TOPIC

The effect of lumbar spine, sacro-iliac and/or hip joint manipulation on muscle activity and performance in road cycling

By

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

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DEDICATION

Life is like riding a bicycle. To keep your balance, you must keep moving - Albert Einstein

To my parents,
Richard and Margurẻte Fuller
Thank you for the incredible example you have set for me. Thank you for your love, support, guidance and for always encouraging me to be the best I can be.

It never gets easier, you just go faster - Greg Lemond

To my Fiancé,
Quentin Gordon
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ABSTRACT

BACKGROUND

Cycling is a highly competitive sport where athletes are continuously looking for ways to improve their performances in order to gain what might be seconds over their components. Chiropractic manipulation has been shown to restore the balances of the kinematic chain and stimulate motoneuron pools and therefore by implementing this technique into their training regime, it may show improvement in muscle activity distributions, demands and efficiency thus resulting in better cycling performance.

OBJECTIVES

To determine the participants muscle activity (amplitude of surface EMG) and cycling performance in terms of power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds) before and after lumbar spine, sacro-iliac joint and/or hip joint manipulation intervention.

METHOD

Sixty-one asymptomatic amateur cyclists performed two 1.5km time-trials pre- and post-manipulative intervention. The pre- and post-intervention data of muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)) were captured. IBM SPSS version 24 was used to analyse the data. A p value <0.05 was considered as statistically significant.

RESULTS

There was no significant change in muscle activity post-lumbar spine manipulation.
There was a significant decrease in cycling performance post-lumbar spine manipulation.

Sacro-iliac joint showed no significant change in muscle activity post-manipulation.
The study data demonstrated a significant decrease in cycling performance post sacro-iliac joint manipulation.

There was no significant change in muscle activity post hip joint manipulation.
A significant decrease in power output and speed post hip joint manipulation, no significant effect of overall performance.

Combination manipulation intervention showed a significant decrease in muscle activity of iliopsoas muscle.
Combination manipulation showed no significant change in cycling performance.

CONCLUSIONS

There was a visual trend that showed, although there was a decrease in overall cycling performance in the lumbar spine and sacro-iliac joint manipulation groups post-intervention, with no significant changes in the hip joint and combination manipulation groups post-intervention – these athletes were more efficient cyclists post manipulative intervention particularly those who received the combination of adjustments.

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LIST OF SYMBOLS AND ABBREVIATIONS

AP – Anterior to Posterior

CP - Contact point

DP - Doctors' position

HVLA – High velocity, low amplitude

IH - Indifferent hand

IND - Indication

IVD - Intervertebral disc

km/h – kilometres per hour

P – Procedure

PA – Posterior to Anterior

PP - Patient position

PSIS – Posterior superior iliac spine

rpm – revolutions per minute

SC – spinal cord

SCP - Second contact point

SIJ – Sacro-iliac Joint

VB - Vertebral body

VCa - Vertebral column

VCb – Vertebral canal

VEC - Vector

VF - Vertebral foramen

W - Watts

GLOSSARY OF TERMS

Bottom bracket (BB): a shell which allows the crank to rotate about an axle relative to the frame, which connects the two arms with or without a spindle (Šinkovskà 2013).

Bottom dead centre (BDC): refers to the pedal positioned at 6 o'clock or the very bottom of its path in the pedal stroke (Burt 2014).

Cadence: the number of revolutions per minute (rpm) – the speed at which the pedals are turned (Burke 2003).

Chain: series of consecutive metal links required to propel the bike forwards by connecting the chainrings to the cassette on the back wheel (Burke 2003; Šinkovskà 2013).

Chainring: a front mounted circular or oval toothed wheel, that meshes with a rolling chain that is required to propel the chain and bike in a forwards direction (Šinkovskà 2013; Burt 2014).

Crank: one of the two levers that are attached to the bottom bracket in order to pedal (Šinkovskà 2013).

Crank arm: the arm which connects the chainring and the bike (Burt 2014).

Derailleur: device required to shift the bicycle gears by moving the chain between the different sized tooth rings (Šinkovskà 2013).

Dismount: to get off of ones' bicycle (Šinkovskà 2013).

Drops: the bottom loop of the handlebars which drops down and back (Burt 2014).

Fork: part of the bicycle that holds the front wheel and allows the rider to direct the bicycle (Šinkovskà 2013).

Frame: main bicycle component onto which the other bicycle components and wheels are fitted to (Šinkovskà 2013).

Handlebars: steering mechanism of bicycle. Attaches to bicycle stem which attaches to the fork. May hold portion of cyclists weight depending on their riding position or style (Šinkovskà 2013).

Hub: the centre part of the bicycle wheel, it consists of an axle, bearing and shell which typically has two metal flangers to which the spokes are attached (Šinkovskà 2013).

Kinetic chain: consecutive chain of limbs, muscles and joints involved in movement kinesis (Burt 2014) **.**

Mount: to get onto ones bicycle in order to ride ones bicycle (Šinkovskà 2013).

Pedal: (noun) bicycle part that the rider pushes with his or her foot in order to propel the bicycle forwards. It provides the connection between the cyclists foot and the crank allowing the leg to turn the bottom bracket axle (crank) (Šinkovskà 2013)**.**

Pedal: (verb) to propel and ride the bicycle somewhere (Šinkovskà 2013).

Pedal stroke: one complete revolution of the pedals around the bottom bracket.

Power: The rate of doing work expressed in joules (J) per second or watts (W) (Burke 2003). Power is the rate of performance per unit of time and therefore power is equivalent to the quantity of energy being transferred to the pedals by the cyclist per unit of time (Burke, 2003).

Road bicycle: a bicycle that is built to ride on paved roads at higher speeds with narrow tires blown up at high-pressures, and are smooth to decrease the rolling resistance. These bikes may have fixed gears however generally have multi-derailleurs to allow for gear changing (Šinkovskà 2013).

Time-trial: a race against the clock, generally an individual event where no drafting is allowed. Each participant starts a few second after the participant ahead of them – the winner is determined by the fastest man/woman across the line (Šinkovskà 2013).

Top dead centre (TDC): refers to the pedal positioned at 12 o'clock or the very top of it path in the pedal stroke (Burt 2014).

Torque: the force applied through a series of levers that results in rotation through an axis in order to turn the pedals (Burt 2014).

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Recently, cycling has evolved from a leisure activity into a multimillion dollar business (Bester 2011). Cyclists can earn salaries from it, and businesses can invest in it. As a result, organisations manage, develop and promote the sport while maintaining a historical sporting culture (Bester 2011). According to Cycling South Africa (2016), there were 175 456 registered cyclists in South Africa in 2016, of which 2 798 were registered across KwaZulu-Natal.

The move from recreational to professional cycling has required a review of factors that impact on performance and the prevention of injuries. Cycling can be optimised not only by anatomical, physiological and biomechanical factors, but also on the engineering factors that are related to cycling (García-López *et al.* 2015). Cycling is highly competitive; therefore, riders are always looking for ways to improve their performance. This need to improve performance has precipitated the need to link participation to evidence-based principles (Burke 2003).

Cyclists aim to improve their mechanical efficiency by employing the most effective riding set-up, in order to ensure that the forces are most effectively applied to the pedals to create efficiency and forward propulsion (Fonda and Sarabon 2010). It is important to study the recruitment patterns of various muscles during cycling in order to determine optimal performance. In this regard, surface electromyography (SEMG) is used to accurately determine, understand and measure the rate of electrical activity of the muscles and the demand they are placed under during cycling (Fonda and Sarabon 2010). One possible form of intervention that may have the ability to enhance neuromuscular performance through the recruitment and rate coding of active muscles is that of manipulation (Perkin 1998; Keller and Colloca 2000; Heloyse Uliam *et al.* 2012; Niazi *et al.* 2015).

The mechanism of joint manipulation and its effectiveness in not fully understood, however the three main theories presented include: biomechanical, neurophysiological and muscular reflexogenic theories, which all appear to have a neurophysiological effect (Keller and Colloca 2000; Bicalho *et al.* 2010; Jones 2014).

To determine the patterns of muscle activation attributed to manipulation, this research will look at manipulation effects on muscle activity pre- and post-manipulative therapy and the related performance in cyclists. In addition, it will also attempt to determine any relationships between muscle activity and cyclist performance. Surface electromyography will be used to monitor muscle activity as it has been shown to be the most valid and reliable measuring tool for muscle activity (Biopac Systems Inc, 2015; Cram 2011; Hof 1984) and has been used in a variety of studies (Dunning and Rushton ; Keller and Colloca 2000; Niazi *et al.* 2015). The outcome of this research would therefore allow for the development of an evidence-based training protocol to enhance performance and reduce biomechanical dysfunction (Burke 2003).

1.2 AIMS

The aim of this study was to determine the effect of lumbar spine, sacro-iliac and/or hip joint manipulation on muscle activity and performance in road cyclists

1.3 OBJECTIVES

The objectives of the study were:

1. To determine the effect of lumbar spine manipulation on muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)).

2. To determine the effect of sacro-iliac joint manipulation on muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)).

3. To determine the effect of hip joint manipulation on muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)).

4. To determine the combined effect of lumbar spine, sacro-iliac joint and hip joint manipulation on muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)).

5. To compare the combined effect of lumbar spine, sacro-iliac joint and hip joint manipulations with that of the individual manipulation groups, with regards to muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)).

1.4 HYPOTHESES OF STUDY

It is hypothesised that a combination of manipulations (lumbar spine, sacro-iliac joint and hip joint) would improve the dependent variables significantly more than when they are applied individually.

The alternate hypothesis states that manipulations of the lumbar spine, sacro-iliac joint and hip joint individually would improve the dependent variables significantly more than when they are applied in combination.

1.5 STUDY RATIONALE

With the increase in popularity of cycling, scientists began doing laboratory studies on cyclists in order to determine and better understand the workloads required during this complex sporting activity (Fonda and Sarabon 2010). The significance of this study was to determine the effects of joint manipulation on cycling performance, and the impact that they might have on muscle activity and performance-determining factors.

According to chiropractic theories, the purpose of manipulation is to remove a subluxation. Korr (1975) concluded that normal neural transmission within the central nervous system (CNS) would have some degree of interruption with spinal fixation. With the growing increase, development and interest in this sport, it is apparent that further research needs to be performed with regards to the effects of manipulative treatment on cycling performance.

Performance during cycling depends on a variety of factors such as mechanical, biomechanical and physiological factors (García-López *et al.* 2015). This highly competitive sport has ignited the need to base participation on evidence-based principles (Burke 2003).The power produced by a cyclist is a direct function of muscle mass (Burke 2003) and in theory, the force generated by a muscle is dependent on the recruitment and rate coding of motor units in the active muscles (Heloyse Uliam *et al.* 2012). Therefore, this research will look at the effect of manipulation on muscle activity of selected muscles pre- and post-manipulative therapy and power output (performance) in cyclists and will determine whether a relationship exists between muscle activity and cycling performance.

1.6 FLOW OF DISSERTATION

Chapter One introduces the reader to this study as well as outlining the aims, objectives and hypotheses. It provides a rationale for the study based on the literature.

Chapter Two, the literature review, provides an overview of the anatomy, physiology, neurology and biomechanics involved in the lumbar and pelvic region, as well as an overview of cycling biomechanics and chiropractic theory and manipulation. It also looked at recent literature so that the aims and objectives could be formulated.

Chapter Three describes and explains the methodology used to achieve the aims and objectives of this study. The study design, population and sampling strategy, methods and objective measurement through the use of equipment, data analysis and ethical issues are described in detail.

Chapter Four presents the results of this study. The cycling data, along with the surface electromyography data are represented using tables and figures.

Chapter Five provides an analysis and discussion of the results in relation to current literature.

Chapter Six will discuss the final conclusion to this study, including limitations and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The aim of this chapter is to familiarise the reader with the current literature surrounding physiology, anatomy, neurology and biomechanics relevant to this study. It aims to identify the most important and most used musculature during cycling, and the mechanisms involved during the activity of cycling. It also addresses the effects and benefits of manipulation.

2.2 ANATOMY

2.2.1 Bony Anatomy

2.2.1.1 Typical Lumbar Vertebra

The lumbar vertebrae are found in the low back region between the thorax (T12 vertebra) and sacral bone. The lumbar vertebrae consist of a large, kidney shaped vertebral body (VB) (superior view), a triangular vertebral canal, which is larger than that of the thoracic spine but smaller than that of the cervical spine. The long and slender transverse processes (TVP) project posterosuperiorly and laterally. The spinous process (SP) is hatchet shaped, short thick, broad and strong (Moore, Dalley and Agur 2008).They have accessory processes (mammillary processes) on the posterior surface at the base of each process to allow for attachment of the multifidus and intertransversarii muscles. The lumbar vertebrae have superior articular processes which are directed more posteromedially, and which are initially orientated in the sagital plane and then towards the coronal plane. By contrast the inferior articulating processes are orientated anterolaterally so that the superior articulating facet is able to articulate with the inferior articulating facet of the superior articulating process (Moore, Dalley and Agur 2008; Tortora and Derrickson 2011).

Between the successive lumbar vertebrae, there are intervertebral foramina, through which the spinal nerves exit to leave the vertebral canal. The fifth lumbar vertebra is atypical as it carries the entire weight of the upper body and thus needs a large VB and adapted TVP's (for iliolumbar ligament attachment) in order to transfer the body weight to the base of the sacrum. The fifth lumbar vertebra has a longer anterior height than its posterior height, making it wedge-shaped and thus partly responsible for the lumbosacral angle (Moore, Dalley and Agur 2008), along with the wedge-shaped lumbosacral disc.

2.2.1.2 Pelvis

The bony pelvis is made up of four bones, which include two os coxae or innominate bones, one sacrum and one coccyx (Ellis 2006; Moore, Dalley and Agur 2008; Tortora and Derrickson 2011). The pelvis is an important aspect of anatomy for cycling as various parts provide for major attachment points for the musculature required for cycling, i.e. ischium is the attachment for the hamstrings (Burt 2014).

2.2.1.2.1 Os Coxae or Innominate Bones

The os coxae is made up of three bones that fuse at approximately 16 years of age – the ilium, ischium and pubis (Ellis 2006; Tortora and Derrickson 2011).

The ilium, the largest of the hip bone components, is composed of an ala and inferior body, which forms part the acetabulum (the socket in which the femoral head articulates). The iliac crest (superior border of the ilium) projects anteriorly to form the anterior superior iliac spine (ASIS), below this point, the anterior inferior iliac spine (AIIS). The iliac crest also projects posteriorly to form the posterior superior iliac spine (PSIS), below this point, the posterior inferior iliac spine (PIIS) – these spines all serve as attachment points for muscles of the trunk, hip and thigh. The sciatic notch, located just below the PSIS, allows for the sciatic nerve to pass through in order to provide innervation to various muscles of the lower limb (Moore, Dalley and Agur 2008).

The posterior inferior aspect of the os coxae is referred to as the ischium, which is formed by a superior body and an inferior ramus. The inferior rami are what fuse with the pubis. Together, the pubis and rami surround the obturator foramen, allowing for blood vessels and nerves to pass through. Other features of this body element include the ischial spine, lesser sciatic notch and ischial tuberosity (Moore, Dalley and Agur 2008).

The pubis forms the most inferior and anterior aspect of the os coxae. The pubis consists of a body, superior ramus and inferior ramus. The bony element of the os coxae unites anteriorly to form the pubic symphysis (Moore, Dalley and Agur 2008). Posteriorly the ilium articulates with the sacrum to form the sacro-iliac joint (Moore, Dalley and Agur 2008).

Together, the same bony aspects that form the os coxae also form the acetabulum, which is a deep fossa that accepts the head of the femur. Together, the acetabulum and the femoral head form the hip joint, technically referred to as the coxal joint (Moore, Dalley and Agur 2008).

2.2.1.2.2 Sacrum

The sacrum, a wedge- or triangular-shaped bone, consists of five fused vertebrae and lies between the os coxae to form the keystone in the posterior half of the pelvic cavity (Moore, Dalley and Agur 2008; Tortora and Derrickson 2011). The sacrum's wedge shape is as a result of the rapid decrease in size of the lateral masses during the developmental stages of life. Strength and stability provided by the os coxae for the sacrum allow for the transfer of body weight to the pelvic girdle. The pelvic girdle or pelvic ring allows for the attachment of the muscles of the lower limbs (Moore, Dalley and Agur 2008). The sacral canal, a continuation of the vertebral canal (VCb), contains the nerve roots that arise from the cauda equine at the level of the first lumbar vertebra. Four pairs of sacral foramina traverse the sacrum ,which are analogous to the intervertebral foramina (IVF) of the lumbar spine, from which the spinal nerves exit (Moore, Dalley and Agur 2008).

2.2.1.2.3 Coccyx

The coccyx, a triangular-shaped bone, is formed by the fusion of four coccygeal vertebrae. These bones fuse between the third and fourth decades of life. The coccygeal corona are two elongated pedicles and superior articular processes found on the dorsolateral surface of the first coccygeal vertebra formed by a series of TVPs. The coccyx orientation for males and females is anteriorly and inferiorly respectively (Tortora and Derrickson 2011).

2.2.1.3 Femur

The femur (thigh bone) is the longest, heaviest and strongest bone found in the human body. The femur is typically angled inwards from the proximal to distal aspects of the bone. The rounded femoral head articulates proximally with the acetabulum of the os coxae to form the hip joint. The head of the femur contains a depression referred to as the fovea capitis, which allows for a ligament attachment to the acetabulum. The neck of the femur joins the femoral head and femoral shaft together (Tortora and Derrickson 2011). The greater and lesser trochanters of the femur are projections found at the neck and shaft junction, and function as an attachment site for thigh muscle tendons and gluteus muscles. The vertical ridges found on the posterior surface of the femur; intertrochanteric crest and gluteal tuberosity as well as the linea aspera, serve as attachment sites for several thigh muscular tendons. The distal femur has a broadened aspect that includes the knuckle (medial and lateral condyle) which allows for articulation with the tibia, and the depression between the condyles allows for articulation of the patella (Tortora and Derrickson 2011).

2.2.2 An overview of the joints

2.2.2.1 Lumbar vertebral joints

Lumbar intervertebral joints are cartilaginous articulations between the inferior facets of the vertebra above and the superior facets of the vertebra below the vertebral bodies. The joints also include the synovial planar articulations between the respective vertebral arches.

The lumbosacral joint is a synovial cartilaginous articulation between the inferior articular facets of the fifth lumbar vertebra and the superior facets of the first sacral vertebra of the sacral base (Moore, Dalley and Agur 2008).

2.2.2.2 Pelvic joints

2.2.2.2.1 The sacro-iliac joint (SIJ)

The SIJ is an articulation on the posterior aspect of the pelvic girdle. This mildly moveable articulation occurs between the lateral aspects of the sacrum and the iliac portion of the os coxae. The limited movement of the sacro-iliac joint allows for sacral nutation. This movement is defined as the sacral promontory moving anteriorly and inferiorly while the coccyx moves posteriorly and superiorly around the x-axis while translating over the iliac portions of the os coxae bilaterally. Nutation is opposed in part by the ridges, depressions and friction of the articular surfaces as well as the integrity of the posterior and anterior sacro-iliac ligaments, interosseous, sacrospinous and sacrotuberous ligaments (Moore, Dalley and Agur 2008). Counter-nutation is opposite to nutation and is opposed by the posterior SI ligament (Moore, Dalley and Agur 2008). It can thus be seen that the sacro-iliac joint is stabilised, strengthened and supported by various ligaments (see Table 9). The SIJ is an important joint in cycling. It is closely related to the lumbar region and often refers discomfort to the lower back due to poor cycling position and posture (Burt 2014).

2.2.2.2.2 Pubic Symphysis

This joint is formed by the articulation between the two pubic rami and consists of a fibrocartilage disc between the two bony structures. Below this joint, the inferior rami of the two pubic bones join to form the pubic arch. The pubic symphysis glide superiorly and inferiorly with some compression and separation occurring in order to transfer the forces of the trunk through the sacrum and to the hip during motion (Moore, Dalley and Agur 2008).

2.2.2.3 Hip joint

The hip joint, a synovial ball and socket, is formed by the acetabulum of the os coxae and the head of the femur (Tortora and Derrickson 2008). The hip is the start of the torque chain required for pedalling (Burt 2014). This joint allows for and guides the motions of flexion, extension, abduction, adduction, circumduction, medial and lateral thigh rotation (Tortora and Derrickson 2008; Burt 2014). The very dense and strong articular labrum extends the acetabular rim to the femur neck. In addition, this joint contains one accessory ligament (foveal ligament) and the capsule is supported by four accessory ligaments (pubofemoral, ischiofemoral, transverse femoral and iliofemoral ligaments), making this joint one of the most stable, yet mobile joints of the human body (Tortora and Derrickson 2011). Accessory ligaments reinforce the longitudinal fibres of the articular capsule, whereas the circular fibres form a collar around the femur neck (Tortora and Derrickson 2011). Because of the large number, size and length of musculature attached to this joint a large amount of torque can be generated from this point (Burt 2014)

2.2.3 Overview of the Musculature

2.2.3.1 Musculature of the Lumbar and Pelvic Region

The musculature of the lumbar region is complex as a result of multiple origins and insertions as well as the overlap in functions for which each muscle is responsible. The muscles involved in the lumbar spine include; intertransversarii, rotator muscles, multifidus, iliocostalis, interspinales, longissimus thoracis, quadratus lumborum, iliopsoas and gluteus maximus.

Described below (Table 1) are the muscle attachments, functions and innervation that were assessed in this study.

Table 1: Lumbar muscle attachments, function and innervation

Muscle	Attachments	Function	Innervation
Iliopsoas (Femoral Triangle Iliopsoas Site)	Arises from first to fifth lumbar vertebral body and inner surface of ilium and inserts onto the less trochanter of the femur.	Hip flexion	Lumbar plexus via spinal nerves L1-L4
Gluteus Maximus	Iliac crest, ala of the ilium, posterior superior iliac spine, sacrum and coccyx to the iliotibial tract and gluteal tuberosity of the femur.	Hip extender and lateral rotator.	Inferior Gluteal Nerve (L5, S1, S2) (Moore, Dalley and Agur 2008) with fibres from the ventral rami of L5 and S1 through the dorsal division of the sacral plexus.

