Muscle recruitment patterns of selected upper extremity muscles in Chiropractors within the eThekwini Municipality while performing a simulated sacroiliac joint manipulation

By

Benjamin Luke Hardy

Dissertation submitted in partial compliance with the requirements for the Masters' Degree in Health Science: Chiropractic

Durban University of Technology

I, Benjamin Luke Hardy, declare that this dissertation represents my work in conception and execution (except where acknowledgments indicate the contrary). This dissertation has not been previously submitted for any degree or examination to any other University.

Date: 29 January 2024

Benjamin Luke Hardy

Approved for Final Submission

Date: 29 January 2024

Supervisor

Professor Bernadette Murphy (PhD)

Date: 29 January 2024

Co - Supervisor

Dr Laura O'Connor (MTech: Chiropractic)

DEDICATION

To my heavenly Father, who graced me with discipline and blessed me with the opportunity and resources to complete this dissertation; all glory, honour and praise go to Him.

Psalm 34:8

Oh, taste and see that the Lord is good! Blessed is the man who takes refuge in him!

To my parents, who relentlessly and sacrificially loved me throughout the journey. Unceasingly providing for me and protecting me without hesitancy.

Thank you.

ACKNOWLEDGEMENTS

To my co-supervisor, Dr Laura O'Connor & supervisor, Professor Murphy, thank you for going above and beyond what I could have ever asked for; for constantly encouraging me to write this dissertation with the utmost excellence. Your hard work and dedication in assisting me, from the concept paper, through to the final draft of the dissertation, has been invaluable.

Dr Korporaal, thank you for all that you have done for the Chiropractic profession at DUT. Your guidance over the past seven years, both in the classroom and out, is highly valued and appreciated.

To all the participants who participated in the study, thank you for your time and willingness to participate.

Dr Gill Hendry, thank you for your time and patience in analysing my statistics.

Dr John Cockcroft, thank you for your time and patience in processing my data.

Mrs Twigg's and the reception staff, your contribution to the DUT Chiropractic Clinic is invaluable. Thank you.

Sandy Nadesan, thank you for your thoroughness and skill in proofreading my dissertation.

To all my friends, thank you for your continual support and community.

Finally to my family, thank you for your unwavering love and support throughout this journey. I could not have accomplished this task without you.

ABSTRACT

Background: Spinal manipulative therapy in the form of a high velocity, low amplitude manipulation, is a specialised therapeutic technique utilised by chiropractors and other manual therapists. Little is known about the shoulder muscular recruitment pattern utilised by practitioners/student's to deliver this technique. This study aims to profile the muscle recruitment patterns of selected upper extremity musculature during a simulated sacroiliac joint manipulation to provide objective teaching material for future spinal manipulative therapy students regarding this specific manipulation.

Methods: A quantitative, descriptive, observational design in which surface electromyography (sEMG) was used captured muscle activation patterns of 11 shoulder muscles in 20 qualified chiropractors who practiced in the eThekwini Municipality. Muscle activity was recorded while the chiropractors performed a simulated sacro-iliac joint manipulation, while simultaneous live video recording was obtained. The manipulation was assessed during its three phases: preload, thrust and resolution. Participants gave informed consent. Raw data was processed and normalised for comparability.

Results: All 11 muscles displayed activity throughout the three phases of the adjustment. During preload, the clavicular and sternal pectoralis major and biceps brachii had the greatest mean and median muscle activation magnitude, with the middle and upper trapezius and clavicular pectoralis major showing the greatest maximum muscle activation magnitude. In the thrust phase all muscles showed high activity levels, except for the posterior deltoid which showed moderate activation. The middle and lower trapezius and infraspinatus had the greatest mean, median and maximum muscle activation magnitude. During the resolution phase, the greatest median muscle activation magnitude was found in the middle and lower trapezius and posterior deltoid muscle. This was similar to the greatest mean and maximum muscle activation with the triceps brachii replacing the lower trapezius. The maximum force output during the adjustment was averaged at ± 1.9 Kg.

Conclusion: This study highlights the role of the shoulder muscles, specifically the pectoralis and the scapular stabilizer muscles, especially the middle trapezius, in the execution of the spinal manipulative technique investigated in this study. Future studies should confirm these findings in larger population where subgroup analysis can be undertaken.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS AND SYMBOLS

SMT: Spinal manipulative therapy

HVLA: High velocity low amplitude thrust

CNS: Central nervous system

AHPCSA: Allied Health Professions Council of South Africa

sEMG: Surface electromyography

EMG: Electromyography

DUT: Durban University of Technology

SM: Spinal manipulation

MSK: Musculoskeletal

LBP: Low back pain

ROM: Range of motion

SIJ: Sacro-iliac joint

AD: Anterior deltoid

MD: Middle deltoid

PD: Posterior deltoid

SS: Subscapularis

UT: Upper trapezius

MT: Middle trapezius

LT: Lower trapezius

PM: Pectoralis major

LD: Latissimus dorsi

IS: Infraspinatus

S: Supraspinatus

TM: Teres major

Tm: Teres minor

SA: Serratus anterior

Tri: Triceps brachii

Bb: Biceps brachii

iEMG: Intramuscular EMG

CASA: Chiropractic Association of South Africa

MVIC: Maximum voluntary isometric contraction

PSIS: Posterior superior iliac spine

IREC: Institutional research ethics committee

DUT CDC: Durban University of Technology chiropractic day clinic

RB: Resting baseline

RMS: Root mean squared

AMM: Muscle activation magnitude median

AMM2: Muscle activation magnitude mean

AMM3 Muscle activation magnitude maximum

MFO: Maximum force output

HAT%: High activation time percentage

MAT%: Medium activation time percentage

LAT%: Low activation time percentage

BMI: Body mass index

ICC: Interclass corelation coefficient

CI: Confidence Interval

DEFINITIONS

Spinal manipulative therapy:	A treatment intended to relieve or heal a spinal joint fixation that consists of the application of a high velocity, low amplitude thrust delivered to the spine manually or via specific instruments (Pasquier et al., 2019).
High velocity, low amplitude thrust:	A rapid use of force over a short duration, distance, and / or rotational area within the anatomical range of motion of a joint to engage the restrictive barrier in one or more planes of motion to elicit the release of restriction (LaPelusa and Bordoni 2023).
Joint dysfunctions:	An alteration of the biomechanical and physiological dynamics of a joint of the axial or appendicular skeleton that may or may not result in pain (Laslett, 2008).
Motor skill:	The ability of the nervous system to control motion performance (Stapa et al., 2021).
Psychomotor training:	Training the development of organized patterns of muscular activities guided by signals from the environment. (Noble and Cratty, 2022).
Muscle recruitment patterns:	The arrangement in which musculature is activated by their corresponding motor units. (Petajan, 1991).
Spinal manipulation:	A passive high-velocity, low-amplitude mechanical movement performed at the end of the patient's spinal range, directed at a specific spinal joint or joint segment in order to restore movement or reduce pain (Batavia, 2006).

Joint fixation: A state of reduced articular mobility, essentially due to soft-tissue changes. (Senzon, 2018).

Common mode rejection: An index on the extent to which common signal components are attenuated from the signal. (Ahmad et al., 2012).

Crosstalk: The signal recorded from electrodes placed on the skin above a muscle of interest (referred to as target muscle), but produced by another muscle (not the target muscle). (Mesin, 2020).

Muscle activation magnitude median: The median value of the magnitude of the muscle activity.

Muscle activation magnitude mean: The mean of the magnitude of the muscle activity.

Muscle activation magnitude maximum: The maximum peak observed for the muscle activity.

Maximum force output: The maximum force exerted by participants during the adjustment (captured by the dynamometer instrument).

High activation time percentage: The percentage of time a muscle's activity is greater than 67% of its normalized EMG amplitude relative to the full duration of the adjustment subphase (preload or thrust or resolution) being investigated.

Medium activation time percentage: The percentage of time a muscle's activity is between 33% and 67% of its normalized EMG amplitude relative to the full duration of the adjustment subphase (preload or thrust or resolution) being investigated.

Low activation time percentage: The percentage of time a muscle's activity is less than 33% of its normalized EMG amplitude relative to the full duration of the adjustment subphase (preload or thrust or resolution) being investigated.

Interclass correlation coefficient: A reliability index in test-retest, intra-rater, and inter-rater reliability analyses (Koo et al., 2016).

Confidence interval: The range of values possibly within which one may find the statistical measure of the population (Simundic, 2008).

Chapter 1 - INTRODUCTION

INTRODUCTION TO THE STUDY

Spinal manipulative therapy (SMT) may be described as a passive manual manoeuvre that incorporates a high velocity, low amplitude (HVLA) thrust applied to specific joints which influences the neurophysiological processes resulting in a physical and potentially psychological therapeutic effect (Williams et al., 2007). SMT is commonly utilised by manual therapists such as chiropractors, osteopaths and physiotherapists. Its therapeutic effects are primarily targeted at the treatment of joint dysfunctions, having the capacity to positively influence, through the central nervous system (Pickar, 2002), the five major characteristics of joint dysfunctions, these being neurophysiological, kinesiopathalogical, myopathic, histopathological and biochemical changes. It achieves this by activating tissue mechanoreceptors which alter the inflow of sensory information to the central nervous system (CNS) therefore changing reflex pathways and inhibiting motor neuron pools. This, amongst many other benefits, causes a reduction of muscle hypertonicity and pain (Navid et al., 2019) and improves over all muscle functionality (Potter et al., 2005).

SMT, as a finely tuned motor skill, requires relentless training and practice to master. During the process of motor skill learning, students are required to learn gross co-ordination of their upper and lower extremity musculature, while simultaneously refining the art and skill of spinal manipulation. This lies in one's ability to control the velocity, magnitude and direction of the adjustment (Pickar, 2002). All of these essential skills are controlled by muscle activity. In order to successfully perform SMT, one is required to undergo extensive psychomotor training. According to Taylor and Ivry (2015), there are three stages that need to be addressed in order to learn a new motor skill. These are the cognitive, integrative / associative, and autonomous stages. Sizer et al. (2007) further describes eight critical skills required for the competent delivery of manual therapy, these being; the ability to assess the joint manually, fine sensorimotor characteristics, manual patient management, bilateral hand-eye coordination, manual gross characteristics of the upper and lower extremities, control of self and patient movement, and discriminate touch.

These skills are imparted to students during their undergraduate chiropractic training over several years and are refined during clinical training (Durban University of Technology, 2021). Although these techniques are well documented and their effect of the patient has been investigated (Triano et al., 2005), little attention has been given to the muscle recruitment patterns required by the practitioner to elicit SMT. Manual therapy places emphasis on the 'core musculature' (Bergman and Peterson, 2010) to stabilise the body while the upper limb delivers the manipulative thrust. It is not clear which muscles in the upper limb are responsible for delivering the therapeutic thrust. By delineating the muscle activation patters of the upper extremity during the application of SMT will assist students in focusing their attention on which muscles to train to effectively produce the manipulative thrust. This will achieve greater cognitive training, setting an evidence-based approach for students to build their SMT techniques upon and further assist skill acquisition. This study aimed to profile the muscle recruitment patterns of selected upper extremity musculature to determine those muscles, which are primarily being utilised during the different phases of the SMT.

STUDY AIM, OBJECTIVES AND HYPOTHESIS

1.2.1 Aim

This study aimed to determine the muscle recruitment patterns of selected upper extremity muscles in Chiropractors within the eThekwini Municipality while performing a simulated sacroiliac joint manipulation to provide objective teaching material for future spinal manipulative therapy students regarding this specific manipulation.

1.2.2 Objectives

1. To determine the activation pattern, in terms of mean, median, maximum activation magnitude and time percentage of activation in high, moderate and low zones, of the bicep brachii, triceps brachii, deltoid, pectoralis major, serratus anterior, upper trapezius / supraspinatus, middle and lower trapezius and infraspinatus muscles during the three phases of the simulated sacroiliac joint manipulation.

2. To assess the reliability of the muscle activation patterns.

DELIMITATIONS

This study recruited twenty chiropractors who currently practice within the eThekwini municipality, each of whom had a minimum of three years of clinical practice, who practiced at least three days a week using the diversified chiropractic technique and who were registered with the Allied Health Professions Council of South Africa (AHPCSA). Participants had to be healthy with no physical ailments that could interfere with their ability to perform the sacro-iliac joint manipulation being investigated in this study. Thus, the results of this study may only be generalisable to those who practice diversified side-posture SMT.

The Bionomadix Dual-Channel wireless EMG Biopac MP150 Data Acquisition System was utilised in this study. Surface electromyographic (sEMG) modules were available to obtain muscle activity from up to 12 muscles. The following muscles due to their potential role in SMT were selected for analysis in this study: bicep brachii, triceps brachii, deltoid (anterior and posterior heads), pectoralis major, serratus anterior, trapezius (upper, middle and lower fibres), supraspinatus and infraspinatus. sEMG has limited capacity to obtain muscles activity from deep muscles (Crams, 2011) thus mostly superficial muscles were selected with the exception of the supraspinatus, which lies deep to the upper trapezius. According to Crams (2011), it is impossible to isolate electromyography (EMG) activity from the supraspinatus (relative to the upper trapezius) with surface electrodes. These two muscles are layered next to each other and function synergistically. Therefore Crams (2011) deems this placement as quasi specific and acknowledges that isolated readings of these two muscles are impossible with sEMG.
A simulated sacroiliac joint manipulation was utilised whereby the SMT was performed on a punching bag. The punching bag simulated a human lying in a side-posture position, and is utilised in the training of manual therapy students to 'mimic' the patient (Korporaal, 2021). Allowing students, the opportunity to practice side-posture manipulative techniques. It was not possible to use a human participant as they would have had to undergo over 80 sacro-iliac joint manipulations, which would infringe on their well-being and would have been un-ethical.

A sacroiliac joint manipulation was selected as the technique to be investigated. It is a specific adjustment, standardised for the sacroiliac joint when an upper flexion fixation is found and preformed with the patient in the lateral recumbent position (Laslett, 2008). It is the recommended technique for treating a patient with a herniated disc and is thus limited in the variability of its execution (Bergmann and Petereson 2011). The generalisability of the findings of this study would be limited to this specific technique.

SIGNIFICANCE OF THE STUDY

Spinal manipulation (SM) is a commonly used modality by Chiropractors and other manual therapists to treat musculoskeletal (MSK) disorders. MSK disorders are a burden that affects approximately 1.71 billion people worldwide (World Health Organization, 2021). Lower back pain has the greatest prevalence and is the leading contributor to disability in 160 countries

(World Health Organization, 2021). Chiropractors treat lower back pain conservatively more than any other health care practitioners (Bussieres et al., 2017).

The main treatment used by chiropractors is SMT. To effectively master this finely tuned motor skill, one is required to undergo several years of psychomotor training. During this process, the student is required to learn gross co-ordination of the muscles of the upper and lower extremities while simultaneously refining the art or skill of spinal manipulation. This lies in one's ability to control the velocity, magnitude, and direction of the adjustment (Pickar, 2002), which are all controlled by muscle activity.

The process of psychomotor training requires one to master a new skill by first understanding it, then integrating it until it becomes automatic (Taylor and Ivry, 2015). For manual therapy students this requires fine tuning their palpation, sensorimotor, hand-eye co-ordination, and spatial awareness skills together with manual control of themselves and the patient (Sizer et al., 2007) Mastering this at a novice level requires hours of practice. Teachers of SMT use simulation techniques to impart these skills, whereby students 'mimic' the lecturer. By understand the muscles involved in the delivery of SMT, lectures can encourage students to practice activation of these muscles which will further assist students in fine tuning their delivery of this essential skill.

FLOW OF DISSERTATION

Chapter one has presented the study's introduction, aim and objectives, delimitations, significance and flow of the dissertation.

Chapter two presents the literature review and provides an overview of the chiropractic profession, manual therapy, spinal manipulative therapy, psychomotor skills training, learning SMT and its delivery, the neuromusculoskeletal system, and electromyography.

Chapter three details the study's methodology used to accomplish the aims and objectives, the study's design, methods, techniques and instruments, as well as any ethical implications relevant to the study.

Chapter four presents the results, including the reliability metrics, of the data analysed in the study.

Chapter five provides the discussion of the results in relation to the current literature.

Chapter six concludes the study and includes the study’s limitations and recommendations.

Chapter 2 - LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents an overview of manual therapy and spinal manipulative therapy, with particular emphasis on the chiropractic profession. It will discuss concepts of learning manipulative therapy and mechanisms through which electromyography may be utilized to assess muscle recruitment patterns.

Literature for this review was gained through searches using the following sources: Google Scholar, Summon, PubMed and ScienceDirect. Key terms used to obtain literature included: chiropractic, manual therapy, spinal manipulative therapy, spinal manipulation, high velocity low amplitude thrust, psychomotor training, neuromusculoskeletal system, shoulder complex, muscle contraction, muscle recruitment patterns and electromyography.

2.2 MANUAL THERAPY

Manual therapy, a hands-on manual healing discipline, referenced as early as 400 BC (Pettman, 2007) of which the origins are unknown, has over the centuries been utilized and refined by individuals such as Hippocrates, Galen, Avicenna, and Leonardo Da Vinci (Jawl, 2017). It is defined as a clinical approach utilizing specific hands-on techniques to diagnose and treat soft tissues and articular structures via accurately determined and specifically directed manual forces applied to a body (Donatelli and McMahon, 2012). This form of therapy is utilized by professions deemed as allied or complimentary, such as, osteopaths, chiropractors, physiotherapists, biokineticists and occupational therapists. Chiropractors are health care practitioners who are concerned with the diagnosis, treatment, and prevention of mechanical disorders of the musculoskeletal system, and the effects that these disorders have on the function of the nervous system and general health. Chiropractors have been treating patients since the 1890's when chiropractic's was invented by D. D. Palmer in the United States of America (Homola, 2006) with a particular emphasis on manual treatments including spinal adjustment, otherwise known as spinal manipulation, and other joint and soft-tissue manipulative techniques (World Federation of Chiropractic, 2001).

Manual therapy can be seen as an umbrella term encompassing multiple different forms of therapy (Donatelli, 2012). These are categorized as: nerve biased-which includes but is not limited to neural dynamics, craniosacral therapy, and neural tissue tension techniques; soft tissue biased-encompassing techniques such as soft tissue mobilization and / or manipulation, cupping, dry needling, and trigger point therapy; and articular based- which includes, but is not limited to, articular mobilization and / or manipulation (Bialosky et al., 2009).

Manual therapy is largely utilized for but is not limited to: improving mobility and extensibility, inducing relaxation, improving contractile and non-contractile tissue repair and improving stability in restricted somatic tissue such as the connective tissues, skeletal muscles and / or joint articulations. Therefore, it facilitates optimal biomechanical movement and somatic function (Deyle et al., 2011).

2.3 SPINAL MANIPULATIVE THERAPY

Spinal manipulative therapy (SMT) is defined as a high velocity, low amplitude force targeted at / delivered into spinal joints (Deutsch, 2008). It is an articular based manual therapy technique utilised to treat joint hypomobility, commonly referred to as a joint fixation, and to modulate pain via mechanical stimulus, neurophysiological, peripheral, spinal and supraspinal mechanisms (Bialosky et al., 2008; Bergmann and Peterson, 2011). Theories for associated pain relief include mechanical / reflexive relaxation of soft tissue, movement of a intervertebral disc bulge away from pain-sensitive structure, and / or proprioceptive input to the spinal cord (Deutsch, 2008).

A joint fixation leads to motion segment dysfunction, which incorporates the interaction of pathological changes within the connective tissue, nerves, muscles and ligaments. This results in abnormal joint motion, lack of joint play and end feel, and the presence of palpable soft tissue changes such as muscle hypertonicity and pain (Senzon, 2018). Joint fixations may occur as a result of either joint derangement, inter-capsular adhesions, intradiscal disorders, segmental muscle spasm or soft tissue fibrosis (Bergmann and Peterson, 2011). In addition, psychological distress (Muscolino, 2011) and / or entrapment of a synovial fold may be causative agents.

There are three zones in which movement takes place in a vertebral motion segment. These include the physiological, paraphsyisological and the pathological zones as seen in Figure 2.1. The physiological zone is defined as the motion from neutral to the elastic barrier. This is where normal active motion, produced by muscular action, and passive motion, produced by traction or springing of the joint (joint play), occurs. The paraphysiological zone is defined as the motion from the elastic barrier of resistance to the limit of anatomical integrity. SMT is proposed to operate within this zone. Lastly, the pathological zone is defined as / located beyond the limit of the joints anatomical integrity. Entering this zone will result in articular and / or soft tissue damage, leading to hypermobility (Leach, 2004: Ebrall, 2022).

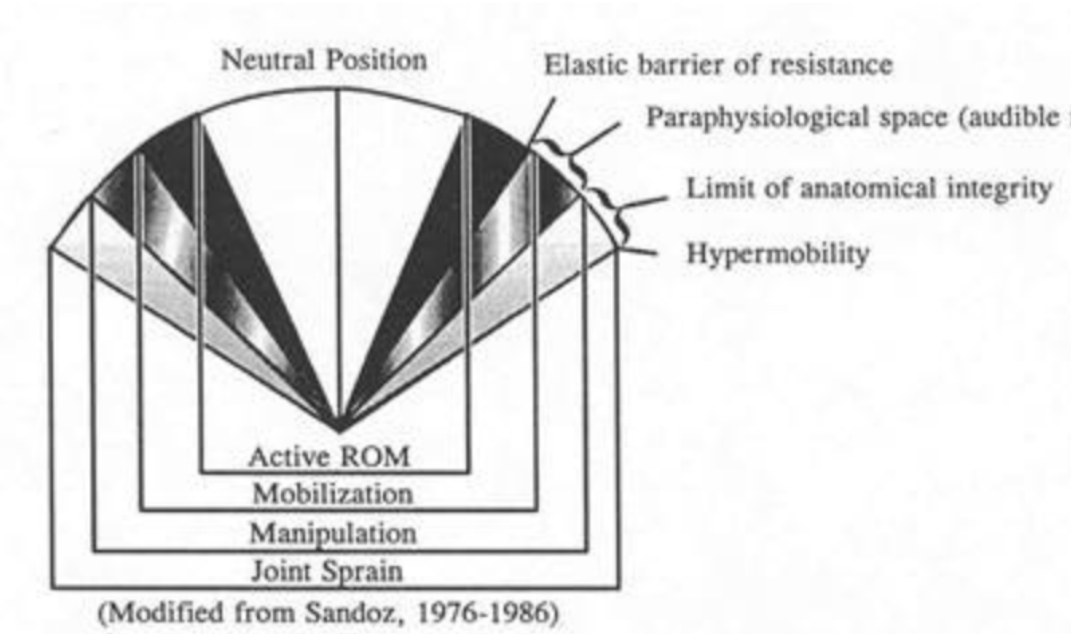


Figure 2.1: Stages of diarthrodial joints range of movement (Source: Gattermann 2001)

In order to target joint fixation of either the axial and / or appendicular skeleton (Sandoz, 2018), chiropractors and other manual therapists would use one of two hands-on SMT approaches. One approach is joint mobilisation which is applied within the physiological passive range of motion of a joint and is characterised by a non-thrust, passive joint movement (Hyde and Gengenbach, 2007). It is graded I through to IV as described in Table 2.1. The other technique is a high velocity, low amplitude (HVLA) manipulative thrust which is characterized as a dynamic, specific thrust of controlled velocity and amplitude and is commonly accompanied by a cavitation (Sandoz, 2018). This HVLA technique is the technique being investigated in this study. HVLA thrusts are considered grade V mobilisations. These techniques are highly specialised and require advanced training.

Table 2.1: Mobilisation grading (Source: Kessler, 1996)

Grade I	Small amplitude movement at the beginning of the available range of motion
Grade II	Large amplitude movement within the available range of motion
Grade III	Large amplitude movement that moves into stiffness or muscle spasm.
Grade IV	Small amplitude movement stretching into stiffness or muscle spasm.
Grade V (manipulation)	High velocity, low amplitude (HVLA) movement at the end of the available range of motion

2.3.1 The effects of SMT

SMT, has the capacity to positively influence the five major characteristics of joint dysfunctions, these being; neurophysiological, kinesiopathalogical, myopathic, histopathological and biochemical changes, through its influence on the central nervous system (Pickar, 2002). It does this by activating tissue mechanoreceptors which alters the inflow of sensory information to the CNS which changes reflex pathways and inhibits motor neuron pools. This causes a reduction of muscle hypertonicity and pain (Navid et al., 2019) and improves muscle functionality (Potter et al., 2005). Several clinical practice guidelines recommended SMT in the treatment of musculoskeletal pain as detailed in Table 2.2.

Table 2.2: Clinical practice guidelines recommending the use of SMT for musculoskeletal pain

Author/s	Condition	Recommendation regarding SMT
De Zoete et al., 2021	Chronic low back pain	"Sufficient evidence suggests that SMT provides similar outcomes to recommended interventions, for pain relief and improvement of functional status. SMT would appear to be a good option for the treatment of chronic low back pain (LBP)".
Chaibi et al., 2017	Acute Cervical pain	"The Cochrane review concluded that for acute and sub-acute neck pain, multiple sessions of cervical SMT were more effective than medications in reducing pain and improving function at immediate and long term follow up".
Gevers-Montoro et al., 2021	General spine pain	"The available clinical research suggests that SMT could be as effective as other conservative approaches used to treat non-specific and chronic primary spine pain".
Chaibi et al., 2021	Cervicogenic headaches	"A Danish RCT found headache intensity to reduce by 36% and 22% in the SMT group at post treatment and 1 week follow-up respectively, as compared to the soft tissue treatment group. An Australian RCT reported 71% of the participants having >50% reduction in headache frequency while 33% reported a 100% improvement in the SMT group. Two American RCTs reported a mean reduction of 43%, 29% and 40% reduction in headache intensity at 4, 12 and 24 weeks follow-up respectively in the SMT group, while mean headache frequency similarly reduced by 49%, 34% and 52% respectively."

Conte da Silva et al., 2019	Shoulder pain	"Thoracic vertebral manipulation provided statistically significant but non clinically significant decreases in pain and an increased shoulder range of motion (ROM) in individuals with shoulder pain."

2.3.2 The Chiropractic profession and the HVLA manipulative technique

There are several different types of manipulative techniques used by chiropractors to elicit motion in a fixated joint. Some of the most common techniques include Diversified, Flexion Distraction, Gonstead, Activator and Thompson (Clijsters, Fronzoni and Jenkins 2014). Not all of these techniques utilise the HVLA thrust its primary treatment modality. The Diversified technique however, which is the most widely utilised technique, does. It is a non-proprietary, broad based approach to spinal manipulation and is seen as the most generic chiropractic manipulative technique used to restore axial and appendicular articular dysfunction, movement and alignment (Cooperstein and Gleberzon, 2004). According to Christensen and Kollasch (2005) 96.2% of Doctor of Chiropractic utilise this technique in the USA. It is also widely taught at chiropractic training institutions across the world including the University of Johannesburg (UJ) and the Durban University of Technology (DUT) in South Africa and will be the type of manipulation technique utilised in this study. (Durban University of Technology, 2021; University of Johannesburg, 2021).

2.3.3 Performing a HVLA joint manipulation

In order to accurately perform HVLA manipulation, the clinician is required to undergo extensive training. The process of delivering a manipulation requires that the manual therapist identifies the correct joint that is in need of HVLA manipulation, then by utilising his / her hands will be required to suddenly take the joint beyond its normal physiological range of motion, through the elastic barrier and into the paraphysiological space without exceeding the limits of the joint's anatomical integrity / entering the pathological zone (Sandoz, 2018). This process can be broken down into three phases (Bergmann and Peterson, 2011):

1) Preload

This phase occurs when the clinician applies, using their hand/fingers a gradual load to the soft tissues structures overlaying the articulation identified to be manipulated. The load is gradually increased to a critical point whereby the soft tissues are compressed and the articulation moved towards the limit of its physiologic range. This aids in facilitating localization of the thrust force through the targeted joint and may simultaneously aid in patient comfort during the procedure. This phase has been documented to last from 200 milliseconds (Downie et al. 2010) to 750 milliseconds (Nougarou et al, 2014).

2) Thrust / impulse

This phase is when a high velocity, low amplitude force is directed into the targeted joint by the clinician, in order to bring about therapeutic alteration. It is the phase depicted by a sudden acceleration in force magnitude to a peak over a short period of time. It is often associated with a cavitation / cracking sound (Harwich 2017). This phase is defined from the downward incisural point: the diminution of preload force just before thrust to the peak force. (Downie et al, 2010).

3) Resolution

This phase refers to the decrease of applied force in the post-thrust phase. It is said to last for approximately 150 milliseconds (Downie et al, 2010).

Spinal manipulation is a complex motor skill and like any other motor task, the learning of spinal manipulation requires pedagogic strategies and a training regimen based on repetition and feedback (Pasquier et al, 2017).

2.4 PSYCHOMOTOR SKILLS TRAINING

In order to learn a new motor skill, the body undergoes a process called psychomotor skills development. This refers to motor action/s directly following on from mental activity. Psychomotor learning may be described as, learning to enhance the relationship between cognitive function and physical movement (Merriam Webster Dictionary, 2022). This type of innate learning allows an individual to acquire skills (Changiz et al., 2021), and exists in an individual from birth remaining almost entirely unchanged throughout life. Neuroscience studies and results showing the neuroplastic process suggest that psychomotor ability may change with training and practice at any age (Chang, 2014; Shumway-Cook and Woollacott, 2007). Changiz et al., (2021) proposed the following equation to highlight the significance of psychomotor ability and training:

Psychomotor ability × Amount of practice = Proficiency in motor skills

Psychomotor skills represent primarily movement-oriented activities in which their execution require neuromuscular coordination. In teaching, importance is placed on the movement component, even though ultimately in practice, performance requires a unification of the cognitive and affective components together with the motor (Oermann, 1990) (Blackstock and Pritchard, 2020).

In order to obtain psychomotor ability one would need to utilise one or more of the three psychomotor skills shown in Table 2.3. Spinal manipulation is a skill that requires all three of the skills to be mastered.

Table 2.3: Classifications of psychomotor skills (Source: Oermann, 1990)

Skill:	Task:
Fine motor	Precision oriented tasks.
Manual	Repetitive manipulative tasks commonly involving eye-arm action.
Gross motor	Tasks involving large body movements and muscle involvement.

2.4.1 Models for psychomotor skills training

When learning a psychomotor skill a person transitions through ‘domains of learning’. Figure 2.2 highlights these domains and shows that a person starts out learning a psychomotor skill through observing and ‘copying’ the action, and then progresses to the domain of naturalization whereby the person performs the task at a high level without conscious input (Bonn. Q. F. n:d).

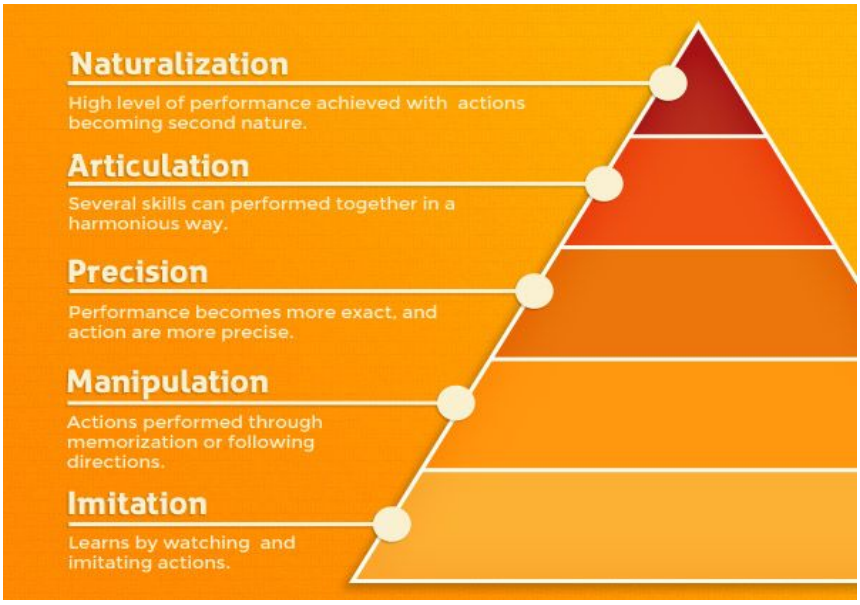


Figure 2.2: Psychomotor domain of learning (Source: Bonn, Q. F. n:d)

Taylor and Ivry (2015) discuss three major steps that are required to allow for motor skills learning: the cognitive, integrative / associative and autonomous. The cognitive step can be explained as understanding what to do. This usually includes verbal education and visual demonstration. The integrative step involves taking what is learnt in the cognitive step and beginning to apply it in real life / simulated scenarios. Finally, the autonomous step occurs when the individual can produce the motor performance almost automatically.

Other theoretical frameworks have been proposed to understand the process of psychomotor learning (Oerman, 1990). These include, behavioural cybernetics, where motor skills are regarded as a closed loop system relying on feedback for efficient performance modification. Information processing, is where the focus is on the individuals' ability to differentiate cues, choose key information, rapidly transmit it, and retrieve information from long term memory, and the adaptation model, where motor skills are viewed as multiplex and consists of mixtures of subskills that must be learned prior to achieving the performance.

