Hides, J. 1999. *Therapeutic exercise for spinal segmental stabilization in low back bain – Scientific basis and clinical approach*. Edinburgh: Churchill Livingstone.

Roy, S.H., De Luca, C.J., Emley, M, Oddsson, L.I.E., Buijs, R.J.C, Levins, J.A., Newcombe, D.S., Jabre, J.F. 1997. Classification of back muscle impairment based on the surface electromyographic signal. *Journal of Rehabilitative Research and Development*, 34(4); 405-414.

Saunders Digital Inclinometer User's Guide. 1998. The Saunders Group Inc. 65020-8.98.

Seth, S.D. 1999. *Textbook of pharmacology.* 2nd ed. New Delhi: Churchill Livingston Reed Elsevier Noida, UP, India.

Skeletal muscle fibre (image). 2014. Available: http://www.medicalook.com/human_anatomy/organs/Skeletal_muscle_fibre.html (Accessed 16 January 2014).

Smolin, L.A. and Grosvenor, M.B. 2008. *Nutrition: Science and applications*. Hoboken NJ: John Wiley & Sons.

Stamos-Papastamos, N., Petty, N.J., Williams, J.M. 2011. Changes in bending stiffness and lumbar spine range of movement following lumbar mobilization and manipulation. *Journal of Manipulative and Physiological Therapeutics,* 34(1): 46-53.

Stedman's medical dictionary for the health professions and nursing. 5th ed. 2005. Philadelphia PA: Lippincott Williams & Wilkins.

Stevens, V.K., Vleeming, A., Bouche, K.G., Mahieu, N.N., Vanderstraeten, G.G., Danneels, L.A. 2007. Electromyographic activity of trunk and hip muscles during stabilization exercises in four-point kneeling in healthy volunteers. *European Spine Journal,* 16(5): 711-718.

Sturesson, B., Uden, A., Vleeming, A. 2000a. A radiostereometric analysis of movements of the sacroiliac joints in the reciprocal straddle position. *Spine*, 25(2): 214-217.

Sturesson, B., Uden, A., Vleeming, A. 2000b. A radiostereometric analysis of movements of the sacroiliac joints during the standing hip flexion test. *Spine,* 25(3): 364-368.

Suter, E., McMorland, G. 2002. Decrease in elbow flexor inhibition after cervical spine manipulation in patients with chronic neck pain. *Clinical Biomechanics,* 17(7): 541-544.

Suter, E., McMorland, G., Herzog, W., Bray, R. 2000. Conservative low back treatment reduces inhibition in knee-extensor muscles: A randomized controlled trial. *Journal of Manipulative and Physiological Therapeutics*, 23(2): 76- 80.

Symons, B.P., Herzog, W., Leonard, T., Nguyen, H. 2000. Reflex responses associated with activator treatment. *Journal of Manipulative and Physiological Therapeutics*, 23(3): 155-159.

The Muscular System (image). 2013. Available: http://classroom.sdmesa.edu/eschmid/Chapter8-Zoo145.htm (Accessed 16 January 2014).

The Neuromechanical System (DVD). 2008. Arizona: Neuromechanical Innovations.

Tortora, G.J., Derrickson, B. 2006. *Principles of anatomy and physiology.* 11th ed. Hoboken NJ: John Wiley & Sons.

Wilder, D.G., Aleksiev, A.R., Magnusson, M.L., Pope, M.H., Spratt, K.F., Goel, V.K. 1996. Muscular response to sudden load. A tool to evaluate fatigue and rehabilitation. *Spine*, 21(22): 2628-2639.

Witvrouw, E., Bellemans, J., Lysens, R., Danneels, L., Cambier, D. 2001. Intrinsic risk factors for the development of patella tendonitis on an athletic population. *American Journal of Sports Medicine*, 29(2): 190-195.

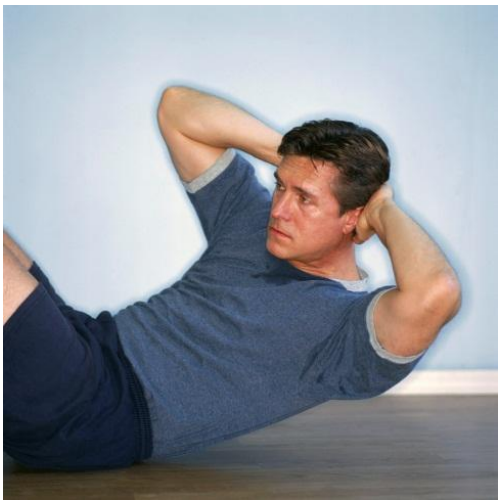
Wyke, B.D. 1972. Articular neurology – A review. *Physiotherapy*, 58(3): 94-99.