(Moore, Dalley and Agur 2008; Cram 2011; Tortora and Derrickson 2011)

2.2.3.2 Musculature of the Lower Limb

Table 2: Muscular anatomy of the lower limb

Muscle	Muscle attachments	Function	Innervation
Rectus Femoris	Arises from the anterior ridge of the iliac crest and inserts on the upper border of the patella via the quadriceps tendon (Cram 2011).	Extends leg at the knee joint, stabilises the hip joint. Helps Iliopsoas flex the thigh (Moore, Dalley and Agur 2008)	Femoral Nerve (L2, L3, L4) (Moore, Dalley and Agur 2008).
Vastus Medialis	Arises from the entire length of the posteromedial aspect of the shaft of the femur to the lower half of the intertrochanteric line, medial lip of linea aspera and the tendon of the adductor longus and magnus. It inserts on the patella via the tendon, while the oblique aspect of the muscle inserts on the medial patella reticulum (Cram 2011).	Extends the leg at the knee joint (Moore, Dalley and Agur 2008).	Femoral Nerve carrying fibres from spinal nerves (L2, L3, L4) (Moore, Dalley and Agur 2008).
Vastus Lateralis	Arises from the lateral surface of the greater trochanter, intertrochanteric line, gluteal tuberosity, lateral lip of linea aspera and inserts on the superior rim of the patella via the patella tendon (Cram 2011).	Extends leg at knee joint (Moore, Dalley and Agur 2008).	Femoral Nerves carrying fibres from spinal nerves (L2, L3, L4) (Moore, Dalley and Agur 2008; Cram 2011).
Biceps Femoris	Arises from the ischial tuberosity and inserts on the lateral head of the tibia (Cram 2011).	Flexes and laterally rotates knee when in flexed position; extends thigh (Moore, Dalley and Agur 2008).	Long head: Tibial division of Sciatic nerve (L5, S1, S2) Short head: common fibular division of sciatic nerve (L5, S1, S2) (Moore, Dalley and Agur 2008).

Medial Hamstring (Semimembranosus / Semitendinosus)	Semitendinosus – arises from ischial tuberosity and inserts on the medial head on the tibia. Semimembranosus – arises from the ischial tuberosity and inserts on the posterior medial tuberosity of the tibia (Cram 2011)	Extends thigh; flexes leg and medially rotates when the knee is flexed; when thigh and leg are flexed these muscles help to extend the trunk (Moore, Dalley and Agur 2008).	Tibial division of sciatic nerve part of tibia (L5, S1, S2) (Moore, Dalley and Agur 2008).

2.2.4 An overview of the nervous system

The complicated and versatile human nervous system detects changes in the external and internal environments, in order to bring about the most appropriate responses in the muscles, organs and glands in the human body (Crossman and Neary 2014). The nervous system is made up of two divisions: the first being the central nervous system (CNS), which includes the spinal cord and brain, and the second division being the peripheral nervous system (PNS), which consists of all the nervous tissue that lies outside of the CNS. The PNS is further divided into the somatic (SNS), autonomic (ANS) and enteric (ENS) nervous systems (Moore, Dalley and Agur 2008; Tortora and Derrickson 2011; Crossman and Neary 2014).

2.2.4.1 Nerve types

There are a variety of types of nerve fibres that make up the nervous system, including sensory, motor and interneurons. Sensory fibre/ afferent neuron sensory receptors are either found on their distal ends (dendrites) or as separate cells. Once the appropriate stimulus occurs, sensory neurons create action potentials in their axons and transmit information to the CNS (Tortora and Derrickson 2011). At the CNS, this sensory information is transferred via the interneurons to stimulate a co-ordinated motor response (Tortora and Derrickson 2011).

Interneurons or association neurons are the internuncial neurons between the sensory and motor neurons. They integrate incoming sensory information with the most appropriate outgoing motor response. These multipolar neurons are located in majority in the CNS (Tortora and Derrickson 2011; Crossman and Neary 2014).

The motor neurons relay action potentials to the effectors (muscles, organs and glands) in the PNS and therefore away from the CNS via the CNS or spinal nerves. The cell body of this multipolar motor neuron, lies within the grey matter of the spinal cord SC or the medulla oblongata, both of which are part of the CNS, and its axons extend to the effectors where it then forms neuromuscular junctions (NMJ) with a muscle (Tortora and Derrickson 2011).

2.2.4.2 Innervation Overview

2.2.4.2.1 The Lumbar Plexus

The lumbar plexus is formed by the anterior rami of spinal nerve roots L1-L4. The peripheral nerves arise from the lumbar plexus, which passes obliquely outward on either side of the first four lumbar vertebrae, between the superficial and deep heads of the psoas major muscle, and anterior to the quadratus lumborum muscle. The lumbar plexus supplies the anterior abdominal wall and part of the lower limbs (Tortora and Derrickson 2011).

Table 3: The lumbar plexus

Nerve	**Origin**	**Distribution**
Iliohypogastric	L1	Muscle: anterolateral abdominal wall. Skin: inferior abdomen and buttock.
Ilioinguinal	L1	Muscle: anterolateral abdominal wall. Skin: superomedial thigh, male scrotum and female labia majora and mons pubis.
Genitofemoral	L1, L2	Muscle: Cremasteric reflex (Cremaster in males) Skin: anteromedial thigh, male scrotum and female labia majora.
Femoral	L2, L3	Largest nerve of the lumbar plexus. Muscles: hip flexors, knee extensors (**vastus medialis, vastus lateralis**, vastus intermedius, **rectus femoris, iliacus**, pectineus, sartorius). Skin: anterior and medial thigh, medial leg and foot.
Lateral cutaneous nerve of the thigh	L2, L3, L4	Skin: lateral, posterior and anterior thigh
Obturator	L2, L3, L4	Muscles: adductors of the hip joint. Skin: medial aspect of thigh

(Tortora and Derrickson 2011)

2.2.4.2.2 The sacral plexus

The sacral plexus is formed by the anterior rami of spinal nerve roots L4, L5, S1-S4. This plexus supplies the buttocks, perineum and lower limbs and is situated anterior to the sacral bone (Tortora and Derrickson 2011).

Table 4: The sacral and coccygeal plexuses		
Nerve	**Origin**	**Distribution**
Superior gluteal	L4, L5, S1	Muscle: Gluteus minimus, gluteus medius and tensor fascia latae.
Inferior gluteal	L5, S1, S2	Muscle: gluteus maximus
Nerve to piriformis	S1, S2	Muscle: piriformis
Nerve to quadratus femoris and inferior gemellus	L4, L5, S1	Muscle: quadratus femoris (**vastus medialis, vastus lateralis**, vastus intermedius, **rectus femoris)**, inferior gemellus
Nerve to obturator internus and superior gemellus	L5, S1, S2	Muscle: obturator internus, superior gemellus
Perforating cutaneous	S2, S3	Skin: inferior medial buttock
Posterior cutaneous nerve of thigh	S1, S2, S3	Skin: anal region, inferolateral buttock, superior posterior thigh, superior calf, male scrotum, female labia majora
Sciatica	L4, L5, S1, S2, S3	Made of two nerves (tibial and common fibular), that split into two divisions at the knee. Descending through the thigh, it also gives off branches to supply the hamstrings (**biceps femoris, semimembranosus, semitendinosus**) and adductor muscles.
Tibial	L4, L5, S1, S2, S3	Muscle: gastrocnemius, plantaris, soleus, popliteus, tibialis posterior, flexor digitorum longus, flexor hallucis longus.
Common fibular	L4, L5, S1, S2	Muscle: fibularis brevis/longus, tibialis anterior, extensor hallucis longus, fibularis tertius, extensor digitorum brevis/longus Skin: distal third anterior leg, dorsum foot, sides of great and second toes
Pudendal	S2, S3, S4	Muscle: perineum, male and female genitalia

(Tortora and Derrickson 2011)

2.2.4.3 Joint innervation

The table below describes the joint innervation from the segmental nerve level of the joints being discussed in this study.

Table 5: Joint innervation	
Joint	**Innervation**
Lumbar Spine Joints	Lumbar plexus (L1-L4) (Moore, Dalley and Agur 2008)
Sacro-iliac Joint	Sacral dorsal rami (L1-S3) OR Ventral rami (L4, L5) Superior gluteal nerve (L5-S2) Dorsal rami (L5-S2) (Fortin *et al.* 1999; Forst *et al.* 2006)
Hip Joint	Femoral nerve (L2-L4) Obturator Nerve (L2-L4) Superior Gluteal Nerve (L4-S1) (Birnbaum *et al.* 1997)

2.2.4.3 Motor neuron and motor neuron pools

Motor neurons are classified into alpha, beta and gamma motor neurons that carry information at varying speeds from the central nervous system to the peripheral nervous system. The motor neuro cell body can be found in the grey matter of the spinal cord or the medulla oblongata, both which lie within the central nervous system and the axons which extend to form the neuromuscular junctions with the effector organ, i.e. skeletal muscle (Tortora and Derrickson 2011).

Motor neuron pools are made up of motor neurons that innervate single skeletal muscle fibres. These individual muscle fibres are innervated by only one motor neuron which has the ability to supply other muscle fibres simultaneously. The size of these motor neuron pools will determine the amount of muscle activity within the muscle that it innervates. Changes in these pools' excitability results in changes in excitatory stimulus, which may either increase or decrease in terms of its electrical excitability and therefore muscle activity (Klykken *et al.* 2011).

The Hoffmann reflex, which measures alpha motor neuron excitability, is located within these motor neuron pools. It has been demonstrated that the electrical stimulus of peripheral nerves, in addition to the afferent and efferent pathways, provokes an efferent response along the alpha motor neurons. This is referred to as a muscle response. This muscle response represents the maximum motor neuron pool excitability (Klykken *et al.* 2011). By exciting these motor neuron pools through manipulation, we are able to increase the activity levels of the motorneuron pools, which in turn increases the muscle activity within the muscle (Beck 2011; Crossman and Neary 2014).

Stimulation of the joints mentioned in 2.2.4.3 will result in a stimulation of the motor neuron pools in the joint, which increases the excitatory stimulus necessary for determining the level of muscle activity within the muscle. This excitatory change can then have an effect on the segmental levels that supply the joints in Table 5. An example of this process would be stimulation via manipulation of the hip joint, which therefore stimulates the mechanoreceptors of that joint and the nerve roots tabulated in Table 5, thus resulting in stimulation of the quadriceps via the innervation of the femoral nerve L2-L4.

2.3 AN OVERVIEW OF CYCLING

The locomotion of cycling is made possible by the co-ordination of all the anatomical structures, particularly by the musculature that produce forces that are transferred through the bony levers via the joints, in order to apply the force required to produce rotation through the axis of the pedals and crank arms (Burt 2014).

When looking at a cyclist who is riding, one is able to analyse the musculature and body position on the bicycle in comparison to the bicycle's geometry and setup. Both 1) bicycle setup and 2) cycling biomechanics can influence the performance of the cyclist. Understanding the biomechanics and the biomechanical demands on an individual's body enables us to determine the best setup to allow for efficient transfer of the energy used and generated, in order to propel the bicycle forwards. Both aspects will be discussed below to as how they affect this study.

2.3.1 Bicycle setup

Figure 1: The road bicycle and its components

Road bicycles comprise many components, including: a bicycle frame, handlebars and stem, brakes, wheels, pedals, gears, saddle and seat-post.

The bicycle frame comprises two triangles which together form a diamond shape in the traditional frame design. The front triangle consists of the down, top and seat tube whilst the rear triangle consists of the back stays and chain stays, as well as the seat tube (Mills 2006; Downs 2010; Barton 2015). Not only does the frame essentially bear the riders weight, but also serves the purpose of holding various components of the bicycle together (Barton 2015).

Bicycle geometry is determined by the relationship that exists between the head angle and seat angle, and thus minor changes in the degree of this relationship may alter the riding style. Bicycle geometry also takes into account the tube lengths of the frame and therefore the geometry should always take into consideration the cyclist’s size and riding style (Downs 2010; Barton 2015). Racing bicycles, in particular, have steeper angles and shortened proportions, thus making the riding style more compact (Barton 2015).

Bicycle frames are currently made from a variety of materials such as titanium and steel, and in 1986 Kestrel introduced the use of carbon fibre for high-end bicycles because it is light, rigid, strong and comfortable to ride (Mills 2006; Barton 2015).

In addition to the frame, there is a drive train, which consists of the crank arms, derailleurs, chain, cleat-in-shoe-pedal interface and gears. The two front chainrings consist of 53 and 39 teeth respectively, multiplied by the rear cassette of 10 or 11 cogs, which requires precise shifting while riding as well as the need to be light and stiff. This all allows for energy to be transferred sufficiently, without interruption, to drive the bicycle forwards (Mills 2006; Wiseman 2014; Barton 2015).

Road bicycle wheels are 700 cc (700mm diameter), the tyres are approximately 23-25mm wide, with racing wheels more commonly being produced from carbon fibre as opposed to aluminium (Barton 2015).

Road bicycles employ drop bar handlebars, allowing the cyclists to get into a low tucked aerodynamic position, but cater for various hand positions allowing for a variety during longer rides. Handlebars typically match the cyclist’s shoulder width. Gear and brake levers are attached to the handlebars forming the hoods, and are one unit that allows for gears to be changed with a flick of the small paddles. (Wiseman 2014; Barton 2015).

Given all the technicalities, when building up a bicycle – as they are individualised to each cyclist – it is also important that the cyclist’s riding setup is professionally adjusted in order to ensure optimal biomechanical functioning while riding. This not only allows the rider to maximise their energy use, but also avoids injury. It is therefore important to understand the kinematic chain that exists when riding a bicycle (Burt 2014).

2.3.2 Cycling biomechanics – lower limb biomechanics and kinematic chain

During cycling, a cyclist places low workloads on their joints, although they demand a relatively high workload from their muscles (Fonda and Sarabon 2010). Differences of only 1% in a rider's performance may determine whether a cyclist is able to beat his counterparts and finish on the podium as opposed to finishing within the peloton (Zadow *et al.* 2016).

The force generated during a cycling pedal stroke is driven predominantly by the downward pushing force of the quadriceps femoris muscles and the gluteus maximus muscles, with involvement of the semimembranosus/semitendinosis and biceps femoris being recruited when the pedal is swept back up through a pulling motion and finally to the top by the iliopsoas muscle.

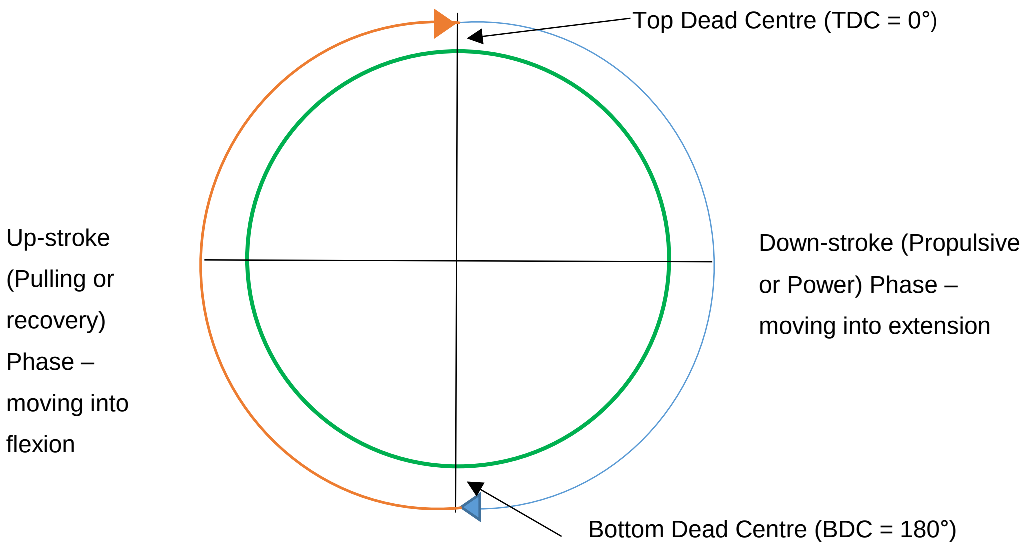

Figure 2: Phases during the pedal stroke references

When discussing the biomechanical parameters of cycling, it must be discussed in relation to the pedal stroke. The pedal stroke is divided into two parts, the down-stroke phase, which is from 0° to 180°, and the up-stroke phase from 180° to 360°. At different points in this 360° revolution, the muscles required for hip and knee flexion and extension are recruited in order to produce the power required to overcome the workloads, and therefore represents the resultant mechanical effect applied to the pedals (Fonda and Sarabon 2010). The quadriceps femoris and semimembranosus/semitendinosis and biceps femoris muscles play an important role in applying torque to the pedals in order to produce the end mechanical effect that results in the power that drives the bicycle forwards.

For the purpose of this study, only the upper leg musculature will be discussed in terms of its points of activation through a cycling pedal stroke. According to Fonda and Sarabon (2010), Ryan and Gregor (1992) performed a study on muscle activation through the cycling pedal stroke indicated diagrammatically in Figure 2 on the previous page. The gluteus maximus muscle is known to be responsible for hip extension and has been shown to activate between 340° and 130°, with its most optimum activation occurring at 80°. Vastus lateralis and vastus medialis are both responsible for knee extension and have been shown to be active between 300° and 130°, with optimal activation at 30° in the pedal revolution. Rectus femoris, a hip flexor and knee extensor, activated between 200° and 110° in the pedal revolution with optimum activation taking place at 20°. Semimembranosus and semitendinosus are responsible for knee flexion and are active between 10° and 230° and are both optimal in activation at 100°. Lastly the biceps femoris flexes the knee and extends the hip and is activated between 250° and 230° with optimum functioning at 110°. Although the iliopsoas muscle is the prime hip flexor, there seem to be no studies that have investigated where in the pedal stroke it is activated.

It is thought that co-activation relationships of muscles occur as a result of the muscles crossing over either one or more joints in the body. These co-activation pairs allow for more energy transfers to occur more efficiently, thus improving the delivery of the generated energy from the kinematic chain to be transferred into mechanical power required to produce the cycling pedal stroke (Raymond, Joseph and Gabriel 2005).

The repetitive pedalling function presents with injury patterns that are mainly as a result of the overuse of certain muscles, which can be related to the riding position (Raymond, Joseph and Gabriel 2005). These patterns may be complicated as a result of the biomechanical setup, the seated (continuous hip flexion) position and forward trunk flexion. This position results in continuous shortening and contraction of Iliopsoas, lengthening of the lower back muscles as well as a tilted pelvis. All these factors negatively impact on cycling efficiency as they are inhibiting optimal mechanical movements, as well as being exerted and stressed for extended periods of time, resulting in some form of muscle fatigue.

Cited by Fonda and Sarabon (2010) taken from Ryan and Gregor (1992)

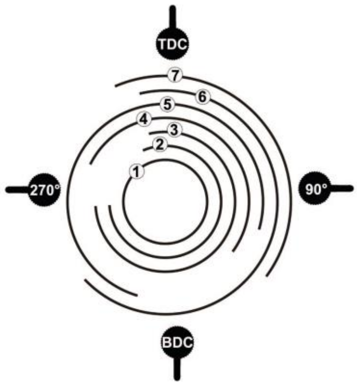

Figure 3: Muscle activity timing in lower extremity in relation to crank angle during cycling. (1=Tibialis Anterior, 2=Soleus; 3= Gluteus Medius; 4= Vastus Lateralis and Vastus Medialis; 5=Rectus Femoris; 6=Biceps Femoris; 7=Gluteus Maximus)

2.3.3 Cycling performance and efficiency factors

2.3.3.1 Cycling performance overview

In the studies performed by Jeukendrup and Martin (2001); Faria, Parker and Faria (2005), it was concluded that the most aerodynamic position that allowed for optimal performance (power, completion time, speed, cadence) was with a cyclist riding with their hands positioned in the hood of the handle bars. This position allowed for the optimal engagement of the musculature required to propel the bicycle forwards. It was also concluded, however, that an over carefully optimised riding position might in fact result in a decrease in performance, as the power production and mechanical energy transfer to the pedals is lost. According to Faria, Parker and Faria (2005), at speeds greater than 50 km/h, aerodynamic resistance results in the most influential performance-determining factor.

Energy transferred to the pedals by a cyclist, according to Burke (2003), is not equivalent to the physiological outputs expended by the rider, but rather a measurement of external work performed. It was found that humans are only 21% to 24% efficient in converting chemical energy to mechanical energy while cycling, and therefore a cyclist riding at an average of 250W is expending an equivalent of 1 000W of metabolic energy (Burke 2003).

Power produced during cycling is the result of a smooth, non-weight bearing activity and the power produced by a cyclist is a direct function of muscle mass (Burke 2003). Power in theory is thus the force generated by a muscle and is dependent on the recruitment and rate coding (electrical signal measured) of motor units in the active muscles (Keller and Colloca 2000; Heloyse Uliam *et al.* 2012; Niazi *et al.* 2015). Therefore a normal expectation on SEMG results would show increased power with increased SEMG activity, however contradictory to this, Chapman *et al.* (2008) suggests that results are different in trained athletes. Chapman *et al.* (2008) describes a decreased SEMG amplitude and a shorter duration in trained athletes, as they have more efficient muscle recruitment. This would result in a more efficient muscle, requiring less work for the same amount of power.

According to Burke (2003), power is defined as the rate of performance per unit of time, watts (W) and therefore when measured at the crank arm it is equivalent to the quantity of energy being transferred by the cyclist to the pedals per unit time. It is the measurement of exercise intensity. This results in cyclists, coaches and scientists identifying power output as one of the most significant measurement of cycling performance (Burke 2003; Wiseman 2014).