Practice is vital in psychomotor skill acquisition to achieve smoothly coordinated movements. Factors that influence the volume of practice needed to develop a particular skill include, but are not limited to, readiness to learn, past experience with related skills and physical resources available (Oermann, 1990) (Muratori et al., 2013).

2.5 LEARNING SPINAL MANIPULATION

To effectively execute the delivery of spinal manipulation, chiropractic students need to undergo the required skills training, this then becomes a 'naturalized' practice as the student transitions to a qualified chiropractor. Sizer et al. (2007) have identified eight critical proficiencies that manual therapy students need to effectively execute in the therapy. These include:

- the ability to assess the joint manually,
- fine sensorimotor characteristics,
- manual patient management,
- bilateral hand-eye coordination,
- manual gross characteristics of the upper and lower extremities,
- control of self and patient movement, and,
- discriminate touch.

These proficiencies need to be mastered in order to be able to accurately deliver the HVLA manipulation. In addition, observational practice, learner's focused attention, feedback, and self-controlled feedback enhances the learning of motor skills (Wulf et al., 2010). Walchli et al. (2016) describes feedback as being either intrinsic or augmented. Intrinsic feedback is an internal feedback process provided by the student themselves and is based off the physical feel of the movement as it is performed. This allows the student to garner information about the movement outcome. Whereas augmented feedback refers to that which is external and provided by teachers / observers. This feedback is based off the knowledge of the result of the action and / or its performance. This type of feedback informs the student about the quality of the movement execution. Augmented feedback training has the potential to modify several biomechanical parameters of spinal manipulation (Pasquier et al., 2017).

When a thrust is produced by an individual to elicit a manipulation, the ability of the neuromuscular system to work in an integrated manner is essential. This is to allow appropriate force production, reduction and dynamic stabilization, which then allows for appropriate execution of the task (Clark., 2011). Besides the muscles that are required to be co-ordinated to affect this task, the force that is delivered during the SMT needs to be modulated.

2.5.1 SMT training in the chiropractic curriculum in South Africa

In South Africa, as stated in act 63 of 1982, chiropractors are required by the Allied Health Professions Council of South Africa (AHPCSA) to obtain a master's degree to practice. The chiropractic curriculum therefore caters for undergraduate and post-graduate training. In the formative years of the qualification students are exposed to manual palpation skills whereby they palpate muscles, joints and bony structures. This improves tactile development thus contributing to tactile maturity (Ardiel and Rankin, 2010). In the third and fourth years diversified manipulative skills training is implemented. This is separated into; theory lectures, whereby students are educated on the theories of spinal manipulation and everything chiropractic; and practical classes, whereby students are exposed to practical demonstrations of spinal adjustments and everything chiropractic and are given opportunity to themselves practice that which they have practically observed. Students have on average three hours of formal / in class practical training a week over the duration of the two years. Additionally, students are occasionally invited to informal classes, workshops and seminars, in which Doctor of Chiropractic further educate the students on chiropractic topics that either reinforce or go beyond that which is taught in the formal syllabus. These may be theoretical or practical sessions (Durban University of Technology, 2021). Throughout these formal and informal classes, unless solely theory focused, practical demonstrations are made by the doctors for students to witness and are followed by time for the students to practically apply that which they witness. This model of education meets the cognitive and integrative steps via the demonstrative and practical application respectively. The practical application also initiates the autonomous step as described by Taylor and Ivry (2015).

In the master's programme students apply these skills in the on-campus Chiropractic Clinic. Clinical training is performed for a minimum of twelve and a half hours a week, where students can further develop the psychomotor skills of manipulative techniques and other modalities taught in the programme. These activities are overseen by qualified chiropractic clinicians (Durban University of Technology, 2021). This allows constant reiteration of the cognitive and integrative steps, but more importantly, it allows significant investment into the autonomous step. Additionally, this four-year training programme allows integration of all eight critical proficiencies described by Sizer et al. (2007).

2.6 NEUROMUSCULAR SKELETAL SYSTEM AND THE DELIVERY OF SMT

To effectively elicit SMT, coordination of many different areas of the body is required. The areas involved will depend on the area of the patient that is being manipulated / treated. For example the manipulative set up for a cervical spine manipulation differs from that of a lumbar spine manipulation. The clinician is required to position their body, their adjusting hand, supporting hand and alter the amount of force utilized as required per area and per patient.

In this study a simulated sacro-iliac joint (SIJ) manipulation – diversified technique – is being utilized and as such the review will focus on the requirements for performance of sacro-iliac joint adjustments. To maintain this posture the clinician needs to engage a stable base over the anchored lower limbs, engage the core and then deliver the thrust through the upper extremity to the SIJ. This allows for the doctor’s centre of gravity to be maintained and thus safely exert the correct amount of force into the targeted joint in a highly controlled and specific manner. This complex sequence of events and the many areas involved makes investigating the motor recruitment patterns for the whole procedure complex. This study thus will focus on the shoulder complex and its muscle recruitment patterns during this procedure.

2.6.1 Shoulder complex and muscular contraction

The shoulder complex is composed of three articulations: the sternoclavicular, acromioclavicular and glenohumeral joints. All three of these articulations are synovial joints, each of which contain a fibrous joint capsule, synovial membrane and articular cartilage encapsulating a joint space filled with synovial fluid (Dutton, 2021). This complex articular arrangement permits the shoulder complex to engage in the widest ROM within the body (Quinne, 2021). To have stability several ligamentous structures re-enforce these joints. It is innovated by the brachial plexus, this network of nerves arises from the anterior rami of nerve roots C5, C6, C7, C8 and T1 (Moore et al. 2014), as seen in Figure 2.3.

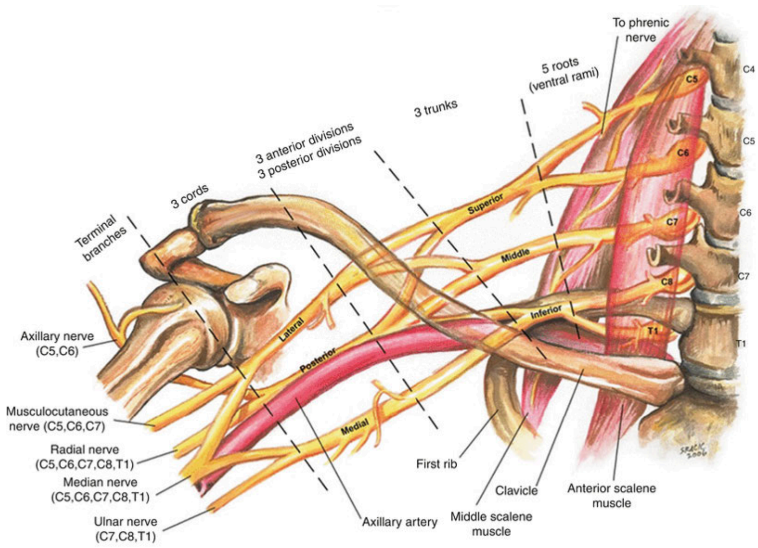


Figure 2.3: Brachial plexus anatomy (Source: Buckenmaier and Bleckner n:d)

The shoulder complex includes approximately twenty muscles (Stryker, 2013). These muscles bring functional stability and mobility to the shoulder complex allowing the shoulder to partake in complex actions. These skeletal muscles attach directly or indirectly to the bones in and around the shoulder complex via tendons or aponeurosis which are extensions of connective tissue enveloping the skeletal muscles referred to as epimysium (Dave et al, 2021; Tortora and Derickson, 2009). These muscles are described in table 2.4.

Table 2.4: Relevant musculature with respective attachments, innovation and action (Moore et al., 2014)

Muscle	Origin	Insertion	Innovation	Action
Biceps Brachii	Long Head: Supraglenoid tubercle of ipsilateral scapular. Short Head: Tip of ipsilateral coracoid process.	Tuberosity of ipsilateral radius and forearm fascia via bicipital aponeurosis.	Musculocutaneous nerve (C5, C6, C7).	Glenohumeral supination and flexion. Ipsilateral radio-ulnar supination. Ulnar-humoral flexion. Short head resists ipsilateral

				anterior glenohumeral dislocation Long head aids ipsilateral glenohumeral internal rotation.
Triceps Brachii	Long head: Infra-glenoid tubercle of ipsilateral scapular. Lateral head: Posterior surface of ipsilateral humerus superior to radial groove. Medial head: Posterior surface of ipsilateral humerus inferior to radial groove.	Proximal end of olecranon of ipsilateral ulna and forearm fascia.	Radial nerve (C6, C7, C8).	Ulnar-humoral extension. Long head resists ipsilateral ulnar-humoral dislocation and aids in ipsilateral glenohumeral extension.
Deltoid	Anterior head: Anterior and superior boarders of lateral third of ipsilateral clavicle.	Deltoid tuberosity of ipsilateral humerus.	Axillary nerve (C5, C6).	Anterior head: Glenohumeral abduction, flexion and internal rotation.

	Middle head: Acromion of ipsilateral scapular. Posterior head: Spine of ipsilateral scapular.			Middle head: Glenohumeral abduction. Posterior head: Glenohumeral abduction, extension and external rotation. In the coronal plain, it aids in ipsilateral glenohumeral abduction.
Pectoralis Major	Clavicular head: Anterior surface of medial half of ipsilateral clavicle. Sternocostal head: Anterior surface of sternum, ipsilateral superior six costal cartilages and aponeurosis of external oblique.	Lateral lip of ipsilateral intertubercular sulcus of humerus.	Lateral and medial pectoral nerves. Clavicular head by nerve roots C5 and C6 Sternocostal head by nerve roots C7, C8, T1.	Glenohumeral adduction and medial rotation. Draws ipsilateral scapular anteriorly and inferiorly. In isolation the clavicular head flexes and the sternocostal head extends the ipsilateral glenohumeral joint from a flexed position respectively.
Trapezius	Medial third of ipsilateral superior nuchal	Ipsilateral lateral third of clavicle,	Spinal accessory nerve (cranial	Upper: Cervical extension,

	line, external occipital protuberance, ligamentum nuchae and C7 to T12 spinous processes.	acromion, and spine of scapular.	nerve XI) and C3, C4 spinal nerves.	elevation and clock wise rotation of scapular. Middle: Retraction of scapular. Lower: Depression and clock wise rotation of scapular.
Serratus Anterior	External surface of lateral parts of ribs one to eight.	Anterior surface of medial boarder of scapular.	Long thoracic nerve (C5, C6, C7).	Protracts and stabilises scapular against thoracic wall. Rotates scapular anti-clockwise. Aids in glenohumeral flexion.
Supraspinatus	Ipsilateral scapular supraspinous fossa.	Superior facet of ipsilateral humerus greater tubercle.	Suprascapular nerve (C4, C5, C6).	Initiates and assists deltoid in glenohumeral abduction. Stabilises humoral head within the glenoid fossa and aids in glenohumeral external rotation.

Infraspinatus	Ipsilateral scapular infraspinous fossa.	Middle facet of ipsilateral humerus greater tubercle.	Suprascapular nerve (C5, C6).	Glenohumeral external rotation and abduction.

Skeletal muscles consist of multiple myofibrils, each of which have multiple sarcomeres - the basic contractile unit of a muscle (Tortora and Derrickson, 2009).
Each sarcomere is composed of two protein filaments, actin and myosin, which are the primary proteins responsible for muscle contractions. The sarcomeres also consist of; Z lines, M lines, H zones, H bands and A bands (Squire, 2016) (Figure 2.4).

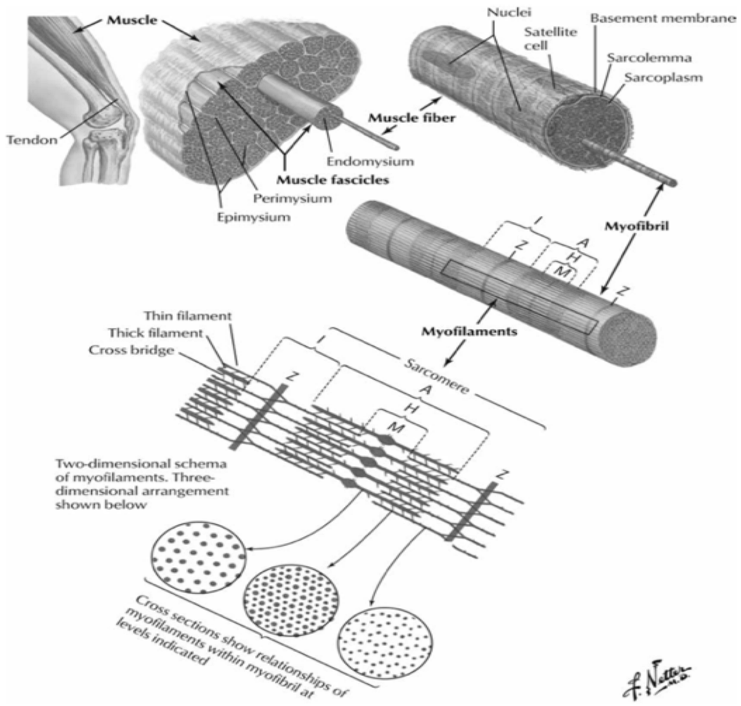


Figure 2.4: The composition of muscle cells, muscle, fascicles, muscle fibre, myofibril, myofilaments, sarcomere, thick and thin filaments. (Source: Netter Anatomy Illustration Collection, © Elsevier, Inc. n.d)

For a muscle to contract an action potential (AP) needs to be received from the central nervous system (CNS). This message originates in the primary motor cortex and then descends down axons of Betz cells (upper motor neurons); either travelling via the corticobulbar tract to the cranial motor nuclei within the brain stem, passing to innovate musculature of the face, head and neck, or via the corticospinal tract to the ventral horn of the spinal cord, passing to innovate musculature of the trunk, upper and lower limb (Andrusca, 2021).

On reaching the muscle at the neuromuscular junction (NMJ), a highly specialized synapse is found between the motor neuron nerve terminal and the muscle fibre (Rodriguez Cruz et al., 2020). As seen in Figure 2.5, a series of neurochemical reactions take place, initiating the sliding filament theory (Tortora and Derrickson, 2009), and allowing muscle contraction to occur.

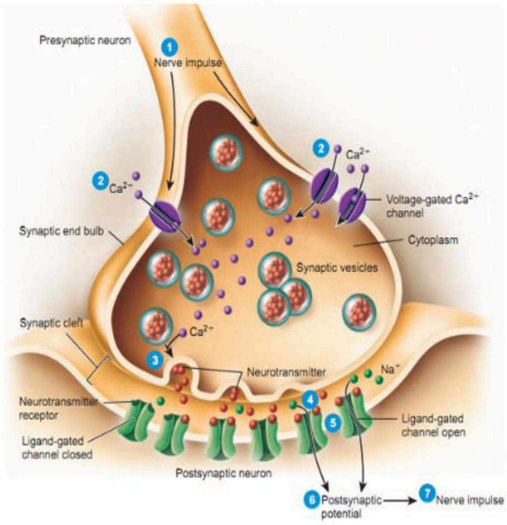


Figure 2.5: Neuromuscular junction (Source: Neuromuscular junction, 2012)

The motor unit is the basic functional unit of a skeletal muscle and the basic level of nervous system organization of the muscle. It consists of a motor-neuron and all the associated muscle fibres it innovates (Monti et al., 2001). A single muscle fibre receives input from only one motor neuron; however, different motor neurons overlap their territories spatially (Criswell, 2011). In order for voluntary muscle contraction to occur, motor unit recruitment, which is "the successive activation of the same and additional motor units with increasing strength” is required (Sandbrink et al., 2019; Tortora and Derrickson, 2009). Due to the asynchronous firing of the many motor neurons innovating a muscle, some motor units’ contract while others relax. This delays muscle fatigue by allowing alternating contracting motor units to relieve each other. This allows longer periods of sustained muscle contraction (Tortora and Derrickson, 2009).

2.6.1.1 Force and muscle length

Muscle contraction is defined as the activation of tension-generating sites within muscle cells (Silverthorn, 2016). Contractions may be described based off two variables, force and length. Force can be differentiated into tension, which is force exerted by muscle onto an object; and load, which is force exerted by an object onto a muscle. There are two main types of muscle contractions: Isometric whereby a change in muscle tension occurs without any change in muscle length, and isotonic, where a change in muscle length occurs without any change in muscle tension. Isotonic contractions may be further differentiated into; eccentric contractions where the muscle lengthens, and concentric contractions where the muscle shortens (Sircar, 2008).

2.6.1.2 Roles of skeletal muscles – agonist, antagonist and synergists

Table 2.5 details the different roles that skeletal muscles may adopt during motion. A muscle is not limited to one role and may change its role dependant on the movement dynamics (Tortora and Derrickson, 2009). For example, in the shoulder joint during external rotation, the infraspinatus acts as the agonist while the subscapularis acts as the antagonist. However, during internal rotation, the roles are reversed. Skeletal muscle contraction dynamics are understood as nonlinear, in that, it depends on instantaneous values of neural activation, the direction of previous movement, external load and activation prehistory, thus demonstrating complex hysteresis like features (Herzog et al., 2006).

Table 2.5: Agonistic, Antagonistic and Synergistic musculature

<table>
<tr><td>Role</td><td colspan="2">Definition</td></tr>
<tr><td>Agonistic</td><td colspan="2">The prime mover/s.
These muscles control / cause movement to occur via their own activation while producing majority of the force and control of an action.</td></tr>
<tr><td>Antagonistic</td><td colspan="2">Produce opposing torque to the agonist muscles.</td></tr>
<tr><td rowspan="2">Synergistic</td><td>Fixators</td><td>Assist with stabilizing / fixing the joints so the agonist may move other joints more effectively.</td></tr>
<tr><td>Neutralizers</td><td>Counter / neutralize the agonistic muscle force.
These muscles help cancel out / neutralize extra motion produced by the agonist thus ensuring the agonistic force operates within the desired plane of motion.</td></tr>
</table>

2.6.1.3 Muscle recruitment patterns of shoulder muscles during different tasks

This subheading includes a series of past studies with a similar nature to that which this study will be operating in / under. This not only provides an evidence-based framework for which we can develop a hypothesis / understanding to what we may expect the results of this study to be, but, going forward it also provides literature to compare and contrast with our study.

Table 2.6 shows how studies have highlighted that during different activities the pattern of muscle recruitment varies in the shoulder complex. This paragraph includes a summary of the literature in Table 2.6. During closed chain activities, such as the simulated sacro-iliac manipulation used in this study, strong middle deltoid activation has been found (Reed et al., 2018) with the middle deltoid decreasing its activation when the humerus is in scapular plane abduction as opposed to coronal plane abduction (Reed et al., 2015).

During internal rotation the pectoralis major and latissimus dorsi muscles are highly active with the pectoralis major muscle decreasing its activity with increasing velocity (Gaudet et al., 2017) and when utilised in a closed chain activity (Neis, 1995). During internal rotation exercises muscle activation in the subscapularis, pectoralis major, latissimus dorsi, infraspinatus, supraspinatus and posterior deltoid muscles occurs (Dark et al., 2007). Escamilla et al. (2009) reported that during erect internal rotation at 0 degrees abduction a significant increase in activity in the teres minor, subscapularis, pectoralis major muscle occurred, whereas during erect internal rotation at 45 degrees abduction there was significantly increased activity in the subscapularis, and at 90 degrees of abduction internal rotation resulted in significantly increased activity in the teres minor, lower trapezius, rhomboids, serratus anterior, posterior deltoid, subscapularis, infraspinatus, middle deltoid and supraspinatus muscles. Highlighting how muscles activity is altered during various positions of the arm.

During shoulder flexion Wattanaprakornkul et al. (2011) reported that the anterior deltoid, pectoralis major, supraspinatus, infraspinatus, serratus anterior, upper and lower trapezius muscles are activated at similar moderate levels during but that the serratus anterior muscle activity decreased when this occurs in a closed chain exercise (Neis, 1995). Supraspinatus and anterior deltoid muscle activation occur simultaneously and prior to shoulder flexion at all loads with the posterior rotator cuff muscles appearing to counterbalance anterior translation forces produced during flexion (Wattanaprakornkul et al., 2011).

During closed chain exercise the biceps and triceps muscle activity is higher than in open chain exercises (Neis, 1995). Similar effects would occur when performing SMT due to the closed chain nature of the activity.

Table 2.6: Studies assessing upper extremity muscle recruitment patterns during activity

Author and year	Study design	Sample size and population	Comparators	Outcome measures	Findings
Reed et al. (2018)	Experimental	N = 29 Asymptomatic shoulder adults	Open chain (OC) vs closed chain (CC) abduction (abd)	Electromyographic (sEMG and iEMG)	Strong positive correlation between OC and CC for middle deltoid (MD) . All other muscles had inconsistent, low or negative correlation. Significantly lower activation found during CC abd in the subscapularis (SS), Upper trapezius (UT), Infraspinatus (IS) and Lower trapezius (LT).
Gaud et al. (2017)	Experimental	N = 29 Asymptomatic shoulder adults	Isokinetic motor patterns during high and low velocity, concentric and eccentric internal rotation (IR) and external rotation (ER) of shoulder	EMG	SS and serratus anterior (SA), showed moderate to high peak activity during each condition. MD, PD, UT, MT, LT, IS and supraspinatus (S) showed higher peak activity during ER. Pectoralis major (PM), and llatissimus dorsi (LD), were more active during IR.

					Only middle trapezius (MT), and PM activity decreased with increasing velocity.
Reed et al. (2015)	Observational laboratory study	N = 14 Asymptomatic shoulder adults	Shoulder abd performed in the scapular plane vs coronal plane	EMG	Similar average muscle activation levels for both planes for all muscles except: MD - higher activation in coronal and lower activation in scapular plane. UT - lower activation in scapular plane.
De Mey et al. (2014)	Controlled lab study	N = 47 Asymptomatic shoulder adults	Four CC exercises [half push up (HPU), knee push up (KPU) , knee prone bridging plus (KPBP, and pull up (PU).] without and with red-cord sling	EMG	UT increased activation in the HPU with a sling. SA and anterior deltoid (AD) decreased activation in the KPU with a sling. PM increased while MT, SA, AD and posterior deltoid (PD), decreased activation in the KPBP with a sling. MT and UT decreased while AD and LD increased activation during the PU.
Wattanaprakornkul et al. (2011)	Experimental	N = 15 Asymptomatic shoulder adults	Shoulder flexion	EMG	AD, PM, S, IS, SA, UT and LT were activated at similar moderate levels. SS activated at low level in relationship to S and IS.

					Onset of activity in S and AD occurred at the same time and prior to movement of the limb at all loads. IS activity occurred prior to movement onset at the medium and high load conditions only. Posterior rotator cuff muscles appear to counter balance anterior translation forces produced during flexion. S appears to be one of the muscles that consistently initiates flexion.
Dark et al. (2007)	Experimental	N = 15 Asymptomatic shoulder adults	Shoulder muscle recruitment patterns exercise for IR vs ER	EMG	IR exercises showed muscle activation in the following muscles (greater to lesser order); SS, PM, LD, IS, S, PD. ER exercises showed muscle activation in the following muscles (greater to lesser order); IS, S, PD, SS, PM, LD.
Neis (1995)	Experimental	N = 5 Asymptomatic shoulder adults	CC Exercise vs OC Exercise in the Upper Extremity	EMG	Elbow musculature (biceps and triceps) was recruited in a higher percentage in CC exercise than the OC exercise.

					Shoulder musculature (PM and SA) was recruited in a higher percentage in the OC than in the CC.
Ekstrom et al. (2003)	Single group repeated measures	N = 30 Asymptomatic shoulder adults	Different exercises to determine those that elicit the greatest level of activity in the trapezius and SA muscles	EMG	Unilateral shoulder shrug produced the greatest activity in UT. Shoulder horizontal extension with ER, and overhead arm raise in line with the LT muscle in the prone position produced the greatest activity in MT. Arm raise overhead exercise in the prone position produced the greatest activity in LT. Shoulder abd in the scapular plane above 120 degrees, and a diagonal exercise with a combo of shoulder flexion , horizontal flexion, and ER produced the greatest activity in SA.
Uhl et al. (2003)	Repeated measures design	N = 18 Asymptomatic shoulder adults	Different weight bearing exercises and its effect on posture and muscle activity of the shoulder	EMG	Significant activation in; (Listed from greatest to least amount of activation). Pointer exercise: IS, Push up: S, One arm push up: IS, PD, AD, PM.

Escamilla et al. (2009)	Review article	Review article	Shoulder Muscle Activity and Function in Common Shoulder Rehabilitation Exercises	EMG	Significant activation in; (Listed from greatest to least amount of activation). push up plus noted in SS, IS, S, PM, SA, LD, TM. Erect IR at 0 degrees abd; Tm, SS, PM. Erect IR at 45 degrees abd; SS. Erect IR at 90 degrees abd; rhomboid, SS , TM, Tm, LT, SA. Standing ER in scapular plane at 45° abd and 30° horizontal add; Tm, IS. Erect ER at 0 degrees abd; Tm, SS, rhomboids, LT, rhomboids. Erect IR at 90 degrees abd; Tm, LT, rhomboids, SA, PD, SS, IS, MD, S. Push up; PM, LD. Push up with hands separated; SA. Erect scapular rows at 45 degrees flexion; Tm, SS, rhomboids, S.

open chain (OC), closed chain (CC), abduction (abd), adduction (add), internal rotation (IR), external rotation (ER), middle deltoid (MD), subscapularis (SS), upper trapezius (UT), lower trapezius (LT), infraspinatus (IS), serratus anterior (SA), posterior deltoid (PD), anterior deltoid (AD) middle trapezius (MT), supraspinatus (S), pectoralis major (PM), latissimus dorsi (LD), teres major (TM), teres minor (Tm), half push up (HPU), knee push up (KPU), knee prone bridging plus (KPBP), pull up (PU), electromyographic (EMG)

2.7 MEASURING MUSCLE ACTIVATION - ELECTROMYOGRAPHY

Electromyography is the detection of electrical activity from a muscle's motor units (Chowdhury et al., 2013). Note that a single muscle contains multiple motor units. With sensors, clinicians may record the activity of motor units via the magnitude of energy / electrical potential these units release (Criswell, 2011). More technically Criswell (2011) describes it as "the sum of the activity that equates to the volume conducted signal, which is identified by electrodes and amplified by instrumentation". The energy generated by muscles has a very small value, therefore it is necessary to use highly specialised and sensitive instruments to amplify the signal so it may be seen. Thus, electromyograph is essentially a highly sensitive voltmeter (Criswell, 2011).

Electromyography (EMG) has many uses. It can be used as a diagnostic tool / procedure to assess the health of motor units (Electromyography, 2019) or for gaining information on the temporal characteristics of muscle activity as a whole or via groups of muscles during functional movements (McManus et al., 2020). It can also be used as a form of therapeutic assistance by enabling the patient to gain more awareness and control of their own muscle activity through biofeedback.

2.7.1 Different types of EMG

There are two forms of EMG. The first is intramuscular EMG (iEMG). This type requires the use of needles inserted into the targeted muscle tissue (Merletti and Farina, 2009). The second is surface EMG (sEMG). This utilises surface electrodes which are adhered to the skin and are positioned on the skin regions immediately above the targeted muscle tissue (Chowdhury et al., 2013).

Each application has its place, sEMG provides a non-invasive, global measurement of muscle activity. This form may be more suitable for applications in movement analysis that require frequent assessments or information on the patterns of activation of multiple muscles

(McManus et al., 2020) as opposed to iEMG which has limited detection volume. This means that the recordings are only capable of reflecting the activity of a small number of motor units whose muscle fibres are in close proximity to the inserted electrode.

In order to reliably extract the activity of individual motor units, iEMG is commonly restricted to low levels of isometric muscle contraction with a small number of active motor units; it is highly invasive which may result in tissue damage, and it may potentially lead to injury electrical potentials. iEMG is also financially expensive and it is difficult to replicate the exact depth and location of the needle's area of insertion, resulting in inferior reliability to sEMG. In addition, it requires highly specialised and trained individuals to insert the needles (Peter et al. 2019) (Kent, 1997). These reasons make the use of iEMG, unsuitable in certain circumstances. In this study sEMG was utilised.

2.7.2 sEMG Signal Source, Impedance, Amplification and Common Mode Rejection

The EMG aims to capture the signal of the motor unit action potential, with the sum of this activity forming the volume conducted signal (Criswell, 2011). The electrodes detect this signal and the instrumentation amplifies it (Jamal, 2012). Due to the electrodes being placed on the skin the motor unit activity closest to the electrode will be detected, with those furthest away being less likely to contribute to the sEMG recording. This is because the further the signal needs to travel, the more resistance it encounters. This resistance absorbs the energy resulting in less of the original energy reaching the surface electrodes (Figure 2.6). Adiposity can add an additional barrier to the signal thus it is recommended that in order to utilise sEMG the skin fold thickness of the individual should not be greater than 19mm (Baniqued et al., 2016).

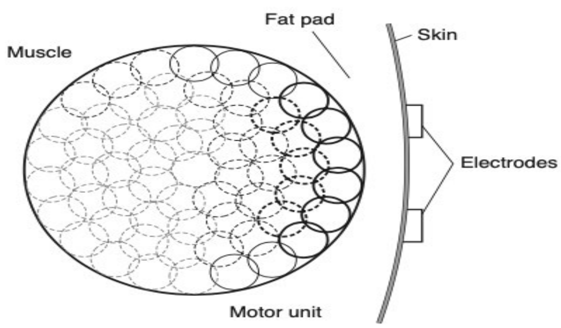


Figure 2.6: Visual depiction of motor unit activity in relation to recording electrodes (Source: Criswell, 2011)

As the signal travels through the skin it is subjected to impedance. Impedance is defined as the resistance of an electrical current and is primarily generated from the skin due to its oil content, and the density of the horny, dead-cell layer (Criswell, 2011). To reduce this impedance the skin is abraded, cleaned with alcohol and excessive hair is shaved / removed (Jamal, 2012). If the impedance at the electrode-skin interface is too high or imbalanced, the common mode rejection of the sEMG amplifier is defeated and the amplification process is affected. Thus, the preamplifier input impedance needs to be greater (10 – 100x greater) than the skin impedance.

Other elements during the recording of sEMG can influence impedance such as the type of electrodes and the cables between the electrode and amplifier (Criswell, 2011). Once the action potential from the muscle has crossed the electrode–skin interface, it undergoes a process of differential amplification and common mode rejection. Amplification is simply boosting the size of the biological signal, making it larger so that it can be detected. The outcome is referred to as gain. The degree of gain determines the size of the signal on the visual display (Wang et al., 2016).

There are three surface electrodes that are utilised in obtaining the signal from one muscle. Two electrodes are placed over pre-specified locations individualised for each muscle and the third is placed on a bony landmark – called the ground electrode. The signal from the ground electrode is taken away from the signal obtained from the muscle. By doing this 'noise', defined as unwanted electrical signal in an EMG signal, is removed (Amrutha and Arul, 2017).

Noise and artifact are seen as anything in the sEMG signal that the practitioner does not want. Common sources of noise include;
ECG artifact: signal arising from the autorhythmic myocardial contractions (Amrutha and Arul, 2017; Criswell, 2011).
Movement artifact: signal arising from electrode slipping on the skin surface thus generating an electrical potential and signals arising from wire movement during the manipulation (Amrutha and Arul, 2017; Criswell, 2011).
60-cycle energy: signal arising from energy used to power lights, offices, and computers used to monitor the sEMG (Haynes and Lisicki, 1996; Criswell, 2011).
Respiration: a biological artifact commonly seen in the superior torso and cervical region and arises due to certain musculature, under the autonomic control of the CNS activated to assist with respiration (Criswell, 2011).
Radio frequency (RF): signals from radio station are picked up by the antenna effect of electrode leads and feed into the amplifiers (Criswell, 2011).

Crosstalk: energy from a distant muscle reaches the electrodes placed over another muscle site (Chowdhury et al., 2013). This phenomenon mainly occurs while investigating deep musculature. Here the activation of overlying muscles may interfere with accurate readings of more superficial muscles (Talib et al., 2018).

After the noise is removed the common mode rejection allow for suppressing of any voltage common to the two inputs (Laplante, 2005) and amplification of the difference between two input voltages (differential amplification). Both of these processes are implemented simultaneously and lead to a suppressing / eliminating of any external electromagnetic noise. This ensures that only the energy unique to each recording electrode is passed on for further signal conditioning and display (Criswell, 2011).

2.7.3 Filtering the sEMG Signal

Once the sEMG signal has been amplified, it is then processed. The first level of processing is known as filtering, as described in Table 2.7. Filtering allows the signal to be 'cleaned' from any extraneous 'noise' while allowing as much of the desired EMG signal frequency spectrum to remain (Criswell, 2011).