Yochum, T.R., Rowe, L.J. 2005. *Essentials of skeletal radiology.* Volume One. 3rd ed. Philadelphia PA: Lippincott Williams & Wilkins.

APPENDICES

APPENDIX A

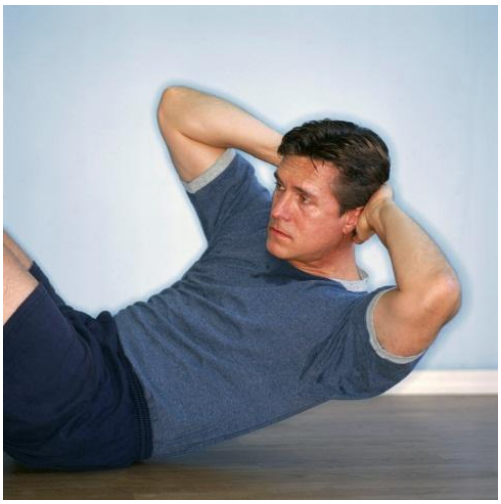
ARE YOU MALE,
HEALTHY AND RIGHT-HANDED?
BETWEEN THE AGES OF
20 AND 40?
WOULD YOU LIKE TO KNOW HOW FIT YOUR BACK MUSCLES ARE?



RESEARCH IS BEING CONDUCTED AT THE CHIROPRACTIC DAY CLINIC AT THE DURBAN UNIVERSITY OF TECHNOLOGY.

IF YOU ARE INTERESTED
CONTACT KATE
0313732205

KUNGABE UNGOWESILISA, OPHILILE OBHALA NGESANDLA SOKUDLA?
UPHAKATHI KWEMINYAKA EWU 20 NO 40?
UNGATHANDA UKWAZI UKUTHI IMISIPHA YAKHO YOMHLANE INAMANDLA KANGAKANANI?



KUNOCWANINGO OLWENZIWAYO E-CHIROPRACTIC KLINIKHI E-DURBAN UNIVERSITY OF TECHNOLOGY.

UMA UFISA UKUZIBANDAKANYA KULOLUCWANINGO
THINTANA NO KATE
0313732205

APPENDIX B

Dear Participant,

Thank you for expressing interest in my research project.

Title of the Research Study: The effect of sacroiliac joint manipulation on lumbar extensor muscle endurance in asymptomatic individuals.

Researcher: Kate Jones, B.Tech: Chiropractic.

Supervisor/s: Dr Laura O'Connor, M.Tech: Chiropractic

Brief Introduction and Purpose of the Study: Spinal manipulation is often used by chiropractors and other manual practitioners to improve movement of the spine. When spinal manipulations are performed they have been documented to change the surrounding muscles, it is unclear if this change will be associated with an increased output of the muscle. Therefore, this study aims to determine if there will be an increased endurance in your back muscles after you have received spinal manipulation applied to the sacro-iliac joint.

Outline of the Procedures: In order to participate in this research you will need to consent to having a case history, physical and low back examination. This will enable the researcher to determine if you meet the study inclusion criteria. Should you meet the requirements, you will then be randomly allocated into one of two groups. You will receive either sacro-iliac joint manipulation or a sham treatment. You will be shown how to contract your back muscles, by lying on a bench with your upper body off the edge of the bench, supported by your arms, you will then be required to lift your back so it is in line with your legs and hold this position for as long as you can. You will be required to do this twice, once before the intervention and once after. An electrical device will be placed over the back muscles to allow the researcher to measure the activity of the back muscles while performing the exercise. This is a safe device and will pose no harm to you. The researcher will also assess the range of motion of your low back before and after the intervention.

Risks or Discomforts to the Participant: Performing the back muscle test may cause transient pain or discomfort, meaning any pain or discomfort should be temporary and last for a short time only. Should the pain become severe you must inform the researcher and the test will be stopped immediately.

Benefits: By participating in this research you will be able to find out if you have weak or strong back muscles. If you have weak back muscles, the researcher will show you what exercises you can do to improve this. Studies have shown that weak back muscles can lead to future episodes of low back

pain. Therefore should you strengthen these muscles, you may be able to prevent future low back pain.

Reason/s why the Participant May Be Withdrawn from the Study: Should you not meet the inclusion criteria you will be excluded from the study. If during the study you wish to withdraw you may do so with no adverse consequences for future treatment at this facility.

Remuneration: There is no remuneration for participating.

Costs of the Study: The participant will not be expected or required to cover any costs towards the study, the costs of the study will be covered by Durban University of Technology.

Confidentiality: All data will be collected in a manner that ensures participant information is kept confidential. Participants' names will not be revealed in the data sheets; they will be coded and used as such during data analysis. Only the researcher and the supervisor will have access to the data.