As cited by Raymond, Joseph and Gabriel (2005), according to Macintosh, Neptune and Horton (2000), as power output increases, so does cadence, which is the number or speed of pedal revolutions per minute (rpm). With the increase in cadence, there is a natural decrease in the recovery phase during the pedal stroke and therefore there is a greater demand for more positive forces from the pedalling leg, in order to return the recovering leg to the top dead centre of the crank (TDC = 0°). This ultimately influences the recruitment patterns of the various muscles used during cycling.

According to Burke (2003) and cited by Nelson (2011), a cyclist's cadence can be influenced by several other factors, including an individual's power, fitness levels and length of exercise. High inter-individual variability exists with regards to optimal cycling cadence as a result of cyclists pedalling at a rate which is comfortable and most economical for them, even when compared with individuals of the same fitness levels (Burke 2003).

According to Faria, Parker and Faria (2005), the cadence rate may have an influence on the types of muscle fibre recruitment pattern, with fewer type II fibres being recruited compared to type I fibres, when the pedalling rate was increased from 50rpm to 100rpm. It was clearly indicated and concluded that muscle fibre type recruitment was as a result of force demands on the pedals as opposed to velocity of the contraction. Factors that influence cadence include crank arm length, riding position, angular and linear movements, velocities and accelerations of body kinematics including forces in both the joints and muscles (Jeukendrup and Martin 2001).

Speed is defined as the distance travelled per unit time. It is the result of the power produced by a cyclist in order to propel the bicycle forwards (Burke 2003). Therefore, cycling speed or velocity is a result of the dynamic equilibrium between the power produced and power demand (Jeukendrup and Martin 2001).

In the professional cycling world, races are very often won by only by a few seconds. In 2017 one of the most prestigious eight-stage cycle tours, Paris-Nice, was won by Sergio Luis Henao by just two seconds, to his second-place competitor Alberto Contador (http://www.procyclingstats.com/race/Paris-Nice_2017). Therefore, it is not always the cyclist who produces the most power that is considered to be the best rider, but rather that individual who uses all these factors (power-to-weight ratio, optimal aerodynamics, nutrition, training, race tactics, team mates, etc.) who produces the best performance and therefore who wins (Jeukendrup and Martin 2001). Having the competitive edge means winning or losing by a fraction of a second in the cycling world, and therefore finding ways to improve an individual’s performance even fractionally becomes desirable.

Chiropractic care is one aspect of care which various athletes, particularly cyclists, can explore and look into helping improve their performance. Various research has shown increased joint range of motion and changes in muscle imbalances through spinal manipulation, thus it may have an influence on performance through changes in biomechanical functions (Hillermann *et al.* 2006; Grindstaff *et al.* 2009).

2.4 CHIROPRACTIC

2.4.1 Theories and manipulation

Korr (1975) concluded that normal neural transmission within the CNS would have some degree of interruption with the presence of a spinal fixation. According to chiropractic theories, the purpose of manipulation is to remove a fixation (Leach 2004). This would thus, in theory, restore normal neurological function, improve neuromotor end plate recruitment and the co-ordination of the motor end plate recruitment patterns.

2.4.2 Spinal manipulative therapy

Manipulation as a manual intervention is applied as a high velocity, low amplitude thrust, with the main aim being to restore normal motion within a joint that was previously restricted (either through macro-trauma or through repetitive micro-trauma) (Leach 2004; Gatterman 2005). The manipulation is thought to do this through a process of reducing joint locking (Gatterman 2005; Vernon and Mrozek 2005; Bergmann and Peterson 2010; Byfield 2011; Haldeman 2012), removing adhesions (Leach 2004), releasing entrapped meniscoid/menisci (Bergmann and Peterson 2010; Byfield 2011; Souza 2014) – particularly in patients with chronic repetitive micro-trauma, as would be the case in cyclists (Leibovitch and Mor 2005). Therefore, manipulation with its resultant increase in joint range of motion allows for optimisation of muscle function (as a result of a normalised relationship of muscle origin and insertion) and may restore normal biomechanical function.

Manipulation has effects on the effective functioning of the neurological system (Lewit 2009; Korr 2012) that controls joint function, both directly and indirectly (Suter *et al.* 1999; Leach 2004; Hillermann *et al.* 2006). These neurological effects are thought to occur as a result of depolarisation of the motor neuron pools at the level at which the manipulation is administered. As a result of manipulation, the mechanoreceptors within the manipulated joint are stimulated by the physical effect on the joint. This causes an increase in the afferent bombardment of the spinal nerve root and dorsal root ganglion. When this barrage of sensory information is received at the spinal segmental level, the level becomes facilitated (the axons are brought closer to threshold, making them easier to depolarise). As a result, both spatial and temporal summation lead to the segment becoming depolarised once the initial information has passed through the segment (Beck 2011; Crossman and Neary 2014).

This depolarisation is thought to be affected though the Wyke receptors (I-III). As a result of manipulation, these receptors have an increase in the afferent bombardment of the spinal nerve root and dorsal root ganglion, through the large A-fibres which carry the sensations to the Rexed's laminae of the grey matter in the dorsal horn of the segment that was manipulated. From these Rexed's laminae there are several pathways (e.g. lateral and anterior spinothalamic tract, cuneate and gracile tracts, dorsal leminscal system) which carry the information to the thalamus, cerebellum and cerebrum (both frontal lobes and the cerebral homonculus), in order for the central nervous system to respond in a co-ordinated manner.

This depolarisation, in theory, would then allow for the segment to become normalised through homoeostatic processes as the thresholds are restored to their physiological norm (Tortora and Derrickson 2008; Tortora and Derrickson 2011; Hall and Guyton 2015).This normalisation of function should theoretically allow for the optimal recruitment of all the pathways that control movement, and thus all neuromotor end plates that control muscle activity and therefore function. This optimal recruitment of neuromotor end plates would thus allow improvement of the rate coding of motor units in the active muscles, power and co-ordination, with the proposed normalisation in muscle function as well as the optimisation of muscle recruitment attributed to manipulation.

2.6 CONCLUSION

Research has shown improved and optimal muscle recruitment and functional activity through intervention by means of spinal manipulation. Other research has shown increased quadriceps strength through spinal manipulation and overall improvement in muscle imbalances of the lower limbs in athletes, thus optimising muscular activity during performance after spinal manipulation (Hillermann *et al.* 2006; Grindstaff *et al.* 2009). Therefore, research into chiropractic manipulation for the potential benefit on cycling performance is important to investigate further.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the procedure used to conduct this study, including the study design, population, sample and recruitment, inclusion and exclusion criteria required to participate, with the objective measuring tools used, manipulative intervention procedures and statistical analysis employed during the study as described.

3.2 STUDY DESIGN

This study was designed as a quantitative paradigm, pre-test and post-test experimental trial. This study allowed for allocation of participants into one of the four groups according to joint fixations found. All participants were tested prior to intervention administration. All participants were retested post-intervention in order to determine the effect of the independent variable on the dependent variables. (Mitchell and Jolley 2012).

The independent variable in this study is the chiropractic manipulation and dependent variables are those factors responsible for measuring cycling performance (power, cadence, speed, completion time and muscle activity).

3.3 POPULATION, SAMPLE AND RECRUITMENT

The population consisted of social and amateur cyclists from within and around the eThekwini Municipality, Durban, who volunteered to participate in the study.

In order to ensure statistical significance, a sample of 60 participants, 15 participants per group, were selected to participate in this study (Singh 2016).

Recruitment of participants occurred via non-probability convenience sampling and were allocated according to the fixations found during their assessment (Ferber 2010). Participants were recruited through advertisements (Appendix A) to various cycling club groups in and around Durban. Word of mouth recruitment was also used by the researcher.

People responding to advertisements were interviewed telephonically to screen for suitability and eligibility to be included in the study. The telephonic screening questions with the corresponding expected answers to be included into the study are listed below.

Table 6: Questions and answers expected from respondents to qualify to participate in the research study

	Telephonic / interview questions	**Required response for inclusion**
1	Are you between the age of 20-59?	Yes
2	Do you own a road bicycle that has a 10-speed or 11-speed groupset?	Yes
3	On average, do you cycle at least three hours per week	Yes
4	Are you currently pain free in the low back and lower extremity (Including the joints)?	Yes
5	Have you had any hip replacement or knee replacement?	No
6	Do you have any changes in the feeling in your legs (e.g. pins and needles / areas of numbness)?	No

The potential participant was required to answer “yes” to questions 1, 2, 3 and 4 and “no” to questions 5 and 6. The participant was only included in this study if they met the qualifying criteria. An appointment was scheduled at the participant’s earliest convenience at the Durban University of Technology Chiropractic Day Clinic (CDC) where the research was conducted. Volunteers had to meet the following criteria to participate in the study.

3.4 INCLUSION AND EXCLUSION CRITERIA

3.4.1 Inclusion criteria

Volunteers were included if they:

- Signed the consent form (Appendix C).
- Were between the ages of 20 and 59.
- Trained on average at least three hours per week, on a bicycle, for the preceding year.
- Were asymptomatic with regards to pain in the regions of the lumbar spine, sacro-iliac and hip joint, and lower extremity at the time of the study.
- Presented with a sacro-iliac joint, lumbar facet and/or hip joint fixation/fixations as determined by a clinical assessment.

3.4.2 Exclusion criteria

Volunteers were excluded if they presented with:

- Contra-indication for manipulation of the lumbar spine, sacro-iliac joints or hip joint eg. Lumbar spinal fusions, hip joint replacements
- Lumbar spine surgery and hip or knee joint replacement.

3.5 MEASUREMENT TOOLS

3.5.1 Wahoo KICKR Power Trainer Cycle Ergometer

Various studies designed to investigate factors affecting cycling efficiency are thought to be limited by the laboratory setting that the cyclist is being tested in (Burke 2003). According to Fonda and Sarabon (2010), multiple researchers believed that outdoor and indoor cycling differed, and that outdoor cycling could not be mimicked by laboratory testing. However, Bertucci *et al.* (2005) carried out a study where they proved that the crank torque profiles in both outdoor riding and indoor training did not differ at all, and therefore concluded that indoor ergometers are indeed able to mimic the outdoor environment. Studies performed have also shown that participants tested on their own bicycles mounted to ergometers produced the most significant data (Burke 2003).

Ergometers that replicate cycling on the road are vital to those who cycle competitively and train in a laboratory setting, as a margin of a few seconds determines whether you cross the line first or within the peloton, according to Zadow *et al.* (2016). Because cyclists cover a large distance during a year, the ability for a rider and coach to reproduce an individual training session and/or race-specific variables indoors has become highly desirable (Zadow *et al.* 2016).

Research conducted by Zadow *et al.* (2016) confirms that the KICKR is within acceptable accuracy and therefore both valid and reliable. Zadow *et al.* (2016) reports an accurate display of measurements of power between 250-700W at cadence of 80-120rpm with a bias of -1.1% (95%LoA: -3.6-1.4%).

The time-trials were performed by the participant on their own road bicycle mounted onto the Wahoo KICKR Power Trainer (KICKR). Using the participant’s own road bicycle, ensures that no bicycle biomechanical factors change and that the cyclist’s performance is not influenced, therefore reliable results are produced along with a good prediction of competitive performance (Burke 2003; Zadow *et al.* 2016). The trainer was calibrated as per the instruction manual prior to the start of the study, on the initial setup of the Wahoo KICKER ergometer equipment. The software was programmed in such a way that the participant took their first pedal stroke as the clock started for the 1.5km time-trial. The following measurements of cycling data [power output (W), cycling speed (km/h), cadence (rpm), and completion time (minutes)] were recorded on the computer.

The participant's bicycle wheel was removed and the bicycle was then mounted onto the Wahoo KICKR trainer by the researcher. The researcher then ensured that all the relative ANT+ devices were being picked up by the computer program (Perf pro) in order to ensure that all the relevant data was being captured.

3.5.2 Surface Electromyography (SEMG)

The electrodes that were used in this study were Philips 35mm round, Ag/AgCl soft cloth solid gel small disposable ECG electrodes. The placement areas were wiped down with a damped towel. The electrodes were placed as described in Appendix N for each muscle respectively.

Surface electromyography, a convenient and non-invasive technique, is frequently used in order to measure electrical potentials produced by contracting muscles (Kent 1997). SEMG is a tool commonly used to assess global functioning of muscles, muscle patterns and normal and abnormal muscle activity, and is considered to have good test-retest reliability (Kent 1997; Chapman *et al.* 2010; Sousa and Tavares 2012). The EMG signal is a measurement of the electrical signal created by the activation of the motor endplate of a muscle fibre as a result of the two depolarisation waves (Hof 1984). SEMG is said to be physiologically influenced by the fibre membrane conduction velocity and firing rates of the motor units (Hug and Dorel 2009). A variety of studies have been conducted which assess the changes that occur in muscle activity pre- and post-spinal and extremity chiropractic manipulative therapy (Suter *et al.* 1999; Keller and Colloca 2000; Suter and McMorland 2002; Murray 2009; Niazi *et al.* 2015).

The best quantified level of muscle activity, during the time-trial, uses the root mean square value (RMS) (Laplaud, Hug and Grélot 2006; Dorel, Couturier and Hug 2008; Duc *et al.* 2008; Fonda and Sarabon 2010). In order to compare the level of muscle activity pre- and -

post intervention, between different muscles and between individuals, it was recommended by multiple authors to normalise the EMG data (Rouffet and Hautier 2008; Hug and Dorel 2009; Sousa and Tavares 2012). The SEMG equipment that was used to conduct this study is the Biopac – Bionomadix complete wireless research system (Biopac Systems Inc, 2015). The system that will be used includes the MP150 Data Acquisition System, AcqKnowledge software and the Bionomadix Dual-channel Wireless EMG Transmitter and Receiver Pair (Biopac Systems Inc, 2015).

3.6 INTERVENTION

The intervention protocol was based on the assessment of the participant by means of full regional evaluation and motion palpation of the lumbar spine, sacro-iliac joint and hip joint (Schafer and Faye 1989; Bergmann and Peterson 2010).

Once the restrictions of the lumbar spine, sacro-iliac joint and/or hip joint were determined, the participant was adjusted according to the high velocity low amplitude short lever adjustment principles of Bergmann and Peterson (2010); Byfield (2011).

Group 1:

Lumbar spine manipulation (L1-L5) of the affected level (Side Lying: Spinous push-pull: Loss of posterior to anterior rotation) (Bergmann and Peterson 2010).

Group 2:

Sacro-iliac joint manipulation of the affected side (Side posture Lumbar Roll: Flexion/Extension: Upper/Lower joint) (Bergmann and Peterson 2010).

Group 3:

Hip joint manipulation (Bimanual Grasp/Proximal Femur; Internal Rotation, Bimanual Grasp/Proximal Femur; External Rotation and/or Bimanual Grasp/Proximal Femur; Inferior Glide in Flexion) (Bergmann and Peterson 2010).

Group 4:

Lumbar spine (L1-L5), sacro-iliac joint (of the affected side) and hip joint manipulations to be performed (Bergmann and Peterson 2010).

See Appendix O for adjustment protocol according to Bergmann and Peterson (2010).

3.7 RESEARCH PROCEDURE

3.7.1 Participant informed consent

On arrival to the consultation the participant was issued with a letter of information (Appendix B) giving a clear description of what this research entailed as well as a verbal description from the researcher. At this point the participant was allowed to ask questions about the research or about matters of concern to them. The participant received a Consent Form (Appendix C) which they were asked to sign and hand back to the researcher if they agreed to participate in this study. All relevant clinical paperwork was completed: case history, physical examination, lumbar regional examination and hip regional examination (Appendix D, E, F, G and H respectively). The participant examination results were discussed with the clinician on duty at the time of the consultation. Participant details were recorded on the clinic record and then coded accordingly for the anonymous data collection.

3.7.2 Procedure for data collection: Flow diagram

Volunteers made contact with the researcher from the advertisement seen on various forums, as well as by word of mouth

↓

Volunteers were included or excluded by telephonic interview

↓

Participants were scheduled for an appointment at the DUT CDC and were instructed to bring the following equipment with them to the consultation:

1. Their own road bike that they ride most regularly.
2. Cleats (Cycling shoes)
3. Cycling gear
4. Identity document

↓

On arrival of the participant at the DUT CDC, they were informed about the study by the researcher.

↓

The participant was provided with a Letter of Information (Appendix B) and Informed Consent (Appendix C),and given a detailed explanation of what the study entailed.

↓

The participant was at this point given the opportunity to ask questions they may have had regarding the study and were advised that they may withdraw from the study at any time if they choose to, without any implications.

↓

The participant was advised that all details would remain confidential and that they would only be accessible by name to the research and research supervisor; information and data would otherwise be coded.

↓

The participant was asked some cycling-demographic information adapted from Wiseman (2014), that was captured by the researcher on the demographic data form (Appendix I).

↓

A case history (Appendix D), physical examination (Appendix E), lumbar spine regional examination (Appendix F), and hip regional examination (Appendix G) were performed on the participant by the researcher. Fixations that the participant presented with were noted, and the participant was allocated into the appropriate research group.

The groups were as follows:

Group 1: Lumbar spine manipulation (L1-L5) of the fixated level.

Group 2: Sacro-iliac joint manipulation of the fixated side.

Group 3: Hip joint manipulation of the fixated side.

Group 4: Lumbar spine (L1-L5), sacro-iliac joint (of the affected side) and hip joint manipulations to be performed.

↓

The surface electromyography (SEMG) electrodes were then placed on the following muscles of the leg on the side that the fixations presented on: Gluteus Maximus (GM), Semimembranous/Semitendinosus (will be referred to as Medial Hamstring (MH)), Biceps femoris (BF), Vastus Medialis (VM), Rectus femoris (RF), Vastus lateralis (VL), Iliopsoas (IP) – Refer to Appendix N on electrode placement.

↓

The participant’s road bicycle was then mounted onto the Wahoo KICKR ergometer by the researcher. The bicycle rear wheel was removed and the bicycle was then placed onto the cassette and skewer of the Wahoo KICKR ergometer. The participant’s bicycle was mounted in such a way that the participant did not face the computer, in order to keep the participant blinded from their cycling data to ensure they rode at maximal performance (did not chase numbers).

↓

The participant then climbed onto their bicycle and assumed their comfortable riding position with their hands in the hoods of the handle bars.

↓

The participant was provided with the following instructions:

1. Remain seated at all times through the time-trial,

2. Ride as hard as they could,

3. Gear changes may be made to the comfort of the rider in order to simulate riding on the road.

↓

The participant was required to warm up for five minutes at their own pace. These five minutes allowed for the participant to ride the time-trial route as easily as they could and then they pedalled easily until the five minutes were complete (Hajoglou *et al.* 2005).

↓

The ergometer was at this point calibrated by the researcher allowing for the ANT+ equipment to link with the computer program Perf pro, which would allow the computer to capture the required data.

↓

The participant began their first virtual 1.5km set time-trial as fast as they could.

↓

During the time-trial the researcher recorded the change in muscle activity grafted by the SEMG at 0.25km, 0.5km, 1.0km, 1.25km and 1.5km electronically.

↓

Cycling data produced by the ergometer on the computer was recorded (Perf Pro) and captured electronically for the entire time-trial. Key points in the data were noted at 0.25km, 0.5km, 1.0km, 1.25km and 1.5km.

↓

On completion of the first time-trial, the participant was requested to dismount their bicycle and move to the chiropractic bed.

↓

The following intervention/s were performed depending on which group the participant was allocated to after the initial clinical examinations took place.

↓

Group 1: Lumbar spine manipulation (L1-L5) of the affected level (Side Lying: Spinous push-pull: Loss of posterior to anterior rotation).

Group 2: Sacro-iliac joint manipulation of the affected side (Side posture Lumbar Roll: Flexion/Extension: Upper/Lower joint).

Group 3: Unilateral hip joint manipulation (Bimanual Grasp/Proximal Femur; Internal Rotation, Bimanual Grasp/Proximal Femur; External Rotation and/or Bimanual Grasp/Proximal Femur; Inferior Glide in Flexion).

Group 4: Lumbar spine (L1-L5), sacro-iliac joint (of the affected side) and hip joint manipulations to be performed.

According to Bergmann and Peterson (2010) – Appendix O

↓

After the intervention and a 10-minute rest, the participant was then requested to again assume the same riding position on their bicycle.

↓

The participant began their second virtual 1.5km set time-trial as instructed.

↓

During the time-trial the researcher recorded the change in muscle activity grafted by the SEMG at 0.25km, 0.5km, 1.0km, 1.25km and 1.5km electronically.

↓

Cycling data produced by the ergometer on the computer was recorded (Perf Pro) and captured electronically.

↓

On completion of the second time-trial, the participant was thanked and they left.

↓

After all data was captured from all participants, the electronic data was then captured by the researcher on Appendix J accordingly.

(Appendix J: TT1/Pre-adjustment; TT1/Post-adjustment; TT2/Pre-adjustment; TT2/Post-adjustment)

Figure 4: Flowchart illustrating overview of experimental chronology

3.8 ETHICAL CONSIDERATIONS

The ethical issues that were considered included:

Prior to commencement of this study, full ethical approval was obtained from the DUT Institutional Research Ethics Committee (IREC: 159/16). Permission to conduct this study in the Durban University of Technology, Chiropractic Day Clinic (DUT CDC), was obtained from the clinic director.

All participants were provided with a letter of information (Appendix B) and were required to sign a consent form (Appendix C), in line with autonomy and person rights, allowing the participant to volunteer to partake in the research, without coercion.

All volunteers who qualified to participate according to the inclusion and exclusion criteria of this study were shown no prejudice in terms of race, gender, nationality and religion in line with the principle of justice.

Participants were informed about transient stiffness and discomfort post manipulative intervention and maximal cycling exertion, which would resolve within a 24-hour period with no further complications, in line with non-maleficence.

All participant information and data was stored in the participant’s DUT CDC, clinic file, with a letter of information (Appendix B) and signed consent form (Appendix C). All research data was coded to ensure confidentiality. All research data will be shredded after a five-year period.