Table 2.7: Types of sEMG filtering

High pass	Allows high frequency signals to pass; filters out signals lower than a certain frequency (Chen, 2004).
Low pass	Allows low frequency signals to pass; filters out signals higher than a certain frequency (Blackledget, 2006)
Notch	Filter out signals between two set frequencies while allowing frequencies above and below to pass through. This functions to eliminate electronic noise (Figure 7 b; Criswell, 2011).
Band pass	Filter out signals above and below two set frequencies while allowing frequencies between to pass through. The lower cut off point aids by eliminating majority of the electrical noise and biological artifacts while the upper cut off point eliminates the tissue noise at the electrode site (Figure 7 a; Criswell, 2011)

2.7.4 sEMG Spectral Analysis

Spectrum analysers are frequency-domain instruments with multiple functions. Its main role is displaying signal frequency versus power, thus allowing one to distinguish between noise and distortion harmonics (Jones, 2012).

Energy from muscles has a frequency spectrum. sEMG signal may be displayed to reveal this range of frequencies. Power spectral density curves plot the frequency components of the sEMG signal as a function of the probability of their occurrence (Stoica and Moses, 2005). Spectral analysis uses a mathematical technique called fast Fourier transform (FFT) to decompose the signal into its various frequency components (Criswell, 2011; Rayner, 2001).

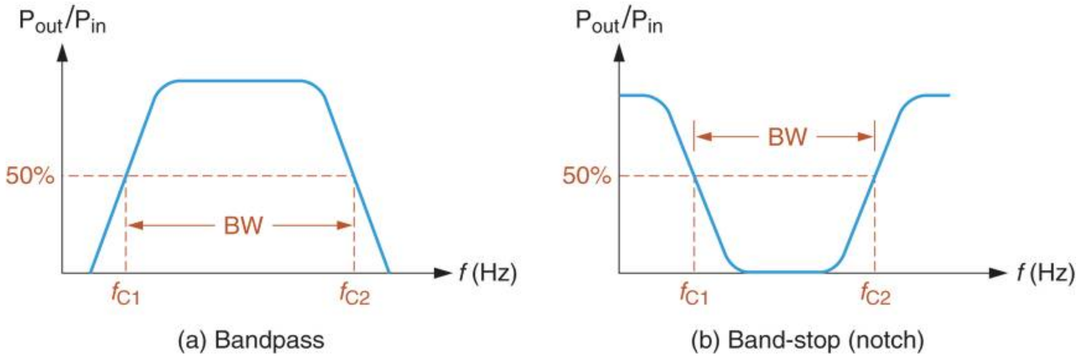


Figure 2.7: Visual representation of A) Bandpass filter, B) Notch filter (Source: Band Pass and Band Stop (Notch) Filter | Circuit | Theory. n:d)

sEMG signals that reach the differential amplifier consists of the sum of many motor units firing. As seen in Figure 2.8 a signal may consist of different energy sources. (A), for example consists of 0.5, 1.0 and 1.5 Hz. but when it reaches the sEMG amplifier it is seen as one composite signal, seen as (B) if Figure 2.8. If one wanted to determine the different signals of the composite an FFT spectral analysis, it would decompose the energy into the spectral graph shown in Figure 2.9, illustrating the composite signal is composed of three frequencies, 0.5, 1.0, and 1.5 Hz (Criswell, 2011).

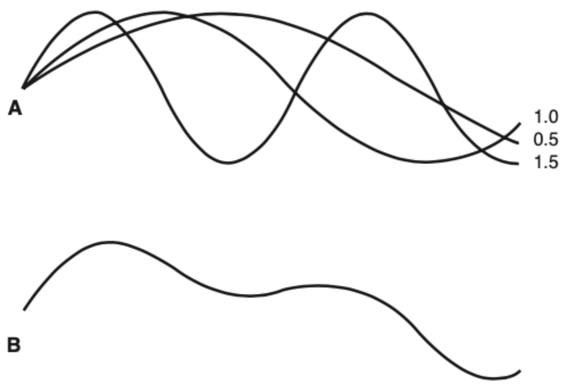


Figure 2.8: A) Three independent signals and B) The composite signal (Source: Criswell, 2011)

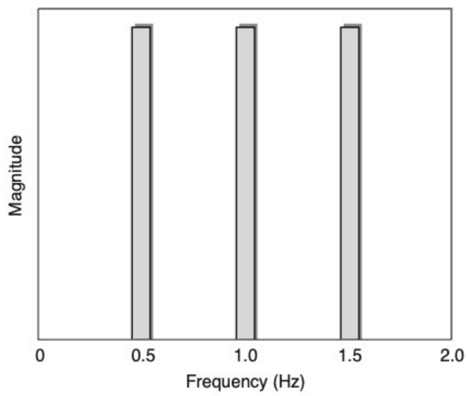


Figure 2.9: Power spectral density of the composite signal of figure 8 (Source: Criswell, 2011)

2.7.5 Processing raw sEMG signals

Once the sEMG signal has been amplified and filtered, it is prepared for visual display where it can be either a raw or processed signal (Criswell, 2011). Each has advantages and disadvantages, as represented in Table 2.8.

Table 2.8: Advantages and disadvantages (Criswell, 2011).

Signal	Advantage	Disadvantage
Raw - unprocessed signal	It contains all of the information from the sEMG signal	Additional information makes it difficult to interpret
Processed - Rectification and smoothing are applied to the signal	Reduced the sEMG variability	It does not contain all of the information from the sEMG signal.

Rectification is when the signal found below zero i.e., the negative electrical potential, is artificially placed above it making it positive (Criswell, 2011), As seen in Figure 2.10.

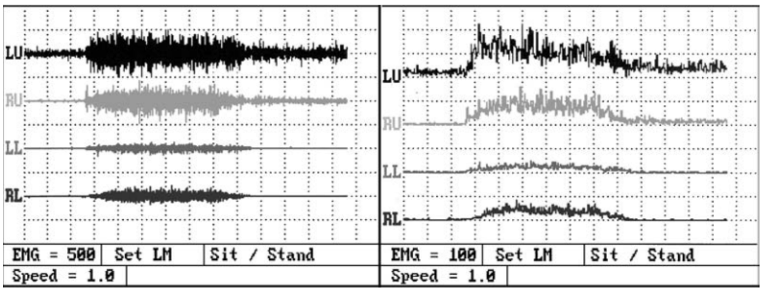


Figure 2.10: Visualisation of raw (left) and the processed (right) sEMG signal (Source: Criswell, 2011)

Smoothing the signal is done mathematically and is based on the premise of, rather than displaying every point of the rectified signal, an average of the data points of sEMG data may be plotted, and is responsible for reducing the sEMG variability (Criswell, 2011).

The EMG signal then needs to be quantified to obtain a numerical description of the muscular energy expended. Because the sEMG signal oscillates between a positive and negative value, it is impossible to sum all of the voltages to determine a quantity as all the positive values would cancel out all the negative values, resulting in a zero net voltage. Therefore, depending on whether the signal is raw or filtered one would select the appropriate method, as highlighted in Table 2.9. When the signal is processed RMS is the preferred method as it creates less signal distortion (Criswell, 2011).

Table 2.9: Quantification of the sEMG signal (Criswell, 2011).

Peak-to-peak	Used in raw sEMG recordings and represents the amount of muscle energy measured from the top to the bottom of the tracing, or its width
Integral averaging	Used in raw sEMG recordings and represents the amount of muscle energy measured from the top to the bottom of the tracing, or its width
RMS	Used in processed sEMG recordings and is performed by squaring the data, summing the squares, dividing this sum by the number of observations, and finally taking the square root

2.7.6 Comparing sEMG across muscles and individuals

Comparing sEMG values within and between individuals is very challenging due to the diversity found between different muscles within the same individual and the same muscles within different individuals (Halakai and Ginn, 2012). Potential factors that may influence comparisons include adipose tissue thickness, resting muscle length, contraction velocity, muscle mass / cross- sectional area, fibre type, age, sex, posture, inter-electrode distance and skin impedance (Criswell, 2011).

When dynamic movements are assessed, it is necessary to normalise the data otherwise comparison of values may be deceptive. Several normalization methods exist, each is based on a muscle/series of muscles contracting, resulting in an sEMG amplitude, from which muscle activity is calculated as a percentage. The three common methods are described in Table 2.10.

Table 2.10: Commonly used methods to normalise sEMG data.

Maximum voluntary isometric contraction (MVIC)	Patient isometrically and maximally contracts the targeted muscle. This is repeated three times. These values are averaged over the three trials. All recordings are then referenced back to the strongest effort as a percentage of MVIC (%MVIC). All sEMG data points are divided by the MVIC value, representing a percentage between 0 and 100%. (Meldrum et al., 2006) (Criswell, 2011).
Submaximal voluntary contraction	Patient, via the use of a Maximum force output, contracts the targeted muscle at 50% of what would commonly be seen for that muscle and that movement. This is repeated three times. These values are then averaged over the three trials. The reference anchor is used to calculate the percentage of reference voluntary contraction (%RVC) (Criswell, 2011).
Record contractions as a function of a dynamic movement cycle	This method provides a reliable anchor point when at least four repetitions of a movement have been conducted. As a variation of using peak values for a single muscle, one could use the average of several muscles that are being monitored during the same movement as the anchoring point (Criswell, 2011).

2.7.7 Determining muscle recruitment patterns – threshold for active / muscle ‘on’ and inactive / muscle ‘off’

Onset of muscle activation / recruitment may be determined through several techniques. Commonly used techniques include:

1) k-means cluster analysis. This is a data mining method used to partition the EMG data of each muscle into “k” clusters. Data assigned to the cluster with the lowest mean EMG amplitude is assumed to correspond with “off” and data assigned to other clusters is classified as muscle activity “on” (Sriastava et al., 2019). An example of this is demonstrated in Tsang et al (2013), here the criteria for a muscle being deemed ‘on’ is the point where resting muscle

activity is three standard deviations greater and the duration of a contraction is greater than 25 ms.
2) By assessing the point at which the muscle sEMG amplitude exceeds 3x that of the muscles resting baseline (Clark, 2011).
3) Basic visualisation / observation of the point at which the sEMG readings dramatically alter (Josephson, 2019). Ritzmann (2019) proposes using the gradient or slope of the sEMG signal tangentially and Yang (2017) proposes using TKE calculations. However insufficient literature was found on both of these techniques.

This study used a form of K-means cluster analysis as used by Tsang et al. (2013): meaning, resting muscle activity will be identified to determine onset of individual muscles by assessing the point where resting muscle activity is three standard deviations greater and the duration of contraction is greater than 25 ms documented for each muscle relative to the phase of the manipulation (Tsang et al., 2013). MVIC will be utilised for the basis of comparing percentiles regarding muscle activation patterns (Gaudet et al., 2017).

2.8 CONCLUSION

From the literature, it is evident that significant psychomotor education occurs, both consciously and subconsciously, to master manipulative therapy. Although the techniques by which manual therapists administer manipulation are well defined there is little published literature describing the muscle patterns required to administer manipulation. This, therefore, requires investigation. Thus, this study has aimed to determine the muscle recruitment patterns of selected upper extremity muscles in Chiropractors while performing a spinal manipulation to add to the existing literature framework regarding education and training of manipulative therapy.

Chapter 3 - METHODOLOGY

3.1 INTRODUCTION

This chapter details the methods used to conduct this study. In addition, the well- being and ethical considerations of the participants are described.

3.2 STUDY DESIGN

This study utilized a quantitative, descriptive, observational design. Descriptive designs are a method which involves observing and describing the behaviour of a subject in its natural setting without influencing it in any way (Shuttleworth, 2008: 1). Observational designs allow the systematic measurement of naturally varying behaviour or phenomena (Turner and Houle, 2019: 1). The choice of this design allowed for the collection of quantifiable information, for statistical analysis, from a sample of the population, which was obtained through direct observation (McCombes, 2020), to draw conclusions related to the study aim. The design suited this study as it allowed the chiropractors to perform a technique that they were familiar with whilst being observed.

3.2.1 Population

The study recruited practicing Chiropractors in the eThekwini Municipality.

3.2.2 Study Setting

The study took place at the DUT Chiropractic Day clinic (CDC), following approval from the Gate Keepers committee (Appendix one) and Clinic Director (Appendix two).

3.2.3 Sampling

3.2.3.1 Sample size

There are approximately 150 Chiropractors working in KwaZulu-Natal (Allied Health Professions Council, 2023). This study was exploratory in nature as no previous investigations had been conducted from which to determine parameters to calculate a sample size. Studies where muscle recruitment patterns had been investigated in the shoulder muscles during different tasks were utilised between 4 (Carson and Riek, 2001) and 25 (Suehiro et al., 2018) participants, with most studies using 15 participants (Dark et al., 2007). It was thus estimated that 20 participants would be sufficient to establish norms from the physiological data.

3.2.3.2 Sample characteristics & recruitment

Participants had to meet the following criteria:

Inclusion Criteria:

1. At least three years of chiropractic clinical practice experience
2. Registered with the Allied Health Professions Council of South Africa (AHPCSA)
3. Involved in an active practice within the eThekwini municipality for at least three days a week
4. Practice Diversified Chiropractic Technique
5. Complete a letter of information and a signed consent form (Appendix three).

Exclusion Criteria:

1. Contra-indications to surface electromyography (sEMG). E.g. hypersensitivity / allergic to sEMG adhesive pads, integumentary lesions at sEMG attachment sites (Watson n:d.).
2. Injury / pain in the upper extremity, trunk or leg that would compromise their normal delivery of the technique.
3. Those who suffer from diseases that result in involuntary muscle movements such as ataxia, dystonia, Huntington's disease, multiple system atrophy, myoclonus, Parkinson's etc as uncontrolled muscle activation will skew the data.
4. Those who are unable to perform the manipulation described by Bergman and Peterson (2010).

3.2.3.3 Recruitment:

Participants were recruited via word of mouth, email, telephonic calls, presentations at local Chiropractic Association of South Africa (CASA) meetings and emails via the CASA regional branch once permission was granted. The above information was gathered from the AHPCSA data base which is freely available on the website (https://ahpcsa.co.za).

3.3 MEASUREMENT TOOLS:

3.3.1 Surface electromyography

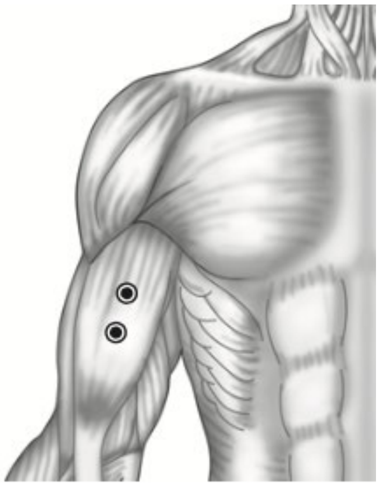
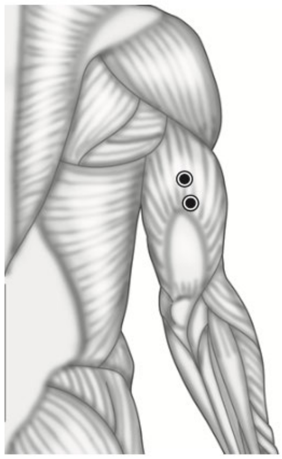
Muscle activity was recorded using the Bionomadix Dual-Channel wireless EMG Biopac MP150 Data Acquisition System. Manufactured by BIOPAC Systems, Incorporated, registered to ISO 9001:2015. This system allows for detection of surface electromyographic signals. It operates through a transmitter and receiver pair that wirelessly feeds back to the data acquisition system. Disposable 35mm round pre-gelled Ag/AgCl sEMG electrodes were placed on the specific areas of the muscles as detailed in Table 3.1 below. Electrode placement was determined by using manual palpation, and an anatomical atlas to determine accurate placement on muscle bellies.

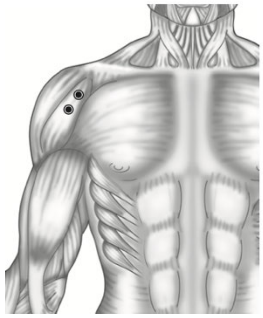
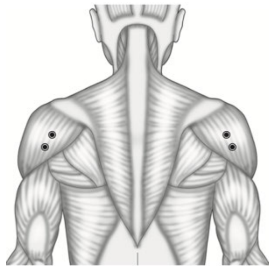
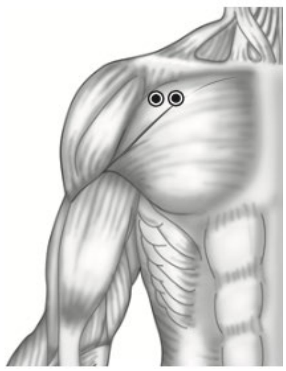
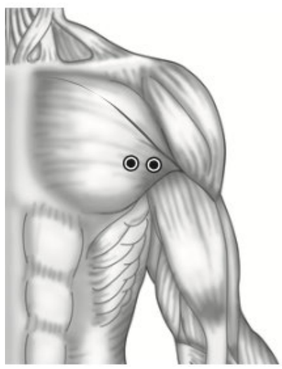
To minimise crosstalk the following was adhered to: an inter electrode distance of 20 mm from centre to centre of the electrodes and the electrodes axis was positioned parallel to the direction of the underlying muscle fibres. The unwanted signal picked up from non-contracting or co-contracting muscles was minimised by correct and accurate electrode placement. Further, only superficial muscles were assessed, with exception to the supraspinatus and infraspinatus, to ensure a more accurate representation of the EMG activity (Blanc and Dimanico, 2010).

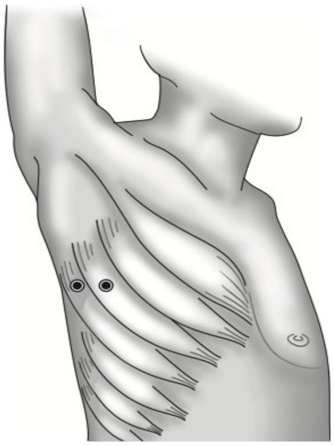
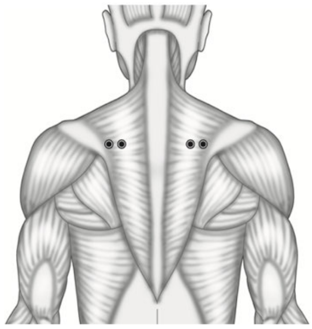
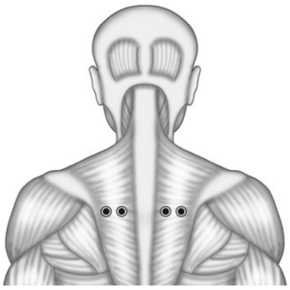
To improve measurement accuracy, when necessary, the skin was lightly abraded and shaved where the electrodes were placed. To avoid distortion / interference of the sEMG signals, the following precautions were taken; the same room was used for data collection throughout the study, the room was sealed from outside interference and noise by closing the door and windows, all other electrical devices were removed and stored away from data acquisition systems and unnecessary movements within the room was avoided (Bordlee and Wong, 2015).

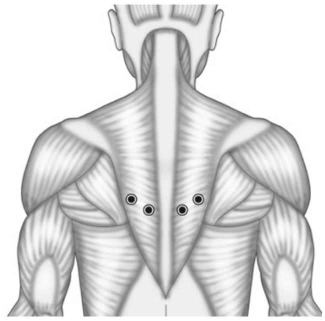
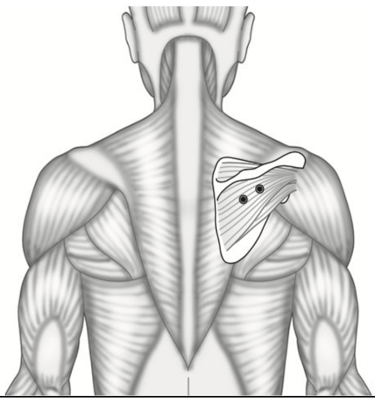
Note, all muscles investigated was assessed unilaterally, ipsilateral to the thrusting arm. Recommended sEMG electrode placement with respect to the selected muscle is between the motor unit and tendinous insertion along and parallel to the longitudinal midline of the muscle with the centre of the electrodes being 2cm apart (Jamal, 2012).

Table 3.1: Electrode Placements (Criswell, 2011)

Muscles investigated	Electrode Placement (Verbal Representation)	Electrode Placement (Visual Representation)
Bicep Brachii (Bi)	Scanning electrodes are placed on the anterior surface of the humerus in a vertical plane, so that the scanning electrodes run parallel to the biceps muscle fibres, i.e., electrodes are placed on and parallel to the line connecting the medial acromion and the cubital fossa at a point approximately 1/3 from the cubital fossa (Criswell, 2011).	
Triceps Brachii (Tri)	Scanning electrodes are placed over the belly of the muscle, approximately half the distance between the shoulder and the elbow. The electrodes are oriented in a vertical plane so as to follow the fibres of the muscle (Criswell, 2011).	

Deltoid	Anterior Head (AD) - Palpate the clavicle. Two active electrodes, 2 cm apart, are placed on the anterior aspect of the arm, approximately 4 cm below the clavicle, so that they run parallel to the muscle fibres (Criswell, 2011). Posterior Head (PD) - Palpate the spine of the scapula. Two active electrodes are placed 2 cm apart and approximately 2 cm below the lateral border of the spine of the scapula and angled on an oblique angle toward the arm so that they run parallel to the muscle fibres (Criswell, 2011).	 
Pectoralis Major (PM)	For clavicular placement, palpate the clavicle. Two active electrodes (2 cm apart) are placed on the chest wall at an oblique angle toward the clavicle, approximately 2 cm below the clavicle, just medial to the axillary fold. For sternal placement, locate the anterior axillary fold (armpit). Palpate just medial to the fold while the patient medially rotates the arm against resistance. Place two active electrodes (2 cm apart) horizontally on the chest wall over the muscle mass that arises (approximately 2 cm	 

	out from the axillary fold) (Criswell, 2011).	
Serratus Anterior (SA)	Have the patient flex the arm against resistance. Palpate this contraction in an area just anterior to the border of the latissimus dorsi muscle at the level of the inferior tip of the scapula. Place two active electrodes horizontally (2 cm apart) just below the axillary area, at the level of the inferior tip of the scapula, and just medial of the latissimus dorsi. It is important that the electrodes are anterior to the latissimus dorsi muscle (Criswell, 2011).	
Suprascapular Fossa (upper trapezius / supraspinatus) (UT)	Palpate the spine of the scapula, locating its lateral distal aspect. The electrodes are placed there 2 cm apart, directly above the spine of the scapula, over the suprascapular fossa (Criswell, 2011).	
Interscapular (Middle Trapezius) (MT)	Locate the medial border of the spine of the scapula (root). Electrodes are placed horizontally, 2 cm apart, just medial / adjacent to the root of the spine of the scapular (Criswell, 2011).	

Lower Interscapular (Lower Trapezius) (LT)	Palpate the interscapular region. Have the patient retract and depress the scapula and then flex the arm to at least 90 degrees. Palpate the inferior medial border of the scapula for the muscle mass that emerges. Place the electrodes on an oblique angle, approximately 5 cm down from the scapular spine. The two active electrodes (2 cm apart) are placed next to the medial edge of the scapula at a 55–degree oblique angle (Criswell, 2011).	
Infraspinatus (IS)	Palpate the spine of the scapula. Two closely spaced electrodes (2 cm apart) are placed parallel to and approximately 4 cm below the spine of the scapula, on the lateral aspect, over the infra-scapular fossa of the scapula. Avoid placement over the posterior deltoid (Criswell, 2011).	

3.3.2 Force

A TSD121 Force transducer collected force data using the Biopac MP150 and DA100C units. Force was recorded in kilograms.

3.3.3 Video analysis

A video recorder was utilised to record the participants performing the SMT. The video recorder was positioned to ensure it did not obstruct the participant, it was easily accessible to the researcher, and it captured the participants in their entirety. The recording was set to continually run throughout the entire experiment. This was done to ensure all relevant imaging was captured in its entirety. The information captured by the video recording included; basic muscle tests to ensure all equipment was appropriately connected, a three minute rest, a ten second resting baseline recording in which the participant stood completely still in a standing anatomical position, three maximum voluntary isometric contractions (MVIC's) with the respective three minute rest intervals between each MVIC and three adjustments, each adjustment being broken down into the three phases, pre load, thrust and resolution, with the respective three minute rest intervals between each adjustment. Synchronization between the different data collection systems was ensured.

3.3.4 Participant data sheet

This sheet captured the participants age, sex, height, weight, years in practice, days / hours practiced per week, dominant arm, institution of Chiropractic graduation and year of graduation (appendix four)

3.4 INTERVENTION

3.4.1 Sacroiliac Spinal Manipulation:

A standardised sacroiliac, upper flexion, lateral recumbent, spinal manipulation as simulated in a herniated disc patient was used in this study according to the technique as described by Bergmann and Peterson (2011):

- Doctor in a square stance whilst using the caudal / contact hands pisiform to contact the posterior superior iliac spine (PSIS) of the upper ilium or directly over the sacroiliac adjacent to the PSIS. The indifferent hand is used to stabilize the patient, preventing the patient from torquing the spine or falling off the bed by pushing the ipsilateral shoulder inferior to superior.
- Patient is in a side lying position, so as not to torque the spine and keep it as straight as possible, with dysfunctional side up. Patient's ipsilateral knee is flexed and extended until maximum tension is felt at the level to be adjusted.
- The contact is then taken after skin slack is removed. Joint slack is then removed. The patient is then rolled into the practitioner so that the practitioner has the ability to place their sternum over the contact point. The vector is directed posterior to anterior and lateral to medial, approximating a 45-degree angle to the chiropractic bed surface. Alternatively, the force should be directed down and along the length of the femur on the ipsilateral side.

- Each participant was given the opportunity to alter the height of the chiropractic bed to ensure doctor comfort and standardization.

It is well documented that there are various chiropractic techniques utilised by chiropractors. This coupled with the common and often necessary act of practitioners adapting a manipulative technique to suit themselves and their patient makes it difficult to objectively determine technique guidelines for practitioners to use (Painter, 2011). Therefore, a very specific manipulation that does not allow for much variance in technique and muscle recruitment was chosen in order to avoid significant outliers and ensure greater consistency in the data. If participants deviated significantly from the original technique as mentioned above, they were removed from the study.

Instead of providing the sacroiliac joint manipulation to a human participant, a punching bag acted as a patient simulation (see chapter 4, page 90 for imagery). The reasoning behind this decision is stated below:

- Punching bags have historically, and are still presently, commonly utilised as simulated patients in the training of manipulative therapies at DUT and other international colleges, to help students gain technique refinement and control (Korporaal, 2021). Therefore, the similarity between the bag and a human is widely accepted in the chiropractic field (Korporaal 2021).
- The punching bag was easily accessible and financially attainable.
- The punching bag was of similar size, height and weight to that of an average patient, therefore adequately mimicking the average human patient. Punching bag dimensions were approximately 1.1m in length, 38cm in diameter and 35kg in weight.
- The punching bag's cylindrical shape allowed for an accurate representation / simulation of the instability of the human patient in a side-lying position.
- Although the consistency of the punching bag provided adequate resistance, yet still allowed a shallow give to accept the thrust of the manipulation, thus again adequately mimicking a human / human tissue, it cannot be said that the bag is completely comparable to a manipulation delivered clinically to a human. Therefor this is noted as a limitation.

3.5 STUDY PROCEDURE

The study was advertised as described above, once ethical (IREC) permission to proceed had been obtained. IREC clearance number 039/22. Potential participants were screened for eligibility via email and / or telephone. Once deemed eligible, research details and other necessary formalities were discussed. If, after being educated on the study, they choose to be included, an appointment was then made at the DUT CDC.

On arrival for their consultation, patients' electronic devices were collected, and all unnecessary electronic devices were stored in a secure location outside the clinic room to avoid sEMG electronic interference. Patients were then given a letter of information, a consent form and patient data sheet (appendix four) to read, complete and sign respectively. Participants then had their skin prepared via abrasion and alcohol application, and if necessary, hair removal via shaving, and the electrodes were then placed on them appropriately. Participants then had an opportunity to perform / practice the manipulative technique with all the equipment attached to themselves, to familiarise themselves with the adjustment on the dummy. This included manipulating with the force transducer as required in the experiment. This familirization process was not standardized. Participants were allowed to familiarize themselves until they felt confident and.comfortable with the process and ready to start, the researcher turned the video recording on and set it to run for the entirety of the experiment. Once the recording started, the researcher instructed participants through a series of muscle tests, to ensure all equipment was operating appropriately. The muscle tests were immediately followed by a three-minute rest interval. For each rest interval, participants were encouraged to stay seated and to avoid any movement of the involved limb / musculature. After the rest interval, participants performed a ten-second resting baseline (RB) recording, in which participants remained completely still in a standing anatomical position. Immediately after the RB, they performed three MVIC's with a three-minute rest interval between each MVIC (MVIC, three-minute rest, MVIC, three-minute rest, MVIC, three-minute rest). For the MVIC, participants positioned themselves exactly how they would if they were to perform the adjustment, however, a force transducer was placed under the contact hand (between the contact hand and dummy) and participants were asked to press against the punching bag with their maximal force in a similar posture to what they would use during the manipulation, holding this contraction for approximately five seconds. As mentioned above, immediately after the MVIC, a three-minute rest interval was taken. This was repeated three times in order to obtain a means of standardization. After the third MVIC and respective rest intervals, participants re-positioned themselves in the manipulation position. On the researchers command, participants initiated the preload phase, then when the participants were comfortable to manipulate, they indicated this to the researcher verbally (this allowed the researcher to differentiate the phases of SMT), the participant then applied the necessary adjustment on the command of the researcher. After the adjustment was completed, a three-minute rest interval was taken. This process (preload, thrust, resolution, rest), was repeated three times. After the final adjustment the video recording was stopped. This recording lasted approximately 22 minutes. There was no strict definition for the onset and end of the preload, thrust and resolution phases in terms of biomechanical events that occur during SM. Therefor this must be noted as a limitation within this study.

After all necessary data was successfully collected, the sEMG was switched off, electrodes were removed and discarded, personal electronic belongings were returned, and participants were free to leave.

The means by which we standardized this procedure include:

- Utilizing a highly specific adjustment technique to prevent variation in technique and muscle recruitment patterns.
- Utilizing the same equipment for each participant (procedure room, chiropractic bed, punching bag, video camera, sEMG unit).
- Standardizing the instructions given to each participant.

3.6 DATA COLLECTION / ANALYSIS

3.6.1 Data reduction:

Muscle activity readings were filtered using a band pass filter at 100 – 200 Hz, to eliminate electrical noise associated with wire sway and miscellaneous biological artefacts. The signal was then smoothed using root mean squared (RMS). RMS is considered the most accurate analysis of the sEMG signal providing a good measure of the power and amplitude of the signal (Suter and McMorland, 2002). A customised MatLab code (MathWaorks®, 1994-2023 The MathWorks, Inc.) was used to determine onset of individual muscles by assessing the point where resting muscle activity was three standard deviations greater than resting baseline and the duration of contraction was greater than 25 ms documented for each muscle relative to the phase of the manipulation (Tsang et al, 2013).

Normalisation of the signal was performed using the preload data, this allowed for normalisation to the activity which was being performed. This “preload normalisation” was utilised for the basis of comparing percentiles regarding muscle activation patterns (Gaudet et al., 2017). The handheld force transducer, which was positioned between the participants thrusting hand and punching bag, collected data regarding the thrust force output (Gorell et al., 2020, Downie et al., 2010).

3.6.2 Data analysis:

All data was coded and captured in an Excel spreadsheet for data processing and analyses. IBM SPSS Statistics, version 28, was used to analyse the data. Significant p value was set at 0.05. Descriptive data analysis was done using count and percentage to describe the categorical variables and mean; and standard deviation for the numerical data. Friedman's test was utilized to analyse and determine any significant difference between the preload, thrust and resolution phases for each of the eleven muscles with respect to the following variables:

- Muscle activation magnitude median (AMM)
- Muscle activation magnitude mean
- Muscle activation magnitude maximum
- Maximum force output (MFO)
- Activation time percentage which was subdivided into:

In order to categorise the muscle activation, it was ranked as high, moderate or low. These thresholds were determined by 0% indicating no activity during the motion and 100% indicating that the muscle was active for 100% of the time, thus breaking this into thirds, allowed for activity less than 33% to be low, between 33-67% medium and over 67-100 as high duration of activation. Bonato et al (1998) recommended that normalized value of muscle activity was high intensity if activation was higher than 50% of the peak, and low intensity when lower than 50%. This was recommended when assessing gait and as this motion is very short and dynamic allowance was made for 3 levels – low, medium and high.

- High: The percentage of time a muscle's activity is greater than 67% of its normalized EMG amplitude relative to the full duration of the adjustment subphase (preload or thrust or resolution) being investigated.
- Moderate: The percentage of time a muscle's activity is between 33% and 67% of its normalized EMG amplitude relative to the full duration of the adjustment subphase (preload or thrust or resolution) being investigated.
- Low: The percentage of time a muscle's activity is less than 33% of

its normalized EMG amplitude relative to the full duration of the adjustment subphase (preload or thrust or resolution) being investigated.