Research-related Injury: Should you develop any adverse reaction to participating in this study please contact me immediately.

Persons to Contact in the Event of Any Problems or Queries:
Please contact the researcher Kate Jones (031 373 2205), my supervisor Dr Laura O'Connor (031 373 2923) or the Institutional Research Ethics administrator on 031 373 2900. Complaints can be reported to the DVC: TIP, Prof F. Otieno on 031 373 2382 or dvctip@dut.ac.za.

Yours sincerely,

Kate Jones
Researcher

INSTITUTIONAL RESEARCH ETHICS COMMITTEE (IREC)
CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, _____ (name of researcher), about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: _____,
- I have also received, read and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

_____	_____	_____	_____
Full Name of Participant	**Date**	**Time**	**Signature / Right Thumbprint**

I, _____ (name of researcher) herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

_____	_____	_____
Full Name of Researcher	**Date**	**Signature**

_____	_____	_____
Full Name of Witness (If applicable)	**Date**	**Signature**

_____	_____	_____
Full Name of Legal Guardian (If applicable)	**Date**	**Signature**

Mbandakanyi Othandekayo

Ngibonge ukuveza kwakho intshisekelo kulolucwaningo.

Isihloko socwaningo: Umphumela wokunyakaziswa kwelunga lesinqe emandleni emisipha yomhlane kubantu abangaguli.

Igama lomcwaningi: Kate Jones, B.Tech: Chiropractic

Igama lowengamele lolucwaningo: Dk Laura O'Connor, M.Tech: Chiropractic

Incazelo nenhloso ngalolucwaningo: Ukunyakaziswa komgogodla kujwayelwe ukusetshenziswa amachiropractors(odokotela bamathambo,umgogodla namalunga omzimba), nabanye ukwenza ngcono umgogodla. Kunemibhalo eshoyo ukuthi uma umgogodla unyakaziswa kushintsha imisipha esendolene nomgogodla, kepha akucacile noma lolushintsho lunyusa indlela imisipha esebenza ngayo. Ngakho ke lolucwaningo luhlose ukuthola ukuthi ngabe ukunyakaziswa komgogodla kunyusa indlela imisipha yomqolo esebenza ngayo.

Inqubo yalolucwaningo: Ukuze ukwazi ukuba ingxenye yalolucwaningo kuzomele usayine incwadi yemvume ukuthi ngizothatha umlando wakho wempilo, ngikuhlole, bese ngihlola nomgogodla wakho. Lokhu kuzosiza ekutheni umcwaningi abone ukuthi unayo imibandela edingekayo kulolucwaningo. Uma unayo yonke lemibandela edingekayo, uzobe usuyafakwa kwelinye lamaqembu amabili. Uzobe usuthola ukunyakaziswa komgogodla noma enye indlela yokwelapha. Uzotshengiswa ukuthi uqinisa/ufinyeza kanjani imisipha yomqolo, ngokuthi ulale ingaphezulu lomzimba sibe sekugcineni kwebhentshi, ubambelele ngezingalo, kuzobe sekudingeka ukuthi uphakamise umqolo wakho uze uqondane nemilenze bese uma kanjalo ngokuqinisela kwakho. Kuzodingeka ukuthi lokhu ukwenze kabili, kanye ngaphambi kokwelashwa nangemva kokwelashwa. Kunomshini ozobekwa emqolowakho ukuze kubonakale ukuthi imisipha yomqolo isebenza kanjani. Lomshini uphephile angeke ukulimaze. Umcwaningi uzohlola ukuthi umgogodla wakho unyakaza kangaka nani ngaphambi kokwelashwa nangemva kokwelashwa.

Ukulimala okuqondene nocwaningo: Lenqubo yokuhlolwa kwemisipha yomqolo ingenza ukungenami/ubuhlungu besikhashana, okusho ukuthi ukungenami/ubuhlungu obesikhashana futhi kuzothatha isikhashana nje. Uma ubuhlungu buqhubeka kumele utshele umcwaningi ukuze angaqhubeki nokukuhlola.

Uzozuzani?
Ngokuzibandakanya kulolucwaningo uzothola ukuthi imisipha yakho yomqolo inamandla yini noma cha. Uma ngabe imisipha yakho yomqolo ingenamandla umcwaningi uzokutshengisa ukuthi ungavocavoca kanjani imisipha ukuze ibe namandla. Uphenyo luyatshengisa ukuthi imisipha yomqolo engenamandla ingadala ukuthi uphathwe iqolo. Ngakhoke uma imisipha yakho iba namandla, lokhu kungavimbela ukuthi ungaphathwa iqolo.