Beneficence was accounted for, as the results of this study will have an impact on how future chiropractors will treat cyclists in order to improve their performance, especially during competitive seasons. This therefore benefits the profession and the cyclists.

3.9 DATA ANALYSIS

Muscle activity during cycling varies considerably as the muscles are recruited and engaged at different points in the cycling pedal stroke, therefore the raw SEMG data needed to be normalised in order to compare the first and second time-trials of that participant and within their allocated groups. This study used the root mean square (RMS) procedure to normalise the data. Each RMS graph (time-trial) consisted of 7 event markers - start, 250m, 500m, 750m, 1km, 1.25km and 1.5km. At each event marker, a focus area was created of each muscle. The BIOPAC program generated the mean value at these points and was captured using Microsoft Excel. These mean values for each muscle were then averaged out in order to produce a mean RMS value per muscle over the entire time-trial.

Cycling data (cadence, power, speed) readings were taken at the following points in each time-trial: start, 250m, 500m, 750m, 1km, 1.25km and 1.5km. These values were averaged out in order to establish a mean value. The mean value of cadence, power and speed, as well as normalised power and completion time for each time-trial for each participant, were captured using Microsoft Excel.

IBM SPSS version 24 was used to analyse the data. A p value <0.05 was considered as statistically significant. Baseline group means were compared using one way, ANOVA tests with Bonferroni post hoc tests in the case of statistically significant overall tests. The effect of the interventions was compared within groups (intra-group) initially to assess whether a change from pre- to post-intervention had occurred for each intervention separately. This was achieved using paired t-tests within each group. Subsequently, inter-group (between groups) comparisons were done to assess whether the change from pre- to post-intervention differed between the groups. This was achieved using repeated measures ANOVA testing. The time x group interaction effect was used to determine the significance of the difference in rate of change between the groups. Profile plots were generated to assess the direction and trend of the intervention effects.

CHAPTER FOUR

STATISTICAL METHODS AND RESULTS

4.1 INTRODUCTION

This chapter presents the results of this study. The cycling data, along with the surface electromyography data will be presented using tables, graphs and figures.

4.2 SAMPLING OUTCOME

In total there were 64 participants between the ages of 20 and 59 years who presented as asymptomatic cyclists and were recruited for this study. Of the 64 participants, one was excluded due to equipment failure, thus the data was not captured effectively, with a further two being excluded due to unavailability for testing. This resulted in a total sample of 61 participants.

4.3 DESCRIPTIVE STATISTICS OF BASELINE OUTCOMES BY GROUPS

Of the 61 participants, the groups were broken down into their dependent variables accordingly. The muscles were broken down into 15 participants for groups 1, 2 and 3 and 16 participants for group 4, however due to an error for the one SEMG lead for the iliopsoas muscle readings – only 15 participants were recorded for this muscle in group 4 (See Appendix P for complete description).

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Table 7: Number of participants per surface electromyography group

Surface Electromyography Data Groups		
Independent Variable per Group		**Number of Participants**
VastusLat.1 BicepsFem.1 VastusMed.1 RectusFem.1 MedialHam.1 GluteMax.1	Lumbar Spine Adjustments	15
	Sacro-iliac joint adjustment	15
	Hip Joint Adjustment	15
	Combination Group	16
	Total	**61**
Iliopsoas.1	Lumbar Spine Adjustments	15
	Sacro-iliac joint adjustment	15
	Hip Joint Adjustment	15
	Combination Group	15
	Total	**60**

The independent variables of cycling data determined the group sizing. For the following variables: completion time, power output, normalised power output, maximum power output, speed and maximum speed; groups 1, 2 and 3 presented with 15 participants, whilst the combination group presented with 16 participants. Cadence and maximum cadence, calculated for smaller groups due to mechanical issues, thus presented as follows: 15 participants in group 1, 14 participants in groups 2 and 3, and 13 participants and group 4 with 13 participants (See Appendix P for complete description).

Table 8: Number of participants per cycling data group

Cycling Data Groups		
Independent Variable per Group		**Number of Participants**
CompletionTime.1 Power.1 Norm.P.1 maxPower.1 Speed.1 maxSpeed.1	Lumbar Spine Adjustments	15
	Sacro-iliac joint adjustment	15
	Hip Joint Adjustment	15
	Combination Group	16
	Total	**61**
Cadence.1 maxCadence.1	Lumbar Spine Adjustments	15
	Sacro-iliac joint adjustment	14
	Hip Joint Adjustment	14
	Combination Group	13
	Total	**56**

4.4 ONE WAY ANOVA TABLE OF BASELINE MEANS COMPARED BETWEEN GROUPS

The baseline means are compared between the four groups using one way ANOVA tests. It can be seen that there were no significant differences between any of the groups at baseline. The most significant value was noted in the rectus femoris muscle (p=0.064). See Appendix P for complete graph.

4.5 INTRA-GROUP ANALYSIS

The raw data from the pre-intervention (time-trial 1) versus the post-intervention (time-trial 2), has been analysed. The mean values between the pre- and post-tests per group have been statistically analysed to answer objectives one to four below.

In order to address the outcomes of the objectives, each objective (one to four) has been analysed, initially through the SEMG data in the first table and followed by analysis of cycling data (speed, time, cadence and power) in the second table.

Surface electromyography data for this study was considered significant if $p<0.05$. In order to compare the muscle activity of the time-trials, the mean values were used to calculate the differences of muscle activity that occurred. This was calculated by the mean value of the second time-trial (TT2) being subtracted from the mean values of the first time-trial (TT1) – therefore the positive mean value indicates a decrease in muscle activity post-manipulation whilst the negative mean value indicates an increase in muscle activity post-manipulation.

4.5.1 Objective One: Lumbar spine manipulation group

Objective one: To determine the effect of lumbar spine manipulation on muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)).

4.5.1.1 Objective One: Lumbar spine manipulation group – Surface Electromyography Data

Table 9: Paired Samples Test[a]: Lumbar Manipulation Group (Group One) – SEMG Data

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Vastus Lateralis.	-.01809114	.03829681	.00988819	-.03929921	.00311692	-1.830	14	.089
Biceps Femoris.	.00287952	.04053788	.01046684	-.01956961	.02532866	.275	14	.787
Iliopsoas	.05123019	.15140946	.03909375	-.03261757	.13507796	1.310	14	.211
Vastus Medialis	.00315743	.01533999	.00396077	-.00533758	.01165243	.797	14	.439
Rectus Femoris	.00817248	.02428782	.00627109	-.00527767	.02162262	1.303	14	.214
Medial Hamstring	.00166819	.02625234	.00677832	-.01286987	.01620625	.246	14	.809
Gluteus Maximus	.00180590	.01924311	.00496855	-.00885057	.01246238	.363	14	.722

Although no significant change was observed within the SEMG data in this group, it was noted that the lumbar spine manipulation had the greatest affect (p=0.089) on the vastus lateralis muscle when compared to the manipulation effect on the other muscles that were tested. The medial hamstring was affected the least (p=0.809).

4.5.1.2 Objective One: Lumbar spine manipulation group – Cycling Data

Table 10: Paired Samples Test[a]: Lumbar Manipulation Group (Group One) – Cycling Data

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Completion Time	-0:00:06,33	0:00:06,799	0:00:01,755	-0:00:10,09	-0:00:02,56	-3.606	14	.003
Power	19.75555556	25.46565277	6.57520327	5.65314711	33.85796400	3.005	14	.009
Normalised Power	26.867	26.616	6.872	12.127	41.606	3.909	14	.002
Speed	1.25800	1.12656	.29088	.63413	1.88187	4.325	14	.001
Cadence	-1.38888889	3.42126095	.88336578	-3.28352005	.50574227	-1.572	14	.138
Maximum Power	92.067	102.727	26.524	35.178	148.955	3.471	14	.004
Maximum Speed	.32667	1.01952	.26324	-.23793	.89126	1.241	14	.235
Maximum Cadence	-1.000	6.990	1.805	-4.871	2.871	-.554	14	.588

The data for lumbar spine manipulation revealed a significant increase in time (p=0.003) and decrease in power (p=0.009), normalised power (p=0.002), maximum power (p=0.004) and speed (p=0.001).

4.5.1.3 Objective One: Lumbar spine manipulation group - Summary

From the data above, the lumbar spine manipulation had no significant effect on the muscle activity of these riders. There was a significant decrease in cycling performance for this group as speed, power and normalised power decreased, whilst completion time increased.

4.5.2 Objective Two: Sacro-iliac joint manipulation group

Objective Two: To determine the effect of sacro-iliac joint manipulation on muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds))

4.5.2.1 Objective Two: Sacro-iliac joint manipulation group – Surface Electromyography Data

Table 11: Paired Samples Test[a]: Sacro-iliac Manipulation Group (Group Two) – SEMG Data

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Vastus Lateralis	-.00646010	.05793426	.01495856	-.03854302	.02562283	-.432	14	.672
Biceps Femoris	-.00413124	.03125419	.00806980	-.02143923	.01317675	-.512	14	.617
Iliopsoas	.04126495	.08168037	.02108978	-.00396813	.08649804	1.957	14	.071
Vastus Medialis	.00877829	.02093330	.00540496	-.00281419	.02037076	1.624	14	.127
Rectus Femoris	.01011676	.02640559	.00681789	-.00450617	.02473969	1.484	14	.160
Medial Hamstring	.00727410	.03893431	.01005280	-.01428701	.02883520	.724	14	.481
Gluteus Maximum	.00686633	.02195453	.00566864	-.00529168	.01902435	1.211	14	.246

There was no significant change between pre- and post-adjustment in this group. The muscle that was most affected by SIJ adjustments in terms of muscle activity was iliopsoas (p=0.071).

4.5.2.2 Objective Two: Sacro-iliac joint manipulation group – Cycling Data

Table 12: Paired Samples Test[a]: Sacro-iliac Manipulation Group (Group Two) – Cycling Data

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Completion Time	-0:00:05,05	0:00:04,662	0:00:01,204	-0:00:07,63	-0:00:02,47	-4.196	14	.001
Power	25.42222222	35.86122207	9.25932772	5.56293938	45.28150507	2.746	14	.016
Normalised Power	33.467	29.842	7.705	16.941	49.993	4.343	14	.001
Speed	1.16867	1.11774	.28860	.54968	1.78765	4.049	14	.001
Cadence	-1.79761905	6.50712252	1.73910165	-5.55471973	1.95948164	-1.034	13	.320
Maximum Power	86.733	109.970	28.394	25.834	147.633	3.055	14	.009
Maximum Speed	.65733	1.03667	.26767	.08325	1.23142	2.456	14	.028
Maximum Cadence	-1.714	10.593	2.831	-7.831	4.402	-.605	13	.555

The significant decrease in power (p=0.016), normalised power (p=0.001), maximum power (p=0.009), as well as speed (p=0.001), maximum speed (p=0.028) and an increased time (p=0.001) after sacro-iliac joint manipulation resulted in an overall decrease in performance.

4.5.2.3 Objective Two: Sacro-iliac joint manipulation group – Summary

The data demonstrated that the sacro-iliac joint manipulation had no significant impact on the muscle activity of these cyclists. There was a significant decrease in overall performance for these athletes as there was a significant decrease in power and speed data and an increase in completion time.

4.5.3 Objective Three: Hip joint manipulation group

Objective Three: To determine the effect of hip joint manipulation on muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)).

4.5.3.1 Objective Three: Hip joint manipulation group – Surface Electromyography Data

Table 13: Paired Samples Test[a]: Hip Joint Manipulation Group (Group Three) – SEMG Data

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Vastus Lateralis	.01326829	.04626673	.01194602	-.01235337	.03888994	1.111	14	.285
Biceps Femoris	.00684990	.02952815	.00762414	-.00950224	.02320205	.898	14	.384
Iliopsoas	.03931610	.07981792	.02060890	-.00488560	.08351779	1.908	14	.077
Vastus Medialis	.00867533	.02183351	.00563739	-.00341566	.02076633	1.539	14	.146
Rectus Femoris	.01243888	.03023702	.00808118	-.00501946	.02989721	1.539	13	.148
Medial Hamstring	-.00570171	.03574169	.00922847	-.02549481	.01409138	-.618	14	.547
Gluteus Maximus	.00670833	.03099549	.00800300	-.01045640	.02387307	.838	14	.416

No significant change between pre- and post-adjustment in this group. The most significantly affected muscle for the adjustment group was iliopsoas (p=0.077), whereas the least affected muscle in terms of muscle activity was the medial hamstring (p=0.547).

4.5.3.2 Objective Three: Hip joint manipulation group – Cycling Data

Table 14: Paired Samples Test[a]: Hip Joint Manipulation Group (Group Three) – Cycling Data

	Paired Differences					T	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Completion Time	-0:00:04,05	0:00:19,152	0:00:04,945	-0:00:14,66	0:00:06,556	-.819	14	.427
Power	24.55555761	37.13048827	9.58705085	3.99337858	45.11773664	2.561	14	.023
Normalised Power	43.733	49.769	12.850	16.172	71.294	3.403	14	.004
Speed	1.49067	1.85182	.47814	.46516	2.51617	3.118	14	.008
Cadence	.21428571	4.46708215	1.19387792	-2.36493073	2.79350216	.179	13	.860
Maximum Power	95.333	142.764	36.861	16.273	174.393	2.586	14	.022
Maximum Speed	.08200	3.61748	.93403	-1.92130	2.08530	.088	14	.931
Maximum Cadence	-.214	8.842	2.363	-5.320	4.891	-.091	13	.929

Analysis showed a significantly decreased power (p=0.023), normalised power (p=0.004), maximum power (p=0.022) and decreased speed (p=0.008). This data shows that according to the power data analysis there is decreased performance. However, there was a significant improvement in performance when analysing time post-intervention.

4.5.3.3 Objective Three: Hip joint manipulation group – Summary

The study showed that the hip joint manipulation had no significant effect on the muscle activity of these cyclists. It was also noted that there was a significant decrease in performance when looking at power output and speed, but no significant effect on overall performance and completion time.

4.5.4 Objective Four – Combination manipulation group

Objective Four: To determine the combined effect of lumbar spine, sacro-iliac joint and hip joint manipulation on muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)).

4.5.4.1 Objective Four: Combination manipulation Group – Surface Electromyography Data

Table 15: Paired Samples Test[a]: Combination Manipulation Group (Group Four) – SEMG Data

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Vastus Lateralis	.00126125	.03694133	.00923533	-.01842340	.02094590	.137	15	.893
Biceps Femoris	.00365241	.02582251	.00645563	-.01010743	.01741225	.566	15	.580
Iliopsoas	.03930362	.05440679	.01404777	.00917414	.06943310	2.798	14	.014
Vastus Medialis	.00604114	.02710559	.00699863	-.00896943	.02105172	.863	14	.403
Rectus Femoris	.01793750	.04128587	.01032147	-.00406219	.03993719	1.738	15	.103
Medial Hamstring	.00379107	.03171101	.00792775	-.01310653	.02068867	.478	15	.639
Gluteus Maximus	.01058210	.04363634	.01090908	-.01267007	.03383426	.970	15	.347

Analysis of the combined manipulation group data demonstrated a significant decrease in the iliopsoas muscle activity (p=0.014) post lumbar spine, sacro-iliac joint and hip joint manipulation intervention. All the other muscles showed no significant change in muscle activity post-manipulation.

4.5.4.2 Objective Four: Combination manipulation Group – Cycling Data

Table 16: Paired Samples Test[a]: Combination Manipulation Group (Group Four) – Cycling Data

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Completion Time	-0:00:01,97	0:00:06,734	0:00:01,684	-0:00:05,55	0:00:01,622	-1.168	15	.261
Power	12.32289701	29.55531720	7.38882930	-3.42601984	28.07181387	1.668	15	.116
Normalised Power	15.875	28.033	7.008	.937	30.813	2.265	15	.039
Speed	-.35125	3.59623	.89906	-2.26755	1.56505	-.391	15	.702
Cadence	-2.08974359	3.48848329	.96753118	-4.19781294	.01832576	-2.160	12	.052
Maximum Power	-2.938	147.602	36.900	-81.589	75.714	-.080	15	.938
Maximum Speed	-.49313	3.24212	.81053	-2.22073	1.23448	-.608	15	.552
Maximum Cadence	.846	7.658	2.124	-3.781	5.474	.398	12	.697

There was no significant change seen in the cycling data post combination manipulation intervention, even though it was shown that the combined effects of the lumbar spine, sacro-iliac and hip joint manipulations resulted in a decreased normalised power (p=0.039) post-intervention.

4.5.3.3 Objective Four: Combination manipulation group – Summary

The study data demonstrated that the combination of lumbar spine, sacro-iliac joint and hip joint manipulation results in a significant decrease in muscle activity of the iliopsoas muscle. It was noted that there was no significant change in overall performance of these participants, however there was a significant decrease in normalised power post-test.

4.6 INTER-GROUP ANALYSIS

Objective Five: To compare the effect of the combined effect of lumbar spine, sacro-iliac joint and hip joint manipulations with that of the individual manipulation groups with regards to muscle activity (amplitude of surface EMG) and cycling performance (power output (W), cycling speed (km/h), cadence (rpm), and completion time (seconds)).

4.6.1 Objective Five: Inter-group Analysis – Surface Electromyography Data

In this section of results, we will analyse the effects of the various manipulations on each muscle individually as well as on the various factors that determine cycling performance.

4.6.1.1 Objective Five: Inter-group analysis - Vastus lateralis

Table 17: Multivariate Test[a]: SEMG Data – Vastus Lateralis

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.003	.185[b]	1.000	57.000	.669
	Wilks' Lambda	.997	.185[b]	1.000	57.000	.669
	Hotelling's Trace	.003	.185[b]	1.000	57.000	.669
	Roy's Largest Root	.003	.185[b]	1.000	57.000	.669
time * group	Pillai's Trace	.062	1.262[b]	3.000	57.000	.296
	Wilks' Lambda	.938	1.262[b]	3.000	57.000	.296
	Hotelling's Trace	.066	1.262[b]	3.000	57.000	.296
	Roy's Largest Root	.066	1.262[b]	3.000	57.000	.296

a. Design: Intercept + group
Within Subjects Design: time

b. Exact statistic

Table 18: Tests of Between-Subjects Effects – Vastus Lateralis

Measure: Vastus Lateralis					
Transformed Variable: Average					
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	7.867	1	7.867	430.599	.000
Group	.013	3	.004	.237	.870
Error	1.041	57	.018		

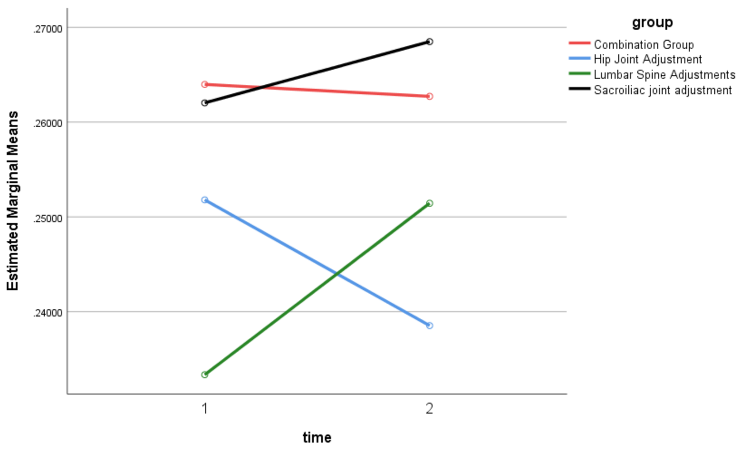

Figure 5: Graph showing estimated marginal means over time (change over time) – vastus lateralis

There was no significant time x group effect (p=0.296) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group for the effect on the vastus lateralis muscle.

4.6.1.2 Objective Five: Inter-group analysis – Biceps Femoris

Table 19: Multivariate Test[a]: SEMG Data - Biceps Femoris

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.006	.316[b]	1.000	57.000	.577
	Wilks' Lambda	.994	.316[b]	1.000	57.000	.577
	Hotelling's Trace	.006	.316[b]	1.000	57.000	.577
	Roy's Largest Root	.006	.316[b]	1.000	57.000	.577
time * group	Pillai's Trace	.016	.311[b]	3.000	57.000	.817
	Wilks' Lambda	.984	.311[b]	3.000	57.000	.817
	Hotelling's Trace	.016	.311[b]	3.000	57.000	.817
	Roy's Largest Root	.016	.311[b]	3.000	57.000	.817
a. Design: Intercept + group Within Subjects Design: time						
b. Exact statistic						

Table 20: Tests of Between-Subjects Effects – Biceps Femoris

Measure: Biceps Femoris					
Transformed Variable: Average					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	3.738	1	3.738	547.459	.000
Group	.040	3	.013	1.940	.133
Error	.389	57	.007		

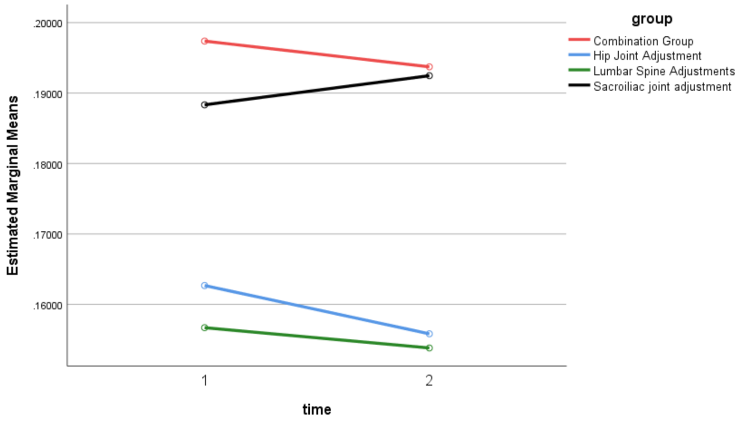

Figure 6: Graph showing estimated marginal means over time (change over time) – Biceps Femoris

There was no significant time x group effect (p=0.817) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group for the effect on the biceps femoris muscle.