Statistical analysis involved using Wilcoxon signed ranks test, to analyse pairs to determine differences between variables. Repeated measures ANOVA was utilised in analysing the comparison between preload, thrust and resolution for each muscle individually. Bonferroni adjustment was utilised to adjust for multiple paired comparisons. Chi squared test was used to compare observed and expected results between categorical variables (Hendry, 2023).

Reliability was assessed using interclass correlation coefficient to demonstrate the correlations within a class of data and therefore the reliability of the data (Liljequist et al., 2019). The ICC values were categorized as poor (ICC < 0.5), moderate (ICC, 0.5-0.75), good (ICC, 0.75-0.9) and excellent (ICC > 0.9) (Liljequist et al., 2019, Koo and Li, 2016, Bobak et al., 2018).

3.7 ETHICAL CONSIDERATIONS:

- Autonomy –The right or condition of self-government. This study achieved this via, allowing participants to independently volunteer, with informed consent, for or, if desired, be removed from the study at any time (Feinburg 1989).
- Justice – Behaviour and or treatment based on what is morally right and fair. This study achieved this via, providing all participants with the same experimental procedure despite inherent variables (Oxford University Press, 2018).
- Non-maleficence' – The obligation to inflict no purposeful harm. Due to the nature of this study, no purposeful harm was inflicted (Varkey, 2021).
- Beneficence – The quality or state of doing or producing good. This study achieved this via, publishing this data to help strengthen the evidence-based data pool of chiropractic's as well as objectively assist institutions in teaching students this specified manipulation technique (Kinsinger 2009).
- Anonymity – The condition of being anonymous. This study achieved this via, the data being de-identified so as to maintain anonymity., supervisor & co supervisor having access to this data and the patient information sheets (Ray and Mishra 2022).
- Confidentiality – The state of keeping or being kept secret or private. This study achieved this via coding all the acquired data with only the researcher, supervisor & co supervisor having access to this data and the patient information sheets Bourke and Wessely 2008).

- Data storage - All electronic physiological data was downloaded and coded onto an excel spreadsheet. This spreadsheet was stored on a password protected hard drive until the research was completed. Thereafter the data will be kept in the chiropractic department for 5 years with any other research documentation. After the five years, the data will be shredded, and the flash drive formatted.

Chapter 4 - RESULTS

4.1 INTRODUCTION

This chapter presents the results obtained in the study. The data will be presented in the form of narrative descriptions, figures and tables.

4.2 SAMPLE SIZE

A total of 20 participants were recruited for this study. There were no dropouts, and all participants data was included in the analysis.

4.3 CHARACTERISTICS OF PARTICIPANTS

Table 4.1 shows the demographic, anthropometric and practice characteristics of the participants. Male participants were more prevalent than females. Ages ranged from 27 to 72 years with over 50% of the participants being between 35-55 years old. BMI ranged from 19.7 to 29.9 with 60% being classified as healthy and 30% being classified as overweight. The remaining 10% was unknown due to two participants not disclosing their height and weight. Years in practice ranged from 3 to 48 and hours in practice ranged from 10 to 48.

Table 4.1: shows the demographic, anthropometric and practice characteristics of the participants.

	n	%
Demographic		
Sex		
Male	13	65
Female	7	35
Age (years: M±SD)	43.4	13.3
Age Category		
< 34	6	30
34 - 544	11	55
> 54	3	15
Anthropometric		
Height (m: M±SD)*	1.8	0.1
Weight (kg: M±SD)**	75.5	14

BMI*	24.4	2.8
BMI Category*		
Underweight (< 18.5)	0	0
Normal (18.5-24.9)	12	60
Overweight (25.0-29.9)	6	30
Obese (> 29.9)	0	0
Hand Dominance		
Right	17	85
Left	3	15
Years in Practice (M±SD)	17.5	12.9
Years in Practice Category		
< 9	7	35
9--24	8	40
> 24	5	25
Hours in Practice (M±SD)	31.9	11.6
Hours in Practice Category	31.9	
< 29	7	35
29 - 39	9	45
> 40	4	20
Year of Graduation		
< 1984	3	15
1984 - 2006	9	45
> 2007	8	40
Institution of Graduation		
DUT	17	85
Palmer	2	10
National College	1	5

(% - percentage, M - Mean, SD - Standard deviation, **n=19, *n=18, reason for numbers differing from the complete 20 participants is due to some refusing to disclose the necessary personal information to calculate their BMI.)

4.4 ANALYSIS OF THE SURFACE EMG DATA

The data will be presented for the three phases of the adjustment (preload, thrust and resolution) under the headings of muscle activation magnitude median (AMM), muscle activation magnitude mean (AMM2), muscle activation magnitude maximum (AMM3), maximum force output (MFO) and the time percentage of activation categorized as high (HAT%), medium (MAT%), and low (LAT%).

For the purpose of reporting, the muscles investigated in this study are presented in three groups, where an attempt was made to combine the reporting of paired antagonistic muscles for the first two groups with the third grouping relating to the scapular stabilizers.

4.4.1 Muscle Activation Magnitude Median

4.4.1.1Muscle activation magnitude median per muscle

- Anterior deltoid (AD), Triceps brachii (Tri), Posterior deltoid (PD) and Biceps brachii (Bi) muscles

Figure 4.1 shows that the AD ($F(2, 38) = 71.8$, $p<0.001$), Tri ($F(1.3, 26.1) = 51.2$, $p<0.001$), PD ($F(1.4, 26.8) = 9.23$, $p<0.002$) and Bi ($F(1.1, 21.7) = 21.8$, $p<0.001$) muscles all had a significant difference in muscle activation magnitude median across the three stages of the adjustment. All four muscles showed the highest levels of muscle activation during the thrust phase of the adjustment when compared to the preload ($p<0.001$) and resolution ($p<0.002$) phases, with the resolution phase showing a higher level of muscle activation when compared to the preload phase ($p<0.050$).

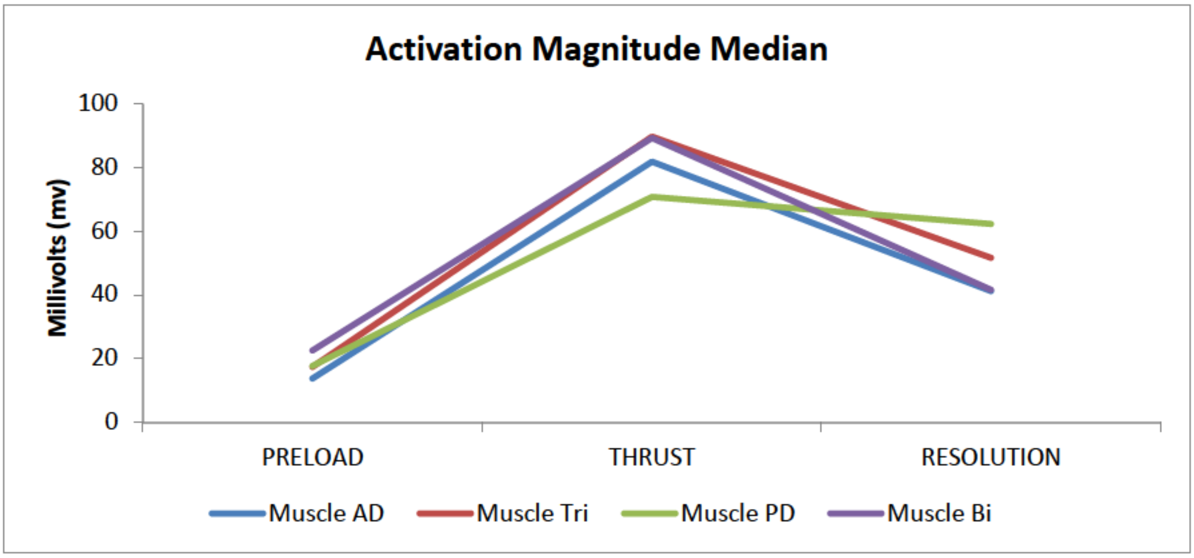


Figure 4.1: The muscle activation magnitude median for the anterior deltoid, triceps brachii, posterior deltoid and biceps brachii muscles.

- Pectoralis Major (Sternal [SP] and Clavicular [CP] Head's) and Infraspinatus (IS) muscles.

Figure 4.2 shows a significant difference for muscle activation magnitude median across the three phases of the adjustment for the sternal (F (1.4, 26.6) = 23.5, $p<0.001$), and clavicular division of the pectoralis major (F (2, 38) = 47.3, $p<0.001$) and the infraspinatus (F (2, 38) = 34.5, $p<0.001$) muscle. For all three muscles the greatest muscle activation was seen during the thrust phase when compared to the preload ($p<0.001$) and resolution ($p<0.002$) phases, with the resolution phase showing a higher level of muscle activation when compared to the preload phase ($p<0.002$).

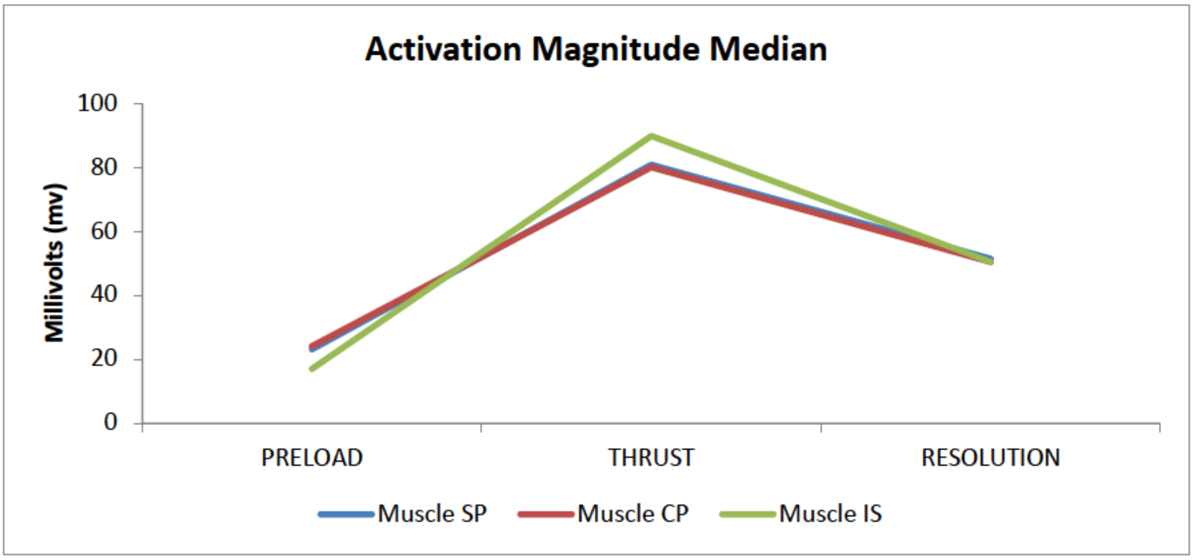


Figure 4.2: The muscle activation magnitude median for the pectoralis major sternal and clavicular head and the infraspinatus muscles.

- Trapezius (Upper [UT], Middle [MT], and Lower [LT] divisions) and Serratus Anterior (SA) muscles

For the scapular stabilizers, as seen in **Figure 4.3**, there was a significant difference in muscle activation during the thrust phase compare to the preload and resolution phases for the MT (F (2, 38) = 26.5, $p<0.001$), UT (F (2, 38) = 48.7, $p<0.001$) and LT (F (2, 38) = 37.9, $p<0.001$) divisions of the trapezius and SA (F (2, 38) = 46.1, $p<0.001$) muscles. All four muscles showed a higher level of muscle activation during the thrust phase when compared to the preload ($p<0.001$) and resolution ($p<0.050$) phases, with the resolution phase showing a higher level of muscle activation when compared to the preload ($p<0.050$) phase.

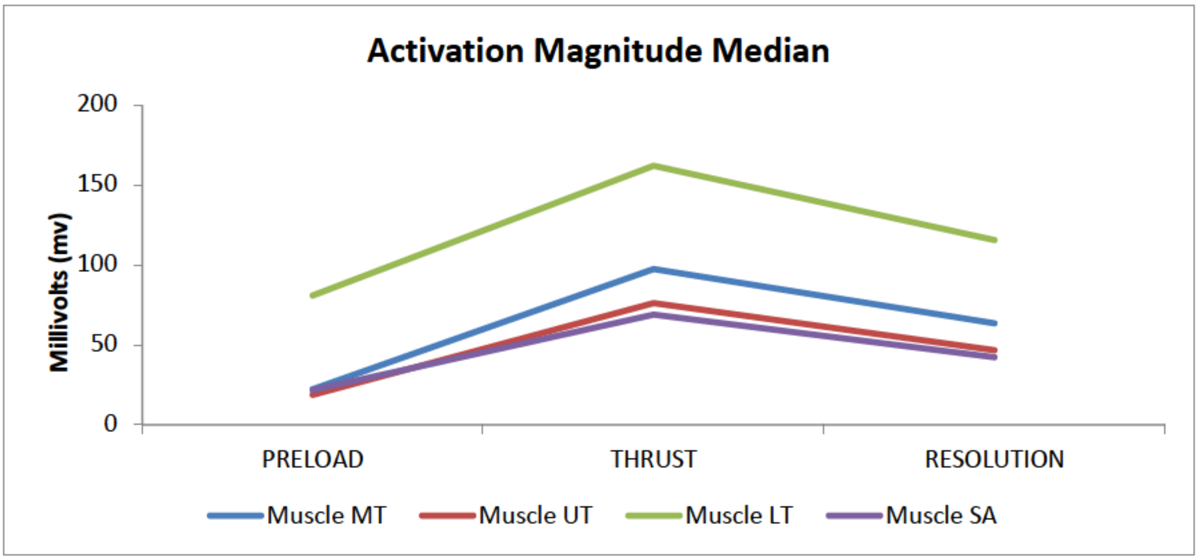


Figure 4.3: The muscle activation magnitude median for the middle, upper and lower divisions of the trapezius) and serratus anterior muscles.

4.4.1.2 **Muscle activation magnitude median across the 11 muscles**

Figure 4.4 shows the muscle activation magnitude median levels of the assessed muscle through the three phases of an adjustment. Appendix 12 provides the raw data.

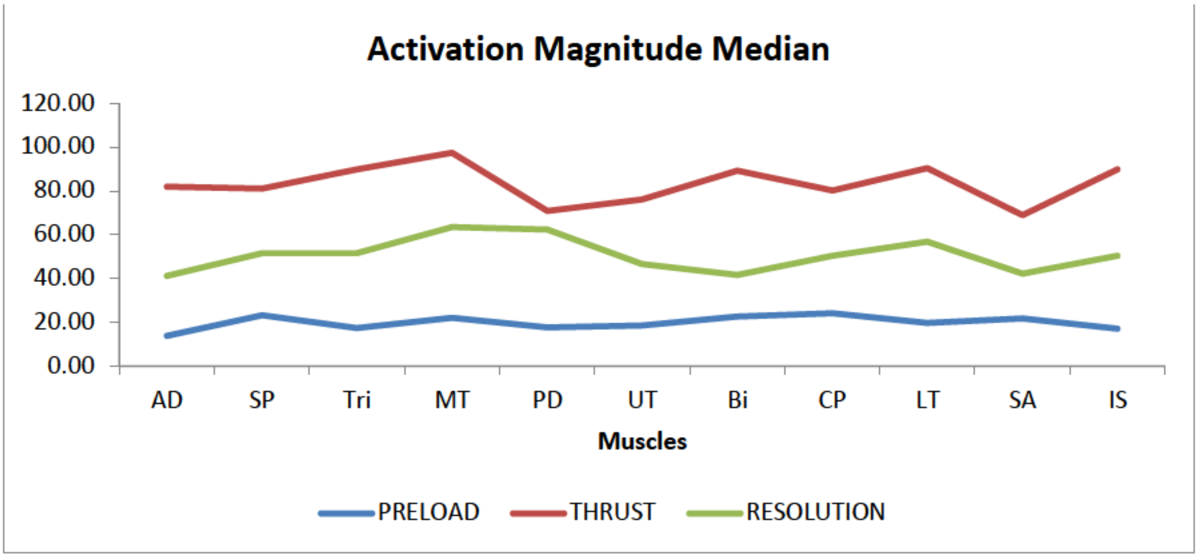


Figure 4.4: Descriptive outcomes regarding the muscle activation magnitude median for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases.

During preload a significant difference was found across the 11 muscles, χ^2 (10) = 32.6, p<0.001, with the anterior deltoid muscle showing significantly less activity than the sternal (p<0.001) and clavicular (p<0.001) pectoral muscles. For the thrust, χ^2 (10) = 10.9, p=0.4, and resolution phases, χ^2 (10) = 14.8, p=0.141 no significant differences were found across the muscles.

4.4.2 Muscle Activation Magnitude Mean

4.4.2.1 Muscle activation magnitude mean per muscle.

- Anterior deltoid, Triceps brachii, Posterior deltoid and Biceps brachii muscles

Figure 4.5 shows that the AD (F (2, 38) = 73.1, p<0.001), Tri (F (2, 38) = 62.3, p<0.001), PD (F (1.2, 22.4) = 6.5, p<0.015), and Bi (F (1.3, 38) = 25.4, p<0.001) muscles all had a significant difference in muscle activation magnitude mean across the three stages of the adjustment. The AD, Tri and Bi muscles showed the highest levels of muscle activation during the thrust phase when compared to the preload (p<0.001) and resolution (p<0.003) phases, with the resolution phase showing a higher level of muscle activation when compared to the preload (p<0.005) phase. The PD similarly showed the greatest muscle activation during the thrust phase in comparison to the preload (p<0.002) phase, however no significant finding was noted when comparing the thrust to resolution or preload to resolution phases.

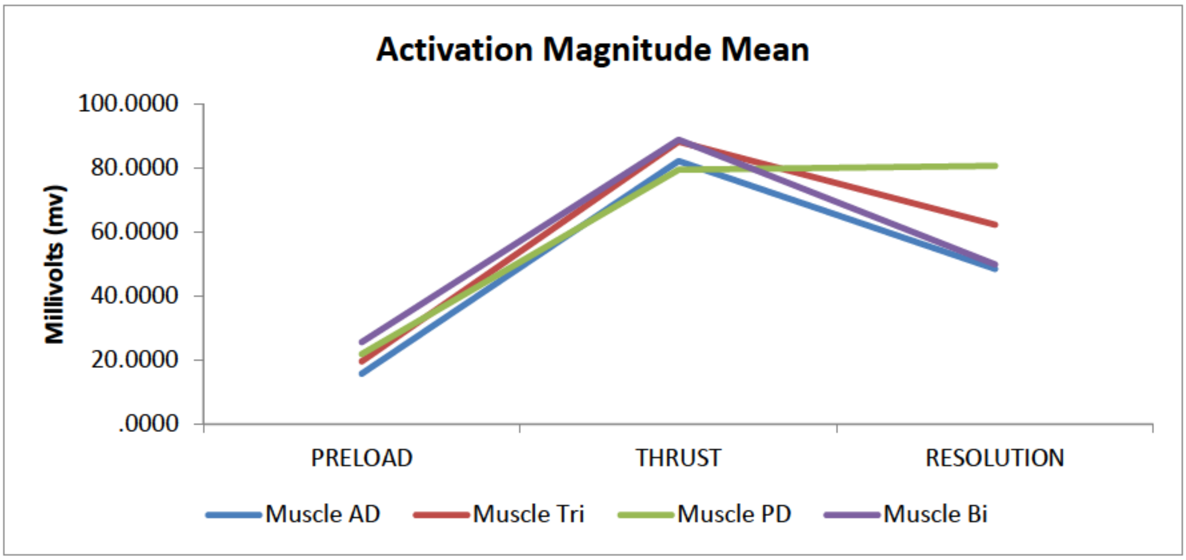


Figure 4.5: The muscle activation magnitude mean for the anterior deltoid, triceps brachii, posterior deltoid and biceps brachii muscles.

- Pectoralis Major (Sternal and Clavicular Head's) and Infraspinatus muscles.

Figure 4.6 shows a significant difference for muscle activation magnitude mean across the three phases of the adjustment for the sternal (F (1.4, 27.2) = 25.3, $p<0.001$), and clavicular division of the pectoralis major (F (2, 38) = 52.1, $p<0.001$) and the IS (F (2, 38) = 37.6, $p<0.001$) muscle. For all three muscles the greatest muscle activation was seen during the thrust phase when compared to the preload ($p<0.001$) and resolution ($p<0.002$) phases, with the resolution phase showing a higher level of muscle activation when compared to the preload ($p<0.001$) phase.

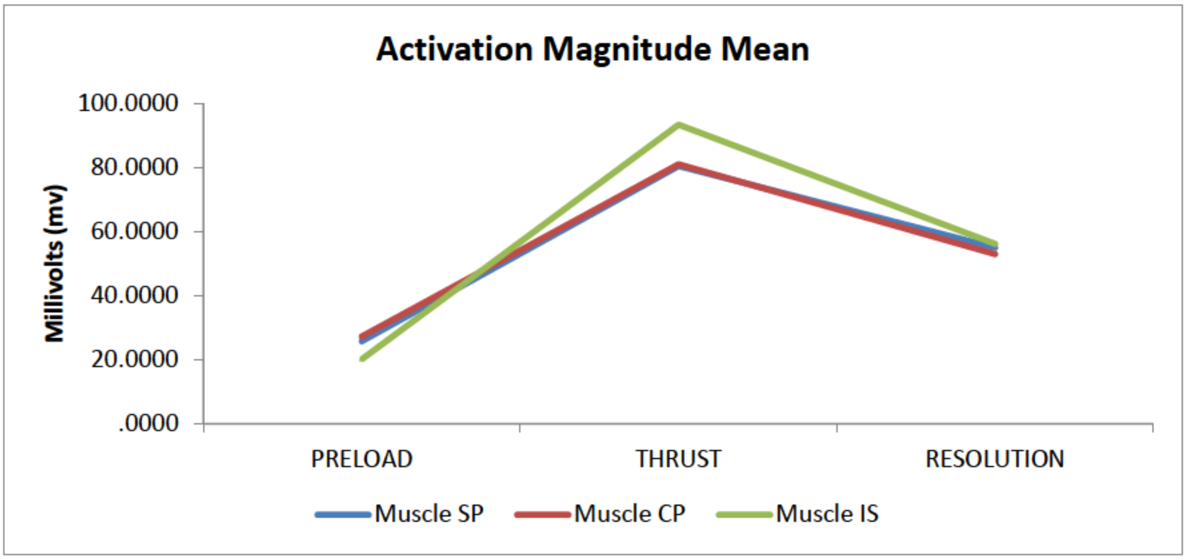


Figure 4.6: The muscle activation magnitude mean for the pectoralis major sternal and clavicular head and the infraspinatus muscles.

- Trapezius (Upper, Middle, and Lower divisions) and Serratus Anterior muscles.

For the scapular stabilizers, as seen in **Figure 4.7** there was a significant difference in muscle activation during the thrust phase compared to the preload and resolution phases for the MT (F (2, 38) = 24.5, $p<0.001$), UT (F (2, 38) = 53.8, $p<0.001$) and LT (F (2, 38) = 38.9, $p<0.001$) divisions of the trapezius and SA (F (2, 38) = 45.7, $p<0.001$) muscles. All four muscles showed a higher level of muscle activation during the thrust phase when compared to the preload ($p<0.001$) and resolution ($p<0.011$) phases, with the resolution phase showing a higher level of muscle activation when compared to the preload ($p<0.005$) phase.

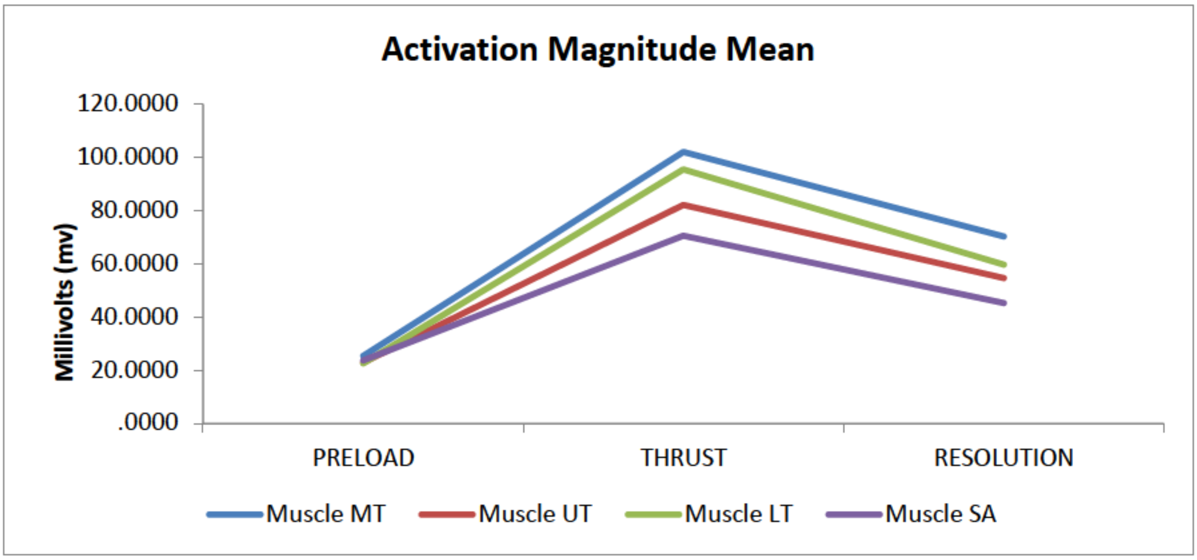


Figure 4.7: The muscle activation magnitude mean for the middle, upper and lower divisions of the trapezius) and serratus anterior muscles.

4.4.2.2 **Muscle activation magnitude mean across the 11 muscles.**

Figure 4.8 shows the muscle activation magnitude mean levels of the assessed muscle through the three phases of an adjustment. Appendix 13 provides the raw data.

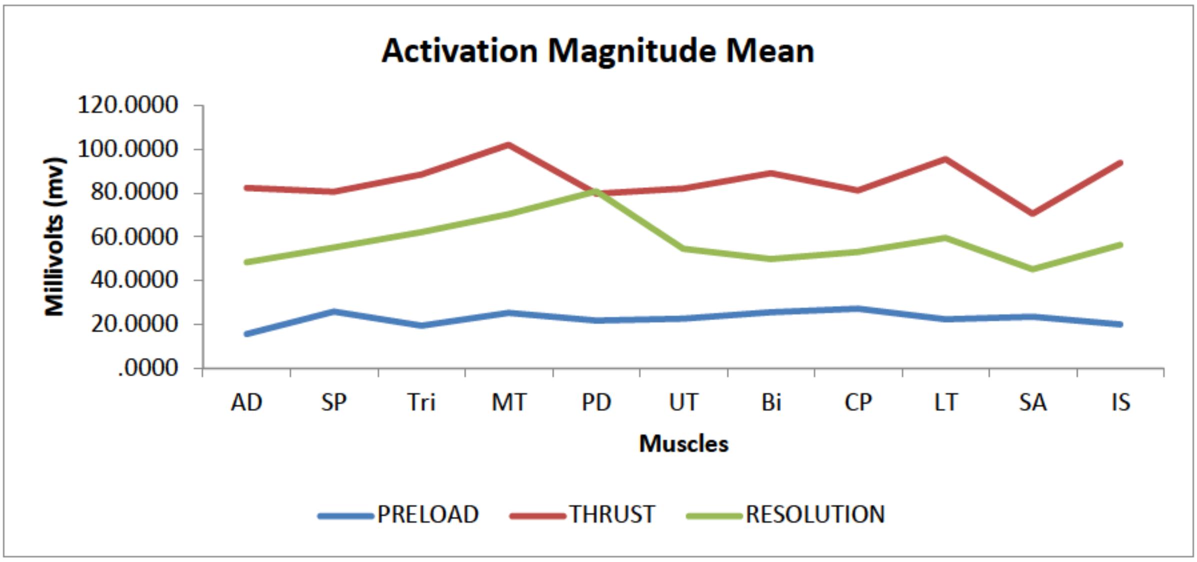


Figure 4.8: Descriptive outcomes regarding the muscle activation magnitude mean for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases.

During preload a significant difference was found across the 11 muscles, χ^2 (10) = 35.8, *p*<0.001, with the AD muscle showing significantly less activity than the sternal (*p*<0.001) and clavicular (*p*<0.001) pectorals muscles. For the thrust, χ^2 (10) = 12.4, *p*<0.257, and resolution phases, χ^2 (10) = 17.3, *p*<0.067 no significant differences were found across the 11 muscles.

4.4.3 Muscle Activation Magnitude Maximum

4.4.3.1 Muscle activation magnitude maximum per muscle

- Anterior deltoid, Triceps brachii, Posterior deltoid and Biceps brachii muscles.

Figure 4.9 shows that the AD (F (1.3, 24.9) = 15.3, *p*<0.001), Tri (F (1.3, 23.8) = 30.1, *p*<0.001, and Bi (F (1.2, 22.5) = 6.2, *p*<0.017) muscles all had a significant difference in muscle activation magnitude maximum across the three stages of the adjustment, with the PD (F (1.2, 22.0) = 4.0, *p*<0.052) revealing no significant differences. The AD showed the highest levels of muscle activation during the thrust phase when compared to the preload (*p*<0.001) and resolution (*p*<0.033) phases, with the resolution showing a higher level of muscle activation when compared to the preload (*p*<0.035) phase. The Tri showed the highest levels of muscle activation during the thrust phase when compared to the preload (*p*<0.001) phase, however no significant finding was noted when comparing the thrust to resolution or preload to resolution phases. When comparing preload to resolution the Tri had a higher muscle activation during resolution (*p*<0.001). The Bi similarly showed the highest levels of muscle activation during the thrust phase when compared to the preload (*p*<0.003) phase, however no significant finding was noted when comparing the thrust to resolution or preload to resolution phase.

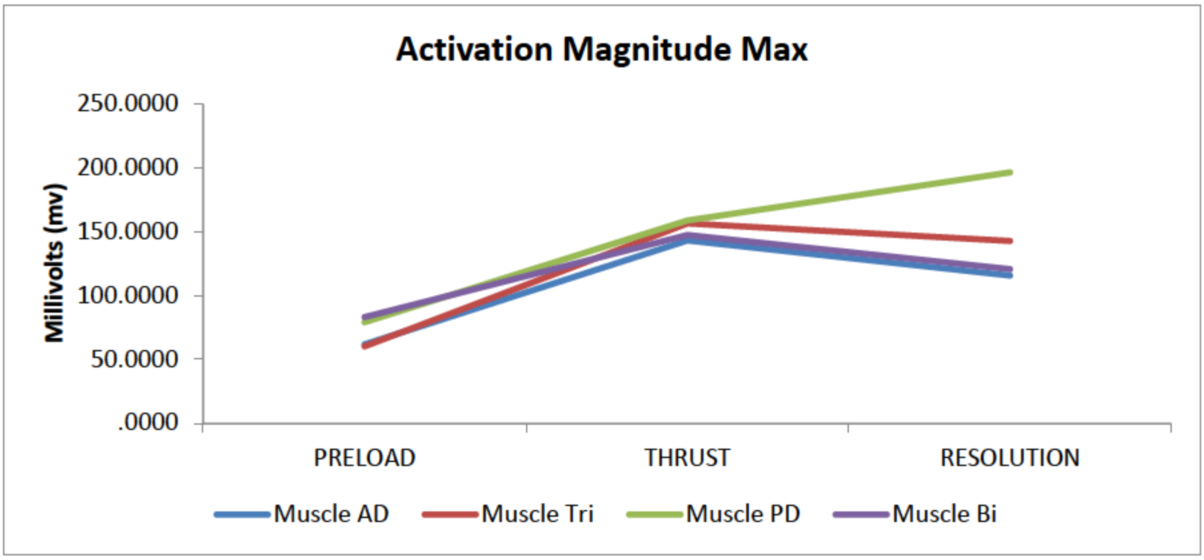


Figure 4.9: The muscle activation magnitude maximum for the anterior deltoid, triceps brachii, posterior deltoid and biceps brachii muscles.

- Pectoralis Major (Sternal and Clavicular Head's) and Infraspinatus muscles.

Figure 4.10 shows a significant difference for muscle activation magnitude maximum across the three phases of the adjustment for the sternal (F (1.4, 27.1) = 10.9, *p*<0.001), and clavicular division of the pectoralis major (F (1.5, 28.6) = 9.1, *p*<0.002) and the IS (F (2, 38) = 12.9, *p*<0.001) muscle. For both the pectoralis major divisions the greatest muscle activation was seen during the thrust phase when compared to the preload (*p*<0.006) and resolution (*p*<0.003) phases, however no significant findings was noted when comparing preload to resolution. The IS showed the greatest muscle activation during the thrust phase when compared to the preload (*p*<0.001) and a higher muscle activation during resolution (*p*<0.049) when comparing preload to resolution.