Izizathu ezingenza ukuthi umuswe kulolucwaningo ngaphandle kwemvume: Uma ungenayo yonke imibandela edingekayo kulolucwaningo angeke ukwazi ukuba ingxenye yalo. Uma udinga ukushiya phakathi lolucwaningo ungenze njalo ngale kokuhlukumezeka kuleliklinikhi.

Ukukhokhelwa imali: Angeke uze ukhokhelwe ngokuzibandakanye kulolucwaningo.

Kungabe uzokhokha yini ngokuzibandakanye kulolucwaningo?
Angeke uze ukhokhe lutho ngokuzibandakanya kulolucwaningo, konke okumayelana nalolucwaningo kukhokhelwe i-Durban University of Technlogy.

Imfihlo(izogcinwa kanjani):
Imininingwane yakho ezotholakela kulolucwaningo izogcinwa iyimfihlo. Igama lakho ngeke livezwe kulelmininigwane yocwaningo, kuzosetshenziswa inombolo ukuze kuhlaziywe imiphumela yocwaningo. Yimina kanye nowengamele lolucwaningo abazokwazi ukuyibona kuphela.

Ukulima kulolucwaningo: Uma ngabe ulimala noma kuba nobungozi ngenxa yokuzibandakanya kulolucwaningo ngesikhathi ucwaningo lusaqhubeka ngazise ngokushesha,

Ongabathinta uma kuba nenkinga noma imibuzo:
Ngicela uxhumane nomcwaningi uKate Jones kulenombolo (031) 373 2205, owengamele lolucwaningo Dk Laura O'Connor (031) 373 2923 noma unobhala wekomiti elimele amalungelo kwezocwaningo(Lavisha Deonarian – 031 373 2900). Izikhalo zingabikwa kwiDVC: TIP, Prof F. Otieno kulenombolo 031 373 2382 noma dvctip@dut.ac.za.

Ozithobayo
Kate Jones
Umcwaningi

INSTITUTIONAL RESEARCH ETHICS COMMITTEE (IREC)
CONSENT

Isitatimende sesivumelwano sokuzibandakanya kulolucwaningo:

- Ngiyaqinisekisa ukuthi ngitsheliwe ngumcwaningi, **Kate Jones** ,ngohlobo, ngokuziphatha, nangosizo, nangobungozi balolucwaningo – Research Ethics Clearance Number: _____,
- Ngiyitholile, futhi ngayifunda, ngayizwa incwadi (incwadi yombandakanyi) echaza ngalolucwaningo(incwadi yombandakanyi).
- Ngiyazi futhi ukuthi imiphumela yalolucwaningo, imininingwane yami ephathelene nobulili, iminyaka, usuku lokuzalwa, amagama afingqiwe(initials) and isifo esingiphethe kuzodalulwa kumbiko walolucwaningo ngale koludalula amagama ami.
- Ngokubuka okudingekayo kulolucwaningo, ngiyavuma ukuthi imininingwane etholakele ngesikhathi lolucwaningo luqhubeka umcwaningi alufake kuhlelo lwekhompuyutha.
- Noma ngasiphi isikhathi, ngale kokucwaseka, ngingayeka ukuba umbandakanyi kulolucwaningo.
- Ngibe nesikhathi esanele sokubuza imibuzo (ngentando yami) nokuzilungiselela ukuba yingxenye yalolucwaningo.
- Ngiyaqonda ukuthi imiphumela ebalulekile etholakele ngesikhathi lolucwaningo luqhubeka egaphathelana name ngizikwaziswa ngayo.

_____	_____	_____
Igama lozibandakanya kulolucwaningo	**Usuku**	**Isiginisha/isithupha**

Mina **Kate Jones** ngiyaqinisekisa ukuthi lombandakanyi ongaphezulu uthole incazelo egcwele mayelana nohlobo, ngokuziphatha, nangosizo, nangobungozi balolucwaningo

_____	_____	_____
Igama lomucwaningi	**Usuku**	**Isiginisha yomcwaningi**

_____	_____	_____
Igama lafakazi	**Usuku**	**Isiginisha kafakazi**

_____	_____	_____
Igama lomlondolozi(uma ekhona)	**Usuku**	**Isiginisha kafakazi**

APPENDIX C

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC AND SOMATOLOGY

CHIROPRACTIC PROGRAMME

CHIROPRACTIC DAY CLINIC CASE HISTORY

Patient: _____ Date: _____

File #: _____ Age: _____

Sex: _____ Occupation: _____

Student: _____ Signature _____

FOR CLINICIANS USE ONLY:

Initial visit

Clinician: Signature:

Case History:

Examination:
Previous: Current:

X-Ray Studies:
Previous: Current:

Clinical Path. lab:
Previous: Current:

CASE STATUS:

PTT: Signature: Date:

CONDITIONAL:
Reason for Conditional:

Signature: Date:

Conditions met in Visit No: Signed into PTT: Date:

Case Summary signed off: Date:

Student's Case History:

1. **Source of History:**

2. **Chief Complaint: (patient's own words):**

3. **Present Illness:**

	Complaint 1 (principle complaint)	Complaint 2 (additional or secondary complaint)
Location		
Onset : Initial:		
Recent:		
Cause:		
Duration		
Frequency		
Pain (Character)		
Progression		
Aggravating Factors		
Relieving Factors		
Associated S & S		
Previous Occurrences		
Past Treatment Outcome:		

4. **Other Complaints:**

5. **Past Medical History:**

General Health Status

Childhood Illnesses

Adult Illnesses

Psychiatric Illnesses

Accidents/Injuries

Surgery

Hospitalizations

6. Current health status and life-style:

Allergies

Immunizations

Screening Tests incl. x-rays

Environmental Hazards (Home, School, Work)

Exercise and Leisure

Sleep Patterns

Diet

Current Medication
Analgesics/week:
Other (please list):

Tobacco
Alcohol
Social Drugs

7. Immediate Family Medical History:

Age of all family members
Health of all family members
Cause of Death of any family members

	Noted	Family member		Noted	Family member
Alcoholism			Headaches		
Anaemia			Heart Disease		
Arthritis			Kidney Disease		
CA			Mental Illness		
DM			Stroke		
Drug Addiction			Thyroid Disease		
Epilepsy			TB		
Other (list)					

8. Psychosocial history:

Home Situation and daily life
Important experiences
Religious Beliefs

9. Review of Systems (please highlight with an asterisk those areas that are a problem for the patient and require further investigation)

General

Skin

Head

Eyes

Ears

Nose/Sinuses

Mouth/Throat

Neck

Breasts

Respiratory

Cardiac

Gastro-intestinal

Urinary

Genital

Vascular

Musculoskeletal

Neurologic

Haematological

Endocrine

Psychiatric

APPENDIX D

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC AND SOMATOLOGY

CHIROPRACTIC PROGRAMME

PHYSICAL EXAMINATION: SENIOR

Patient Name: _____				**File no:** _____	**Date:** _____
Student:		**Signature:**			
VITALS:					
Pulse rate:			Respiratory rate:		
Blood pressure:	R	L	Medication if hypertensive:		
Temperature:			Height:		
Weight:	Any recent change?	Y / N	If Yes: How much gain/loss		Over what period
GENERAL EXAMINATION:					
General Impression					
Skin					
Jaundice					
Pallor					
Clubbing					
Cyanosis (Central/Peripheral)					
Oedema					
Lymph nodes	Head and neck				
	Axillary				
	Epitrochlear				
	Inguinal				
Pulses					
Urinalysis					
SYSTEM SPECIFIC EXAMINATION:					
CARDIOVASCULAR EXAMINATION					
RESPIRATORY EXAMINATION					
ABDOMINAL EXAMINATION					
NEUROLOGICAL EXAMINATION					
COMMENTS					
Clinician:			**Signature:**		

APPENDIX E

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC AND SOMATOLOGY

CHIROPRACTIC PROGRAMME

REGIONAL EXAMINATION
LUMBAR SPINE AND PELVIS

Patient: _____ File#: _____ Date: _____

Student: _____ Clinician: _____

STANDING:

Posture– scoliosis, antalgia, kyphosis
Body Type
Skin
Scars
Discolouration

Minor's Sign
Muscle tone
Spinous Percussion
Schober's Test (6cm)
Bony and Soft Tissue Contours

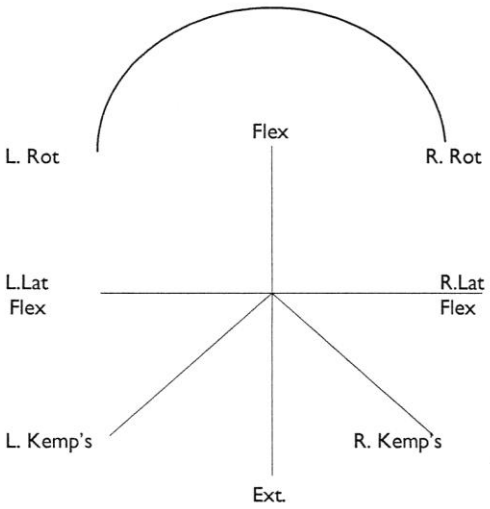
GAIT:

Normal walking
Toe walking
Heel Walking
Half squat

ROM:

Forward Flexion = 40-60° (15 cm from floor)

Extension = 20-35°
L/R Rotation = 3-18°
L/R Lateral Flexion = 15-20°



Which movement reproduces the pain or is the worst?