4.6.1.3 Objective Five: Inter-group analysis – Iliopsoas

Table 21: Multivariate Test[a]: SEMG Data - Iliopsoas

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.168	11.283[b]	1.000	56.000	.001
	Wilks' Lambda	.832	11.283[b]	1.000	56.000	.001
	Hotelling's Trace	.201	11.283[b]	1.000	56.000	.001
	Roy's Largest Root	.201	11.283[b]	1.000	56.000	.001
time * group	Pillai's Trace	.003	.050[b]	3.000	56.000	.985
	Wilks' Lambda	.997	.050[b]	3.000	56.000	.985
	Hotelling's Trace	.003	.050[b]	3.000	56.000	.985
	Roy's Largest Root	.003	.050[b]	3.000	56.000	.985
a. Design: Intercept + group Within Subjects Design: time						
b. Exact statistic						

Table 22: Tests of Between-Subjects Effects – Iliopsoas

Measure: Iliopsoas					
Transformed Variable: Average					
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	3.686	1	3.686	239.295	.000
Group	.003	3	.001	.066	.978
Error	.863	56	.015		

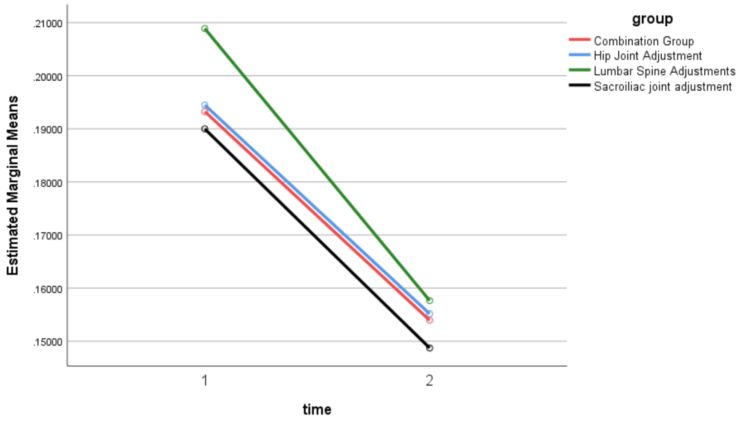

Figure 7: Graph showing estimated marginal means over time (change over time) – iliopsoas

There was no significant time x group effect (p=0.985) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group for the effect on the iliopsoas muscle.

4.6.1.4 Objective Five: Inter-group analysis – Vastus Medialis

Table 23: Multivariate Test[a]: SEMG Data – Vastus Medialis

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.092	5.653[b]	1.000	56.000	.021
	Wilks' Lambda	.908	5.653[b]	1.000	56.000	.021
	Hotelling's Trace	.101	5.653[b]	1.000	56.000	.021
	Roy's Largest Root	.101	5.653[b]	1.000	56.000	.021
time * group	Pillai's Trace	.012	.225[b]	3.000	56.000	.879
	Wilks' Lambda	.988	.225[b]	3.000	56.000	.879
	Hotelling's Trace	.012	.225[b]	3.000	56.000	.879
	Roy's Largest Root	.012	.225[b]	3.000	56.000	.879
a. Design: Intercept + group Within Subjects Design: time						
b. Exact statistic						

Table 24: Tests of Between-Subjects Effects – Vastus Medialis

Measure: Vastus Medialis					
Transformed Variable: Average					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1.526	1	1.526	286.722	.000
Group	.036	3	.012	2.255	.092
Error	.298	56	.005		

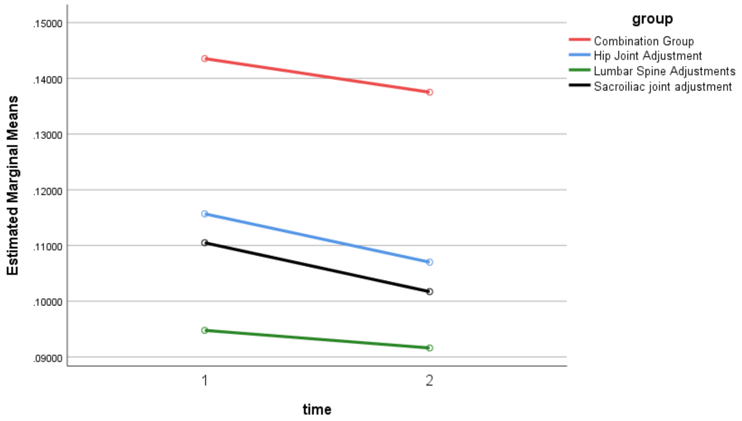

Figure 8: Graph showing estimated marginal means over time (change over time) – vastus medialis

There was no significant time x group effect (p=0.879) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group for the effect on the vastus medialis muscle.

4.6.1.5 Objective Five: Inter-group analysis – Rectus Femoris

Table 25:Multivariate Test[a]: SEMG Data - Rectus Femoris

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.138	8.946[b]	1.000	56.000	.004
	Wilks' Lambda	.862	8.946[b]	1.000	56.000	.004
	Hotelling's Trace	.160	8.946[b]	1.000	56.000	.004
	Roy's Largest Root	.160	8.946[b]	1.000	56.000	.004
time * group	Pillai's Trace	.015	.281[b]	3.000	56.000	.839
	Wilks' Lambda	.985	.281[b]	3.000	56.000	.839
	Hotelling's Trace	.015	.281[b]	3.000	56.000	.839
	Roy's Largest Root	.015	.281[b]	3.000	56.000	.839
a. Design: Intercept + group Within Subjects Design: time						
b. Exact statistic						

Table 26: Tests of Between-Subjects Effects - Rectus Femoris

Measure: Rectus Femoris					
Transformed Variable: Average					
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	4.947	1	4.947	591.389	.000
Group	.063	3	.021	2.528	.067
Error	.468	56	.008		

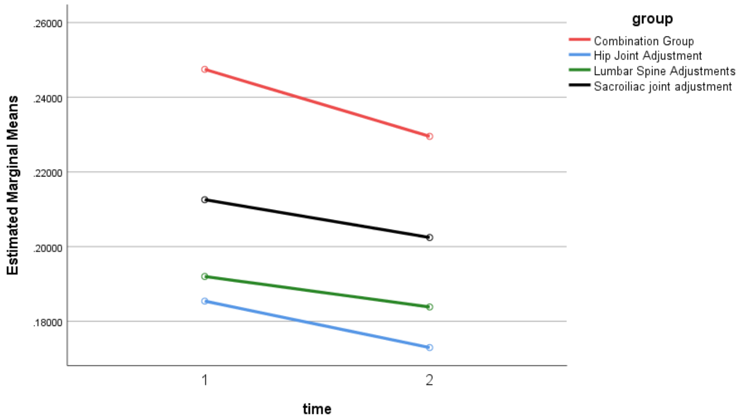

Figure 9: Graph showing estimated marginal means over time (change over time) – Rectus Femoris

There was no significant time x group effect (p=0.839) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group for the effect on the rectus femoris muscle.

4.6.1.6 Objective Five: Inter-group analysis – Medial Hamstrings

Table 27: Multivariate Test[a]: SEMG Data - Medial Hamstrings

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.003	.168[b]	1.000	57.000	.683
	Wilks' Lambda	.997	.168[b]	1.000	57.000	.683
	Hotelling's Trace	.003	.168[b]	1.000	57.000	.683
	Roy's Largest Root	.003	.168[b]	1.000	57.000	.683
time * group	Pillai's Trace	.021	.404[b]	3.000	57.000	.751
	Wilks' Lambda	.979	.404[b]	3.000	57.000	.751
	Hotelling's Trace	.021	.404[b]	3.000	57.000	.751
	Roy's Largest Root	.021	.404[b]	3.000	57.000	.751
a. Design: Intercept + group Within Subjects Design: time						
b. Exact statistic						

Table 28: Tests of Between-Subjects Effects – Medial Hamstrings

Measure: Medial Hamstrings					
Transformed Variable: Average					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	2.591	1	2.591	412.771	.000
Group	.003	3	.001	.150	.929
Error	.358	57	.006		

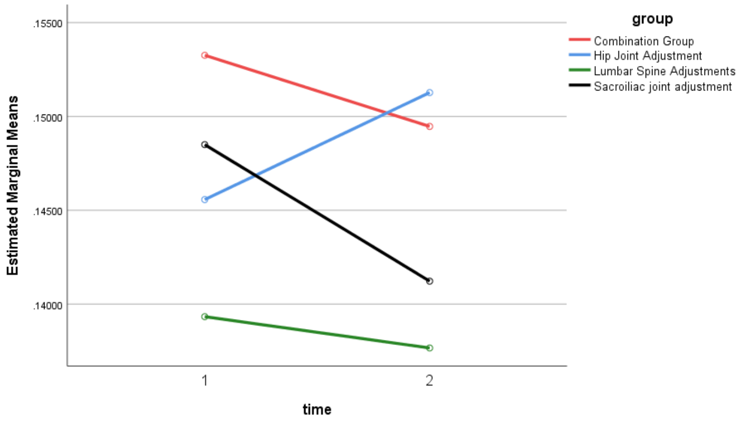

Figure 10: Graph showing estimated marginal means over time (change over time) – medial hamstring

There was no significant time x group effect (p=0.751) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group for the effect on the medial hamstrings muscle.

4.6.1.7 Objective Five: Inter-group analysis – Gluteus Maximus

Table 29: Multivariate Test[a]: SEMG Data – Gluteus Maximus

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.045	2.713[b]	1.000	57.000	.105
	Wilks' Lambda	.955	2.713[b]	1.000	57.000	.105
	Hotelling's Trace	.048	2.713[b]	1.000	57.000	.105
	Roy's Largest Root	.048	2.713[b]	1.000	57.000	.105
time * group_n	Pillai's Trace	.011	.211[b]	3.000	57.000	.888
	Wilks' Lambda	.989	.211[b]	3.000	57.000	.888
	Hotelling's Trace	.011	.211[b]	3.000	57.000	.888
	Roy's Largest Root	.011	.211[b]	3.000	57.000	.888
a. Design: Intercept + group_n Within Subjects Design: time						
b. Exact statistic						

Table 30: Tests of Between-Subjects Effects – Gluteus Maximus

Measure: Gluteus Maximus					
Transformed Variable: Average					
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	3.292	1	3.292	533.135	.000
group_n	.033	3	.011	1.758	.166
Error	.352	57	.006		

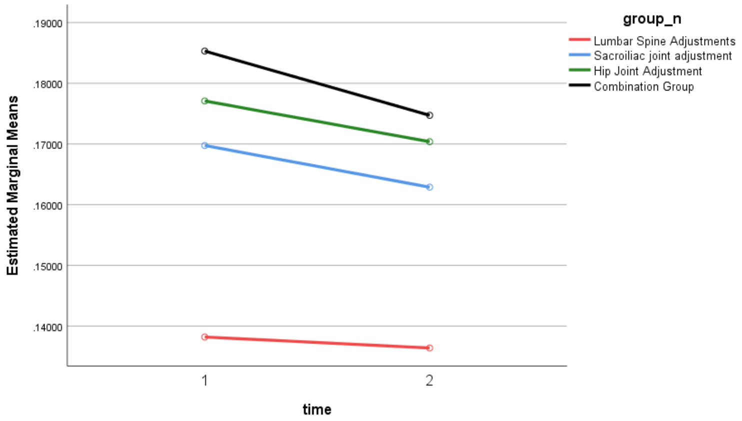

Figure 11: Graph showing estimated marginal means over time (change over time) – gluteus maximus

There was no significant time x group effect (p=0.888) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group for the effect on the gluteus maximus muscle.

4.6.1.8 Objective Five: Inter-group analysis – Surface Electromyography Summary

The inter-group analysis above showed no significant time change in any muscle activity and therefore no manipulation group outperformed the other manipulation group.

4.6.2 Objective Five: Inter-group analysis – Cycling Data

4.6.2.1 Objective Five: Inter-group analysis – Completion time

Table 31: Multivariate Test[a]: Cycling Data – Completion Time

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.146	9.712[b]	1.000	57.000	.003
	Wilks' Lambda	.854	9.712[b]	1.000	57.000	.003
	Hotelling's Trace	.170	9.712[b]	1.000	57.000	.003
	Roy's Largest Root	.170	9.712[b]	1.000	57.000	.003
time * group_n	Pillai's Trace	.023	.445[b]	3.000	57.000	.722
	Wilks' Lambda	.977	.445[b]	3.000	57.000	.722
	Hotelling's Trace	.023	.445[b]	3.000	57.000	.722
	Roy's Largest Root	.023	.445[b]	3.000	57.000	.722
a. Design: Intercept + group_n Within Subjects Design: time						
b. Exact statistic						

Table 32: Tests of Between-Subjects Effects – Completion Time

Measure: Completion Time					
Transformed Variable: Average					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	3189959.787	1	3189959.787	1808.974	.000
group_n	7057.783	3	2352.594	1.334	.272
Error	100514.258	57	1763.408		

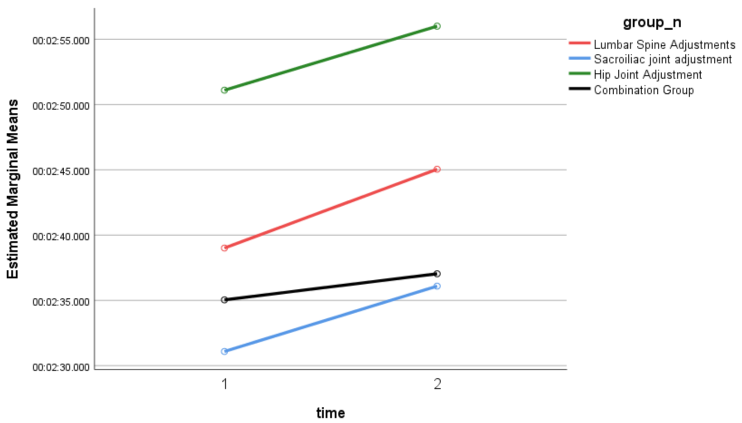

Figure 12: Graph showing estimated marginal means over time (change over time) – completion time

There was no significant time x group effect (p=0.722) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group when analysing completion time.

4.6.2.2 Objective Five: Inter-group analysis – Power Output

Table 33: Multivariate Test[a]: Cycling Data – Power Output

Effect		Value	F	Hypothesis df	Error df	Sig.
time	Pillai's Trace	.301	24.578[b]	1.000	57.000	.000
	Wilks' Lambda	.699	24.578[b]	1.000	57.000	.000
	Hotelling's Trace	.431	24.578[b]	1.000	57.000	.000
	Roy's Largest Root	.431	24.578[b]	1.000	57.000	.000
time * group_n	Pillai's Trace	.028	.539[b]	3.000	57.000	.658
	Wilks' Lambda	.972	.539[b]	3.000	57.000	.658
	Hotelling's Trace	.028	.539[b]	3.000	57.000	.658
	Roy's Largest Root	.028	.539[b]	3.000	57.000	.658
a. Design: Intercept + group_n Within Subjects Design: time						
b. Exact statistic						

Table 34: Tests of Between-Subjects Effects – Power

Measure: Power					
Transformed Variable: Average					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	14086442.261	1	14086442.261	1037.696	.000
group_n	47142.519	3	15714.173	1.158	.334
Error	773759.747	57	13574.732		

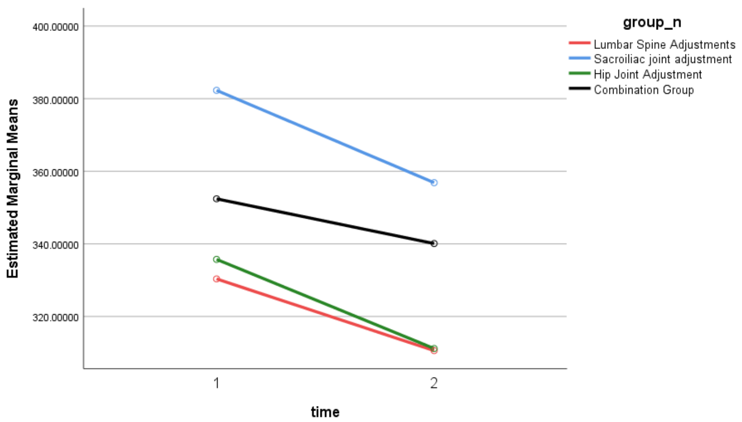

Figure 13: Graph showing estimated marginal means over time (change over time) – completion time

There was no significant time x group effect (p=0.658) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group when analysing power output.

4.6.2.3 Objective Five: Inter-group analysis – Normalised Power Output

Table 35: Multivariate Test[a]: Cycling Data – Normalised power

Effect		Value	F	Hypothesis df	Error df	Sig.
time	Pillai's Trace	.443	45.371[b]	1.000	57.000	.000
	Wilks' Lambda	.557	45.371[b]	1.000	57.000	.000
	Hotelling's Trace	.796	45.371[b]	1.000	57.000	.000
	Roy's Largest Root	.796	45.371[b]	1.000	57.000	.000
time * group_n	Pillai's Trace	.084	1.751[b]	3.000	57.000	.167
	Wilks' Lambda	.916	1.751[b]	3.000	57.000	.167
	Hotelling's Trace	.092	1.751[b]	3.000	57.000	.167
	Roy's Largest Root	.092	1.751[b]	3.000	57.000	.167
a. Design: Intercept + group_n Within Subjects Design: time						
b. Exact statistic						

Table 36: Tests of Between-Subjects Effects – Normalised Power

Measure: Normalised Power					
Transformed Variable: Average					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	17085952.064	1	17085952.064	1186.705	.000
group_n	66653.872	3	22217.957	1.543	.213
Error	820674.833	57	14397.804		

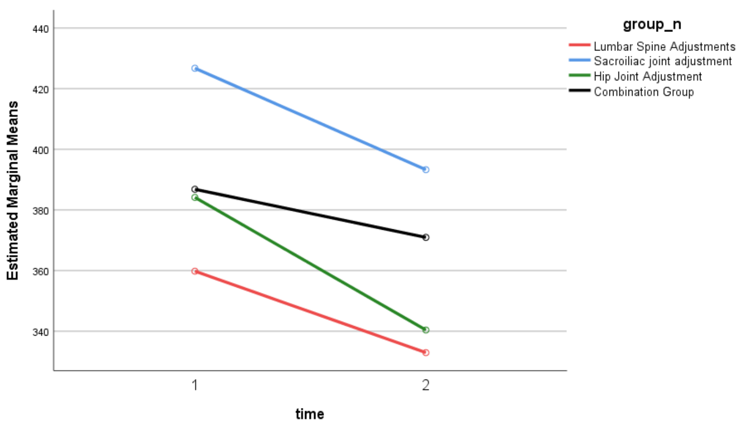

Figure 14: Graph showing estimated marginal means over time (change over time) – normalised power

There was no significant time x group effect (p=0.167) therefore the rate of change over time was the same in the different groups therefore no manipulation group outperformed the other manipulation group when analysing normalised power data.

4.6.2.4 Objective Five: Inter-group analysis – Speed

Table 37: Multivariate Test[a]: Cycling Data – Speed

Effect		Value	F	Hypothesis df	Error df	Sig.
time	Pillai's Trace	.149	9.960[b]	1.000	57.000	.003
	Wilks' Lambda	.851	9.960[b]	1.000	57.000	.003
	Hotelling's Trace	.175	9.960[b]	1.000	57.000	.003
	Roy's Largest Root	.175	9.960[b]	1.000	57.000	.003
time * group_n	Pillai's Trace	.107	2.278[b]	3.000	57.000	.089
	Wilks' Lambda	.893	2.278[b]	3.000	57.000	.089
	Hotelling's Trace	.120	2.278[b]	3.000	57.000	.089
	Roy's Largest Root	.120	2.278[b]	3.000	57.000	.089
a. Design: Intercept + group_n Within Subjects Design: time						
b. Exact statistic						

Table 38: Tests of Between-Subjects Effects – Speed

Measure: Speed

Transformed Variable: Average

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	142355.388	1	142355.388	4618.550	.000
group_n	137.318	3	45.773	1.485	.228
Error	1756.884	57	30.823		

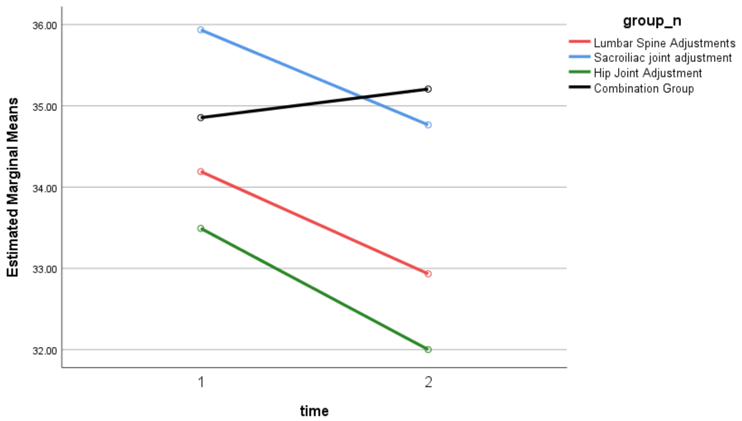

Figure 15: Graph showing estimated marginal means over time (change over time) – speed

There was no significant time x group effect (p=0.089) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group when analysing speed.