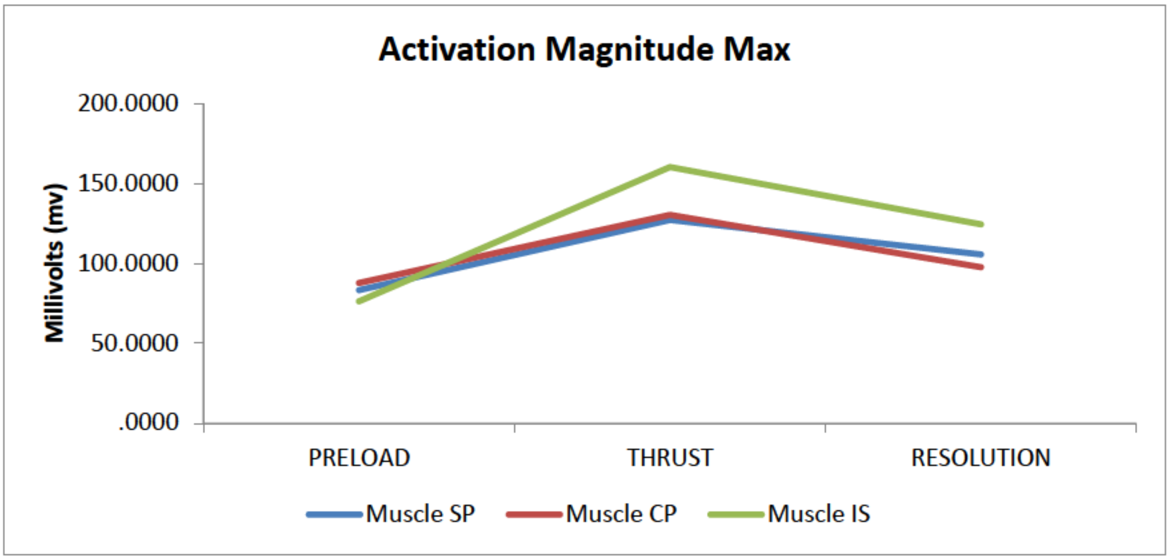


Figure 4.10: The muscle activation magnitude maximum for the anterior deltoid, triceps brachii, posterior deltoid and biceps brachii muscles.

- Trapezius (Upper, Middle, and Lower divisions) and Serratus Anterior muscles.

For the scapular stabilizers, as seen in **Figure 4.11** there was a significant difference in muscle activation during the thrust phase compared to the preload and resolution phases for the MT (F (1.4, 25.9) = 7.8, *p*<0.005), UT (F (1.3, 24.6) = 8.3, *p*<0.005) and LT (F (2, 38) = 17.2, *p*<0.001) divisions of the trapezius and SA (F (2, 38) = 14.2, *p*<0.001) muscles. The MT showed a high level of muscle activation during the thrust phase when compared to the preload (*p*<0.001) phase, however no significant finding was noted when comparing the thrust to resolution or preload to resolution phases. The UT and LT both showed a higher level of muscle activation during the thrust phase when compared to the preload (*p*<0.007) and resolution (*p*<0.013) phases. The SA similarly showed a higher level of muscle activation during the thrust phase when compared to the preload (*p*<0.001) and resolution (*p*<0.002) phases, however no significant finding was noted when comparing the preload to resolution phase.

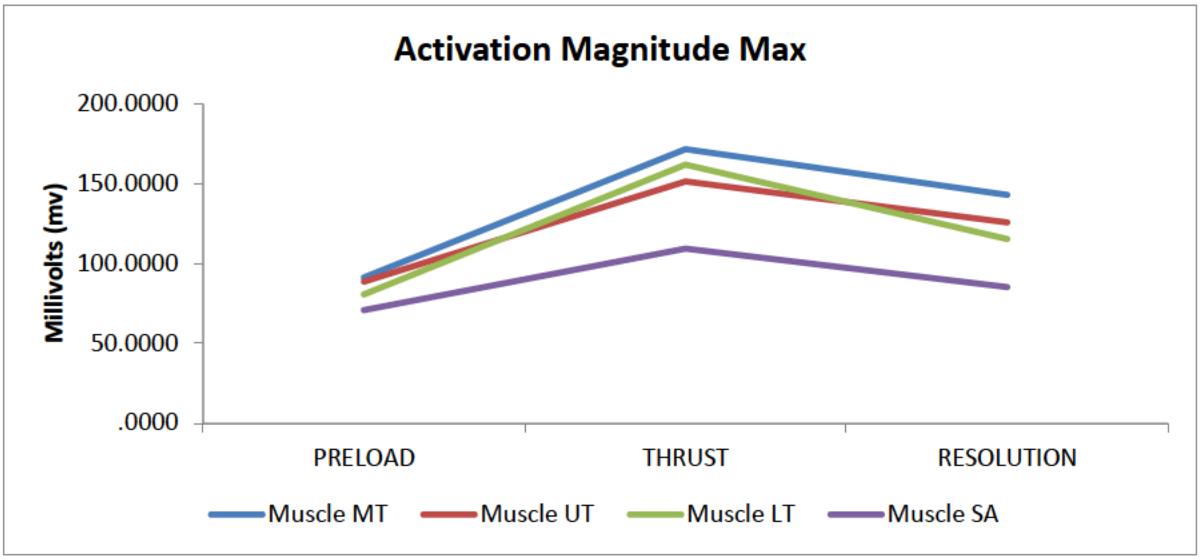


Figure 4.11: The muscle activation magnitude maximum for the middle, upper and lower divisions of the trapezius) and serratus anterior muscles.

4.4.3.2 Muscle activation magnitude maximum across the 11 muscles

Figure 4.12 shows the muscle activation magnitude maximum levels of the assessed muscle through the three phases of an adjustment. Appendix 14 provides the raw data.

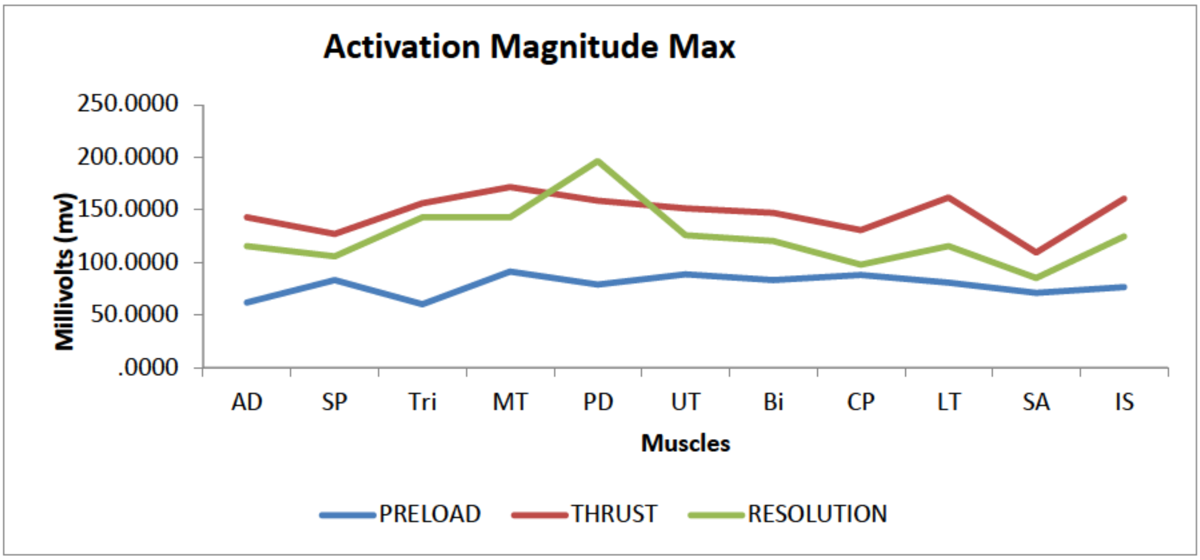


Figure 4.12: Descriptive outcomes regarding the muscle activation magnitude maximum for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases.

During preload no specific difference could be found across the 11 muscles, χ^2 (10) = 18.7, *p*=0.045, as the *p* value was not strong enough to determine the differences. For the thrust,

χ^2 (10) = 13.4, p<0.201, and resolution phases, χ^2 (10) = 17.4, p<0.066, no significant differences were found across the muscles with respect to activation magnitude maximum.

4.4.4 Maximum Force Output

The mean maximum force output obtained by the participants when executing the adjustment was 1.9 Kg (±SD 1.4 Kg; range 0.5-4.9 Kg). Appendix 15 provides the raw data.

4.4.5 Muscle Activation Time Percentage

Muscle activation time percentage indicates the percentage time that each was active in a high, moderate, and low activation zone. Each category refers to the percentage of time, relative to the full duration of the adjustment subphase (preload or thrust or resolution) being investigated. The high zone was when a muscle's activity was greater than 67% of the MVIC, moderate was when the activation was between 33% and 67% of MVIC, and low when it was less than 33% of its normalized MVIC EMG amplitude.

4.4.5.1 High activation time percentage

Figure 4.13 shows the high activation time percentage levels of the assessed muscle through the three phases of an adjustment. Appendix 16 provides the raw data. All 11 muscles showed some time in high activation, with time percentage in high activation ranging from 1.4% (AD) to 5.3% (LT) for the preload phase, 19.7% (LT) to 34.3% (Bi) for the resolution phase and 38.1% (PD) to 63.4% (MT) for the thrust phase. The thrust phase showed the greatest amount of time with high activity, with the preload showing the least amount of high activity across all 11 muscles.

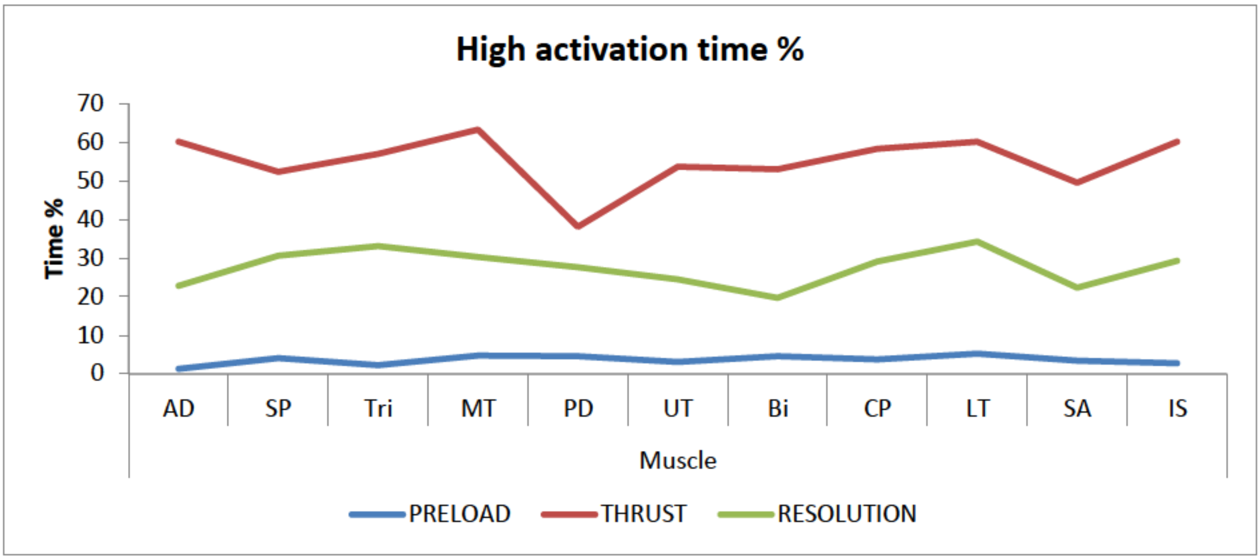


Figure 4.13: High activation time percentage for all participants (n=20) across the 11 investigated muscles for the preload, thrust and resolution adjustment phases.

No significant differences were found across the 11 muscles for each phase of the adjustment in the preload, χ^2 (10) = 18.7, *p*=0.05, thrust, χ^2 (10) =15.6, *p*=0.110, and resolution phases, χ^2 (10) = 11.5, *p*=0.322. A trend in the data for the thrust phase can be seen in the PD where it's had the least amount of time spent in the high activation time zone (38.1%) in comparison to the other muscles.

4.4.5.2 Moderate activation time percentage

Figure 4.14 shows moderate activation time percentage levels of the assessed muscle through the three phases of an adjustment. Appendix 17 provides the raw data. All 11 muscles showed moderate activation levels ranging from 11.1% (AD) to 25.3% (CP) for the preload phase, 21.2% (MT) to 35.2% (SP) for the thrust phase and 27.7% (PD) to 38.3% (CP) for the resolution phase. The resolution phase showed the greatest moderate level of activation with the preload showing the least amount of moderate activity across all 11 muscles. The exception being the PD which showed the greatest moderate activation in the thrust phase.

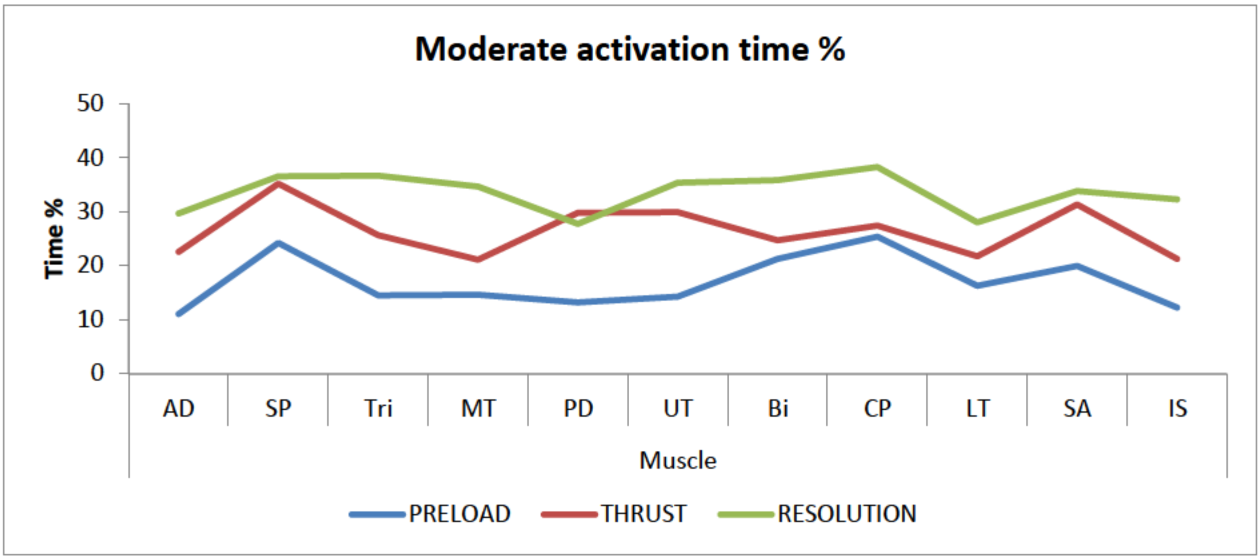


Figure 4.14: Descriptive outcomes regarding the moderate activation time percentage for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases.

During preload, a significant difference was found across the 11 muscles, χ^2 (10) = 21.5, *p*=0.018, however, no specific difference between the 11 muscles was identifiable. In the preload phase the SP, Bi, CP, and SA showed moderate activation for 20.0% - 25.4% of the adjustment phase, whereas the AD, Tri, MT, PD, UT, LT and IS showed moderate activation levels for 11.1% - 16.3% of the adjustment phase. No significant difference was found across the 11 muscles for the thrust, χ^2 (10) = 18.0, *p*=0.055, and resolution phases, χ^2 (10) = 11.3, *p*=0.333.

4.4.5.3 Low activation time percentage

Figure 4.15 shows low activation time percentage levels of the assessed muscle through the three phases of an adjustment. Appendix 18 provides the raw data. All 11 muscles showed low activation levels ranging from 12.4% (SP) to 31.9% (PD) for the thrust phase, 30.1% (Tri) to 47.4% (AD) for the resolution phase and 70.8% (CP) to 87.5% (AD) for the preload phase. The preload phase showed the greatest amount of low activity, with the thrust phase showing the least amount of low activity across all 11 muscles.

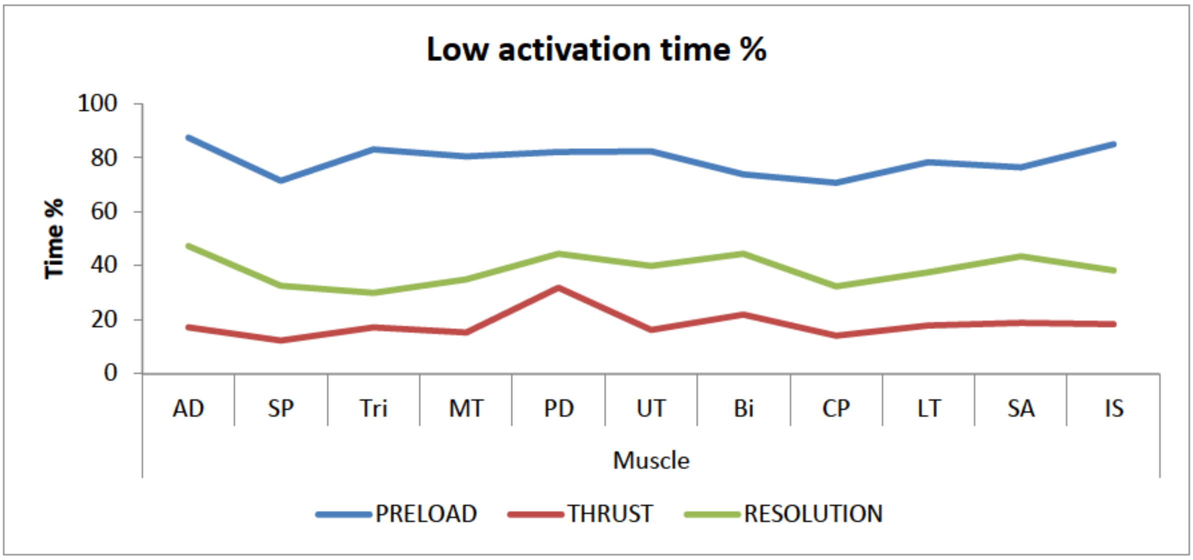


Figure 4.15: Low activation time percentage for all participants (n=20) across the 11 investigated muscles for the preload, thrust and resolution adjustment phases.

During preload a significant difference was found across the 11 muscles, χ^2 (10) = 23.*6*, *p*<0.009, with the (AD) showing significantly more activity in the low activation time percentage category when compared to the clavicular pectorals (*p*<0.00014). No significant differences were found across the 11 muscles for the thrust, χ^2 (10) = 18.*0*, *p*=0.055 and resolution, χ^2 (10) = 12.*0*, *p*=0.28 phases.

4.5 RELIABILITY ASSESSMENT

4.5.1 Preload Phase

The intra-class correlation for reliability between the three adjustments across the 11 muscles, showed that for activation magnitude median (AMM) and activation magnitude mean there was good to excellent ICC values. For activation magnitude maximum only one muscle had an excellent result (IT), with the rest of the muscles scoring a moderate to good ICC statistic, but the AD and UT received a poor ICC value, as seen in Table 4.2.

4.5.2 Thrust Phase

Table 4.3 shows the ICC's for the muscles for activation magnitude median (AMM), mean and maximum during the thrust phase. The reliability was good to excellent across the three measures except for the AD which showed moderate reliability for activation median and mean and for activation magnitude the UT had moderate reliability.

4.5.3 Resolution Phase

Table 4.4 Shows each of the assessed muscles mean, standard deviation (SD), interclass correlation coefficients (ICC) and confidence intervals (CI) for the three adjustments with respect to activation magnitude median (AMM) during the resolution phase. It reveals that the SP and PD showed excellent reliability (ICC > 0.9). The MT, Bi, CP and SA showed good reliability (ICC between 0.75-0.9) while the AD, Tri, UT, LT and IS showed moderate reliability (ICC between 0.5-0.75).

Table 4.2: The ICC and CIs for activation magnitude median, mean and maximum for each of the assessed muscles over the three adjustments during the preload phase.

	ACTIVATION MAGNITUDE MEDIAN								ACTIVATION MAGNITUDE MEAN								ACTIVATION MAGNITUDE MAXIMUM							
	T1		T2		T3		ICC	CI	T1		T2		T3		ICC	CI	T1		T2		T3		ICC	CI
	M	SD	M	SD	M	SD			M	SD	M	SD	M	SD			M	SD	M	SD	M	SD		
AD	13.8	11.2	14.6	12.4	12.9	10.6	0.958	0.9-1.0	15.8	11.9	16.8	12.0	14.6	10.0	0.946	0.9-1.0	67.1	56.5	63.2	34.9	55.4	35.6	0.476	-0.1
SP	21.2	12.1	26.0	17.1	22.3	14.1	0.935	0.9-1.0	23.2	12.8	28.5	15.9	25.8	14.7	0.931	0.9-1.0	71.7	47.2	88.5	44.7	90.3	61.1	0.620	0.2-0.8
TRI	16.9	12.3	17.2	11.9	18.1	14.6	0.924	0.8-1.0	19.2	13.2	19.3	12.0	20.3	15.2	0.918	0.8-1.0	65.3	65.7	56.1	30.6	59.7	43.6	0.612	0.2-0.8
MT	20.1	12.8	19.9	12.0	26.4	31.5	0.628	0.2-0.8	22.6	13.6	22.6	11.8	30.9	35.1	0.646	0.3-0.8	74.7	55.5	91.9	69.0	107.6	131.2	0.666	0.3-0.9
PD	17.8	14.0	16.9	12.3	18.5	17.1	0.837	0.7-0.9	22.0	15.3	19.5	13.5	24.1	26.4	0.775	0.5-0.9	87.1	66.6	61.9	44.2	88.7	121.3	0.665	0.3-0.9
UT	16.5	10.3	19.9	11.9	19.6	10.1	0.871	0.7-0.9	19.9	11.5	23.1	11.8	25.6	17.1	0.692	0.4-0.9	78.5	53.2	82.2	56.6	105.7	106.3	0.442	-0.2-0.8
BI	20.8	14.1	23.8	20.7	23.1	17.1	0.922	0.8-1.0	23.3	16.2	26.4	20.2	27.1	21.3	0.941	0.9-1.0	83.2	102.4	77.5	58.7	89.0	73.4	0.847	0.7-0.9
P	22.7	10.2	25.4	13.5	24.2	13.5	0.907	0.8-1.0	25.4	11.7	29.3	14.2	27.2	15.2	0.912	0.8-1,0	79.4	45.6	102.0	70.5	82.6	55.5	0.829	0.6-0.9
LT	18.2	15.3	17.6	14.2	23.5	21.2	0.855	0.7-0.9	20.3	17.1	21.2	16.6	26.3	22.4	0.896	0.8-1.0	72.1	77.2	86.3	77.6	84.0	65.2	0.805	0.6-0.9
SA	20.5	13.4	23.0	15.0	21.3	14.3	0.940	0.9-1.0	22.0	14.0	25.6	16.1	23.5	15.8	0.935	0.9-1.0	68.7	46.8	72.6	37.3	71.8	39.7	0.690	0.3-0.9
IS	16.2	11.4	17.3	11.6	17.5	11.3	0.882	0.8-1.0	19.3	14.0	20.5	12.3	20.7	13.1	0.899	0.8-1.0	81.7	91.6	79.3	58.0	68.4	45.1	0.912	0.8-0.9

(T1: adjustment 1, T2: adjustment 2, T3: adjustment 3 , M: mean, SD: standard deviation)

Table 4.3: The ICC and CIs for activation magnitude median, mean and maximum for each of the assessed muscles over the three adjustments during the thrust phase

	ACTIVATION MAGNITUDE MEDIAN								ACTIVATION MAGNITUDE MEAN								ACTIVATION MAGNITUDE MAXIMUM							
	T1		T2		T3		ICC	CI	T1		T2		T3		ICC	CI	T1		T2		T3		ICC	CI
	M	SD	M	SD	M	SD			M	SD	M	SD	M	SD			M	SD	M	SD	M	SD		
AD	77.9	32.9	82.1	41.8	85.4	31.8	0.571	0.1-0.8	79.9	32.0	84.5	42.0	82.6	27.2	0.635	0.2-0.8	147.1	61.2	147.7	98.9	135.0	46.0	0.718	0.4-0.9
SP	78.5	49.6	77.5	42.5	86.8	62.6	0.924	0.8-1.0	80.4	47.8	78.0	42.7	83.6	52.9	0.938	0.9-0.1	129.0	73.7	118.9	58.5	134.3	82.8	0.923	0.8-1.0
TRI	85.0	47.4	86.5	49.5	97.5	46.4	0.803	0.6-0.9	81.5	37.9	87.8	42.2	95.7	42.0	0.881	0.8-0.9	146.8	56.3	159.9	87.7	163.0	76.4	0.846	0.7-0.9
MT	95.8	61.7	100.1	56.4	96.3	61.0	0.847	0.7-0.9	100.6	70.6	107.7	63.3	97.7	63.9	0.885	0.8-1.0	176.5	157.3	181.0	131.2	157.6	115.5	0.930	0.9-1.0
PD	70.6	59.7	64.7	40.7	77.0	83.2	0.867	0.7-0.9	76.3	63.9	79.8	78.9	82.6	96.4	0.939	0.9-0.1	153.2	157.0	167.3	258.0	156.0	185.8	0.927	0.8-1.0
UT	76.5	40.5	71.9	40.2	79.8	36.2	0.785	0.5-0.9	80.7	34.5	77.9	41.3	87.7	44.3	0.746	0.5-0.9	148.9	68.3	134.8	70.6	170.9	152.4	0.548	0.0-0,8
BI	84.3	79.6	86.5	60.8	96.9	82.6	0.934	0.9-0.1	82.5	75.9	88.1	61.4	96.3	71.8	0.940	0.9-0.1	125.1	99.3	147.3	105.7	170.1	160.3	0.902	0.8-1.0
CP	77.2	35.6	83.1	34.3	80.1	26.7	0.870	0.7-0.9	80.2	33.5	82.9	35.3	80.6	26.8	0.859	0.7-0.9	142.9	64.5	127.1	46.9	121.7	37.7	0.788	0.6-0.9
LT	94.7	53.8	88.6	41.6	88.0	59.7	0.790	0.6-0.9	97.6	56.8	97.9	41.9	90.9	57.7	0.835	0.7-0.9	162.8	91.2	179.1	79.0	144.2	96.8	0.786	0.5-0.9
SA	63.4	30.1	73.2	33.5	70.0	32.8	0.877	0.7-0.9	67.1	30.7	74.7	31.4	69.8	32.0	0.886	0.8-1.0	109.9	49.7	111.8	39.1	106.8	42.4	.889	0.8-1.0
IS	87.2	47.7	91.2	64.4	91.3	48.4	0.894	0.8-1.0	91.4	46.9	95.5	64.5	93.9	48.0	0.893	0.8-1.0	163.5	80.7	162.5	113.4	155.5	100.5	.847	0.7-0.9

(T1: adjustment 1, T2: adjustment 2, T3: adjustment 3 , M: mean, SD: standard deviation)

Table 4.4: The ICC and CIs for activation magnitude median, mean and maximum for each of the assessed muscles over the three adjustments during the resolution phase

	ACTIVATION MAGNITUDE MEDIAN								ACTIVATION MAGNITUDE MEAN								ACTIVATION MAGNITUDE MAXIMUM							
	T1		T2		T3		ICC	CI	T1		T2		T3		ICC	CI	T1		T2		T3		ICC	CI
	M	SD	M	SD	M	SD			M	SD	M	SD	M	SD			M	SD	M	SD	M	SD		
AD	38.7	36.3	48.9	43.7	35.8	23.3	0.728	0.4-0.9	45.5	39.6	54.3	43.5	45.8	26.6	0.819	0.6-0.9	104.7	79.6	122.7	110.6	119.8	70.5	0.920	0.8-1.0
SP	45.9	29.0	58.3	42.6	50.3	28.7	0.909	0.8-1.0	49.7	31.2	61.0	40.9	54.5	25.3	0.894	0.8-1.0	106.1	80.5	108.2	71.7	102.7	42.9	0.828	0.6-0.9
TRI	50.2	29.3	51.8	28.1	53.1	17.7	0.736	0.4-0.9	59.9	32.7	65.5	27.9	61.5	21.9	0.809	0.6-0.9	128.4	76.3	154.8	93.8	145.4	71.6	0.836	0.7-0.9
MT	67.6	85.2	65.7	67.5	57.1	42.9	0.838	0.7-0.9	75.0	94.7	70.0	68.4	65.9	59.6	0.845	0.7-09	153.0	201.7	140.2	136.5	136.3	127.8	0.905	0.8-1.0
PD	50.3	51.5	68.6	97.9	68.0	106.5	0.942	0.9-1.0	63.6	69.4	93.8	161.2	85.0	147.1	0.937	0.9-1.0	150.7	171.5	238.8	432.5	199.8	309.1	0.904	0.8-1.0
UT	42.4	22.6	53.4	48.4	44.3	19.3	0.622	0.2-0.8	50.4	28.1	61.9	51.0	51.8	27.9	0.717	0.4-0.9	116.0	87.2	118.8	78.3	142.7	111.7	0.798	0.6-0.9
BI	40.9	30.7	42.7	30.1	41.2	29.4	0.890	0.8-1.0	48.3	41.2	49.7	42.4	51.7	51.6	0.904	0.8-1.0	109.1	120.5	110.3	121.6	142.6	214.9	0.899	0.8-1.0
P	49.0	35.6	54.5	32.8	47.9	26.7	0.887	0.8-1.0	49.9	35.7	56.5	30.8	52.7	24.4	0.878	0.7-0.9	92.6	63.5	100.1	51.7	101.4	40.3	0.817	0.6-0.9
LT	54.4	36.9	63.2	52.3	53.1	37.6	0.559	0.1-0.8	56.4	35.6	66.4	51.3	55.9	37.7	0.607	0.2-0.8	98.7	49.4	129.2	84.0	118.2	63.4	0.664	0.3-0.9
SA	36.0	22.4	47.8	26.8	42.9	25.2	0.849	0.7-0.9	38.2	22.8	49.9	25.6	47.7	23.9	0.864	0.7-0.9	74.3	50.7	89.5	36.1	92.0	40.1	0.801	0.6-0.9
IS	50.3	36.2	56.9	53.7	44.3	23.9	0.658	0.3-0.9	56.1	35.3	61.4	53.0	51.4	26.3	0.699	0.4-0.9	118.3	68.8	135.4	116.7	120.3	67.3	0.770	0.5-0.9

(T1: adjustment 1, T2: adjustment 2, T3: adjustment 3 , M: mean, SD: standard deviation)

4.6 VIDEO ANALYSIS

A video was taken during each participants execution of the adjustment. All participants were instructed on how to perform the selected adjustment under investigation in this study. Figure 4.16 is a picture taken from one of the participants during the preload phase. The participant's thrusting arm is seen to be in slight glenohumeral flexion, abduction, and internal rotation. The elbow is in flexion and slight supination, with the wrist in extension. The spine is in a neutral position with the hips flexed allowing the sternum to be centred over the "articulation" that is being adjusted in preparation for the thrust phase. When assessing the change in the degree of movement change that occurs from preload, through thrust and then resolution it was observed that the doctors thrusting arm underwent minimal change with majority of the movement occurring at the trunk in what is commonly termed a "body drop". Thus, one screenshot during the preload has been used to describe all three phases.

In the thrust phase, the doctors position changes slightly with majority of the movement occurring in the trunk due to the "body drop". The only noticeable change was that the doctors thrusting arm moved into slight glenohumeral joint adduction. During the resolution phase, no noticeable positional change of the thrusting arm could be noticed, when compared to the thrust phase, with the exception that the thrusting arm was now stationary in the same position as mentioned in the preload, prior to the doctor removing his / her hand from the punching bag. It should be noted that no kinematic analysis was used to assess these changes in degrees of movement.

Figure 4.16: Doctor's body position during the adjustment.

4.7 CONCLUSION

Activation magnitude median, mean and maximum revealed that all 11 muscles showed the greatest activation during the thrust and lowest activation during the preload phase. The only exception to this was during the activation magnitude maximum, where the PD showed highest activation in the resolution phase. The mean maximum force output obtained by the participants when executing the adjustment was 1.9 (±SD 1.4; range 0.5-4.9).

When assessing the time spent by the muscles in the high, medium or low activation zones all muscles had the most activation during the thrust phase with the AD showing the least activation at 1.4% during preload and the MT showing the greatest at 63.4% during the thrust phases for high activation time percentage. During the moderate zone all 11 muscles showed the greatest moderate activation levels during the resolution phase and least during the preload phase, except for the PD which showed the greatest moderate level activation during the thrust phase. The AD showed the least activation at 11.1% during preload and the CP showing the greatest at 38.3% during the resolution. Low activation time percentage revealed that all 11 muscles showed the greatest low activation levels during the preload phase and least during the thrust phase: with the SP showing the least activation at 12.4% during the thrust and the AD showing the greatest at 87.5% during the preload.

Regarding the reliability statistics, the AD and UT were the only muscles that showed poor reliability. This occurred for activation magnitude maximum during the preload phase. All other tests showed results that ranged from moderate to excellent reliability.