- Location of pain
- Supported Adams: Relief? (SI)
- Aggravates? (disc, muscle strain)

SUPINE:

Observe abdomen (hair, skin, nails)
Palpate abdomen\groin
Pulses - abdominal
- lower extremity
Abdominal reflexes

		Degree	LBP?	Location	Leg pain	Buttock	Thigh	Calf	Heel	Foot	Braggard
SLR	**L**										
	R										

	L	**R**
Bowstring		
Sciatic notch		
Circumference (thigh and calf)		
Leg length: actual -		
apparent -		
Patrick FABERE: pos\neg – location of pain?		
Gaenslen's Test		
Gluteus max stretch		
Piriformis test (hypertonicity?)		
Thomas test: hip \ psoas \ rectus femoris ?		
Psoas Test		

SITTING:

Spinous Percussion
Lhermitte

Valsalva

TRIPOD SI, +, ++		Degree	LBP?	Location	Leg pain	Buttock	Thigh	Calf	Heel	Foot	Braggard
	L										
	R										

SLUMP 7 TEST											
	L										
	R										

LATERAL RECUMBENT:	**L**	**R**
Ober's		
Femoral n. stretch		
SI Compression		

PRONE:	**L**	**R**
Gluteal skyline		
Skin rolling		
Iliac crest compression		
Facet joint challenge		
SI tenderness		
SI compression		
Erichson's		
Pheasant's		

MF tp's	**Latent**	**Active**	**Radiation**
QL			
Paraspinal			
Glut Max			
Glut Med			
Glut Min			
Piriformis			
Hamstring			
TFL			
Iliopsoas			
Rectus Abdominis			
Ext/Int Oblique muscles			

NON ORGANIC SIGNS:

Pin point pain
Trunk rotation
Flip Test
Ankle dorsiflexion test
Axial compression
Burn's Bench test
Hoover's test
Repeat Pin point test

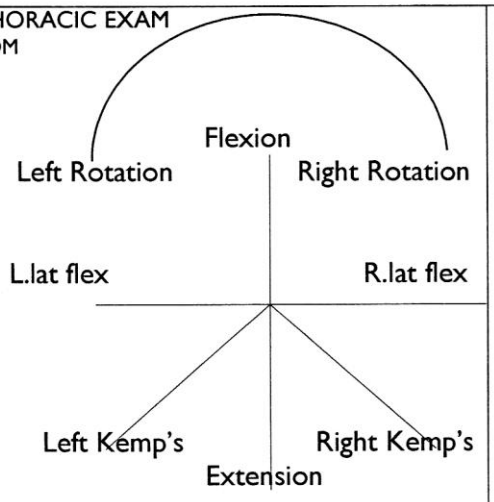
NEUROLOGICAL EXAMINATION

Fasciculations						
Plantar reflex						
level	**Tender?**	**Dermatomes**		**DTR**		
		L	**R**		**L**	**R**
T12				Patellar		
L1				Achilles		
L2						
L3				Proprioception		
L4						
L5						
S1						
S2						
S3						

MYOTOMES

Action	Muscles	Levels	L	R	
Lateral Flexion spine	Muscle QL				
Hip flexion	Psoas, Rectus femoris				5+ Full strength
Hip extension	Hamstring, glutes				4+ Weakness
Hip internal rotation	Glutmed, min, TFL, adductors				3+ Weak against grav
Hip external rotation	Gluteus max, Piriformis				2+ Weak w\o gravity
Hip abduction	TFL, Glut med and minimus				1+ Fascic w\o gross movt
Hip adduction	Adductors				0 No movement
Knee flexion	Hamstring,				
Knee extension	Quad				W - wasting
Ankle plantarflexion	Gastrocnemius, soleus				
Ankle dorsiflexion	Tibialis anterior				
Inversion	Tibialis anterior				
Eversion	Peroneus longus				
Great toe extensor	EHL				

BASIC THORACIC EXAM
Passive ROM



History :

Orthopedic assessment:

BASIC HIP EXAM

History
ROM: Active
Passive: Medial rotation: A) Supine (neutral) If reduced
- hard \ soft end feel

B) Supine (hip flexed):
- Trochanteric bursa

MOTION PALPATION AND JOINT PLAY	L	R
Thoracic Spine		
Lumbar Spine		
Sacroiliac Joint		

APPENDIX F

Date: _____

Participant's code: _____

File no: _____

Height: _____m

Weight: _____kg

BMI (Body mass index): _____kg/m²

Subjective measurement:

Pre-intervention: Did you experience any pain or discomfort? Y / N _____ seconds.