4.2.6.5 Objective Five: Inter-group analysis – Cadence

Table 39: Multivariate Test^{a}: Cycling Data – Cadence

Effect		Value	F	Hypothesis df	Error df	Sig.
time	Pillai's Trace	.074	4.154^{b}	1.000	52.000	.047
	Wilks' Lambda	.926	4.154^{b}	1.000	52.000	.047
	Hotelling's Trace	.080	4.154^{b}	1.000	52.000	.047
	Roy's Largest Root	.080	4.154^{b}	1.000	52.000	.047
time * group_n	Pillai's Trace	.038	.676^{b}	3.000	52.000	.571
	Wilks' Lambda	.962	.676^{b}	3.000	52.000	.571
	Hotelling's Trace	.039	.676^{b}	3.000	52.000	.571
	Roy's Largest Root	.039	.676^{b}	3.000	52.000	.571
a. Design: Intercept + group_n Within Subjects Design: time						
b. Exact statistic						

Table 40: Tests of Between-Subjects Effects – Cadence

Measure: Cadence

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1059066.613	1	1059066.613	9581.746	.000
group_n	451.639	3	150.546	1.362	.265
Error	5747.540	52	110.530		

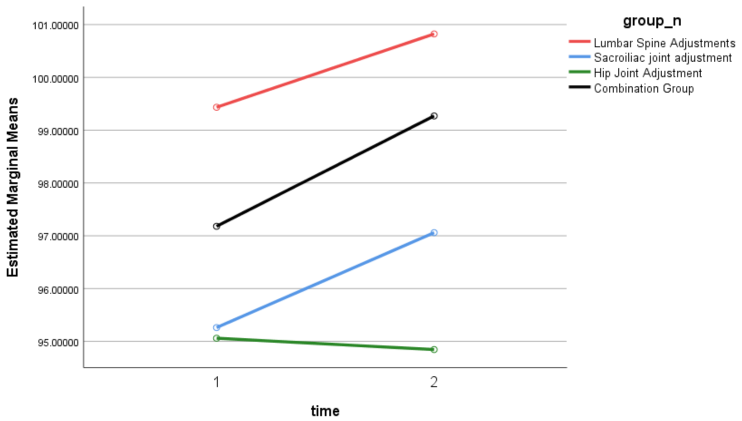

Figure 16: Graph showing estimated marginal means over time (change over time) – cadence

There was no significant time x group effect (p=0.571) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group when analysing cadence.

4.2.6.6 Objective Five: Inter-group analysis – Maximum power

Table 41: Multivariate Test[a]: Cycling Data - Maximum power

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.232	17.187[b]	1.000	57.000	.000
	Wilks' Lambda	.768	17.187[b]	1.000	57.000	.000
	Hotelling's Trace	.302	17.187[b]	1.000	57.000	.000
	Roy's Largest Root	.302	17.187[b]	1.000	57.000	.000
time * group_n	Pillai's Trace	.102	2.158[b]	3.000	57.000	.103
	Wilks' Lambda	.898	2.158[b]	3.000	57.000	.103
	Hotelling's Trace	.114	2.158[b]	3.000	57.000	.103
	Roy's Largest Root	.114	2.158[b]	3.000	57.000	.103

a. Design: Intercept + group_n
Within Subjects Design: time

b. Exact statistic

Table 42: Tests of Between-Subjects Effects - Maximum Power

Measure: Maximum power

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	46190012.184	1	46190012.184	1008.723	.000
group_n	241893.542	3	80631.181	1.761	.165
Error	2610063.802	57	45790.593		

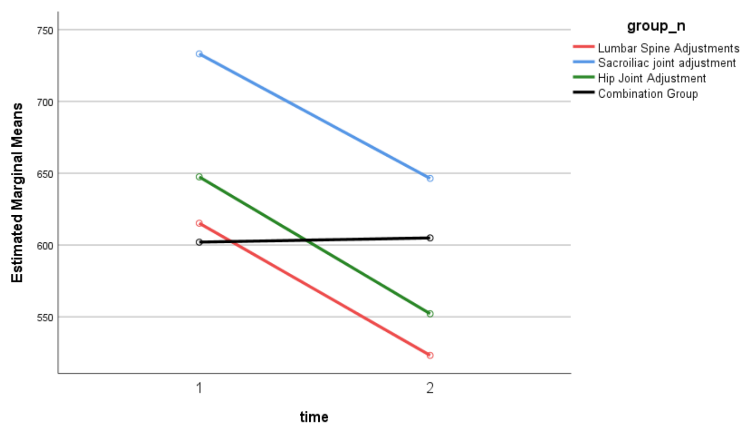

Figure 17: Graph showing estimated marginal means over time (change over time) – maximum power

There was no significant time x group effect (p=0.103) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group when analysing maximum power.

4.2.6.7 Objective Five: Inter-group analysis – Maximum Speed

Table 43: Multivariate Test[a]: Cycling Data – Maximum Speed

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.003	.192[b]	1.000	57.000	.663
	Wilks' Lambda	.997	.192[b]	1.000	57.000	.663
	Hotelling's Trace	.003	.192[b]	1.000	57.000	.663
	Roy's Largest Root	.003	.192[b]	1.000	57.000	.663
time * group_n	Pillai's Trace	.029	.564[b]	3.000	57.000	.641
	Wilks' Lambda	.971	.564[b]	3.000	57.000	.641
	Hotelling's Trace	.030	.564[b]	3.000	57.000	.641
	Roy's Largest Root	.030	.564[b]	3.000	57.000	.641

a. Design: Intercept + group_n
 Within Subjects Design: time

b. Exact statistic

Table 44: Tests of Between-Subjects Effects – Maximum Speed

Measure: Maximum speed

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	258264.072	1	258264.072	6873.757	.000
group_n	89.670	3	29.890	.796	.501
Error	2141.631	57	37.572		

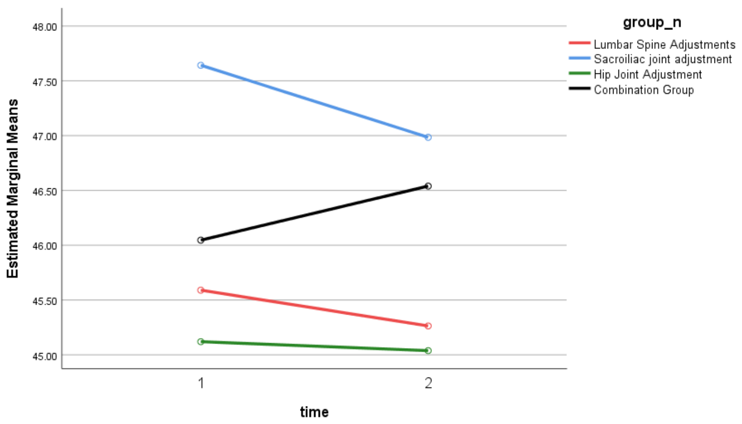

Figure 18: Graph showing estimated marginal means over time (change over time) – maximum speed

There was no significant time x group effect (p=0.641) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group when analysing maximum speed.

4.2.6.8 Objective Five: Inter-group analysis – Maximum Cadence

Table 45: Multivariate Test[a]: Cycling Data – Maximum cadence

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.004	.204[b]	1.000	52.000	.654
	Wilks' Lambda	.996	.204[b]	1.000	52.000	.654
	Hotelling's Trace	.004	.204[b]	1.000	52.000	.654
	Roy's Largest Root	.004	.204[b]	1.000	52.000	.654
time * group_n	Pillai's Trace	.013	.220[b]	3.000	52.000	.882
	Wilks' Lambda	.987	.220[b]	3.000	52.000	.882
	Hotelling's Trace	.013	.220[b]	3.000	52.000	.882
	Roy's Largest Root	.013	.220[b]	3.000	52.000	.882

a. Design: Intercept + group_n
Within Subjects Design: time

b. Exact statistic

Table 46: Tests of Between-Subjects Effects – Maximum Cadence

Measure: Maximum cadence
Transformed Variable: Average

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	1516706.093	1	1516706.093	7324.554	.000
group_n	97.347	3	32.449	.157	.925
Error	10767.716	52	207.071		

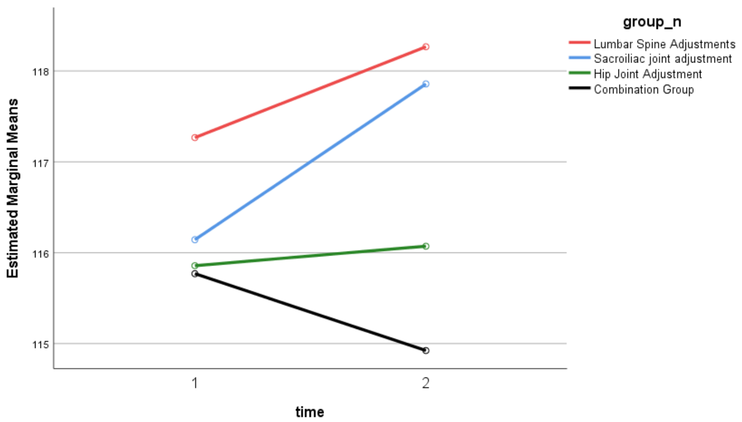

Figure 19: Graph showing estimated marginal means over time (change over time) – maximum cadence

There was no significant time x group effect (p=0.882) therefore the rate of change over time was the same in the different groups, therefore no manipulation group outperformed the other manipulation group when analysing maximum cadence.

2.4.6.9 Objective Five: Inter-group analysis – Cycling Data Summary

There was no significant effect on overall performance, referring to completion time, speed, power and cadence – when comparing the four manipulation groups post-manipulative intervention.

CHAPTER FIVE

DISCUSSION

5.1 INTRODUCTION

This chapter will discuss and outline the outcomes of this study.

5.1 INTRA-GROUP ANALYSIS

According to a study performed by Chapman *et al.* (2008), a lower amplitude of SEMG data seen in cyclists shows greater efficiency during cycling. He also stated that a more highly trained athlete would have greater variations in amplitude of muscle activations during the pedal stroke, as opposed to a more novice athlete who would produce a higher amplitude at longer duration, thus not using energy as efficiently as the more trained athlete. This would be as a result of the amount of power and strength that these athletes are able to produce when their muscles are being engaged as opposed to the lesser power produced by the more novice athlete.

It is important to bear in mind that the sample group for this study was well trained cyclists, therefore the SEMG findings by Chapman *et al.* (2008) may be applicable to this study.

5.1.1 Objective One: Lumbar spine manipulation group

The results of this study demonstrated that there was no significant change in muscle activity seen after lumbar spine manipulation, however there was change that occurred when comparing time-trials pre-intervention and post-intervention. By analysing the results, vastus lateralis (L2-L4) was found to have been most affected by lumbar spine manipulation and showed an increase in muscle activity, which is in line with the theory that manipulation results in neurological effects that results in depolarisation of the motor neuron pools at the level of the adjustment. This increases the afferent bombardment of the spinal nerve ganglion (Beck 2011; Crossman and Neary 2014).

However, iliopsoas, rectus femoris, vastus medialis, medial hamstrings, biceps femoris and gluteus maximus showed a decrease in muscle activity post-intervention (which was not statistically significant). Whilst this is not in keeping with the motorneuron pool theory described above (Beck 2011; Crossman and Neary 2014), this result could still indicate an improved muscle efficiency post-intervention according to Chapman *et al.* (2008), as they describe a lower muscle electrical amplitude to indicate a more efficient muscle output, especially in a trained muscle. Since this study's sample criteria was based on trained cyclists, this might explain why a decrease in electrical activity was found in this study.

The same explanation from Chapman *et al.* (2008), of decreased SEMG activity in trained muscles can be used to explain the outcomes of this study for cycling performance. This study found a significant decrease in power, normalised power and maximum power in terms of change in the cycling data. This data can be correlated to the decrease in muscle activity post-intervention in this group, as power is a direct function of muscle mass and is dependent on the recruitment and rate coding, referred to as muscle activity (Keller and Colloca 2000; Burke 2003; Heloyse Uliam *et al.* 2012; Niazi *et al.* 2015). A decrease in SEMG activity would correlate to a decrease in power output in the muscle, so the results of this study are in keeping in that a decrease in SEMG activity was found and a subsequent decrease in power.

However, the cycling data also showed a significant decrease in speed (p=0.001) and increase in time (p=0.003). These findings are not what was to be expected with improved muscle efficiency. This could be attributed to varies factors including fatigue.

5.1.2 Objective Two: Sacro-iliac joint manipulation group

The results of this study demonstrated that there was no significant change in muscle activity after sacro-iliac joint manipulation, however sacro-iliac joint manipulation resulted in an increase in vastus lateralis and biceps femoris muscle activity, whilst iliopsoas, vastus medialis, rectus femoris, medial hamstrings and gluteus maximus showed a decrease in muscle activity.

The increased activity seen in vastus lateralis (L2-L4) and biceps femoris (L5, S1 and S2) after sacro-iliac manipulation was to be expected because an SIJ manipulation would cause stimulation of the SIJ joint capsule mechanoreceptors as well as the nerve roots of L1-S3 (Fortin *et al.* 1999). This would cause an afferent bombardment over neural pathways within its motorneuron pool (Moore, Dalley and Agur 2008; Beck 2011; Crossman and Neary 2014). This would lead to stimulation of vastus lateralis and biceps femoris, which fall within the SIJ motorneuron pools.

However, there was a decrease in activity in the remaining muscles, which correlates with the change in cycling data, which showed a decrease in power (Keller and Colloca 2000; Burke 2003; Heloyse Uliam *et al.* 2012; Niazi *et al.* 2015).

There was a significant decrease in power (p=0.016), normalised power (p=0.001) and maximum power (p=0.009) in line with the decreased muscle activity data, however this study's data is in contrast to the multiple studies by Suter, McMorland and Herzog (2005), Suter *et al.* (1999) and Suter *et al.* (2000), which showed a significant increase in quadriceps (vastus lateralis, vastus medialis, rectus femoris) strength (power) after sacro-iliac joint manipulation. However these studies had samples that were not specific with regards to training. Chapman *et al.* (2008) reported that SEMG results in a trained population could differ from the general population, which could account for the results in this study, as this study only included trained cyclists.

5.1.3 Objective Three: Hip joint manipulation group

The results of this study demonstrated that there was no significant change in muscle activity seen post-hip joint manipulation, however there was change that occurred when comparing time-trials pre- and post-manipulation. Analysis of the results revealed an increase in medial hamstring (L4-S1) muscle activity, which is in line with the theory that manipulation results in gapping of the hip joint stimulating the joint capsule mechanoreceptors and stimulation of neural pathways. This results in the depolarisation of motor neuron pools, resulting in afferent bombardment of the spinal nerve roots (femoral nerve, obturator nerve and superior gluteal nerve) (Beck 2011; Crossman and Neary 2014).

It was expected that spinal nerve roots (femoral nerve L2-L4, obturator nerve L2-L4, superior gluteal nerve L4-S1) that are responsible for the hip joint innervation would have been equally stimulated resulting in stimulation of motor neuron pools L2-S1. However the results of this study show a decrease in muscle activity in vastus lateralis, biceps femoris, iliopsoas, vastus medialis, rectus femoris and gluteus maximus (which is not statistically significant) after sacro-iliac joint manipulation, all of which have shared spinal segmental innervations with that of the hip joint innervations. Although these findings are not in keeping with the motor neuron theory of Crossman and Neary (2014), Beck (2011), according to Chapman *et al.* (2008), these findings could still indicate improved muscle efficiency post-hip joint manipulation, as they describe low muscle electrical amplitude to indicate a more efficient muscle output, especially in trained cyclists, thus possibly explaining the decrease in muscle activity.

The explanation by Chapman *et al.* (2008) of decreased SEMG activity in trained muscles, can be used to explain the decreased performance demonstrated in the cycling data. This study demonstrated a significant decrease in power (p=0.023), normalised power (p=0.004) and maximum power (p=0.022), which correlates to the decreased muscle activity post-hip joint manipulation found in this study. The cycling data showed a significant decrease in speed (p=0.008) and although not significant, a decreased completion time, cadence and maximum speed.

5.1.4 Objective Four: Combination manipulation group

The results of this study demonstrate a significant decrease in muscle activity of Iliopsoas (p=0.014) and although not significant, the results showed decreased muscle activity of the remaining muscles post-manipulation. These results are in line with the research by Chapman *et al.* (2008) which found that trained cyclists who showed a decreased SEMG amplitude were more efficient with regards to muscle activity.

There is a visual trend which showed that the combination manipulation group goes against the trend of the previous manipulation groups. The individual administration of lumbar spine, sacro-iliac joint or hip joint manipulation showed that some muscles increased in muscle activity. This can be explained by the motor neuron pool theory where manipulation causes stimulation of the nerve roots and ganglia at the level of manipulation, which results in increased electrical activity of the muscle being innervated (Beck 2011; Crossman and Neary 2014).

Other muscles' muscle activity decreased post-manipulation. The combination manipulation group SEMG data demonstrated a decrease in every muscle being assessed in this study, which is not in keeping with the theory that stimulated motor neuron pools result in increased muscle activity (Beck 2011; Crossman and Neary 2014). However this decreased activity can be explained by Chapman *et al.* (2008), who demonstrated that decreased amplitude and contraction time proved greater muscle efficiency in trained athletes.

The cycling data demonstrated a significant decrease in normalised power (p=0.039), which correlates with the theory of Chapman *et al.* (2008) that decreased amplitude and contraction time results in an efficient muscle activity, since muscle activity is a direct measure of muscle mass. However, although not significant, the data demonstrated an increase in cadence, speed, maximum speed and maximum power, which is in contrast to Chapman *et al.* (2008) theory and in line with the motor neuron theory.

This increase in cycling data statistics is in contrast to the individually administered manipulation groups. In addition to the data discussed, it showed that there was an increase in completion time, which does not tie in with the speed analysis that occurred, as it was expected that an increased speed would result in a decrease in completion time. This speed was calculated on average speed of all participants in this manipulation group at given points (described in Chapter 3) in the time-trial as opposed to calculated average speed of the entire time-trial. These data calculations are in line with the readings taken for the SEMG data.

Although not significant, overall, the combination manipulation group showed a greater improvement in performance over the other manipulation groups, as the combination manipulation group demonstrated that there was a greater improvement in performance in terms of cadence, speed, maximum speed and maximum power post-combination manipulation when compared to the individually administered lumbar spine, sacro-iliac joint or hip joint manipulation groups.

5.2 INTER-GROUP ANALYSIS

5.2.1 Objective 5: Inter-group analysis

5.2.1.1 Objective Five: Inter-group Analysis – Surface Electromyography Data

Intra-group analysis demonstrated that no single manipulation group significantly out-performed the other manipulation groups post-manipulative intervention.

It was expected that the combination manipulation group would significantly outperform the individually administered manipulation groups, post-manipulative intervention, based on the theory that states that manipulation causes a neurological effect that results in electrical stimulation which in turn results in the depolarisation of motor neuron pools at the level of innervation where the adjustment is administered. The combination of lumbar spine, sacro-iliac joint and hip joint manipulations would therefore result in multi-level electrical stimulation, which would be expected to result in increases in the afferent bombardment of the spinal nerve roots and ganglia (Beck 2011; Crossman and Neary 2014). This study's results may have been affected by muscle fatigue between time-trials pre- and post-manipulation, and therefore this factor needs to be taken into consideration for future studies.

5.2.1.2 Objective Five: Inter-group Analysis – Cycling Data

The study data demonstrated no significant change in the cycling performance data post-manipulation when comparing manipulation groups, and therefore no single manipulation group significantly out-performed the other in terms of cycling performance post-manipulation.

This result may be attributed to the fact that the participants who participated in this study are all well-trained athletes and are therefore fit enough to perform at a relatively equal level over the two time-trial efforts and therefore the time-trials pre- and post-manipulation showed no statistically significant data changes post-manipulation.

5.3 IN SUMMARY

This study has shown some contradictory results to other studies performed over the years. This may be as a result of sampling factors. Although these participants are considered to be well-trained or highly trained athletes, these participants had varying cycling ability and experience (Chapman *et al.* 2008).

It can be concluded from the data produced that chiropractic manipulations had no significant effect on cycling performance in the sample groups. It was demonstrated that the combination manipulation group was the only group that showed a significant decrease across muscle activity of all the muscles being assessed in this study.

A contributing factor to the decreased performance statistics could be as a result of fatigue in the second time-trial. A second factor could be that while participants were trained cyclists, they were of varying capability.

CHAPTER SIX

CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

This chapter will discuss and conclude the outcomes of this study, by determining the effect of lumbar spine, sacro-iliac, hip joint and a combination manipulation of these interventions, on muscle activity and cycling performance in asymptomatic cyclists. A conclusion will be drawn from the results in Chapter 4 and discussions from Chapter 5. The limitations of this study will be discussed, as well as recommendations made with regards to future research into this field of study.

6.2 CONCLUSION

At the onset of this study it was proposed that the aim of this study was to determine the effect of lumbar spine, sacro-iliac and/or hip joint manipulation on muscle activity and performance in road cyclists.

In terms of the hypotheses:

1. It is hypothesised that a combination of manipulations (lumbar spine, sacro-iliac joint and hip joint) would improve the dependent variables significantly more than when they are applied individually.

2. The alternate hypothesis states that manipulations of the lumbar spine, sacro-iliac joint and hip joint individually would improve the dependent variables significantly more than when they are applied in combination.

It can be concluded that there was no significant improvement in muscle activity and cycling performance for cyclists, but the combination manipulations had more of an impact than when manipulations were applied individually.

6.3 LIMITATIONS

1. SEMG equipment only allowed for measurements of the seven muscles – thus not allowing for complete assessment of the lower limb musculature required during cycling.
2. The sample group size required for this study led to a much wider range of athlete ability, instead of a more focused athlete capability.
3. Not all lumbar levels were adjusted for every lumbar group participant, but rather only the level that presented with a joint fixation, and therefore there may not have been optimal stimulation of each lumbar plexus level, thus impacting the results.

6.3 RECOMMENDATIONS

1. This study could be repeated with participants resting for a longer period than the given 10 minutes in this study, as a greater rest period would allow for better recovery between time-trials.
2. This study could be repeated with participants doing a warm-up before each time-trial, as the build-up of lactic acid from the first time-trial needs to be flushed out before the second time-trial due to the body reaching its anabolic threshold so suddenly.
3. This study could be repeated with participants being allowed to watch the course route but not see their cycling data being produced (cadence, power, speed, time), as this would allow for cyclists to mentally prepare for the change in terrain before the change occurs.
4. This study could be repeated with the addition of other factors such as capturing heart rate, VO2 max, bicycle setup, training regimes and nutrition, as these are other major factors which influence performance.
5. Research could be repeated with a sample size of a more equal athletic performance ability to allow for better comparisons between athletes.
6. This study could be repeated with the use of a control group that does not receive a manipulation intervention, to better analyse the post-manipulative data.
7. This study could be repeated assessing the lower leg musculature in addition to the muscles assessed, in order to analyse the full lower limb kinematic chain during cycling.
8. Research could be conducted to compare sides and the various manipulative effects on either side.