Chapter 5 - DISCUSSION

5.1 INTRODUCTION

This chapter provides a discussion of the results and their contribution to this area of study.

5.2 CHARACTERISTICS OF THE PARTICIPANTS

The participants were practicing chiropractors in the eThekwini Municipality of KwaZulu-Natal, South Africa. Themajority of patients were male, which is in alignment with the male dominated profession in South Africa (Yelverton et al., 2015). Sex differences can have an influence on sEMG readings due to men, on average, having relatively greater muscle strength and power, with greater variability occurring between the upper body verses the lower body musculature when compared to females (Bartolomei et al., 2021). This may consequentially result in variability in the recruitment patterns when comparing males and females due to females compensating by utilizing additional or alternative musculature to provide the same degree of force and power as males. However, when tested for significant differences between females and males none was found, thus reducing the likelihood of this impacting the results.

In terms of age most participants were between the ages of 34 to 55 years and had been in practice for more than 11 years. Age is an important consideration when performing sEMG studies, due to the proportional relationship between aging and a loss in neuromuscular function. This can result from a loss of motor units, decreased muscle fibre size, muscle fibre quantity, motor unit firing rate, agonist antagonist muscle activation / coactivation, and force steadiness amongst others; all of which consequentially impair maximal muscle strength, power, and rate of force development (Billot et al., 2010, Hairi et al., 2010, Siparsky et al., 2014, Boccia et al., 2015). Older individuals require greater muscle activity levels to produce equal force levels compared to younger people (Billot et al., 2010) thus potentially affecting the quality and reliability of sEMG recordings. Although there was a range of participants in this study in terms of their ages, based off the maximal force output results, there were no significant differences observed. Years in practice and hours in practice similarly was a variable of significance, as those in practice for longer periods of time repeatedly performing an adjustment technique would build muscle memory thus bettering their psychomotor skill development. However, with majority (65%) of the participants practicing for over 11 years and more than 29 hours per week this variable would have had little influence on the results.

Remaining variables such as age, BMI, hand dominance, year of graduation and institution of graduation all have the potential of yielding significant differences in terms of muscle recruitment patterns during the adjustment, however, with the small sample size, there were too few participants to group and compare in order to yield results of significance.

5.3 DISCUSSION OF RESULTS

SMT is a skill-based technique that requires specific training and repeated execution to master the art and skill level required to effectively deliver this treatment modality. Literature describing the muscles that are involved and the need to be targeted during the training of SMT technique is scant. Emphasis has been placed on the ‘core musculature’ (Bergman and Peterson, 2010) while the upper limb delivers the manipulative thrust. Yet, no consensus exists in terms of the role of the various muscles of the upper limb in the execution of this technique. Therefore, the process of teaching SMT is primarily based on expert opinion. Understanding the upper extremity muscle activation during SMT will assist learners of manipulative techniques and their teachers in the cognitive phase of learning this skill. Thus, allowing those teaching SMT, to more objectively direct students to target their attention to these muscles and further assist SMT skill acquisition. This study aimed to profile the muscle recruitment patterns of selected upper extremity musculature, during a standardized lateral recumbent sacroiliac adjustment described by Bergman and Peterson (2010), to determine the primary muscles being utilized during the different phases of the SMT.

Two important factors needed to be considered when reading this discussion include the fact that the normalisation used to get these results was taken off the preload as the baseline reading and due to this study utilising sEMG, and crosstalk is a limitation that may have contaminated the results, especially when investigating the IS due to its ‘deep’ anatomical location.

The results indicated that for muscle activation magnitude, during the preload phase of this technique, all investigated muscles were active with the most consistent, greatest, muscle activation being observed in the CP & MT with the lowest activation occurring in the AD and Tri. The primary movement pattern of the pectoralis major muscle is an effective adductor (Ackland et al., 2008), shoulder flexor (Chang et al., 2022) and it aids with internal rotation (Mansfield and Neumann., 2019), whereas the middle trapezius functions primarily as a scapular stabilizer and retractor (Ourieff et al., 2023).

This is aligned, as seen in the video footage, with the position of the upper arm during the preload phase and highlights the importance of the CP in the early stages of the adjustment with the MT providing scapular stabilization and retraction.

In addition to the pectoralis major, the anterior deltoid is also important in the motion of arm adductor, flexion, and internal rotator (Ackland et al., 2008, Mansfield and Neumann. 2019, Chang et al., 2023). One would then have presumed that there would be high AD activity during preload, however this is contrary to what this study revealed. The AD showed a low level of muscle activation in the preload phase. A possible reason for this may be muscle length-tension relationships. Landin et al., (2017) stated that the forces a muscle can produce may be influenced by the length of the muscle when it is stimulated. This “muscle length” is directly influenced by joint angles. Length-tension curves indicate that when a muscle is shortened or lengthened outside this optimal length range, it reduces the power it can generate. If excessively shortened, the actin filaments not only fully overlap the myosin filaments but also overlap themselves, and if excessively lengthened the extent of overlap between the actin and myosin filaments is significantly reduced. Both situations reduce the power that the muscle may produce. The position of the upper arm during preload may shorten the AD, thus initiating the above phenomenon, and resulting in reduced sEMG activity being produced.

During the thrust phase, all investigated muscles were active with the most consistent, greatest, muscle activation being observed in the MT with the lowest in the SA. As both these muscles are scapular stabilizers (Ourieff et al., 2021) (Lung et al., 2023), one would think that they would work synergistically and therefore have similar activation patterns, yet this was not the case. This may be as a result of the degree of the thrusting arms abduction. Yoo (2017) stated that the middle trapezius showed higher isolation ratio at 60° than at 120°, while the serratus anterior showed a higher isolation ratio at 120° than at 60°. Therefore, based off the adjustment video analysis, since there appears to be qualitatively less than 120° abduction of the thrusting arm for majority of the participants during the thrust, even though the SA is a scapular stabilizer, the MT may be more dominant. This, coupled with the principle of reciprocal inhibition (Bater and Jordan, 2017), due to the MT and SA working antagonistically with reference to scapular movement and with scapular retraction being the dominant movement during the thrust, may account for the low levels of SA activity (Neumann and Camargo, 2019). Additionally, the MT may be considered a dominant stabilizer of the scapula while the serratus anterior may be considered a dominant mover of the scapula (Camargo and Neumann, 2019). This coupled with the little amount of motion seen in the thrusting arm and scapular in the thrust phase, may explain this high MT and low SA activation pattern.

During the resolution phase, once the high-velocity, low-amplitude thrust had been delivered, and recorded, all investigated muscles were active with the most consistent, greatest, muscle activation being observed in the PD and MT with the lowest being in the SA and AD. The primary movement patterns of the PD are glenohumeral extension and external rotation with the MT, as describe earlier, being a scapular stabilizer and retractor (Elzanie and Varacallo, 2023). This, coupled with the video recording analysis, showed that the glenohumeral joint of the thrusting arm was abducted, internally rotated and slightly forward flexed. This pattern could be potentially explained as being the result of the counter forces required to bring the thrusting arm into a stationary position, in other words, the PD activates to 'release' the arm from the flexion, internal rotation and adduction movements generated during the preload and thrust phases thus preparing the thrusting arm for rest while the MT still being required to fire due to its scapular stabilizing role. The reduced activity observed in the SA and AD may be as a result of reciprocal inhibition (Bater and Jordan, 2017) caused by the scapular retraction - initiated by the MT - and glenohumeral extension, with external rotation, initiated by the PD respectively.

This study showed that the greatest high activation time percentage during preload was in the LT, MT and Bi which change to the MT, IS and AD during the thrust phase and then to the LT, Tri and SP for the resolution phase. A key finding here is that the trapezius muscle (initially the MT in the preload and thrust, then in the LT in the resolution) was the only muscle that was highly active throughout the entire adjustment. This highlights the role of scapular stabilization, slight retraction, depression and upward rotation required during performance of the adjustment. A second key finding is that many of these muscles (except the SP and the triceps) have a glenohumeral stabilizing role (Blache et al., 2017) in addition to their primary functions of glenohumeral flexion, internal rotation, and adduction. (Landin et al., 2017, Elzanie and Varacallo, 2023, Tiwana et al., 2022), again emphasizing the high emphasis on a stable thrusting arm. Although the above musculature, besides the trapezius muscle, varies throughout the phases with regards to high activation, they are essentially synergistic, except for the Tri which may enter the high activation time percentage during the resolution phase to assist in glenohumeral adduction and potentially elbow extension. (Tiwana et al., 2022). However, a more likely explanation would be that the Tri is activating to counter the forces produced during the preload and thrust to stop the arm flexion, internal rotation and adduction movements generated during the preload and thrust phases to bring the thrusting arm to a stationary position. This however then begs the question as to why the SP simultaneously has a great high activation time percentage during the resolution phase as the SP solely functions to adduct, internal rotate and flex of the glenohumeral joint and therefore would be countering the triceps action which is according to the principle of reciprocal inhibition. This is highly unlikely however, according to Latash (2018), coactivation of antagonistic muscles is possible and is hypothesized to be a neural control strategy to maintain effector-level control and to prevent making it degenerate and facing the necessity to control at the level of signals to individual muscles as well as efficiently stabilizing the articulation by increasing the joint stiffness. This is compatible with the mechanical advantages of coactivation such as increasing movement speed and apparent stiffness of kinematic chains primarily with a fixed origin. The reason behind why the remaining muscle recruited at a high activation time percentage varies throughout the phases, going from Bi in preload to AD in thrust to SP & Tri in resolution, while the scapular stabilizers remaining constant throughout may be accredited to one or a combination of the phenomena previously discussed.

The shift from Bi in preload to AD in thrust may be explained by muscle length-tension relationships. Although the degree of change with respect to the glenohumeral and elbow joint articulations varying only slightly from preload to thrust, it is possible that the changes may be significant enough to alter the mechanical advantage of the biceps, thus encouraging the AD to activate for greater speed and power that is required during the thrust phase. Moon et al (2023) identified that the best glenohumeral position for optimal Bi activation was 75° flexion, while Alizadehkhaiyat et al (2015) stated that the greater the amount of glenohumeral internal rotation the greater the activation of the AD. This, in conjunction with the video analysis which predominantly showed the degree of glenohumeral joint flexion decreasing while internal rotation remains fairly constant at a high degree from preload to thrust may justify this muscle variation. The shift from the AD in thrust to SP & Tri in resolution may be explained by the coactivation of antagonistic muscles phenomena.

The musculature showing the greatest low activation time percentage during preload were the AD, IS and Tri, for the thrust phase it was the PD, Bi and SA, and during the resolution phase it was the AD, PD and Bi. Unusual findings here include, during preload the AD and IS, during the thrust the Bi and during the resolution the PD, all showed low activation time percentage. Reason why this may be seen as unusual is that these muscles act synergistically to the prime movers during these phases respectively and therefore would be assumed to have a greater activation time percentage. This however, may be explained from the perspective of these muscles not acting as prime movers but rather stabilizers which would naturally activate at low levels but for prolonged times. This is coherent with Reed et al (2010) who stated that during isometric shoulder adduction, glenohumeral stabilizers activate at lower levels. The stabilizers will need to be active throughout the entire adjustment for effective glenohumeral movement

(Blache et al., 2017), explaining why these muscles exhibit the greatest low activation time percentage.

Finally, the maximum force output during the adjustment was averaged at ± 1.9 Kg. This is unusually low in comparison to other studies such as Owens et al (2016), where the average peak force was reported to be ± 10Kg – 142Kg, compared to average peak forces at± 6 Kg – 88 Kg (Owens et al., 2018; Mikhail et al., 2020) who reported average peak forces around ± 13 Kg. Potential reasons behind this may include participant's hesitancy and unfamiliarity with the object being adjusted. Those comparative studies assessed prone thoracic adjustments which may justify the differences in force output when compared to this study which assessed the sacro-iliac side lying adjustment. In this study, the simulation of the punching bag with the force transducer between the hand and the bag could have influenced the force, and finally in those comparative studies a force platform was utilized to measure the force outcomes which potentially allows for errors where the force plate, being under the patient, not directly where the hand contacts the patient, may yield skewed results.

It is important to note that the findings should be considered in relation to the task assessed in this study and that although the doctor's adjusting position was standardized it is impossible to have human participants position themselves in the same manner repeatedly let alone in other positions. Yet when one considers the reliability of the muscle activation readings over the three adjustments the reliability was good to excellent for most of the readings. However, according to Koo and Li (2016), it is important to understand that there are no standard values for acceptable reliability using ICC. A low ICC could reflect the low degree of rater or measurement agreement but also relate to the lack of sampled subject variability, small sample size, and / or small number of raters being tested, amongst others; either one of these being a potential explanation for the two muscles that showed poor reliability (AD and UT) and three muscles that showed moderate reliability (Tri, LT and IS) during the specific phases for the variables mentioned above.

5.4 CONCLUSION

The results of this study demonstrate that all muscles were active through the three phases with the results highlighting the role of the scapular stabilizers in the adjustment.

Other interesting findings included the following:

1) Preload phase of this technique, all muscles were active with the most consistent muscle activation found in the CP & MT and the lowest activation occurring in the AD and Tri. 2) Thrust

phase, all muscles were active with the most consistent, greatest, muscle activation being observed in the MT with the lowest in the SA.

3) Resolution phase the most consistent, greatest, muscle activation was in the PD and MT with the lowest being in the SA and AD.

The musculature showing the greatest high activation time percentage during preload was the LT, MT and Bi which changed to the MT, IS and AD during thrust and then for resolution it was the LT, Tri and SP. The musculature showing the greatest low activation time percentage during preload was the AD, IS and Tri, for the thrust phase it was the PD, Bi and SA and during the resolution phase it was the AD, PD and Bi.

In an era of evidence-based medicine it is imperative that the chiropractic profession continues to further its investigations on the chiropractic manipulation to contribute to a greater understanding of the popular treatment modality and continue to solidify its acceptance amongst the public and other health care professions. This does not only apply to the therapeutic effects of the adjustment but simultaneously objective and repetitive means of how the manual manoeuvre / s are performed and how skills are taught.

Chapter 6 - CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

6.1 CONCLUSION

The aim of this study was to determine the muscle recruitment patterns of selected upper extremity muscles in Chiropractors within the eThekwini Municipality while performing a simulated sacroiliac joint manipulation. The study utilizes a quantitative, descriptive, observational design to collect the data.

The analysis of the data revealed that all muscles were active throughout all the phases of the manipulation but for each phase there were muscles that had increased activation when compared to the others. In terms of mean and median muscle activation magnitude for the preload phase, the CP, SP and Bi had the greatest activation followed by the MT; whereas for the thrust phase it was the MT, LT and IS, followed by the Tri, and for resolution the median muscle activation magnitude showed the greatest activity in the MT, PD and LT followed by the Tri, whereas for mean muscle activation magnitude the LT was replaced with the Tri and followed the LT.

When assessing the maximum muscle activation magnitude during preload the greatest activity was found in the MT, UT and CP muscles, followed closely by the SP; whereas for the thrust phase, it was in the MT, LT and IS followed by the PD and Tri. For the resolution phase the PD, MT and Tri had the greatest maximum muscle activation magnitude, followed by the UT and IS.

On assessing activation time percentage, during the thrust phase all muscles showed a high level of activation, compared to the preload and resolution phases, with the preload showing the lowest level of muscle activation.
During preload the LT, MT and Bi had the greatest time spent in a high activation zone followed by the PD and SP. This changed to the MT, AD, LT and IS followed by the CP during the thrust phase, and during resolution the LT, Tri and SP showed the highest activation followed by the MT.

For moderate activation time percentage zone, the resolution phase showed the greatest level of moderate activation with the preload showing the least across 10 muscles with the exception of the PD which showed the greatest moderate activation during the thrust phase. The muscle which displayed high moderate levels for preload were the CP, SP and Bi followed by the SA, then during thrust it was the SP, SA, PD and UT followed by the CP, Tri and SP, then followed by Bi during resolution.

For the low activation time percentage, the preload phase had the greatest amount of low activity in the 11 muscles, with the thrust phase showing the least amount of low activity. During preload the AD, IS and Tri had the greatest low activation followed by the UT. This changed to the PD, Bi and SA followed by the IS during thrust and then the AD, MT and UT, followed by the SA, during the resolution phase.

The maximum force output during the adjustment was averaged at ± 1.9 Kg.

The muscle activation patterns when assessed for reliability, showed good to excellent reliability with the exception of the AD and UT during preload for activation magnitude maximum, for the AD and UT during the thrust phase for activation magnitude median, mean and maximum and for the AD, Tri, UT, LT and IS for the resolution's activation magnitude median.

The implications of these findings are that, with the findings of this study one can now delineate the muscle recruitment patterns unique to this adjustment, further assisting with psychomotor skills training and development. This will further the cognitive training of SMT by assisting students in focusing their attention on the specific muscles to train to effectively produce the manipulative thrust and thus further assist the skill acquisition. Essentially this study's findings will benefit any educator teaching the adjustment, student learning the adjustment and / or practitioner performing the adjustment in a more objective evidence-based perspective.

According to the researcher's knowledge, this is the first study investigating muscle recruitment patterns during any type of chiropractic spinal manipulation. Therefore, further research into this field would be recommended. Most of the literature to date has focused on muscle activity during less specific functional tasks mainly focused around general movement patterns or functional exercises for rehabilitation purposes. Considering that this was a quantitative, descriptive, observational design, future studies with larger sample sizes from a broader range of locations may provide more reliable results.

6.2 LIMITATIONS

During the study, the following limitations were recognized:

1. The sample size was relatively small (n=20) for the population being investigated and may have influenced the external validity of the results.
2. Only one SMT technique was investigated, and although 12 muscles were assessed not all the potential muscles that could have been involved were monitored.
3. The Infraspinatus musculature was investigated despite being an anatomically "deep" muscle. This allowed for the potential of yielding skewed sEMG data readings due to crosstalk.
4. Although a punching bag was utilized in place of a human being, for ethical reasons, the results could be influenced by this simulation due to human tissue and texture being different to that of a punching bag.
5. The laboratory nature of this study required that the sEMG modules were attached to the participants arms. This may have led them to act in a manner dissimilar to private practice that could have influenced the results due to a lack of comfort.
6. Potential thrusting arm positional variation (the arms position could not be completely standardized due to this investigating chiropractor's natural adjustment in the confines of a specific adjustment) may have resulted in alternative recruitment patterns. This however could also be seen as a strength as it reflects what happens clinically, thus strengthening external validity.
7. There was no strict definition for the onset and termination of the preload, thrust and resolution phases in terms of biomechanical events that occur during SM.

6.3 RECOMMENDATIONS

6.3.1 Recommendations for future studies

The following recommendations are made for future studies based on the findings of this study:

1. A larger sample size and equal numbers of males and females would allow for subgroup analysis to assess if there are differences between the sexes with regards to muscle recruitment during SMT.

2. Future studies should consider using intramuscular EMG to investigate deeper musculature in greater detail and with more reliability / accuracy, however the pain associated with this type of EMG may preclude its use.
3. Adjustments may be performed on humans for greater reliability in the data collected.
4. Bluetooth synced sEMG modules may be used in future studies to avoid sEMG cables and bulky modules from being attached to the participants and potentially interfering with participants adjustments due to comfort.
5. Investigate the remaining musculature of the upper limb with particular interest on the deeper shoulder musculature (rotator cuff and periscapular musculature).
6. Identify the order of the measured muscles activation.
7. Quantify the magnitude of activation of the measured muscles, with respect to the kinematics of SM.
8. Due to the high-speed (ballistic) nature of a SM, the delay between the onset of the thrust (true start of SM) and the time when the participants muscle activity was 3 SD greater than the resting baseline, especially considering the differing locations of the muscles, may be seen as a limitation.

6.3.2 Recommendations for the Chiropractic Profession

1) This study highlighted the role of the pectoralis muscle and the scapular stabilizers in the execution of the adjustment. Lecturers should, during technique classes, have students cognitively focus on utilizing / activating these muscles during the adjustment and potentially include exercises for students to do to increase the strength and reactivity of these muscles; both of which would assist in the delivery of the technique.
2) More research on how SMT is taught and how specific exercise targeting these muscles may be implemented to improve skill acquisition.

REFERENCES

Ackland, D. C., Pak, P., Richardson, M. and Pandy, M. G. 2008. Moment arms of the muscles crossing the anatomical shoulder. *Journal of Anatomy* 213(4): 383-390. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2644775/pdf/joa0213-0383.pdf. (Accessed 12 October 2022).

Action potential propagation (image) 2020: Available: http://myriverside.sd43.bc.ca/makaylac2017/2020/10/15/neuron-and-synapse-anatomy-physiology/. (Accessed 1 February 2023).

Ahmad. I., Ansari. F. and Dey. U. K. 2012. A review of EMG recording technique. International Journal of Engineering Science and Technology 4(2):531. Available: https://www.researchgate.net/publication/265007093_A_Review_of_EMG_recording_technique/fulltext/543bc7810cf24a6ddb97a132/A-Review-of-EMG-recording-technique.pdf. (Accessed 6 May 2023).

Alizadehkhaiyat, O., Hawkes, D. H., Kemp, G. J. and Frostick, S. P. 2015. Electromyographic analysis of shoulder girdle muscles during common internal rotation exercises. *International Journal of Sports Physical Therapy* 10(5): 645-654. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4595918/. (Accessed 19 October 2022).

Amrutha. N. and Arul. V. H. 2017. A review on noises in emg signal and its removal. International Journal of Scientific and Research Publications 7(5):23-25. Available: https://www.ijsrp.org/research-paper-0517.php?rp=P656368. (Accessed 6 May 2023).

Ardiel, E. L. and Rankin, C. H. 2010. The importance of touch in development. *Paediatr Child Health* 15(3): 153-156. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2865952/. (Accessed 15 March 2022).

Arias, A. n:d. Brachial Plexus anatomy (image). Pinterest. Available: https://www.pinterest.at/pin/260434790932947566/?amp_client_id=CLIENT_ID(_)&mweb_unauth_id=%7B%7Bdefault.session%7D%7D&simplified=true. (Accessed 1 February 2022).

Band Pass and Band Stop (Notch) Filter | Circuit | Theory. n:d. Available: https://electricalacademia.com/(Barnett and Larkman 2007)electronics/band-pass-notch-filter-circuit-theory/. (Accessed 28 February 2022).

Baniqued, A. N., Zuniga, J. M., Strunc, T. C., Keenan, K. M., Boken, A. K. and Anderson, J. J. 2016. The effect of skinfold on the assessment of the mean power frequency at the fatigue threshold. *International Journal of Exercise Sciences* 9(3): 376-383. Available: https://pubmed.ncbi.nlm.nih.gov/27766128/. (Accessed 15 November 2022).

Barberini, F. 2014. The clavicular part of the pectoralis major: a true entity of the upper limb on anatomical, phylogenetic, ontogenetic, functional and clinical bases. Case report and review of the literature. *Italian Journal of Anatomy and Embryology* 119(1): 49-59. Available: https://pubmed.ncbi.nlm.nih.gov/25345076/. (Accessed 17 May 2022).

Barnett, M. W. and Larkman, P. M. 2007. The action potential. *Practical Neurology* 7(3): 192-197. Available: https://pubmed.ncbi.nlm.nih.gov/17515599/. (Accessed 17 May 2022).

Bartolomei, S., Grillone, G., Di Michele, R. and Cortesi, M. 2021. A comparison between male and female athletes in relative strength and power performances. *Journal of Functional Morphology and Kinesiology* 6(1). Available: https://pubmed.ncbi.nlm.nih.gov/33572280/. (Accessed 10 March 2022).

Bater, L. and Jordan, S. 2017.Reciprocal inhibition by reviewed in, 1-4. Available: https://www.researchgate.net/publication/317802469_Reciprocal_Inhibition. (Accessed 19 May 2022).

Bear. M. F. and Connors. B. W. 2015. Neuroscience: Exploring the brain. 4th ed. Available: https://www.amazon.com/Neuroscience-Exploring-Mark-F-Bear/dp/0781778174. (Accessed 10 February 2022).

Bergmann. T. F. and Peterson. D. F. 2011. Chiropractic technique: principles and procedures. 3rd ed. St Louis: Elsevier/Mosby.

Bialosky, J. E., Bishop, M. D., Price, D. D., Robinson, M. E. and George, S. Z. 2009. The mechanisms of manual therapy in the treatment of musculoskeletal pain: A comprehensive model. *Manual Therapy* 14(5): 531-538. Available: https://www.sciencedirect.com/science/article/pii/S1356689X08001598. (Accessed 15 February 2022).

Billot, B., Bocchetta, M., Todd, E., Dalca, A. V., Rohrer, J. D. and Iglesias, J. E. 2020. Automated segmentation of the hypothalamus and associated subunits in brain MRI. *NeuroImage* 223: 117287. Available: https://pubmed.ncbi.nlm.nih.gov/32853816/. (Accessed 10 May 2022).

Blache, Y., Begon, M., Michaud, B., Desmoulins, L., Allard, P. and Dal Maso, F. 2017. Muscle function in glenohumeral joint stability during lifting task. *PLoS One* 12(12): e0189406. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5731701/#:~:text=We%20observed%20that%20only%20the,healthy%20population%20during%20lifting%20task. (Accessed 12 May 2022).

Blackstock, F. and Pritchard, S. 2020.Psychomotor skill development: Learning what and how to do by Moy, M. L., Blackstock, F. and Nici, L., reviewed in *Cham*, 27-40. Available: https://doi.org/10.1007/978-3-030-44889-9_3. (Accessed 9 February 2022).

Bobak, C. A., Barr, P. J. and O'Malley, A. J. 2018. Estimation of an inter-rater intra-class correlation coefficient that overcomes common assumption violations in the assessment of health measurement scales. *BMC Medical Research Methodology* 18(1): 93. Available: https://doi.org/10.1186/s12874-018-0550-6. (Accessed 1 January 2022).

Boccia, G., Dardanello, D., Rosso, V., Pizzigalli, L. and Rainoldi, A. 2015. The application of semg in aging: A mini review. *Gerontology* 61(5): 477-484. Available: https://pubmed.ncbi.nlm.nih.gov/25502864/. (Accessed 10 March 2022).

Bordlee. R and Wong. C. 2015. Surface EMG: A how-to guide for practitioners. 1-8. Available: https://lermagazine.com/article/surface-emg-a-how-to-guide-for-practitioners. (Accessed 30 January 2022).

Bourke, J. and Wessely, S. 2008. Confidentiality. *Bmj* 336(7649): 888-891. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2323098/. (Accessed 17 May 2021).

Camargo, P. R. and Neumann, D. A. 2019. Kinesiologic considerations for targeting activation of scapulothoracic muscles - part 2: trapezius. *Brazilian Journal of Physical Therapy* 23(6): 467-475. Available: https://pubmed.ncbi.nlm.nih.gov/30797676/. (Accessed 5 January 2022).

Canedo, A. 2003. [Functional heterogeneity of the piramidal system: corticobulbar and corticospinal tracts]. *Revista de Neurolgia* 36(5): 438-452. Available: https://pubmed.ncbi.nlm.nih.gov/12640598/. (Accessed 5 February 2023).

Carnes, M. and Goodman, B. 1995.[7] - frequency domain analysis of high-frequency ultradian plasma adrenocorticotropic hormone and glucocorticoid fluctuations by Johnson, M. L. and Veldhuis, J. D., reviewed in, 28(156-187. Available: https://www.sciencedirect.com/science/article/pii/S1043947106800339. (Accessed 16 November 2021).

Carson, R. G. and Riek, S. 2001. Changes in muscle recruitment patterns during skill acquisition. *Experimental Brain Research* 138(1): 71-87. Available: https://pubmed.ncbi.nlm.nih.gov/11374085/. (Accessed 30 January 2022).

Chaibi, A., Knackstedt, H., Tuchin, P. J. and Russell, M. B. 2017. Chiropractic spinal manipulative therapy for cervicogenic headache: a single-blinded, placebo, randomized controlled trial. *BMC Research Notes* 10(1): 310. Available: https://doi.org/10.1186/s13104-017-2651-4. (Accessed 9 December 2021).

Chaibi, A., Stavem, K. and Russell, M. B. 2021. Spinal manipulative therapy for acute neck pain: A systematic review and meta-analysis of randomised controlled trials. *Journal of Clinical Medicine* 10(21): 5011. Available: https://www.mdpi.com/2077-0383/10/21/5011. (Accessed 12 December 2022).

Chang, L. R., Anand, P. and Varacallo, M. 2023.Anatomy, shoulder and upper limb, glenohumeral joint by reviewed in *Treasure Island (FL)*, Available: https://www.ncbi.nlm.nih.gov/books/NBK537018/#:~:text=The%20glenohumeral%20joint%20is%20structurally,articulation%20of%20the%20shoulder%20girdle. (Accessed 15 October 2022).

Changiz, T., Amouzeshi, Z., Najimi, A. and Adibi, P. 2021. A narrative review of psychomotor abilities in medical sciences: Definition, categorization, tests, and training. *Journal of research in medical sciences : the official journal of Isfahan University of Medical Sciences* 26: 69-69. Available: https://pubmed.ncbi.nlm.nih.gov/34759986
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8548887/. (Accessed 12 March 2023).

Chen. W. 2004. The electrical engineering handbook: high pass filter. 1st Ed. ELSEVIER. Available:
http://www.iqytechnicalcollege.com/The%20Electrical%20Engineering%20Handbook.pdf. (Accessed 30 January 2022).

Choi, J., Lee, S. and Jeon, C. 2015. Effects of flexion-distraction manipulation therapy on pain and disability in patients with lumbar spinal stenosis. *Journal of physical therapy science* 27(6): 1937-1939. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4500015/pdf/jpts-27-1937.pdf (Accessed 15 March 2023).

Chowdhury, R. H., Reaz, M. B. I., Ali, M. A. B. M., Bakar, A. A. A., Chellappan, K. and Chang, T. G. 2013. Surface electromyography signal processing and classification techniques. *Sensors* 13(9): 12431-12466. Available: https://www.mdpi.com/1424-8220/13/9/12431 (Accessed 5 February 2023).

Christensen. M. G. and Kollasch. M. W. 2005. Job analysis of chiropractic. National board of chiropractic examiners. Colorado: Avenue, Greenley. Available:

https://www.google.com/search?client=safari&rls=en&q=Christensen.+M.+G.+and+Kollasch.+M.+W.+2005.+Job+analysis+of+chiropractic.+National+board+of+chiropractic+examiners.&ie=UTF-8&oe=UTF-8. (Accessed 3 May 2022).

Clar, C., Tsertsvadze, A., Court, R., Hundt, G. L., Clarke, A. and Sutcliffe, P. 2014. Clinical effectiveness of manual therapy for the management of musculoskeletal and non-musculoskeletal conditions: systematic review and update of UK evidence report. *Chiropractic & Manual Therapies* 22(1): 12. Available: https://doi.org/10.1186/2045-709X-22-12. (Accessed 5 March 2022).

Clark. M. 2011. Integrated training for the new millennium. Calabasas, CA: National Academy of Sports Medicine. USA. Burlington, MA : Jones & Bartlett Learning. Available: https://catalog.nlm.nih.gov/discovery/search?vid=01NLM_INST:01NLM_INST&query=lds04,exact,101618368. (Accessed 31 August 2022).

Clijsters, M., Fronzoni, F. and Jenkins, H. 2014. Chiropractic treatment approaches for spinal musculoskeletal conditions: a cross-sectional survey. *Chiropr Man Therap*, 22 (1): 33. Available: https://pubmed.ncbi.nlm.nih.gov/25309722/. (Accessed June 2022).

Corticospinal tract (image) 2013. Available: https://commons.wikimedia.org/wiki/File:1426_Corticospinal_Pathway.jpg. (Accessed 1 February 2023).

Cooperstein. R and Gleberzon. B. J. 2004. Technique Systems in Chiropractic. Churchill Livingstone. Available: https://www.amazon.com/Technique-Systems-Chiropractic-Robert-Cooperstein/dp/1983577545. (Accessed 8 January 2022).

Criswell. E. 2011. Crams introduction to surface electromyography, Spectral analysis, fatigue and band pass filters, Composite signals (image). Canada: Jones & Bartlett Publishers.

Criswell. E. 2011. Crams introduction to surface electromyography, , Spectral analysis, fatigue and band pass filters , Power spectral density (image). Canada: Jones & Bartlett Publishers.

Criswell. E. 2011. Crams introduction to surface electromyography, Types of surface electromyography visual displays, Raw EMG (image). Canada: Jones & Bartlett Publishers.

Criswell. E. 2011. Crams introduction to surface electromyography, Types of surface electromyography visual displays, Processed EMG. (image). Canada: Jones & Bartlett Publishers.

Criswell. E. 2011. Crams introduction to surface electromyography, Quantification of the surface electromyography signal, Smoothing. (image). Canada: Jones & Bartlett Publishers.

Dark, A., Ginn, K. A. and Halaki, M. 2007. Shoulder muscle recruitment patterns during commonly used rotator cuff exercises: an electromyographic study. *Physical Therapy* 87(8): 1039-1046. Available: https://pubmed.ncbi.nlm.nih.gov/17578940/. (Accessed 12 May 2023).