Post-intervention: Did you experience any pain or discomfort? Y / N _____ seconds.

Objective measurements:

Pre-intervention: Muscle length assessment of the paraspinal muscles: _____cm

Post-intervention: Muscle length assessment of the paraspinal muscles: _____cm

	Pre-intervention	**Post-intervention**
Endurance time (seconds)		
Average SEMG reading (mV) Channel A		
Average SEMG reading (mV) Channel B		
Peak SEMG reading (mV) Channel A		
Peak SEMG reading (mV) Channel B		
Minimum SEMG reading (mV) Channel A		
Minimum SEMG reading (mV) Channel B		

Active lumbar ROM pre-intervention:

	Flexion	**Extension**
Reading 1		
Reading 2		
Reading 3		
Average reading		

Active lumbar ROM post-intervention:

	Flexion	**Extension**
Reading 1		
Reading 2		
Reading 3		
Average reading		

APPENDIX G

Dear Sir/Madam

I am currently registered for my Masters in Chiropractic at the Durban University of Technology. I would like permission to place an advertisement, which is attached, on your premises to recruit participants for my research project.

Yours sincerely,

Kate Jones
Researcher

I, ……..give permission for an advert to be placed on my premises.

_____ _____

Signed Date

APPENDIX H

MEMORANDUM

To : Prof Puckree
Chair : RHDC

Prof Adam
Chair : IREC

From : Dr Charmaine Korporaal
Clinic Director : Chiropractic Day Clinic : Chiropractic and Somatology

Date : 01.08.2013

Re : Request for permission to use the Chiropractic Day Clinic for research purposes

---

Permission is hereby granted to :

Ms Kate Jones (Student Number: 20601351)

Research title : "The effect of sacroiliac joint manipulation on lumbar extensor muscle endurance in asymptomatic individuals".

It is requested that Ms Jones submit a copy of her RHDC / IREC approved proposal to the Clinic Administrators before she starts with her research in order that any special procedures with regards to her research can be implemented prior to the commencement of her seeing patients.

Thank you for your time.

Kind regards

Dr Charmaine Korporaal

Clinic Director : Chiropractic Day Clinic : Chiropractic and Somatology

Cc: Mrs Pat van den Berg : Chiropractic Day Clinic
Dr L O'Connor : Supervisor and Research co-ordinator

APPENDIX I

DUT
DURBAN
UNIVERSITY OF
TECHNOLOGY

Institutional Research Ethics Committee
Faculty of Health Sciences
Room MS 49, Mansfield School Site
Gate 8, Ritson Campus
Durban University of Technology

P O Box 1334, Durban, South Africa, 4001

Tel: 031 373 2900
Fax: 031 373 2407
Email: lavishad@dut.ac.za
http://www.dut.ac.za/research/institutional_research_ethics

www.dut.ac.za

20 August 2013

IREC Reference Number: **REC 50/13**

Ms K E Jones
P O Box 615
Gillitts
3603

Dear Ms Jones

The effect of sacroiliac joint manipulation on lumbar extensor muscle endurance in asymptomatic individuals

I am pleased to inform you that Full Approval has been granted to your proposal REC 50/13.

The Proposal has been allocated the following Ethical Clearance number IREC 066/13. Please use this number in all communication with this office.

Approval has been granted for a period of one year, before the expiry of which you are required to apply for safety monitoring and annual recertification. Please use the Safety Monitoring and Annual Recertification Report form which can be found in the Standard Operating Procedures [SOP's] of the IREC. This form must be submitted to the IREC at least 3 months before the ethics approval for the study expires.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the IREC according to the IREC SOP's. In addition, you will be responsible to ensure gatekeeper permission.
Please note that any deviations from the approved proposal require the approval of the IREC as outlined in the IREC SOP's.

Yours Sincerely

Prof J K Adam
Chairperson: IREC

APPENDIX J

Institutional Research Ethics Committee
Faculty of Health Sciences
Room MS 49, Mansfield School Site
Gate 8, Ritson Campus
Durban University of Technology

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17 September 2013

IREC Reference Number: **REC 50/13**

Ms K E Jones
P O Box 615
Gillitts
3603

Dear Ms Jones

Application for Amendment of Approved Research Proposal

The effect of sacroiliac joint manipulation on lumbar extensor muscle endurance in asymptomatic individuals

I am pleased to inform you that your application for amendment to your research proposal has been **approved**.

Yours Sincerely

[redacted]

Prof J K Adam
Chairperson: IREC

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19 November 2013

Ms K E Jones
P O Box 615
Gillitts
3603

Dear Ms Jones

Application for Amendment of Approved Research Proposal

The effect of sacroiliac joint manipulation on lumbar extensor muscle endurance in asymptomatic individuals

I am pleased to inform you that your application for amendment to your research proposal has been Approved.