9. The study only looked at the effect of manipulation on the fixated segments, so future studies could look at manipulation at all lumbar segments in each participant in order to maximise stimulation of the motor neuron pools of the lumbar plexus.
10. It is recommended that future studies calculate for fatigue that occurs between the first and second time-trial. This has an impact on the results, as muscle fatigue can result in decreased performance in the second time-trial, especially in those athletes who are not as fit.
11. It is recommended that this study be repeated over a period of time, ie. would the participants return to their baseline time-trial values after a 24hour period.

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APPENDICES

Appendix A: Research Advertisement

Attention all Cyclists

Are you healthy, between the ages of 20-59 years old, have cycled (for the last 3 months) and still cycling for more than 3 hours a week and interested in participating in a 1.5km virtual time-trial as part of a research study.

Research being conducted at the Durban University of Technology on an intervention that may have an effect on your cycling performance.

If you are interested in participating in this study, please contact Pia via phone call, message or WhatsApp – 0722798549/ via email piafuller@gmail.com

Appendix B: Letter of Information

DUT DURBAN UNIVERSITY OF TECHNOLOGY INSTITUTIONAL RESEARCH ETHICS COMMITTEE

LETTER OF INFORMATION

Dear Participant

Welcome to my research study. The purpose of my study is to determine whether or not chiropractic care has the ability to immediately affect a cyclists' muscle activity and cycling performance, and whether or not there is a relationship that exists between muscle activity and cycling performance in terms of power output.

Title of the Research Study: The effect of lumbar spine, sacro-iliac and/or hip joint manipulation on muscle activity and performance in road cycling.

Principal Investigator/s/researcher: Pia Fuller (Contact: 0722798549 or piafuller@gmail.com)

Co-Investigator/s/supervisor/s: Dr Grant Matkovich (MTech: Chiropractic)
Prof. L. Puckree (PhD Exercise physiology)

Brief Introduction and Purpose of the Study:
The aim of this study is to determine the effect of lumbar spine, sacro-iliac and/or hip joint manipulation on muscle activity of those muscles most frequently used by cyclists and their power output during road cycling. Sixty cyclists between the age of 20-59 will be recruited to participate in this study. You will undergo a range of motion assessments, two 1.5km time-trials and adjustments during this study.

Outline of the Procedures: Consultations will take place at the Durban University of Technology Chiropractic Day Clinic. You will be required to only have one consultation for this research study. You, the participant will be required to bring your own road bicycle to the consultation along with your cleats and a set of riding kit. A case history, physical examination, lumbar spine and hip regional assessment will be performed. You will then need to participate in a 5-minute warm-up on your bicycle which will mounted onto an ergometer (indoor trainer) by the researcher. The warm-up will consist of 5 minutes of riding time in an easy gear. You will then cycle a 1.5 km all out virtual time-trial route from which measurements of maximum and average power, maximum and average speed, maximum and average cadence, and completion time will be recorded. A chiropractic manipulation will then be performed according to the group you get allocated to. You will then again complete the same 1.5 km time-trial route and again the same measurements will be recorded. The consultation is expected to last about two to three hours.

Risks or Discomforts to the Participant: The testing involves chiropractic manipulation. This form of treatment is relatively harmless but may result in transient muscle pain.

Benefits: (To the participant and to the researcher/s e.g. publications)

Reason/s why the participant may Be Withdrawn from the Study: You may withdraw at any stage of this study with no negative repercussions whatsoever.

Remuneration: The are no financial rewards offered in this study.

Costs of the Study: There are no costs involved in order for you as the participant to take part in this study.

Confidentiality: All patient information will be kept confidential and will be stored in the Chiropractic Day Clinic for 5 years, after which it will be shredded. Only the researcher and her supervisor will have access to the data information.
If you have any queries about this study, please do not hesitate to ask the researcher. You are not forced to take part in this study and therefore optionally chosen to participate. Please kindly notes that you may withdraw for this study at any stage and there will be no negative repercussions if you do so.

Persons to Contact in the Event of Any Problems or Queries:

Dr Grant Matkovich: Please contact the researcher (0722798549), my supervisor (grantmatko@mweb.co.za) or the Institutional
Research Ethics Administrator on 031 373 2900. Complaints can be reported to the Director: Research and
Postgraduate Support, Prof S Moyo on 031 373 2577 or moyos@dut.ac.za

Researcher	Date	Signature
Research Supervisor	Date	Signature

Appendix C: Consent Form

CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Pia Alexa Fuller, about the nature, conduct, benefits and risks of this study – Research Ethics Clearance Number: 159/16 ,
- 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, Pia Alexa Fuller 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

Date Signature

Full Name of Witness (If applicable)

Full Name of Legal Guardian (If applicable) Date Signature

Appendix D: Case History

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:

Page 1 of 4

<u>Student's Case History:</u>

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 E: Physical Examination

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:**

Page 1

Appendix F: Lumbar Spine Regional Examination

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC AND SOMATOLOGY

CHIROPRACTIC PROGRAMME

REGIONAL EXAMINATION
LUMBAR SPINE AND PELVIS

Patient: ______________________ File#: ____________ Date: ________

Student: ______________________ Clinician: ______________________

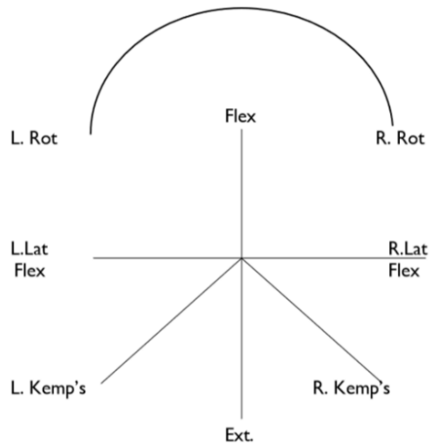
STANDING:

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

Page **1** of **4**

TRIPOD Sl, +, ++		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

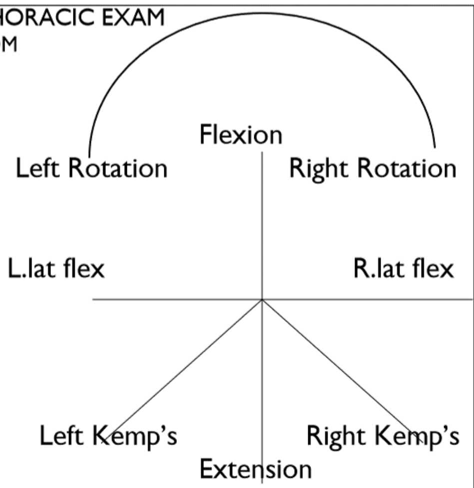
Fasciculations						
Plantar reflex						
level	**Tender?**	**Dermatomes**		**DTR**		
		L	**R**		**L**	**R**
T12				Patellar		
L1				Achilles		
L2						
L3				Proprioception		
L4						
L5						
S1						
S2						
S3						

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 G: Hip Regional Examination

DUT DURBAN UNIVERSITY OF TECHNOLOGY | DEPARTMENT OF CHIROPRACTIC AND SOMATOLOGY

CHIROPRACTIC PROGRAMME

HIP REGIONAL EXAMINATION

Patient: ______________________ File no: __________ Date: ______________

Student: ______________________ Signature: ______________________

Clinician: ______________________ Signature: ______________________

Hip with complaint: Right ☐ Left: ☐

OBSERVATION

- Gait: ______________________
- Posture: ______________________
- Weight-bearing symmetry: ______________________
- Balance and proprioception (Stork-standing test): ______________________
- Bony / soft tissue contours: Buttock contour ______________________
  Hip flexion contracture ______________________
  Lumbar lordosis ______________________
  Scoliosis ______________________
- Skin: ______________________
- Swelling: ______________________

PALPATION

· **Anterior aspect**			**Right**	**Left**
1.	Iliac crests			
2.	Greater trochanter			
3.	Pubic symphysis and tubercle			
4.	Femoral head			
5.	Femoral triangle	Femoral artery		
		Lymph nodes		
6.	ASIS's			
7.	Inguinal ligament			
8.	Inguinal hernia			
9.	Muscles -	Quadriceps		
		Adductors		
		Abductors		
		Psoas		
· **Posterior aspect**			**Right**	**Left**
1.	Iliac crests posteriorly			
2.	Ischial tuberosity			
3.	Muscles	Piriformis		
		Gluteals		
		Hamstrings		
4.	PSIS's			
5.	Sciatic notch			
6.	SI joints			
7.	Lumbar Spine			
8.	Sacrum + coccyx			

ACTIVE MOVEMENTS (*note rom and pain*)		Right	Left
1.	Flexion (110-120°)		
2.	Extension (10-15°)		
3.	Adduction (30°)		
4.	Abduction (30-50°)		
5.	Medial rotation (30-40°)		
6.	Lateral rotation (40-60°)		
PASSIVE MOVEMENTS (*note end-feel, rom and pain*)		**Right**	**Left**
1.	Flexion (tissue stretch or approximation)		
2.	Extension (tissue stretch)		
3.	Adduction (tissue stretch or approximation)		
4.	Abduction (tissue stretch)		
5.	Medial rotation (tissue stretch)		
6.	Lateral rotation (tissue stretch)		
RESISTED ISOMETRIC MOVEMENTS (*note strength and pain*)		**Right**	**Left**
1.	Hip Flexion		
2.	Hip Extension		
3.	Adduction		
4.	Abduction		
5.	Medial rotation		
6.	Lateral rotation		
7.	Knee flexion		
8.	Knee extension		
REFLEXES		**Right**	**Left**
1.	Patella		
2.	Achilles		
DERMATOMES (*indicate deficits by level and location*)			
1.	Level		
2.	Location		
JOINT PLAY MOVEMENTS		**Right**	**Left**
1.	Caudal glide (long axis traction superior – inferior)		
2.	Compression @ 90° (inferior – superior)		
3.	Medial ➢ lateral @ 180° / @ 90°		
4.	Lateral ➢ medial @ 180° / @ 90°		
5.	Internal rotation		
6.	External rotation		
7.	Anterior ➢ posterior		
8.	Posterior ➢ anterior		
9.	Quadrant (scouring) test		
SPECIAL TESTS		**Right**	**Left**
1.	Patrick FABER Test		
2.	Trendelenberg's Test		
3.	Craig's Test		
4.	Leg Length – Actual		
	Leg Length – Apparent		
5.	Sign of the Buttock		
6.	Thomas Test (hip flexion contracture)		
7.	Rectus Femoris Contracture Test		
8.	Iliopsoas contracture Test		
9.	Ely's Test (rectus femoris hypertonicity)		
10.	Ober's Test (ITB contracture)		
11.	Noble Compression Test (ITB Friction Syndrome)		
12.	Piriformis Test		
13.	Hamstrings – Hamstring Contracture Test		
	Hamstrings – Tripod Test		

Appendix H: SOAPE Note

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC AND SOMATOLOGY

CHIROPRACTIC PROGRAMME

Patient Name: **File number:** **Page:**

Date: **Visit:** **Student:**
Attending Clinician: **Signature:**

S: Numerical Pain Rating Scale (Patient) Student Rating

Least **0 1 2 3 4 5 6 7 8 9 10** Worst ☐

A:

0:

P:

E:

Special attention to: **Next appointment:**

Date: **Visit:** **Student:**
Attending Clinician: **Signature:**

S: Numerical Pain Rating Scale (Patient) Student Rating

Least **0 1 2 3 4 5 6 7 8 9 10** Worst ☐

A:

O:

P:

E:

Special attention to: **Next appointment:**

Date: **Visit:** **Student:**
Attending Clinician: **Signature**

S: Numerical Pain Rating Scale (Patient) Student Rating

Least **0 1 2 3 4 5 6 7 8 9 10** Worst ☐

A:

O:

P:

E:

Special attention to: **Next appointment:**

Appendix I: Demographic Data Form

Participant Code: ______________________________ Participant Side of Dominance: L R

Participant File Number: ________________________ Participant Group Allocation: 1 2 3 4

Height ______________________________________ Weight__________________

Researcher to fill in correct patient details and tick the appropriate boxes

On average, how many hours do you spend riding your bicycle?	
<3 hours	
4-6 hours	
7-9 hours	
10-12 hours	
13-15 hours	
16-19 hours	
20+ hours	

On average, for how many years have you been actively participating in cycling?	
1-5 Years	
6-10 Years	
11-15 Years	
16-20 Years	
20+ Years	

How would you classify your riding ability?	
Social Fun (weekend riding only)	
Serious Amateur (>5 races per year)	
Elite (regular top 10% finisher in your age category)	
Professional (paid to ride)	

Do you participate in any other physical activities regularly? If so, please specify type of activity and average weekly hour spent on this activity.

Triathlon | Running | Paddling | Swimming | Gym | MTB | Other

Appendix J: Data Sheet Templates

Table A: Raw Cycling Data Sheet Template

	T T	0,25km				0,50km				0,75km				1,0km				1,25km				1,50km				Average Values					Maximum Values		
Group		Time	Power	Speed	Cadence	Time	Power	Speed	Cadence	Time	Power	Speed	Cadence	Time	Power	Speed	Cadence	Time	Power	Speed	Cadence	Time	Power	Speed	Cadence	Completion	Power	Norm. P	Speed	Cadence	Power	Speed	Cadence

Table B: Final Data Sheet Template (sent to statistician)

Group	Average Values					Maximum Values		
	Completion Time	Power	Norm. P	Speed	Cadence	Power	Speed	Cadence

Appendix K: Permission Memorandum – DUT Chiropractic Day Clinic

MEMORANDUM

To : Prof Puckree
Chair : RHDC

Prof Adam
Chair : IREC

From : Dr Charmaine Korporaal
Clinic Director : FoHS Clinic

Date : 08.11.2016

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

---

Permission is hereby granted to :

Ms Pia Fuller (Student Number: 21325888)

Research title:"The effect of lumbar spine, sacroiliac and/or hip joint manipulation on muscle activity and performance in road cycling."

It is requested that Ms Fuller 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

[redacted]

Dr Charmaine Korporaal

Clinic Director : FoHS Clinic

Cc: Mrs Linda Twiggs : Chiropractic Day Clinic
Dr G Matkovich : Research supervisor
Prof L Puckree : Research co-supervisor

Appendix L: IREC Clearance

DUT DURBAN UNIVERSITY OF TECHNOLOGY

Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate l, Steve Biko Campus
Durban University of Technology
P O Box 1334, Durban, South Africa, 4001
Tel: 03 1 373 2375 Email: lavishad@dut.ac.za
http://www.dut.ac.za/research/institutional_research_ethics
www.dut.ac.za

30 January 2017

IRC Reference Number: REC 1 59/ 16

Ms PA Fuller

PO Box 25 16
Country Club
4301

Dear Ms Fuller

The effect of lumbar spine, sacro-iliac and/or hip joint manipulation on muscle activity and performance in road cycling

I am pleased to inform you that Full Approval has been granted to your proposal REC 159/16.

The Proposal has been allocated the following Ethical Clearance number IREC 002/1 7. Please use this number in all communication with this office.

Approval has been granted for a period of two years, 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.

Please note that any deviations from the approved proposal require the approval of the IREC as outlined in the IREC SOP's.

Yours Sincerely

[redacted]

Professor J K Adam
Chairperson: IREC

DUT DURBAN UNIVERSITY OF TECHNOLOGY
2017 -01- 30
INSITUTUTIONAL RESEARCH ETHICS COMMITTEE
P O BOX 1334 DURBAN 4000 SOUTH AFRICA

Appendix M: IREC Amendment Clearance

Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology

P O Box 1334, Durban, South Africa, 4001

Tel: 031 373 2375
Email: lavishad@dut.ac.za
http://www.dut.ac.za/research/institutional_research_ethics

www.dut.ac.za

16 May 2017

Ms PA Fuller

PO Box 25 1 6

Country Club

4301

Dear Ms Fuller

Application for Amendment of Approved Research Proposal

The effect of lumbar spine, sacro-iliac and/or hip joint manipulation on muscle activity and performance in road cycling

I am pleased to inform you that your application for amendment to include a 10 speed bicycle as part of the telephonic interview question has been Approved.

Yours Sincerely

[redacted]

Professor J K Adam

Chairperson: IREC

DUT DURBAN UNIVERSITY OF TECHNOLOGY

2017 -05- 1 6

INSITUTUTIONAL RESEARCH ETHICS COMMITTEE
P O BOX 1334 DURBAN 4000 SOUTH AFRICA

Appendix N: Electrode Placement Protocol

Table 1: Electrode Placement - Rectus Femoris

Rectus Femoris	
Electrode Placement	
Start Position	Sitting on the table, knees slight flexion, upper body slightly bend backward.
Location	The 2 electrodes (2cm apart) are placed half way between the anterior superior iliac spine and superior aspect of the patella.
Orientation	Parallel to the line anterior superior iliac spine and superior aspect of the patella.
Test	Participant seated, ask them to extend the knee and contract the quadriceps, mark the point.

(Cram 2011)

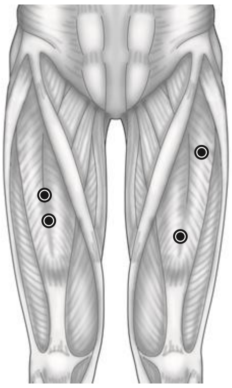


Figure 20: Electrode placement for the rectus femoris site (left side) and quadriceps muscles in general (right side).

Table 2: Electrode Placement - Vastus Medialis

Vastus Medialis	
Electrode Placement	
Type	Specific placement.
Start Position	Sitting on table, knees in slight flexion, upper body slightly bend backward.
Location	Electrodes placed at an oblique angle (55degrees), 2 cm medially from the superior rim of the patella. Palpate for the muscle during knee extension. Electrodes placed on the distal third of the vastus medialis (Cram 2011).
Orientation	Almost perpendicular to the line from the anterior superior iliac spine to anterior border of the medial ligament.
Test	Extend the knee while pressing against the leg above the ankle in the direction of flexion (Cram 2011).

(Biomedicine and Movement Sciences-University of Verona 2016)

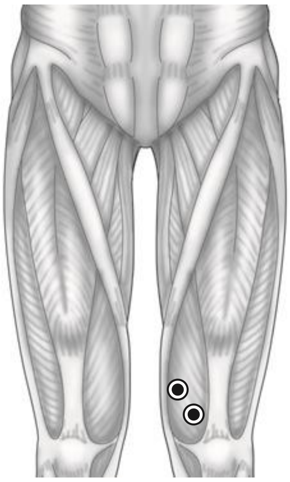


Figure 2: Electrode placement for the vastus medialis.

(Cram 2011) Copyright © Clinical Resources, Inc.

Table 3: Electrode Placement Vastus Lateralis

Vastus Lateralis	
Electrode Placement	
Type	Specific placement
Start Position	Sitting on table, knees in slight flexion, upper body slightly bend backward.
Location	2 electrodes placed 2cm apart at a point 2/3 of the line from anterior superior iliac spine to the lateral border of the patella (3 to 5 cm above the patella, just lateral to the midline (Cram 2011)).
Orientation	In the direction of the muscle fibre at an oblique angle.
Test	Extend the knee while seated and squat while standing.

(Cram 2011)

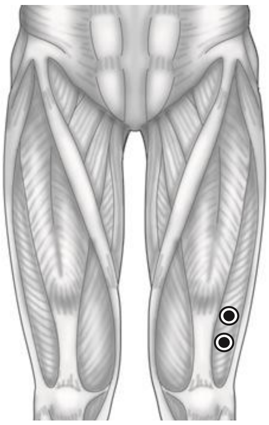


Figure 321: Electrode placement for the vastus lateralis site.

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Table 4: Electrode Placement - Biceps Femoris

Biceps Femoris	
Electrode Placement	
Type	Specific Placement
Start Position	Lying on the belly, thigh down on the table, knees flexed, thigh in slight lateral rotation, leg in slight lateral rotation with respect to the thigh.
Location	Two electrodes placed 2cm apart, parallel to muscle fibres on the lateral aspect of the thigh, two thirds of the distance between the trochanter and the back of the knee. Palpate the muscle while manually muscle testing the knee at 90degrees and the thigh in a slight rotation (Cram 2011).
Orientation	Parallel to the line from the ischial tuberosity to the lateral epicondyle of the tibia (Cram 2011).
Test	Participant in prone position, ask participant to flex the knee against resistance. In the standing position, have the participant flex the knee (Cram 2011).

(Biomedicine and Movement Sciences-University of Verona 2016)

Table 5: Electrode Placement - Medial Hamstring

Medial Hamstring	
Electrode Placement	
Type	Specific placement.
Start Position	Lying prone on the table, and the thigh held down on the table, in medial rotation, and the leg medially rotated with respect to the thigh. The knee needs to be flexed to less than 90 degrees.
Location	Electrode placed half way along the line from the ischial tuberosity and the medial epicondyle of the tibia.
Orientation	In the direction of the line from the ischial tuberosity and the medial epicondyle of the tibia.
Test	Press against the leg proximal to the ankle in the direction of knee extension.

(Biomedicine and Movement Sciences-University of Verona 2016)

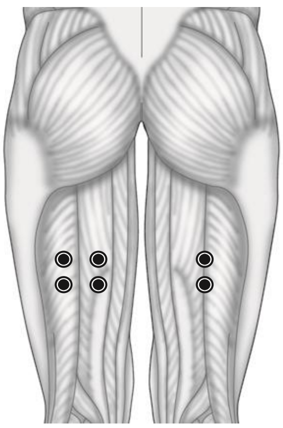

Figure 4: Electrode placement for the biceps femoris and medial hamstrings (left) and general placement (right)

(Cram 2011) Copyright © Clinical Resources, Inc.