Dave, H. D., Shook, M. and Varacallo, M. 2023. Anatomy, skeletal muscle by reviewed in *Treasure Island (FL)*. Available: https://pubmed.ncbi.nlm.nih.gov/30725921/. (Accessed 12 August 2022).

Definition of chiropractic. 2001. World Federation of Chiropractic. Available: https://www.wfc.org/website/index.php?option=com_content&view=article&id=90. (Accessed 5 January 2022).

De Mey, K., Danneels, L., Cagnie, B., Borms, D., T'Jonck, Z., Van Damme, E. and Cools, A. M. 2014. Shoulder muscle activation levels during four closed kinetic chain exercises with and without Redcord slings. *Journal of Strength and Conditioning Research* 28(6): 1626-1635. Available: https://pubmed.ncbi.nlm.nih.gov/24172720/. (Accessed 12 April 2022).

de Zoete, A., Rubinstein, S. M., de Boer, M. R., Ostelo, R., Underwood, M., Hayden, J. A., Buffart, L. M., van Tulder, M. W., Bronfort, G., Foster, N. E., Maher, C. G., Hartvigsen, J., Balthazard, P., Cecchi, F., Ferreira, M. L., Gudavalli, M. R., Haas, M., Hidalgo, B., Hondras, M. A., Hsieh, C. Y., Learman, K., McCarthy, P. W., Petersen, T., Rasmussen-Barr, E., Skillgate, E., Verma, Y., Vismara, L., Walker, B. F., Xia, T. and Zaproudina, N. 2021. The effect of spinal manipulative therapy on pain relief and function in patients with chronic low back pain: an individual participant data meta-analysis. *Physiotherapy* 112: 121-134. Available: https://www.sciencedirect.com/science/article/pii/S0031940621000250. (Accessed 21 June 2023).

Department of Chiropractic. 2021. University of Johannesburg. Faculty of health sciences, department of chiropractic handbook. Johannesburg. Available: https://www.uj.ac.za/faculties/health-sciences/courses-and-programmes/postgraduate-programmes/. (Accessed 5 January 2022).

Descarreaux, M., Dugas, C., Raymond, J. and Normand, M. C. 2005. Kinetic analysis of expertise in spinal manipulative therapy using an instrumented manikin. *Journal of Chiropractic Medicine* 4(2): 53-60. Available: https://pubmed.ncbi.nlm.nih.gov/19674647/. (Accessed 5 November 2022).

Descarreaux, M. and Dugas, C. 2010. Learning spinal manipulation skills: assessment of biomechanical parameters in a 5-year longitudinal study. *Journal of Manipulative Physiological Therapy* 33(3): 226-230. Available: https://pubmed.ncbi.nlm.nih.gov/20350677/. (Accessed 12 March 2022).

Descarreaux, M., Dugas, C., Treboz, J., Cheron, C. and Nougarou, F. 2015. Learning spinal manipulation: the effect of expertise on transfer capability. *J Manipulative Physiol Ther* 38(4): 269-274. Available: https://pubmed.ncbi.nlm.nih.gov/25925020/. (Accessed 15 June 2023).

Deutsch, J. E. 2008.Chapter 18 – manipulative and body-based therapies by Deutsch, J. E. and Anderson, E. Z., reviewed in *Saint Louis*, 249-263. Available: https://www.sciencedirect.com/science/article/pii/B9780721601113500245. (Accessed 5 June 2023).

Deyle, G. D., Henderson, N. E., Matekel, R. L., Ryder, M. G., Garber, M. B. and Allison, S. C. 2000. Effectiveness of manual physical therapy and exercise in osteoarthritis of the knee. A randomized, controlled trial. *Annals of Internal Medicine* 132(3): 173-181. Available: https://pubmed.ncbi.nlm.nih.gov/10651597/. (Accessed 8 July 2023).

Donatelli, R. A. and McMahon, T. J. 2012.CHAPTER 14 - Manual Therapy Techniques by Donatelli, R. A., reviewed in *Saint Louis*, 305-327. Available: https://www.sciencedirect.com/science/article/pii/B9781437707403000131. (Accessed 17 May 2022).

Downie, A., Vemulpad, S. and Bull, P. 2010. Quantifying the High-Velocity, Low-Amplitude Spinal Manipulative Thrust: A Systematic Review. *Journal of manipulative and physiological therapeutics* 33: 542-553. Available: https://pubmed.ncbi.nlm.nih.gov/20937432/. (Accessed 29 June 2023).

Dutton. M. 2020. The musculoskeletal system. Dutton's Orthopaedic Examination, Evaluation, and Intervention. 5th Ed. McGraw-Hill. Available: https://accessphysiotherapy.mhmedical.com/content.aspx?bookid=2707&sectionid=224662311. (Accessed 5 March 2022).

Ebrall, P. 2022. *The paraphysiological space of manipulation: A pragmatist's appraisal* Available: https://www.researchgate.net/publication/360080041_The_Paraphysiological_Space_of_Manipulation_A_Pragmatist%27s_Appraisal. (Accessed 15 May 2022).

Ekstrom, R. A., Donatelli, R. A. and Soderberg, G. L. 2003. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. *Journal of Orthopedic Sports Physical Therapy* 33(5): 247-258. Available: https://pubmed.ncbi.nlm.nih.gov/12774999/. (Accessed 22 October 2022).

Electromyography (EMG). 2019. Available: https://www.mayoclinic.org/tests-procedures/emg/about/pac-20393913. (Accessed 5 March 2022).

Elzanie, A. and Varacallo, M. 2023.Anatomy, shoulder and upper limb, deltoid muscle by reviewed in *Treasure Island (FL)*, Available: https://www.ncbi.nlm.nih.gov/books/NBK537056/. (Accessed 20 November 2022).

Escamilla, R. F., Yamashiro, K., Paulos, L. and Andrews, J. R. 2009. Shoulder muscle activity and function in common shoulder rehabilitation exercises. *Sports Medicine* 39(8): 663-685. Available: https://pubmed.ncbi.nlm.nih.gov/19769415/. (Accessed 1 April 2023).

Everett. N. C. and Bryant. J. 2022. "psychomotor learning". *Encyclopedia Britannica*. Available: https://www.britannica.com/science/psychomotor-learning. (Accessed 12 October 2022).

Feinberg, J. and Feinberg, J. 1989. 27Autonomy. In: *The Moral Limits of the Criminal Law Volume 3: Harm to Self*. Oxford University Press, 0. Available: https://doi.org/10.1093/0195059239.003.0002 (Accessed 1/26/2024).

Gahl. W. n:d. Plasma Membrane (Cell Membrane). Available: https://www.genome.gov/genetics-glossary/Plasma-Membrane. (Accessed 1 February 2022).

Gaudet, S., Tremblay, J. and Begon, M. 2018. Muscle recruitment patterns of the subscapularis, serratus anterior and other shoulder girdle muscles during isokinetic internal and external rotations. *Journal of Sports Sciences* 36(9): 985-993. Available: https://pubmed.ncbi.nlm.nih.gov/28673118/. (Accessed 21 April 2023).

Gevers-Montoro, C., Provencher, B., Descarreaux, M., Ortega- de Mues, A. and Piché, M. 2021. Clinical effectiveness and efficacy of chiropractic spinal manipulation for spine pain. *Frontiers in Pain Research* 2. Available: https://pubmed.ncbi.nlm.nih.gov/35295422/. (Accessed 10 June 2023).

Gorrell, L. M., Conway, P. J. and Herzog, W. 2020. Differences in force-time parameters and electromyographic characteristics of two high-velocity, low-amplitude spinal manipulations following one another in quick succession. *Chiropractic & Manual Therapies* 28(1): 67. Available: https://doi.org/10.1186/s12998-020-00355-0. (Accessed 29 July 2023).

Grider, M. H., Jessu, R. and Kabir, R. 2023.Physiology, action potential by reviewed in *Treasure Island (FL)*, Available: https://pubmed.ncbi.nlm.nih.gov/30844170/. (Accessed 17 May 2022).

Hairi, N. N., Cumming, R. G., Naganathan, V., Handelsman, D. J., Le Couteur, D. G., Creasey, H., Waite, L. M., Seibel, M. J. and Sambrook, P. N. 2010. Loss of muscle strength, mass (sarcopenia), and quality (specific force) and its relationship with functional limitation and physical disability: the Concord Health and Ageing in Men Project. *Journal of American Geriatric Society* 58(11): 2055-2062. Available: https://pubmed.ncbi.nlm.nih.gov/21054284/. (Accessed 10 January 2023).

Harwich, A. S. 2017. Joint manipulation: Toward a general theory of high-velocity, low-amplitude thrust techniques. *Journal of Chiropractic Humanities* 24(1): 15-23. Available: https://www.sciencedirect.com/science/article/pii/S1556349916300134. (Accessed 10 January 2023).

Haynes, G. R. and Lisicki, A. 1996. Unique cause for 60-cycle interference. *Anesthesiology* 85(5): 1215-1216. Available: https://pubs.asahq.org/anesthesiology/article/85/5/1215/35798/Unique-Cause-for-60-Cycle-Interference#:~:text=Sixty%2Dcycle%20noise%20usually%20originates,traceable%20to%20any%20external%20source. (Accessed 19 May 2023).

Hertling. D. and Kessler. R. M. 1996. Management of common musculoskeletal disorders: physical therapy principles and methods. 6th Ed. Philadelphia, J.B. Lippincott.

Herzog, W., Lee, E. J. and Rassier, D. E. 2006. Residual force enhancement in skeletal muscle. *The Journal of physiology* 574(Pt 3): 635-642. Available: https://pubmed.ncbi.nlm.nih.gov/16709641 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1817744/. (Accessed 30 December 2022).

Hoke, A. P., McCord, P. and Tichenor, C. J. 2011. *Educational standards in orthopaedic manual physical therapy*. Available: https://www.ifompt.org/site/ifompt/IFOMPT%20Standards%20Document%20definitive%202016.pdf. (Accessed 30 January 2023).

Homola, S. 2006. Chiropractic: history and overview of theories and methods. *Clinical Orthopedics and Related Research* 444: 236-242. Available: https://pubmed.ncbi.nlm.nih.gov/16446588/#:~:text=Chiropractic%20is%20one%20of%20the,formulated%20the%20vertebral%20subluxation%20theory. (Accessed 21 February 2023).

Howard, R. 2017. The composition of muscle cells, muscle, fascicles, muscle fiber, myofibril, myofilaments, sarcomere, thick and thin filaments. (image). ReserachGate. Available: https://www.researchgate.net/publication/316688980_The_application_of_data_analysis_methods_for_surface_electromyography_in_shot_putting_and_sprinting/figures?lo=1&utm_source=google&utm_medium=organic. (Accessed 1 February 2022).

Hyde. T. E. and Gengenbach. M. S. 2007. Conservative management of sports injuries. The Journal of the Canadian Chiropractic Association. 2nd ed. Sudbury MASS: Jones and Bartlett Publishers. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2732261/. (Accessed 17 November 2022).

Jamal. Muhammad Zahak. 2012.Signal acquisition using surface EMG and circuit design considerations for robotic prosthesis by Ganesh, R. N., reviewed in *Rijeka*, Ch. 18. Available: https://doi.org/10.5772/52556. (Accessed 31 August 2022).

Jawl. B. 2017. Mechanisms and history of manual therapy: Part 1. AMP. (blog). Available: https://www.ampphysio.com/blog/2017/4/26/mechanisms-and-history-of-manual-therapy-part-1#. (Accessed 5 January 2022).

Kadaba, M. P., Ramakrishnan, H. K., Wootten, M. E., Gainey, J., Gorton, G. and Cochran, G. V. 1989. Repeatability of kinematic, kinetic, and electromyographic data in normal adult gait. *Journal of Orthopeadic Research* 7(6): 849-860. Available: https://pubmed.ncbi.nlm.nih.gov/2795325/. (Accessed 12 May 2022).

Katavich, L. 1998. Differential effects of spinal manipulative therapy on acute and chronic muscle spasm: a proposal for mechanisms and efficacy. *Manual Therapy* 3(3): 132-139. Available: https://www.sciencedirect.com/science/article/pii/S1356689X98800039. (Accessed 12 May 2022).

Kent. C. 1997. Surface electromyography in the assessment of changes in paraspinal muscle activity associated with vertebral subluxation: A review. Journal of Vertebral Subluxation Research. 1(3): 1-8. Available: https://www.semanticscholar.org/paper/Surface-Electromyography-in-the-Assessment-of-in-A-Kent/5ee843f22b0469a2af58f25913e2b08fa786fe50. (Accessed 25 October 2022).

Khanna, A. 2023. Action potential (image). TeachMePhysiology. Available: https://teachmephysiology.com/nervous-system/synapses/action-potential/. (Accessed 1 February 2022).

Kinsinger, F. S. 2009. Beneficence and the professional's moral imperative. *Journal of Chiropractic Humanities*, 16 (1): 44-46. Available: https://doi.org/10.1016/j.echu.2010.02.006. (Accessed 17 March 2021).

Koo, T. K. and Li, M. Y. 2016. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine* 15(2): 155-163. Available: https://pubmed.ncbi.nlm.nih.gov/27330520/. (Accessed 28 February 2023).

Landin, D., Thompson, M. and Jackson, M. R. 2017. Actions of the biceps brachii at the shoulder: A review. *Journal of Clinical Medicine Research* 9(8): 667-670. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5505302/. (Accessed 19 March 2023).

Laplante. P. A. 2018. Comprehensive dictionary of electrical engineering. ResearchGate. CRC Pres. Taylor & Francis. Available: https://www.routledge.com/Comprehensive-Dictionary-of-Electrical-Engineering/Laplante/p/book/9780849330865. (Accessed 25 October 2022).

LaPelusa, A. and Bordoni, B. 2023.High-velocity low-amplitude manipulation techniques by reviewed in *Treasure Island (FL)*, Available: https://pubmed.ncbi.nlm.nih.gov/34662041/. (Accessed 29 November 2022).

Laslett, M. 2008. Evidence-based diagnosis and treatment of the painful sacroiliac joint. *Journal of Manual Manipulation Therapy* 16(3): 142-152. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2582421/. (Accessed 19 March 2022).

Latash, M. L. 2018. Muscle coactivation: definitions, mechanisms, and functions. *Journal of Neurophysiology* 120(1): 88-104. Available: https://pubmed.ncbi.nlm.nih.gov/29589812/. (Accessed 25 April 2022).

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

Liljequist, D., Elfving, B. and Skavberg Roaldsen, K. 2019. Intraclass correlation - A discussion and demonstration of basic features. *PLoS One* 14(7): e0219854. Available: https://pubmed.ncbi.nlm.nih.gov/31329615/. (Accessed 31 May 2022).

Loranger, M., Treboz, J., Boucher, J. A., Nougarou, F., Dugas, C. and Descarreaux, M. 2016. Correlation of expertise with error detection skills of force application during spinal manipulation learning. *Journal of Chiropr Education* 30(1): 1-6. Available: https://pubmed.ncbi.nlm.nih.gov/26270897/. (Accessed 5 March 2022).

Lung, K., St Lucia, K. and Lui, F. 2023.Anatomy, thorax, serratus anterior muscles by reviewed in *Treasure Island (FL)*, Available: https://pubmed.ncbi.nlm.nih.gov/30285352/#:~:text=The%20serratus%20anterior%20is%20a,inferior%20angle%20of%20the%20scapula. (Accessed 19 October 2022).

Manipulation/mobilization - Manipulation/adjustment. 2001. Available: https://sdlegislature.gov/api/Rules/20:41:01:02.html. (Accessed 5 January 2022).

Mansfield. P. J. and Neumann. D. A. 2019. Essentials of Kinesiology for the Physical Therapist Assistant. 3rd ed. Available: https://books.google.co.za/books?hl=en&lr=&id=H2N0DwAAQBAJ&oi=fnd&pg=PP1&dq=Mansfield+and+Neumann.+2019+shoulder+internal+rotators&ots=O7xJd_Dyei&sig=DQP5SN1wOiNKeC8WNjRxAWwRCYM#v=onepage&q&f=false. (Accessed 26 June 2023).

Mechanisms and history of manual therapy: part 1. 2017. Available: https://www.ampphysio.com/blog/2017/4/26/mechanisms-and-history-of-manual-therapy-part-1 . (Accessed 1 February 2022).

Merletti, R. and Farina, D. 2009. Analysis of intramuscular electromyogram signals. *Philosophical transactions. Seriesa, mathimatical, physical and engineering sciences* 367(1887): 357-368. Available: https://pubmed.ncbi.nlm.nih.gov/19008187/#:~:text=The%20current%20clinical%20use%20of,full%20decomposition%20of%20the%20signal. (Accessed 21 May 2023).

Mesin, L. 2020. Crosstalk in surface electromyogram: literature review and some insights. *Physical and Engineering Sciences in Medicine* 43(2): 481-492. Available: https://doi.org/10.1007/s13246-020-00868-1. (Accessed 17 May 2023).

McCombes. S. 2020. Descriptive Research. Scribbr. Available: https://www.scribbr.com/methodology/descriptive-research/. (Accessed 24 September 2021).

McManus, L., De Vito, G. and Lowery, M. M. 2020. Analysis and biophysics of surface emg for physiotherapists and kinesiologists: Toward a common language with rehabilitation engineers. *Frontiers in Neurology* (Methods), 11. Available: https://www.frontiersin.org/articles/10.3389/fneur.2020.576729. (Accessed 25 July 2021).

Mikhail, J., Funabashi, M., Descarreaux, M. and Pagé, I. 2020. Assessing forces during spinal manipulation and mobilization: factors influencing the difference between forces at the patient-table and clinician-patient interfaces. *Chiropractic & Manual Therapies* 28(1): 57. Available: https://doi.org/10.1186/s12998-020-00346-1. (Accessed 17 May 2023).

Minx. E. 2020. Activator method chiropractic technique. Available: https://www.spine-health.com/treatment/chiropractic/activator-method-chiropractic-technique2. (Accessed 12 October 2022).

Monti, R. J., Roy, R. R. and Edgerton, V. R. 2001. Role of motor unit structure in defining function. *Muscle Nerve* 24(7): 848-866. Available: https://pubmed.ncbi.nlm.nih.gov/11410913/#:~:text=Abstract,control%20has%20been%20widely%20studied. (Accessed 12 October 2022).

Moon, J., Shin, I., Kang, M., Kim, Y., Lee, K., Park, J., Kim, K., Hong, D., Koo, D. and O'Sullivan, D. 2013. The effect of shoulder flexion angles on the recruitment of upper-extremity muscles during isometric contraction. *Journal of Physical Therapy Sciences* 25(10): 1299-1301. Available: https://pubmed.ncbi.nlm.nih.gov/24259780/#:~:text=The%20largest%20resultant%20force%20was,the%20exercise%20for%20the%20BB. (Accessed 25 December 2022).

Motor neuron fires (image). 2022. Available: https://quizlet.com/569957292/mod-107-109-muscle-tension-at-the-organ-level-skeletal-muscle-performance-smooth-and-cardiac-muscle-flash-cards/. (Accessed 1 April 2022).

Muratori, L. M., Lamberg, E. M., Quinn, L. and Duff, S. V. 2013. Applying principles of motor learning and control to upper extremity rehabilitation. *Journal of hand therapy : official journal of the American Society of Hand Therapists* 26(2): 94-103. Available: https://pubmed.ncbi.nlm.nih.gov/23598082 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3773509/. (Accessed 30 January 2023).

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

Navid, M. S., Lelic, D., Niazi, I. K., Holt, K., Mark, E. B., Drewes, A. M. and Haavik, H. 2019. The effects of chiropractic spinal manipulation on central processing of tonic pain - a pilot study using standardized low-resolution brain electromagnetic tomography (sLORETA). *Scientific Reports* 9(1): 6925. Available: https://doi.org/10.1038/s41598-019-42984-3. (Accessed 30 December 2022).

Nelson, C. F., Lawrence, D. J., Triano, J. J., Bronfort, G., Perle, S. M., Metz, R. D., Hegetschweiler, K. and LaBrot, T. 2005. Chiropractic as spine care: a model for the profession. *Chiropractic & Osteopathy* 13(1): 9. Available: https://doi.org/10.1186/1746-1340-13-9. (Accessed 30 December 2022).

Neumann, D. A. and Camargo, P. R. 2019. Kinesiologic considerations for targeting activation of scapulothoracic muscles - part 1: serratus anterior. *Brazilian Journal of Physical Therapy* 23(6): 459-466. Available: https://pubmed.ncbi.nlm.nih.gov/30737019/. (Accessed 19 January 2023).

Neuromuscular junction (image). 2012. Available: https://quizlet.com/107043741/27-neuromuscular-junction-flash-cards/. (Accessed 1 January 2023).

Oermann, M. H. P. R. N. 1990. Psychomotor skill development. *The Journal of Continuing Education in Nursing* 21(5): 202-204. Available: https://www.proquest.com/scholarly-journals/psychomotor-skill-development/docview/915651512/se-2?accountid=10612. (Accessed 17 April 2023).

Oh, H., Lee, S., Lee, K. and Jeong, M. 2018. The effects of flexion-distraction and drop techniques on disorders and Ferguson's angle in female patients with lumbar intervertebral disc herniation. *Journal of Physical Therapy Science* 30(4): 536-539. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5908997/#:~:text=%5BConclusion%5D%20Flexion%2Ddistraction%20and,with%20lumbar%20intervertebral%20disc%20herniation. (Accessed 12 May 2023).

Ourieff, J., Scheckel, B. and Agarwal, A. 2023.Anatomy, back, trapezius by reviewed in *Treasure Island (FL)*, Available: https://pubmed.ncbi.nlm.nih.gov/30085536/. (Accessed 12 May 2023).

Owens, E. F., Jr, Hosek, R. S., Sullivan, S. G., Russell, B. S., Mullin, L. E. and Dever, L. L. 2016. Establishing force and speed training targets for lumbar spine high-velocity, low-amplitude chiropractic adjustments. *Journal of Chiropractic Education* 30(1): 7-13. Available: https://pubmed.ncbi.nlm.nih.gov/26600272/. (Accessed 17 March 2023).

Owens, E. F., Jr, Russell, B. S., Hosek, R. S., Sullivan, S. G. B., Dever, L. L. and Mullin, L. 2017. Changes in adjustment force, speed, and direction factors in chiropractic students after 10 weeks undergoing standard technique training. *Journal of Chiropractic Education* 32(1): 3-9. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5834298/. (Accessed 17 March 2023).

Painter. M. F. 2011. Chiropractic Techniques. ChiroFusion. Available: https://chiro.org/LINKS/ABSTRACTS/Chiropractic_Techniques.shtml. (Accessed 13 October 2021).

Pasquier, M., Cheron, C., Dugas, C., Lardon, A. and Descarreaux, M. 2017. The effect of augmented feedback and expertise on spinal manipulation skills: An experimental study. *Journal of Manipulative Physical Therapy* 40(6): 404-410. Available: https://pubmed.ncbi.nlm.nih.gov/28822474/. (Accessed 12 February 2023).

Pasquier, M., Daneau, C., Marchand, A.-A., Lardon, A. and Descarreaux, M. 2019. Spinal manipulation frequency and dosage effects on clinical and physiological outcomes: a scoping review. *Chiropractic & Manual Therapies* 27(1): 23. Available: https://doi.org/10.1186/s12998-019-0244-0. (Accessed 19 October 2022).

Pedro, M., Rodríguez, C., Cossins, J., Beeson, D. and Vincent, A. 2020. The neuromuscular junction in health and disease: Molecular mechanisms governing synaptic formation and homeostasis. *frontiers in Molecular Neuroscience* Available: https://pubmed.ncbi.nlm.nih.gov/33343299/. (Accessed 17 November 2022).

Petajan, J. H. 1991. AAEM minimonograph #3: motor unit recruitment. *Muscle Nerve* 14(6): 489-502. Available: https://pubmed.ncbi.nlm.nih.gov/1852155/. (Accessed 12 December 2022).

Péter, A., Andersson, E., Hegyi, A., Finni, T., Tarassova, O., Cronin, N., Grundström, H. and Arndt, A. 2019. Comparing surface and fine-wire electromyography activity of lower leg muscles at different walking speeds. *Frontiers in Physiology* 10: 1283. Available: https://pubmed.ncbi.nlm.nih.gov/31649557/. (Accessed 19 October 2022).

Pettman, E. 2007. A history of manipulative therapy. *Journal of Manual & Manipulative Therapy* 15(3): 165-174. Available: https://doi.org/10.1179/106698107790819873. (Accessed 10 May 2022).

Pickar, J. G. 2002. Neurophysiological effects of spinal manipulation. *The Spine Journal* 2(5): 357-371. Available: https://pubmed.ncbi.nlm.nih.gov/14589467/. (Accessed 12 April 2022).

Potter, L., McCarthy, C. and Oldham, J. 2005. Physiological effects of spinal manipulation: a review of proposed theories. *Physical Therapy Reviews* 10(3): 163-170. Available: https://doi.org/10.1179/108331905X55820. (Accessed 15 November 2022).

Psychological outcomes in randomised controlled trials. n:d. Complementary Therapies in Medicine. 15(4):271-283.

Psychomotor domain of learning (image). 2014. Available: https://www.vectorsolutions.com/resources/blogs/teaching-skills-the-psychomotor-domain-of-learning-and-learning-objectives/. (Accessed 1 August 2022).

Quinn. E. and Olufade. O. 2021. Generally accepted values for normal range of motion (ROM) in joints. Verywellhealth. Available: https://www.verywellhealth.com/what-is-normal-range-of-motion-in-a-joint-3120361. (Accessed 1 February 2022).

Ray, P. and Mishra, S. 2022. Chapter 15 - Preserving healthcare data: from traditional encryption to cognitive deep learning perspective. In: Mishra, S., Tripathy, H. K., Mallick, P. K., Sangaiah, A. K. and Chae, G.-S. eds. *Cognitive Big Data Intelligence with a Metaheuristic Approach.* Academic Press, 323-345. Available: https://www.sciencedirect.com/science/article/pii/B9780323851176000017 (Accessed 17 May 2021)

Ravn, M. K., Ostergaard, T. I., Schroeder, H. D., Nyengaard, J. R., Lambertsen, K. L. and Frich, L. H. 2020. Supraspinatus and deltoid muscle fiber composition in rotator cuff tear conditions. *JSES International* 4(3): 431-437. Available: https://pubmed.ncbi.nlm.nih.gov/32939464/. (Accessed 10 May 2022).

Rayner. J. N. 2001. Spectral analysis. International Encyclopedia of the Social & Behavioral Sciences. Available: https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/spectral-analysis. (Accessed 15 February 2022).

Reed, D., Cathers, I., Halaki, M. and Ginn, K. A. 2016. Does changing the plane of abduction influence shoulder muscle recruitment patterns in healthy individuals? *Manual Therapy* 21: 63-68. Available: https://pubmed.ncbi.nlm.nih.gov/25920341/. (Accessed 12 July 2023).

Reed, D., Cathers, I., Halaki, M. and Ginn, K. A. 2018. Shoulder muscle activation patterns and levels differ between open and closed-chain abduction. *Journal of science and medicine in sport* 21(5): 462-466. Available: https://pubmed.ncbi.nlm.nih.gov/28803796/. (Accessed 17 March 2023).

Reed, D., Halaki, M. and Ginn, K. 2010. The rotator cuff muscles are activated at low levels during shoulder adduction: an experimental study. *Journal of Physiotherapy* 56(4): 259-264. Available: https://pubmed.ncbi.nlm.nih.gov/21091416/. (Accessed 10 June 2023).

Rodríguez Cruz, P. M., Cossins, J., Beeson, D. and Vincent, A. 2020. The neuromuscular junction in health and disease: Molecular mechanisms governing synaptic formation and homeostasis. *Frontiers in molecular neuroscience* 13: 610964-610964. Available: https://pubmed.ncbi.nlm.nih.gov/33343299 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7744297/. (Accessed 10 June 2023).

Senzon, S. A. 2018. The chiropractic vertebral subluxation part 9: Complexes, models, and consensus from 1979 to 1995. *Journal of Chiropractic Humanities* 25: 130-145. Available: https://www.sciencedirect.com/science/article/pii/S1556349918300172. (Accessed 15 March 2023).

Silva, A. C. d., Santos, G. M., Marques, C. M. d. G. and Marques, J. L. B. 2019. Immediate effects of spinal manipulation on shoulder motion range and pain in individuals with shoulder pain: A randomized trial. *Journal of Chiropractic Medicine* 18(1): 19-26. Available: https://www.sciencedirect.com/science/article/pii/S1556370718300464. (Accessed 10 June 2022).

Silverthorn. D. U. 2016. Human Physiology: An Integrated Approach. 7th Ed. Pearson. Available: https://www.amazon.com/Human-Physiology-Integrated-Approach-7th/dp/0321981227. (Accessed 15 October 2021).

Simundic, A.-M. 2008. Confidence interval. *Biochemia Medica* 18: 154-161. Available: https://www.researchgate.net/publication/255710466_Confidence_interval. (Accessed 12 June 2022).

Siparsky, P. N., Kirkendall, D. T. and Garrett, W. E., Jr. 2014. Muscle changes in aging: understanding sarcopenia. *Sports Health* 6(1): 36-40. Available: https://pubmed.ncbi.nlm.nih.gov/24427440/. (Accessed 15 July 2022).

Sircar, S. 2008. *Principles of medical physiology* Thieme. Available: https://books.google.co.za/books?id=zFI7y5xqHj4C. (Accessed 21 October 2022).

Skeletal muscle (image). 2017. Available: https://za.pinterest.com/pin/397090892129846511/?d=t&mt=login. (Accessed 1 August 2022).

Squire, J. M. 2016. Muscle contraction: Sliding filament history, sarcomere dynamics and the two huxleys. *Global cardiology science & practice* 2016(2): e201611-e201611. Available: https://pubmed.ncbi.nlm.nih.gov/29043260
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5642817/. (Accessed 17 May 2023).

Srivastava, S., Patten, C. and Kautz, S. A. 2019. Altered muscle activation patterns (AMAP): an analytical tool to compare muscle activity patterns of hemiparetic gait with a normative profile. *Journal of NeuroEngineering and Rehabilitation* 16(1): 21. Available: https://doi.org/10.1186/s12984-019-0487-y. (Accessed 12 October 2022).

Stoica, P. and Moses, R. 2005. Spectral analysis of signals. *Prentice Hall*. Available: https://www.researchgate.net/publication/265949092_Spectral_Analysis_of_Signals/citation/download. (Accessed 19 May 2022).

Stryker. S. 2013. Shoulders & their complexity. Life's Work Physical Therapy. Available: https://lifesworkpt.com/2013/07/shoulders-their-complexity/. (Accessed 1 February 2022).

Suehiro, T., Ishida, H., Kobara, K., Osaka, H. and Watanabe, S. 2018. Altered trunk muscle recruitment patterns during lifting in individuals in remission from recurrent low back pain. *Journal of Electromyographic Kinesiology* 39: 128-133. Available: https://pubmed.ncbi.nlm.nih.gov/29486424/. (Accessed 19 June 2022).

Sutapa, P., Pratama, K. W., Rosly, M. M., Ali, S. K. S. and Karakauki, M. 2021. Improving motor skills in early childhood through goal-oriented play activity. *Children (Basel)* 8(11). Available: https://pubmed.ncbi.nlm.nih.gov/34828707/. (Accessed 19 May 2023).

Talib, I., Sundaraj, K., Lam, C. K., Hussain, J. and Ali, M. A. 2019. A review on crosstalk in myographic signals. *European Journal of Applied Physiology* 119(1): 9-28. Available: https://pubmed.ncbi.nlm.nih.gov/30242464/. (Accessed 12 May 2022).

Taylor, J. A. and Ivry, R. B. 2012. The role of strategies in motor learning. *Annals of the New York Academy of Sciences* 1251: 1-12. Available: https://pubmed.ncbi.nlm.nih.gov/22329960/. (Accessed 12 May 2022).

Teaching Skills: The Psychomotor Domain of Learning and Learning (image). n:d. Available: https://www.vectorsolutions.com/resources/blogs/teaching-skills-the-psychomotor-domain-learning-and-learning-objectives/. (Accessed 12 February 2022).

Teaching skills: The psychomotor domain of learning and learning objectives. 2014. Available: https://www.vectorsolutions.com/resources/blogs/teaching-skills-the-psychomotor-domain-of-learning-and-learning-objectives/. (Accessed 20 February 2022).

Technique summary: Gonstead technique. 2010. Available: http://www.chiroaccess.com/Articles/Technique-Summary-Gonstead-Technique.aspx?id=0000128. (Accessed 1 February 2023).

Terry, J. 1994. The major electrolytes: sodium, potassium, and chloride. *Journal of Intravenous Nursing* 17(5): 240-247. Available: https://pubmed.ncbi.nlm.nih.gov/7965369/#:~:text=These%20substances%20are%20located%20in,important%20role%20in%20maintaining%20homeostasis. (Accessed 21 October 2022).