Please note that you are to ensure that the number of participants recruited for the study does not exceed 40 as approved in your proposal.

Yours Sincerely

[redacted]

Prof J K Adam
Chairperson: IREC

APPENDIX K

NHREC

South African Human Research Electronic Application System

TRIAL APPLICATION

Application ID:	3604	DOH Number	Pending	Page:	1/3

Applicant Details

Organisation :	Durban University of Technology
Applicant Type :	Academic Investigator
Contact Name :	L. O'Connor
Address :	11 Ritson Rd Berea 4000
Telephone :	0313732923
Fax :	0865624209
E-mail :	lauraw@dut.ac.za
Responsible Contact person (for public)	L. O'Connor
Telephone :	0313732923
Research contact person	K. Jones
Telephone :	0826710508

Trial Application Details

Issue Date :	2013/11/08
Sponsors :	Durban University of Technology
Primary Sponsor :	
FundingType :	Not Funded
Research Site Names :	Durban University of Technology Chiropractic Clinic
Primary Research Site Name :	
Total National Budget for Trial :	R 7002.00
Protocol / Grant Reference Number	REC 50/13

Study Descriptive Information

Brief Tiltle of Study :	The effect of sacroiliac joint manipulation on lumbar extensor muscle endurance in asymptomatic individuals
Full Title of Study :	The effect of sacroiliac joint manipulation on lumbar extensor muscle endurance in asymptomatic individuals
Anticipated Start Date :	2013/11/01
Anticipated End Date :	2013/11/29
Target Sample Size :	40
Study Phase :	Other
Study Scope :	Single Site
Study Type :	Interventional
Disease Type Heading :	Muscle, Bone and Cartilage Diseases
Disease Type Condition :	Musculoskeletal Diseases
Intervention Name (Generic) :	Spinal Manipulation
Intervention Duration :	No. Type 1 Days

NHREC

South African Human Research Electronic Application System

TRIAL APPLICATION

Application ID:	3604	DOH Number	Pending	Page:	2/3

Interventional

Intervention Type :	Procedure
Purpose :	Treatment
Allocation :	Randomised
Masking :	Single Blind
Control :	Placebo
Assignment :	Parallel
Endpoints :	Efficacy

NHREC

South African Human Research Electronic Application System

TRIAL APPLICATION

Application ID:	3604	DOH Number	Pending	Page:	3/3

Study Descriptive Information

Recruitment Status as at Date:	2013/11/01
Recruitment Status :	Recruiting
Gender :	Males
Ethnicity :	All
Age :	From 20 Years To 40 Years
Qualifying Disease Condition for Inclusion :	Asymptomatic males: 1) Participants must read, agree to and sign the Letter of Information and Informed Consent 2) Participants must be between the ages of 20 and 40 years old 3) Participants must be right handed 4) Participants must have a Body Mass Index (BMI) between 18.5 kg/m² and 24.9 kg/m² 5) Participants who hold the Biering-Sorensen extensor muscle endurance test for less than 176 seconds will be included in the study. 6) Participant must be free of low back pain (LBP) within the past three months 7) Participants must have a sacroiliac joint (SIJ) restriction 8) Participants must have hypertonicity of the paraspinal muscles
Major Exclusion Criteria :	1) Medical conditions which could make physical activity unsafe for the participant, including but not limited to hypertension, cardiac or respiratory disease, musculoskeletal disorders and neurological symptoms 2) Significant trauma affecting the low back or if the clinical assessment warrants that the participant needs radiographic analysis. 3) Previous spinal surgery 4) On-going treatment for low back pain by other health care providers. 5) Any mechanical or manual intervention to the thoracic or lumbar spine three weeks prior to the study will be excluded. 6) The use of any muscle relaxants for any reason may be excluded from the study, unless they have a 72 hour (three day) wash out period before commencement of the study 7) Contraindications to sacroiliac joint manipulation 8) Contraindications to surface EMG
Key Primary Outcome :	To determine the effect of sacroiliac joint manipulation compared to a placebo sacroiliac joint treatment on lumbar extensor muscle endurance in terms of objective findings by measuring the endurance timed during the Biering-Sorensen test and fatigue of the lumbar extensor muscles using sEMG, as well as the lumbar active ranges of motion pre and post-intervention using an Inclinometer
Key Secondary Outcomes :	To determine the effect of sacroiliac joint manipulation compared to a placebo sacroiliac joint treatment on lumbar extensor muscle endurance in terms of subjective findings of pain or discomfort experienced during the Biering-Sorensen test.