Table 6: Electrode Placement - Gluteus Maximus

Gluteus Maximus	
Electrode Placement	
Type	Placement specific
Start Position	Participant lying in the prone position on the table.
Location	For upper gluteus maximus – 2 active electrodes (3cm apart) are placed half was between the greater trochanter (hip) and the sacral vertebrae at the level or the trochanter or slightly above (Cram 2011).
Orientation	In the direction of the line from the posterior superior iliac spine to the middle of the posterior aspect of the thigh.
Test	Participant in prone posture, extend the leg backwards against manual resistance.

(Biomedicine and Movement Sciences-University of Verona 2016)

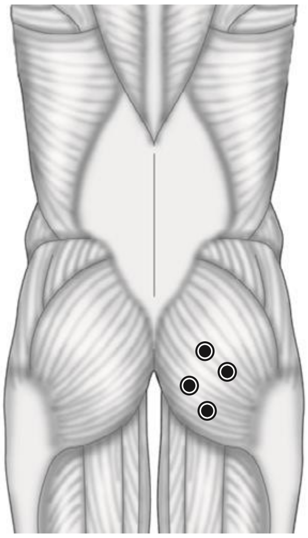

Figure 5: Electrode placement for the upper and lower gluteus maximus sites.

(Cram 2011) Copyright © Clinical Resources, Inc.

Table 7: Electrode Placement - Iliopsoas

Iliopsoas (Femoral Triangle)	
Electrode Placement	
Type	Quasi-specific
Start Position	Participant supine on bed
Location	Palpate the thigh for the femoral triangle just below the pelvis. Locate femoral pulse. Go lateral to this point, but stay medial of quadriceps femoris and inferior to inguinal ligament. Place 2 electrodes, 2 cm apart parallel to the muscle fibre.
Orientation	Parallel to muscle fibres
Test	Quadrupedal stance (on hands and knees) and flex the hip.

(Cram 2011)

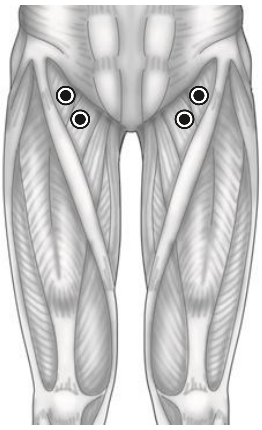

Figure 622: Electrode placement for Iliopsoas (femoral triangle) site.

Appendix O: Adjustment Protocol

<u>The protocol will be as follows:</u>

Abbreviations

- IND = Indication
- PP = Participant position
- DP = Doctors' position
- CP = Contact point
- SCP = Second contact point
- IH = Indifferent hand
- VEC = Vector
- P = Procedure

1. Lumbar Spine Adjustment

Side Lying: Spinous push-pull: Loss of posterior to anterior rotation

IND: Loss of PA motion.

PP: Participant position as follows:

1. ***<u>Lumbar roll</u>***, participant in torqued, side lying position. Shoulders in contact with the chiropractic bed and the pelvis perpendicular (90degrees) to the chiropractic bed.
   Participant to lie with dysfunctional side up. If required, raise headrest to support the participants head.

DP: Square stance.

CP: Fingers to hook spinous process of affected vertebra.

SCP: Reinforce finger-tips of CP.

IH: Stabilize and prevent participant from rolling off the bed. At the same time, contact vertebra above involved vertebra to block/ "push" its spinous process downwards during the manipulation. A thumb contact may be used.

VEC: PA rotatory motion of the affected vertebra.

P: Participant placed in lumbar roll position. Participants knee is motioned (flexed and extended) until maximum tension is felt at the level to be adjusted. Skin slack and joint slack is removed. CP and IH contact takes place. The participant is then rolled into the researcher. This allows the researcher to place their sternum over the CP. Ensure adequate torque and traction are applied to the participants' body. Deliver a drop generated through the abdominal muscles as the same time as delivering a HVLA thrust.

(Bergmann and Peterson 2010)

2. Sacro-iliac Joint Adjustment

Side posture: Flexion: Upper joint

IND: Flexion dysfunction of Upper SIJ.

PP: Participant position as follows:

1. ***Lumbar roll***, participant positioned in side lying, torqued position. Shoulders in contact with the chiropractic bed and the pelvis perpendicular (90degrees) to the chiropractic bed. Dysfunction side up. If required, raise headrest to support the participants head.

DP: Lunge stance.

CP: Doctors caudal hand, pisiform contact.

SCP: PSIS / SIJ adjacent to PSIS.

IH: In the lumbar roll position, IH applied posterior force to ipsilateral shoulder maximizing torque on participants' lumbar spine. IH was also required to stabilize participant on the chiropractic bed.

VEC: PA, lateral-medial HVLA thrust applied at, approximating 45degrees angle to the chiropractic bed surface. Alternatively, apply force directly down and along femur length of the ipsilateral femur.

P: Participant placed in lumbar roll position. Participants knee is motioned (flexed and extended) until maximum tension is felt at the level to be adjusted. Skin slack and joint slack is removed. CP and IH contact takes place. The participant is then rolled into the researcher. This allows the researcher to place their sternum over the CP. Ensure adequate torque and traction are applied to the participants' body. Deliver a drop, generated through the abdominal muscles, at the same time as delivering a HVLA thrust.

(Bergmann and Peterson 2010)

Side posture: Extension: Upper joint

IND: Extension dysfunction of Upper SIJ.

PP: Participant position as follows:

1. ***Lumbar roll***, participant positioned in side lying, torqued position. Shoulders in contact with the chiropractic bed and the pelvis perpendicular (90degrees) to the chiropractic bed. Dysfunction side down in contact with the bed. If required, raise headrest to support the participants head.

DP: Lunge stance.

CP: Doctor caudal hand, pisiform contact.

SCP: PSIS / SIJ adjacent to PSIS.

IH: In the lumbar roll position, IH applied posterior force to ipsilateral shoulder maximizing torque on participants' lumbar spine. IH also required to stabilize participant on the chiropractic bed.

VEC: PA, lateral-medial HVLA thrust applied at, approximating 45degrees angle to the chiropractic bed surface.

P: Participant in lumbar roll position. Stabilize participants' contralateral limb against researchers' thighs. SIJ placed under stress. CP and IH contact take place. The participant is then rolled into the researcher. This allows the researcher to place their sternum over the CP. Ensure adequate torque and traction are applied to the participants' body. Deliver a drop, generated through the abdominal muscles, at the same time as delivering a HVLA thrust.

(Bergmann and Peterson 2010)

Side posture: Flexion: Lower joint

IND: Flexion dysfunction of Lower SIJ.

PP: Participant position as follows:

1. ***Lumbar roll***, participant positioned in side lying, torqued position. Shoulders in contact with the chiropractic bed and the pelvis perpendicular (90degrees) to the chiropractic bed. Dysfunction side up. If required, raise headrest to support the participants head.

DP: Lunge stance.

CP: Doctors caudal hand, pisiform contact.

SCP: PIIS / SIJ adjacent to PIIS.

IH: In the lumbar roll position, IH applied posterior force to ipsilateral shoulder maximizing torque on participants' lumbar spine. IH also required to stabilize participant on the chiropractic bed.

VEC: PA, lateral-medial HVLA thrust applied at, approximating 45degrees angle to the chiropractic bed surface. Alternatively, apply force directly down and along femur length of the ipsilateral femur.

P: Participant placed in lumbar roll position. Participants knee is motioned (flexed and extended) until maximum tension is felt at the level to be adjusted. Skin slack and joint slack is removed. CP and IH contact takes place. The participant is then rolled into the researcher. This allows the researcher to place their sternum over the CP. Ensure adequate torque and traction are applied to the participants' body. Deliver a drop, generated through the abdominal muscles, at the same time as delivering a HVLA thrust.

(Bergmann and Peterson 2010)

Side posture: Extension: Lower joint

IND: Extension dysfunction of Lower SIJ.

PP: Participant position as follows:

1. ***Lumbar roll***, participant positioned in side lying, torqued position. Shoulders in contact with the chiropractic bed and the pelvis perpendicular (90degrees) to the chiropractic bed. Dysfunction side down in contact with the bed. If required, raise headrest to support the participants head.

DP: Lunge stance.

CP: Doctor caudal hand, pisiform contact.

SCP: PSIS / SIJ adjacent to PSIS.

IH: In the lumbar roll position, IH applied posterior force to ipsilateral shoulder maximizing torque on participants' lumbar spine. IH also required to stabilize participant on the chiropractic bed.

VEC: PA, lateral-medial HVLA thrust applied at, 45 degree angle to the chiropractic bed surface.

P: Participant in lumbar roll position. Stabilize participants' contralateral limb against researchers' thighs. SIJ placed under stress. CP and IH contact take place. The participant is then rolled into the researcher. This allows the researcher to place their sternum over the CP. Ensure adequate torque and traction are applied to the participants' body. Deliver a drop, generated through the abdominal muscles, at the same time as delivering a HVLA thrust.

(Bergmann and Peterson 2010)

3. Hip Joint Adjustment

Bimanual Grasp/Proximal Femur; Internal Rotation

IND: Loss of internal rotation, accessory movement of the hip joint.

PP: Participant is supine. Unaffected leg relaxed and straight on the bed, with the involved hip and knee flexed to 90 degrees.

DP: Face cephalad on ipsilateral side of involved hip.

SCP: Midshaft of the femur.

CP: Doctor grasps the proximal aspect of the involved femur with cephalic hand.

IH: Doctors caudal hand reinforcing CP at proximal femur.

VEC: Internal rotation.

P: Induce internal rotation with your IH and then deliver an impulse thrust with the CP hand.

(Bergmann and Peterson 2010)

Bimanual Grasp/Proximal Femur; External Rotation

IND: Loss of external rotation, accessory movement of the hip joint.

PP: Participant supine Unaffected leg relaxed and straight on the bed, with the involved hip (slightly abducted) and knee flexed to 90 degrees.

DP: Facing cephalad, stand on the ipsilateral side to the involved hip, between the participants leg and the chiropractic bed.

SCP: Medial aspect of the proximal femur.

CP: Doctors cephalic hand to grasp the proximal femur on its medial aspect.

IH: Caudal hand reinforces CP.

VEC: External rotation.

P: induce external rotation of involved hip with your IH and then deliver an impulse thrust with the contact hand.

(Bergmann and Peterson 2010)

Bimanual Grasp/Proximal Femur; Inferior Glide in Flexion

IND: Loss of inferior glide in flexion-accessory of the hip joint.

PP: Participant supine. Involved hip and knee flexed to 90 degrees.

DP: Stand on the involved side, facing the participant, flexed forward, with the participant’s calf resting on your shoulder.

CP: Grasp the anterior aspect of the proximal thigh with both hands.

SCP: Anterior aspect of the proximal femur.

VEC: Superior to Inferior

P: With both hands, deliver an impulse thrust caudal.

(Bergmann and Peterson 2010)

Appendix P: Statistical Data

Table 1: Descriptive statistics of baseline outcomes by group

Descriptive									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
VastusLat.1	Lumbar Spine Adjustments	15	.2333419	.08567404	.02212094	.1858972	.2807866	.08545	.37049
	Sacro-iliac joint adjustment	15	.2620308	.11594372	.02993654	.1978233	.3262383	.07791	.45269
	Hip Joint Adjustment	15	.2517956	.07811232	.02016851	.2085385	.2950528	.06042	.39364
	Combination Group	16	.2639758	.09486856	.02371714	.2134239	.3145277	.09639	.44848
	Total	61	.2529695	.09312653	.01192363	.2291186	.2768203	.06042	.45269
BicepsFem.1	Lumbar Spine Adjustments	15	.1566941	.05109301	.01319216	.1283997	.1849885	.09931	.30430
	Sacro-iliac joint adjustment	15	.1883310	.07803169	.02014770	.1451184	.2315435	.05558	.27814
	Hip Joint Adjustment	15	.1626771	.06358014	.01641632	.1274676	.1978867	.04995	.31154
	Combination Group	16	.1973770	.04833109	.01208277	.1716231	.2231308	.14046	.30678
	Total	61	.1766158	.06208155	.00794873	.1607160	.1925156	.04995	.31154
Iliopsoas.1	Lumbar Spine Adjustments	15	.2088818	.17815598	.04599968	.1102223	.3075413	.06713	.64913
	Sacro-iliac joint adjustment	15	.1899910	.10423415	.02691314	.1322681	.2477140	.07351	.46293
	Hip Joint Adjustment	15	.1944805	.11092558	.02864086	.1330519	.2559090	.06765	.46873
	Combination Group	15	.1932585	.08742319	.02257257	.1448451	.2416718	.11630	.46584
	Total	60	.1966530	.12204994	.01575658	.1651241	.2281818	.06713	.64913
VastusMed.1	Lumbar Spine Adjustments	15	.0947620	.03048074	.00787009	.0778823	.1116417	.05254	.15008
	Sacro-iliac joint adjustment	15	.1104893	.06932222	.01789892	.0721000	.1488787	.02691	.22193
	Hip Joint Adjustment	15	.1156758	.06451980	.01665894	.0799459	.1514057	.02035	.23351
	Combination Group	16	.1397118	.04771860	.01192965	.1142843	.1651392	.06447	.21905
	Total	61	.1155622	.05611409	.00718467	.1011907	.1299337	.02035	.23351
RectusFem.1	Lumbar Spine Adjustments	15	.1920040	.05444342	.01405723	.1618542	.2221538	.08767	.28131

	Sacro-iliac joint adjustment	15	.2125585	.06722279	.01735685	.1753317	.2497852	.12295	.34182
	Hip Joint Adjustment	15	.1864989	.07343180	.01896001	.1458337	.2271640	.06040	.34786
	Combination Group	16	.2474662	.07510722	.01877681	.2074443	.2874880	.13570	.41960
	Total	61	.2102521	.07077730	.00906211	.1921252	.2283790	.06040	.41960
MedialHam.1	Lumbar Spine Adjustments	15	.1393312	.04715225	.01217466	.1132192	.1654433	.08961	.27739
	Sacro-iliac joint adjustment	15	.1484978	.06475033	.01671846	.1126403	.1843553	.05438	.25562
	Hip Joint Adjustment	15	.1455693	.05467882	.01411801	.1152892	.1758495	.06253	.23303
	Combination Group	16	.1532579	.05823364	.01455841	.1222274	.1842885	.04856	.23868
	Total	61	.1467722	.05539513	.00709262	.1325848	.1609595	.04856	.27739
GluteMax.1	Lumbar Spine Adjustments	15	.1381972	.02730872	.00705108	.1230741	.1533203	.09270	.18969
	Sacro-iliac joint adjustment	15	.1697500	.07973189	.02058669	.1255959	.2139041	.05726	.30851
	Hip Joint Adjustment	15	.1770875	.06734038	.01738721	.1397956	.2143793	.03202	.31861
	Combination Group	16	.1853056	.04732558	.01183139	.1600876	.2105236	.10612	.28359
	Total	61	.1678756	.05998911	.00768082	.1525116	.1832395	.03202	.31861
CompletionTime.1	Lumbar Spine Adjustments	15	0:02:39,10	0:00:12,873	0:00:03,324	0:02:31,97	0:02:46,23	0:02:28,32	0:03:15,01
	Sacro-iliac joint adjustment	15	0:02:31,87	0:00:17,466	0:00:04,510	0:02:22,20	0:02:41,54	0:02:13,90	0:03:20,89
	Hip Joint Adjustment	15	0:02:51,98	0:01:02,653	0:00:16,177	0:02:17,29	0:03:26,68	0:02:13,17	0:06:30,34
	Combination Group	16	0:02:35,41	0:00:10,481	0:00:02,620	0:02:29,82	0:02:40,99	0:02:22,74	0:02:58,53
	Total	61	0:02:39,52	0:00:33,336	0:00:04,268	0:02:30,98	0:02:48,06	0:02:13,17	0:06:30,34
Power.1	Lumbar Spine Adjustments	15	330.3444444	60.14078941	15.52828505	297.0395854	363.6493035	186.66667	388.33333
	Sacro-iliac joint adjustment	15	382.2777778	94.52839639	24.40712700	329.9296967	434.6258589	160.83333	510.50000
	Hip Joint Adjustment	15	335.7222432	114.73340419	29.62403758	272.1850017	399.2594846	73.66667	529.16667
	Combination Group	16	352.4062500	61.99026115	15.49756529	319.3739715	385.4385285	219.00000	449.66667
	Total	61	350.2240489	85.85260879	10.99230016	328.2361748	372.2119229	73.66667	529.16667
Norm.P.1	Lumbar Spine Adjustments	15	359.80	62.039	16.019	325.44	394.16	195	417
	Sacro-iliac joint adjustment	15	426.73	104.979	27.106	368.60	484.87	171	567
	Hip Joint Adjustment	15	384.13	122.730	31.689	316.17	452.10	137	606

	Combination Group	16	386.81	54.538	13.635	357.75	415.87	253	472
	Total	61	389.33	91.126	11.667	365.99	412.67	137	606
Speed.1	Lumbar Spine Adjustments	15	34.1913	2.50913	.64785	32.8018	35.5808	27.68	36.40
	Sacro-iliac joint adjustment	15	35.9347	3.63370	.93822	33.9224	37.9469	26.88	40.31
	Hip Joint Adjustment	15	33.4920	6.46374	1.66893	29.9125	37.0715	13.84	40.54
	Combination Group	16	34.8550	2.21147	.55287	33.6766	36.0334	30.24	37.82
	Total	61	34.6221	4.04129	.51743	33.5871	35.6572	13.84	40.54
Cadence.1	Lumbar Spine Adjustments	15	99.4333333	6.66184349	1.72008059	95.7441274	103.1225393	88.50000	110.50000
	Sacro-iliac joint adjustment	14	95.2619048	6.71225257	1.79392496	91.3863655	99.1374440	84.00000	112.00000
	Hip Joint Adjustment	14	95.0595238	8.78290082	2.34732898	89.9884279	100.1306198	81.83333	115.16667
	Combination Group	13	97.1794872	8.41197932	2.33306329	92.0961790	102.2627954	88.33333	112.16667
	Total	56	96.7738095	7.67564879	1.02570171	94.7182574	98.8293617	81.83333	115.16667
maxPower.1	Lumbar Spine Adjustments	15	615.20	147.602	38.111	533.46	696.94	289	865
	Sacro-iliac joint adjustment	15	733.13	192.308	49.654	626.64	839.63	356	1128
	Hip Joint Adjustment	15	647.47	237.104	61.220	516.16	778.77	210	953
	Combination Group	16	602.00	127.518	31.879	534.05	669.95	380	841
	Total	61	648.67	183.140	23.449	601.77	695.58	210	1128
maxSpeed.1	Lumbar Spine Adjustments	15	45.5900	1.96500	.50736	44.5018	46.6782	40.05	48.62
	Sacro-iliac joint adjustment	15	47.6420	2.98515	.77076	45.9889	49.2951	41.04	51.28
	Hip Joint Adjustment	15	45.1200	8.77268	2.26510	40.2619	49.9781	15.51	52.23
	Combination Group	16	46.0462	3.91082	.97771	43.9623	48.1302	36.92	51.13
	Total	61	46.0987	5.06572	.64860	44.8013	47.3961	15.51	52.23
maxCadence.1	Lumbar Spine Adjustments	15	117.27	8.819	2.277	112.38	122.15	98	135
	Sacro-iliac joint adjustment	14	116.14	10.683	2.855	109.97	122.31	96	132
	Hip Joint Adjustment	14	115.86	13.955	3.730	107.80	123.91	93	141
	Combination Group	13	115.77	11.706	3.247	108.70	122.84	100	139
	Total	56	116.29	11.094	1.483	113.31	119.26	93	141

Table 2: One way ANOVA table of baseline means compared between groups

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
VastusLat.1	Between Groups	.009	3	.003	.333	.801
	Within Groups	.511	57	.009		
	Total	.520	60			
BicepsFem.1	Between Groups	.018	3	.006	1.587	.203
	Within Groups	.213	57	.004		
	Total	.231	60			
Iliopsoas.1	Between Groups	.003	3	.001	.067	.977
	Within Groups	.876	56	.016		
	Total	.879	59			
VastusMed.1	Between Groups	.016	3	.005	1.783	.161
	Within Groups	.173	57	.003		
	Total	.189	60			
RectusFem.1	Between Groups	.036	3	.012	2.561	.064
	Within Groups	.265	57	.005		
	Total	.301	60			
MedialHam.1	Between Groups	.002	3	.001	.163	.921
	Within Groups	.183	57	.003		
	Total	.184	60			
GluteMax.1	Between Groups	.019	3	.006	1.875	.144
	Within Groups	.197	57	.003		
	Total	.216	60			
CompletionTime.1	Between Groups	3481.613	3	1160.538	1.047	.379
	Within Groups	63194.074	57	1108.668		
	Total	66675.687	60			
Power.1	Between Groups	24570.331	3	8190.110	1.118	.350
	Within Groups	417669.896	57	7327.542		
	Total	442240.226	60			
Norm.P.1	Between Groups	34571.938	3	11523.979	1.417	.247
	Within Groups	463665.504	57	8134.483		
	Total	498237.443	60			
Speed.1	Between Groups	48.651	3	16.217	.993	.403
	Within Groups	931.271	57	16.338		
	Total	979.921	60			
Cadence.1	Between Groups	181.380	3	60.460	1.028	.388
	Within Groups	3058.977	52	58.826		
	Total	3240.357	55			
maxPower.1	Between Groups	158685.576	3	52895.192	1.626	.193
	Within Groups	1853735.867	57	32521.682		
	Total	2012421.443	60			
maxSpeed.1	Between Groups	54.020	3	18.007	.691	.561
	Within Groups	1485.670	57	26.064		
	Total	1539.690	60			
maxCadence.1	Between Groups	20.759	3	6.920	.053	.984
	Within Groups	6748.670	52	129.782		
	Total	6769.429	55			