The four stages of range of movement in diarthrodial joints (image). 2001. Available: https://sdlegislature.gov/api/Rules/20:41:01:02.html. (Accessed 1 February 2023).

The Muscular System (image). 2013. Available: https://www.google.com/search?q=sliding+filament+theory&client=safari&rls=en&sxsrf=APq-WBsuucD_uu5VaXVc9bEP9XEpXk8sQ:1646639219894&source=lnms&tbm=isch&sa=X&ved=2ahUKEwjxl5mOwbP2AhUGilwKHSq5A5oQ_AUoAXoECAIQAw&biw=875&bih=736&dpr=2#imgrc=XKUJyFGOZQNg4M&imgdii=Qb0nNJ0K4wgZiM. (Accessed 19 March 2023).

Thompson Technique. (blog). 2018. Available: https://www.chiroeco.com/thompson-technique/. (Accessed 20 February 2022).

Tiwana, M. S., Sinkler, M. A. and Bordoni, B. 2023.Anatomy, shoulder and upper limb, triceps muscle by reviewed in *Treasure Island (FL)*, Available: https://pubmed.ncbi.nlm.nih.gov/30725681/. (Accessed 19 December 2022).

Tsang, S. M., Szeto, G. P. and Lee, R. Y. 2014. Altered spinal kinematics and muscle recruitment pattern of the cervical and thoracic spine in people with chronic neck pain during functional task. *Journal of Electromyographic Kinesiology* 24(1): 104-113. Available: https://pubmed.ncbi.nlm.nih.gov/24295545/. (Accessed 21 January 2023).

Turner, D. P. and Houle, T. T. 2019. Observational study designs. *Headache* 59(7): 981-987. Available: https://pubmed.ncbi.nlm.nih.gov/31297809/. (Accessed 12 June 2022).

Types of Muscle Contractions: Isotonic and Isometric (image). 2020. Available: https://med.libretexts.org/Bookshelves/Anatomy_and_Physiology/Book%3A_Anatomy_and_Physiology_(Boundless)/9%3A_Muscular_System/9.3%3A_Control_of_Muscle_Tension/9.3E%3A_Types_of_Muscle_Contractions%3A_Isotonic_and_Isometric. (Accessed 5 June 2023).

Types of muscle contractions: Isotonic and isometric. LibreTextsMEDICINE. 2020. Available: https://med.libretexts.org/Bookshelves/Anatomy_and_Physiology/Book%3A_Anatomy_and_Physiology_(Boundless)/9%3A_Muscular_System/9.3%3A_Control_of_Muscle_Tension/9.3E%3A_Types_of_Muscle_Contractions%3A_Isotonic_and_Isometric. (Accessed 12 June 2022).

Uhl, T. L., Carver, T. J., Mattacola, C. G., Mair, S. D. and Nitz, A. J. 2003. Shoulder musculature activation during upper extremity weight-bearing exercise. *Journal of Orthopedic Sports Physical Therapy* 33(3): 109-117. Available: https://www.jospt.org/doi/pdf/10.2519/jospt.2003.33.3.109. (Accessed 15 March 2023).

Vaskovic. J. 2021. Action potential. Available: https://www.kenhub.com/en/library/anatomy/action-potential. (Accessed 19 June 2022).

Visual depiction of motor unit activity in relation to recording electrodes (image). 2011. Available: https://www.google.com/search?q=%3A+Visual+depiction+of+motor+unit+activity+in+relation+to++recording+electrodes&tbm=isch&ved=2ahUKEwjc0JnawrP2AhUrIf0HHR7CChIQ2-cCegQIABAA&oq=%3A+Visual+depiction+of+motor+unit+activity+in+relation+to++recording+electrodes&gs_lcp=CgNpbWcQAzIHCCMQ7wMQJzIECAAQQzIECAAQQzIECAAQQzIECAAQQzIFCAAQgAQyBQgAEIAEMgUIABCABDIFCAAQgAQyBQgAEIAEUKoFWKoFYOgHaABwAHgAgAGyAogBsgKSAQMzLTGYAQCgAQGqAQtnd3Mtd2l6LWltZ8ABAQ&sclient=img&ei=H7olYpzFK6uq9u8PnoSrkAE&bih=736&biw=875&client=safari. (Accessed 21 July 2023).

Wälchli, M., Ruffieux, J., Bourquin, Y., Keller, M. and Taube, W. 2016. Maximizing performance: Augmented feedback, focus of attention, and/or reward? *Medicine & Science in Sports & Exercise* 48(4): 714-719. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5638420/. (Accessed 17 May 2023).

Wang. J., Tang. L., Bronlund. J. E. 2013. Surface EMG signal amplification and filtering. International Journal of Computer Applications. Available: https://research.ijcaonline.org/volume82/number1/pxc3892073.pdf. (Accessed 12 February 2022).

Watson. T. n.d. Contraindications and precautions electro stimulators manuals. Available: http://www.electrostimulateurs-manuels.fr/fichiers/publications/Contraindications-et-Precautions/contraindications.pdf. (Accessed 27 October 2021).

Watson, T. and Radwan, H. 2001. Comparison of three teaching methods for learning spinal manipulation skill: A pilot study. *Journal of Manual & Manipulative Therapy* 9: 48-52. Available: https://www.researchgate.net/publication/233587863_Comparison_of_Three_Teaching_Methods_for_Learning_Spinal_Manipulation_Skill_A_Pilot_Study/citation/download. (Accessed 19 June 2022).

Wattanaprakornkul, D., Halaki, M., Boettcher, C., Cathers, I. and Ginn, K. A. 2011. A comprehensive analysis of muscle recruitment patterns during shoulder flexion: an electromyographic study. *Clinical Anatomy* 24(5): 619-626. Available: https://pubmed.ncbi.nlm.nih.gov/21647962/. (Accessed 29 October 2022).

Welniarz, Q., Dusart, I. and Roze, E. 2017. The corticospinal tract: Evolution, development, and human disorders. *Developmental Neurobiology* 77(7): 810-829. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/dneu.22455. (Accessed 6 August 2022).

Widmaier, E. P., Raff, H. and Strang, K. T. 2010. Vander's human physiology: The mechanisms of body function. *Science and Education*: 250-291. (Accessed 1 February 2022).

Widmaier, E. P., Raff, H., Strang, K. T. and Vander, A. J. 2016. *Vander's human physiology : the mechanisms of body function.* (Accessed 19 August 2022).

Wu, J., Li, X., Liu, W. and Jane Wang, Z. 2019. Semg signal processing methods: A review. *Journal of Physics: Conference Series* 1237(3): 032008. Available: http://dx.doi.org/10.1088/1742-6596/1237/3/032008. (Accessed 21 November 2022).

Wulf, G., Shea, C. and Lewthwaite, R. 2010. Motor skill learning and performance: a review of influential factors. *Med Educ* 44(1): 75-84. Available: https://pubmed.ncbi.nlm.nih.gov/20078758/. (Accessed 21 May 2022).

Yelverton, C., Zietsman, A., Johl, G. and Peterson, C. 2022. Differences in practice characteristics between male and female chiropractors in south africa: Secondary analysis of data from scope of practice survey 2015. *Journal of Manipulative and Physiological Therapeutics* 45(1): 90-96. Available: https://www.sciencedirect.com/science/article/pii/S0161475422000306. (Accessed 12 January 2023).

Yin, G., Zhang, X., Chen, D., Li, H., Chen, J., Chen, C. and Lemos, S. 2020. Processing surface emg signals for exoskeleton motion control. *Frontiers in neurorobotics* 14: 40-40. Available: https://pubmed.ncbi.nlm.nih.gov/32765250
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7381241/. (Accessed 17 May 2022).

Yoo, W. G. 2017. Comparison of the trapezius and serratus anterior muscles isolation ratio during different shoulder abduction exercises. *Journal of Physical Therapy Sciences* 29(6): 964-965. Available: https://pubmed.ncbi.nlm.nih.gov/28626300/. (Accessed 17 May 2023).

APPENDICES

Appendix 1: Gatekeeper-permission-letter_DRC

[27/07/21]

Benjamin Hardy
Student in master's Research Program
Student number: 21717391

Request for Permission to Conduct Research

To Dr Linganiso

My name is Benjamin Hardy, a 5th year (masters) Chiropractic student at the Durban University of Technology. The research I wish to conduct for my master's dissertation involves, Muscle recruitment patterns of selected upper extremity muscles in Chiropractors within the eThekwini Municipality while performing a simulated sacroiliac joint manipulation.

I am hereby seeking your consent to conduct my study on the DUT premises and use the appropriate equipment.

I have provided you with a copy of my proposal which includes copies of the data collection tools and consent and / or assent forms to be used in the research process, as well as a copy of the approval letter which I received from the Institutional Research Ethics Committee (IREC).

If you require any further information, please do not hesitate to contact me at benlukehardy15@gmail.com.

Thank you for your time and consideration in this matter.

Yours sincerely,

Benjamin Hardy
Durban University of Technology

Appendix 2: Memorandum

MEMORANDUM

To	:	Prof Adam Chair: IREC
From	:	Dr Desiree Varatharajullu Head of Department: Chiropractic Clinic Director: Chiropractic Day Clinic: Chiropractic
Date	:	24.03.2022
Re	:	Request for permission to use the Chiropractic Day Clinic for research purposes

Permission is hereby granted to:

Mr Benjamin Hardy (Student Number: 21717391)

Research title: "Muscle recruitment patterns of selected upper extremity muscles while performing spinal manipulation in chiropractors within the eThekwini Municipality".

Mr Hardy is requested to submit a copy of his FRC/IREC approved proposal along with proof of his MHSc: Chiropractic registration to the Clinic Administrator/s before he starts with his research in order that any special procedures with regards to his research can be implemented prior to the commencement of him seeing patients.

Thank you for your time.

Kind regards

Dr D Varatharajullu

Head of Department: Chiropractic

Clinic Director: Chiropractic Day Clinic: Chiropractic

Cc: Mrs Linda Twiggs: Chiropractic Day Clinic

Dr B. Murphy: Supervisor

Dr L. O'Connor: Co-supervisor

Appendix 3: Clinic director permission DRC

To : Dr D. Varatharajullu
HoD and Clinic Director, Department of Chiropractic

From : Benjamin Luke Hardy
Registered student: MHSc
Student number: 21717391

RE : Request to utilise DUT Chiropractic Clinic for research purposes

Date : 24/03/2022

I would like to request to utilise the DUT Chiropractic Clinic to collect data for my Masters research project titled: Muscle recruitment patterns of selected upper extremity muscles in Chiropractors within the eThekwini Municipality while performing a simulated sacroiliac joint manipulation

I would be requiring access to the surface electromyography machine. I will source my own participants. However should there be participants who are wanting to enrol in the study from the clinic clinician base, I request the option is open for them to join the study should they meet the required inclusion criteria.

The study aims and objectives pertaining to using the clinic are detailed below:

Aim: To identify the muscle recruitment patterns of selected upper extremity muscles in Chiropractors within the eThekwini Municipality while performing a simulated sacroiliac joint manipulation

Objectives:

1. To determine the activation patterns (onset, percentage and duration) of the targeted muscles (bicep brachii, triceps brachii, deltoid, pectoralis major, serratus anterior, upper trapezius / supraspinatus, middle and lower trapezius and infraspinatus) during the phases of the sacroiliac joint manipulation.

2. To assess the reliability of the muscle activation patterns between the three preformed sacroiliac joint manipulations.

I envisage utilising the facility from April 2022 to June 2022.

Should you require any further information from me please do not hesitate to contact me at
Email: benlukehardy15@gmail.com.
Cell: +27 71 156 1111

Yours sincerely,
Benjamin Luke Hardy

Appendix 4: Consent Form

CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Benjamin Hardy (name of researcher), about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: ______039/22
- 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 computerized 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 this research which may relate to my participation will be made available to me.

______________________ ___________ _______ ________________

Full Name of Participant Date Time

Signature / Right Thumbprint

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

___________________ ___________ _____________________

Full Name of Researcher Date Signature

___________________ ___________ _____________________

Full Name of Witness (If applicable) Date Signature

_________________ __________ ___________________

Full Name of Legal Guardian (If applicable

Appendix 5: Data Sheet

Name: ______________________________ Date: __________________

Please complete the following information about yourself. Where necessary please place an 'X' in the appropriate box.

Demographic Characteristics:			
1.	Age		years
2.	Sex	Female	Male
3.	Height		cm
4.	Weight		kg
5.	Hand dominance	Left	Right
Practice characteristics:			
1.	Years in practice		years
2.	Hours practiced per week		hours
3.	Institution of Chiropractic graduation		Durban University of Technology/ Durban Institute of Technology/Natal Technikon
			University of Johannesburg/WITS Technikon
			Other (please specify):
4.	Year of graduation		year

Thank you for

Appendix 6: Letter of information

Dear Chiropractor,

My name is Benjamin Hardy. I am currently registered in the Master of Health Sciences Chiropractic program at the Durban University of Technology.

Thank you for volunteering to participate in this research.

Title of the Research Study:

Muscle recruitment patterns of selected upper extremity muscles in Chiropractors within the eThekwini Municipality while performing a simulated sacroiliac joint manipulation.

Field of Research:

Chiropractic, Spinal Manipulation, Electromyography.

Principal Investigator/s / Researcher:

Benjamin Hardy; B. Tech Chiropractic.

Co-Investigator/s / Supervisor/s:

- Dr Laura O'Connor; Senior Lecturer; M. Tech Chiropractic.
- Professor Bernadette Murphy; Interim Dean at Ontario University of Technology; PhD.

Introduction

Spinal manipulation (SM) is commonly used in the treatment of musculoskeletal disorder. Although the literature regarding the forces transmitted during SM is extensive, it is simultaneously limited in terms of the muscles used to generate these forces and enable the execution of the SM. This study aims to contribute to the literature by investigating the muscle recruitment patterns of selected upper extremity muscles in Chiropractors, within the eThekwini Municipality, while performing a simulated sacroiliac joint manipulation.

Identifying which muscles, one primarily uses during a specific manipulation will aid the profession in terms of the training and development of future chiropractors, allowing students to fully engage in the phases of motor learning. This will have the potential to improve the standard of practical and theoretical education in the chiropractic field and inevitably improving the calibre of chiropractic graduates.

Outline of the Procedures

To obtain muscle activity patterns, surface electromyography (sEMG) will be utilized together with a simultaneous video recording of you executing the sacro-iliac simulated manipulation on a punching bag.

On arrival for your appointment, you will be given a letter of information, consent form and patient data sheet to read, complete and sign. You will then demonstrate the manipulative technique (MT) on the dummy to ensure participation eligibility. If you are not deemed eligible you will be thanked and removed from the study. If you are deemed eligible you will be required to give the researcher your personal electronic devices which will be collected and stored in a secure location outside the clinic room for the extent of the session and returned to you at the end of the session to avoid any electronic interference with the sEMG. Electrodes will then be placed on your manipulating arm on the following muscles: bicep brachii, triceps brachii, deltoid, pectoralis major, serratus anterior, upper trapezius / supraspinatus, middle and lower trapezius, and infraspinatus. To ensure good contact, only, if necessary, the area where the electrodes will be placed will be shaved and cleaned with alcohol. You will then have an opportunity to practice the MT, with a maximum of three attempts, to familiarize yourself with the dummy and performing the MT with the sEMG equipment on.

Once you are ready to start, you will position yourself to perform the adjustment. A force transducer will be placed under your manipulation hand, and you will be asked to press against the punching bag with your maximal force in a similar posture to what you will use during the manipulation. You will hold this contraction for approximately five seconds. This will be repeated three times to obtain a means of standardization. Thereafter you will have a two-to-three-minute break.

After the break and when you are ready, you will re-position yourself in your manipulation position with the video recorder being switched on to document the adjustment. On the researchers command you will initiate the preload phase. When you are comfortable to manipulate, you will indicate this to the researcher verbally (this allows the researcher to differentiate the phases of SMT). You will then apply the necessary adjustment. After the adjustment is completed, a three-minute rest interval will be taken to allow your muscles to return to a relaxed state. This process (preload, thrust, rest) will be repeated three times.

After all necessary data is successfully collected, the sEMG will be switched off, electrodes will be removed and discarded, personal electronic belongings will be returned, and you will be free to leave.

This procedure should take approximately 45 minutes to 1 hour.

Risks or Discomforts to the Participant

There are no risks to you in participating in this study. Removal of the electrodes and potential shaving of the hair where the electrodes are placed may be minimally uncomfortable but transient. Please note that this study may be terminated early or suspended due to government rulings which prohibit personal contact between people.

Reasons for Withdrawal from Study

If you no longer wish to partake in the study, you may at any point inform the researcher or supervisor and you will be withdrawn from the project.

Benefits

By participating in this study, you will be contributing to the expansion of the literature about manipulation and how it is performed.

Remuneration

Participation in this study is voluntary, therefore no remuneration will be awarded to you.

Costs of the Study

There will be no expense to you for participating in this study except transport costs to and from the DUT Day clinic for data collection.

Confidentiality

The details and information obtained from this study will be treated with utmost confidence. All data will be coded to ensure anonymity of the data.

Results

Results of the study will be available in a dissertation and will be published in a journal.

Research-related Injury

Should you incur any research related injury please inform the researcher immediately. However due to the nature of this study, injury is unlikely, as the procedure is one that is performed often by chiropractors.

Storage of data

The data collected will be transferred onto a flash drive where it will then be placed in the Chiropractic Program archive where it will be stored for five years after which it will be destroyed. Your personal details will only be accessible by the researcher and supervisors. Your personal details will be omitted to ensure confidentiality and professionalism.

Persons to contact in the Event of Any Problems or Queries

If you have any queries, please contact either the:

-

- Researcher at Benlukehardy15@gmail.com
- Supervisor at lauraw@dut.ac.za
- Institutional Research Ethics Administrator @ 031 373 2375.
- Complaints can be reported to the Director: Research and Postgraduate Support Dr L Linganiso @ 031 373 2577 or researchdirector@dut.ac.za

Thank you for your time and willingness to participate in this study.

Appendix 7: Advertisement

Chiropractic Research Needs Volunteers

Request for AHPCSA Registered Chiropractors Within eThekwini

To volunteer for the research project titled:

Muscle recruitment patterns of selected upper extremity muscles in Chiropractors within the eThekwini Municipality while performing a simulated sacroiliac joint manipulation

Study Location

Durban University of Technology
(11 Ritson Road, Berea, Durban)

If you are interested in volunteering or have any query's, please **contact**;

- Researcher: - 071 156 1111
  - Benjamin Hardy @ Benlukehardy15@gmail.com
- Supervisor: - Dr Laura O'Connor @ lauraw@dut.ac.za

Appendix 8: Ethics certificates

Module 1_Training Certificate


Zertifikat

Certificado

Certificat

Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale

Promoting the highest ethical standards in the protection of biomedical research participants

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Benjamin Hardy

a complété avec succès - has successfully completed

Introduction to Research Ethics

du programme de formation TRREE en évaluation éthique de la recherche

of the TRREE training programme in research ethics evaluation

Release Date: 2019/10/30

Professeur Dominique Sprumont

Coordinateur TRREE Coordinator

Ce programme est soutenu par - This program is supported by :

Module 2.1_Training Certificate


Zertifikat

Certificado

Certificat

Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale

Promoting the highest ethical standards in the protection of biomedical research participants

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Benjamin Hardy

a complété avec succès - has successfully completed

Research Ethics Evaluation

du programme de formation TRREE en évaluation éthique de la recherche

of the TRREE training progr

Release Date: 2022/01/18

Professeur Dominique Sprumont

Coordinateur TRREE Coordinator

Ce programme est soutenu par - This program is supported by :

Module 3.1_Training Certificate

Zertifikat
Certificat
Certificado
Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Benjamin Hardy

a complété avec succès - has successfully completed

Informed Consent

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2022/01/18

Professeur Dominique Sprumont
Coordinateur TRREE Coordinator

FMH Continuing Education Program (5 Credits)
Programme de Formation continue (5 Crédits)

FPH Programmes de formation continue
Continuing Education Programs
Programmes de formation continue

Ce programme est soutenu par - This program is supported by :
European and Developing Countries Clinical Trials Partnership (EDCTP) (www.edctp.org) - Swiss National Science Foundation (www.snf.ch) - Canadian Institutes of Health Research - Swiss Academy of Medical Science (SAMS/ASSM/SAMW) (www.samw.ch) - Commission for Research Partnerships with Developing Countries (www.kfpe.ch)

Module 3.2_Download Training Certificate

Zertifikat
Certificat
Certificado
Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Benjamin Hardy

a complété avec succès - has successfully completed

Good Clinical Practice (GCP-E6(R2) 2016)

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2022/01/19

Coordinateur TRREE Coordinator

FMH Continuing Education Program (5 Credits)
Programme de Formation continue (5 Crédits)

FPH Programmes de formation continue
Continuing Education Programs
Programmes de formation continue

Ce programme est soutenu par - This program is supported by :
European and Developing Countries Clinical Trials Partnership (EDCTP) (www.edctp.org) - Swiss National Science Foundation (www.snf.ch) - Canadian Institutes of Health Research - Swiss Academy of Medical Science (SAMS/ASSM/SAMW) (www.samw.ch) - Commission for Research Partnerships with Developing Countries (www.kfpe.ch)

Appendix 9: Consent to Chiropractic treatment during COVID19

DUT DURBAN UNIVERSITY OF TECHNOLOGY | FACULTY OF HEALTH SCIENCES | DEPARTMENT OF CHIROPRACTIC

Department of Chiropractic

Faculty of Health Sciences
Ritson Campus
Durban University of Technology

11 Ritson Road, Berea, Durban 4001
P O Box 1334, Durban, 4000, South Africa
Tel: (031)373 2205
www.dut.ac.za

CONSENT FOR CHIROPRACTIC TREATMENT DURING THE COVID-19 PANDEMIC

I, ____, knowingly and willingly consent for myself or for a minor_________________________________, under my care, to receive elective Chiropractic or emergency Chiropractic treatment from the Durban University of Technology Chiropractic Day clinic during the COVID-19 pandemic.

I understand the COVID-19 virus has a long incubation period during which carriers of the virus may not show symptoms but still be highly contagious.
Chiropractic procedures/treatment take place with the patient in very close proximity to the practitioner. This potentially exposes the patient and the practitioner to the COVID-19 virus.

I understand that due to the frequency of other Chiropractic patients, the characteristics of the virus, and the characteristics of Chiropractic practice, that I have an elevated risk of contracting the virus simply by being in the Chiropractic clinic.
___________ (Initial)

I confirm that I am not presenting with ANY of the following symptoms of COVID-19 listed below:

- Fever
- Shortness of Breath
- Dry Cough
- Runny Nose
- Sore throat

High risk patients relating to the severity of COVID-19 are persons of the age of 60 and persons who have pre-existing medical conditions such as: asthma; chronic lung conditions; hypertension; autoimmune diseases; organ transplants; cancer; immunocompromised; obesity (BMI over 40); more than 27 weeks pregnant; and liver or kidney conditions.

a.) I confirm that I do not fall into any of these high risk categories ___________(Initial) or

b.) I confirm that I do fall into these high health risk categories and I am aware of the increased risk of severe infection due to my age/pre-existing medical conditions should I contract Covid-19 ____________ (Initial)

I am aware of the risks involved with the spread of COVID-19 and the risks it may hold to my health and the health of others I come into contact with. I accept those risks and hereby indemnify and hold the Durban University of Technology Chiropractic Day Clinic and its students and staff blameless should I contract the disease at the clinic premises or from the clinic staff and/or students.

___________________________	_________________
Patient's signature	DATE
___________________________	_______________________
Student Signature	Clinician Signature

PRACTICAL GUIDELINES TO THE CONSULTATION

1.1 I, ____ have read and understand the practical guidelines as set out hereunder and confirm that I will comply thereto and prepare accordingly.

1. 1.1.1 I will sign all consent forms at home and bring the forms to the Chiropractic Day Clinic at the time of my appointment, failing which I will not be treated. I may also sign same electronically and email same to the clinic.
2. 1.1.2 Patients will be contacted and screened the day before consultations, and requested to take appropriate action if they are presenting with any risk symptoms or history.
3. 1.1.3 Patients will be prohibited from entering the campus/clinic if the patient hasn't complied with proper control measures.

   .
4. 1.1.4 Patients will not be allowed in the waiting room and will be requested to wait in their cars

   until called by the reception staff to enter the clinic.
5. 1.1.5 All patients will be sprayed with hand sanitizer upon entry.
6. 1.1.6 All patients must wear a face mask at all times once on campus.
7. 1.1.7 Patients are to requested to ensure that they arrive on time for their appointment otherwise their appointment may need to rescheduled.
8. 1.1.8 On arrival, patients will again be screened for risk factors including the taking of temperature.
9. 1.1.9 Between consultations, the necessary hygiene/cleaning protocols will be done by the students/staff and this may cause a delay and prolong waiting periods.
10. 1.1.10 Patients are requested to avoid touching anything inside the clinic.
11. 1.1.11 Patients are requested to remove any jewellery and leave the same at home as it can be a carrier of infection droplets.
12. 1.1.12 Friends and family members will be requested to wait in the car and will not be permitted into the clinic except in the case of patients who require assistance or a minor.
13. 1.1.13 Patients are requested to pay for their appointments using a card. If this is not possible then please ensure that you have the correct denomination of cash available as we will not be able to issue change.
14. 1.1.14 Patients are requested to please bring their own towel, gown and shorts to avoid having to use clinic attire.

______________________________ ____________________

Patient's signature DATE

Appendix 10: Declaration for entry into the Chiropractic Day Clinic

DUT DURBAN UNIVERSITY OF TECHNOLOGY | FACULTY OF HEALTH SCIENCES | DEPARTMENT OF CHIROPRACTIC

Department of Chiropractic
Faculty of Health Sciences
Ritson Campus
Durban University of Technology

11 Ritson Road, Berea, Durban 4001

P O Box 1334, Durban, 4000, South Africa

Tel: (031)373 2205

www.dut.ac.za

COVID-19
Declaration for entry into the Chiropractic Day Clinic

Name and Surname	
File No	
Contact number	
Reason for entry	Appointment
Body temperature reading at time of entry	

TICK AS APPLICABLE	**YES**	**NO**
Have you been in contact in the last 14 days with someone who is confirmed to have COVID-19?		
Have you been for a COVID-19 test in the last 14 days?		
Have you received test results for COVID-19 in the last 14 days?		
What was the outcome: ______________________	N/A	
Do you have any results pending for COVID-19 testing?		
Are you currently suffering with any of the following symptoms or have you had any of these symptoms within the past 14 days?		
• Cough		
• Fever		
• Sore throat		
• Shortness of breath (or difficulty of breathing)		
• Fatigue, weakness or tiredness		
• Aches and pains or headaches		
• Loss of smell		
• Loss of taste		
• Redness of eyes		
• Nausea		
• Vomiting		
• Diarrhoea		

Declaration
I hereby declare that the information I have disclosed is correct at the time of completion. To the best of my knowledge I have not had direct contact with any person who has tested positive for COVID-19 symptoms in the past 14 days, nor have I presented with any of the above COVID-19 symptoms within the past 14 days.

_________________________________ Signature

_______________ Date

Appendix 11: Patient information letter - Covid-19.

Department of Chiropractic
Faculty of Health Sciences
Ritson Campus
Durban University of Technology

11 Ritson Road, Berea, Durban 4001

P O Box 1334, Durban, 4000, South Africa

Tel: (031)373 2205

www.dut.ac.za

Dear patient,

Given the current situation with the COVID-19 Virus around the world we have implemented some measures to ensure the safety of all our patients, staff and students.

With this in mind please take note of the following protocols that have been implemented in our clinic:

1. Patients will be contacted and screened the day before consultations, and requested to take appropriate action if they are presenting with any risk symptoms or history.

2. Access to campus will be strictly controlled. Upon arrival at gate 6 you will be required to present your ID as well as confirmation of your appointment which will be sent to you either via email, WhatsApp or SMS.

3. Please note that it is essential that you arrive **on time for your appointment** as we cannot admit more than one patient at a time to the clinic and should you arrive late, your appointment may have to be rescheduled.

4. Upon arrival you will need to please telephone the clinic reception on 031 3732205 **from the parking area** to advise them that you have arrived for your appointment. Once you have done this **please wait in your vehicle** until you are notified via telephone to enter the building. You will once again be screened and your temperature will be checked upon entry and you will be required to sign a consent to treatment as well as a declaration for entry into the Chiropractic clinic. Please bring your own pen with you in order to complete/sign any relevant documentation.

5. All patients, staff and students will be required to wear masks at all times. **Any person not wearing a mask will strictly not be permitted access to the campus and/or clinic**. Should you need more information on the AHPCSA's guidelines for good practice hygiene, please consult www.ahpcsa.co.za

6. Patients will be required to sanitise their hands in the reception prior to treatment.

7. Please leave as many accessory items at home or in the car as you are able to. This includes watches/jewellery etc. the less there is on you, the less chance there is of contamination.

8. Please bring your own shorts/gowns or wear loose comfy clothing that you do not need to change into the clinic attire.

9. Please note that for health and security reasons we will not be retaining cash on our premises so it would be preferable for you to make payment by card. If you choose to pay with cash, please ensure that you have the correct denominations available as **it will not be possible for us to give change**.

10. Please note that all friends and family will be asked to wait in the car.

11. Appointment times will be made longer due to the time taken to disinfect all handles/machines and treatment surfaces. Please keep this is mind when making your appointment.

12. Patients are requested to avoid touching anything inside the clinic.

13. If you are experiencing **any signs and symptoms of COVID-19 please reschedule your appointment** (cough, fever (above 38degrees), sore throat, tiredness, exposure to anyone with suspected or diagnosed with COVID-19 in the last 14 days or if you have worked or attended a clinic facility treating COVID-19 patient/s).

    Please note that under South African law any person who intentionally exposes another person to COVID-19, may be prosecuted for an offence, including assault, attempted murder or murder.

14. Patients who are at **high risk** of contracting severe COVID-19***(see table below)** are advised to only book an appointment in the event of an emergency. Otherwise you are urged to rather stay at home in the interest of your own health and safety.

Risk Factors for Severe COVID-19

Risk Factor	**Detail**	**Definition**
Age	People 60 years and older with comorbidities	Aged 60 years or older with one or more disorders or conditions
People of all ages with the following underlying medical conditions, particularly if not well controlled:		
Cardiovascular disease	Moderate/Severe Hypertension	Moderate hypertension: Systolic BP 160-179mmHg and/or systolic BP ≥180mmHg. Severe hypertension: systolic BP≥180mmHg and/or diastolic BP≥110mmHg.
	Congestive cardiac failure or other serious cardiovascular disease	Confirmed clinicial diagnosis of congestive cardiac failure or other serious cardiovascular disease
	Cerebrovascular disease, including stroke and transient ischaemic attack	Confirmed clinical diagnosis of cerebrovascular disease.
Respiratory Disease	Pulmonary Tuberculosis –untreated or in early treatment	People who have not completed the intensive phase or first two months of treatment in line with the National Department of Health Standard Treatment Guidelines.
	Moderate to severe asthma	Asthma which requires treatment with high dose inhaled corticosteroids, plus a second controller (and/or systemic corticosteroids) to prevent it from becoming 'uncontrolled' or which remains 'uncontrolled' despite this therapy.
	Chronic Obstructive Pulmonary Disease (COPD)	Confirmed clinical diagnosis of COPD
	Other severe chronic lung pathology, including cystic fibrosis and bronchiectasis	Confirmed clinical diagnosis – irrespective of severity.

Kidney Disease	Chronic Kidney Disease	eGFR< 45
Pregnancy	Third trimester pregnancy	Estimated to be further than week 27 of pregnancy
Immunosuppression	Poorly controlled type II Diabetes Mellitus	HBAIc ≥7.5% within last 6 months
	Cancer undergoing active treatment	Currently undergoing chemotherapy and/or radiotherapy
	Human Immunodeficiency Virus with advanced immunosuppression	HIV positive persons with CD4 count <200 cells/mm^3 who are ART-naïve or who initiated ART within the last three months.
	Chronic immunosuppressant use	Chronic use of corticosteroids of >20mg prednisone per day or equivalent, methotrexate, biologicals or other immunosuppresants.
	Transplant	On chronic immunosuppressants.
Metabolic Syndrome	Severe Obesity	Body mass index (BMI) of 40 and higher.

Please feel free to contact us if you have any queries. Stay safe.

Appendix 12: Descriptive outcomes regarding the activation magnitude median for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases.

Table 4.2: Descriptive outcomes regarding the activation magnitude median for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases.

MUSCULATURE	ADJUSTMENT PHASES								
	PRELOAD			THRUST			RESOLUTION		
	Mean	SD	Mean Rank	Mean	SD	Mean Rank	Mean	SD	Mean Rank
AD	13.8	11.0	3.4	81.8	26.3	6.2	41.2	28.6	4.6
SP	23.1	13.7	7.4	80.9	48.7	5.6	51.5	31.3	6.4
Tri	17.4	12.1	5.6	89.7	40.4	6.8	51.7	20.7	7.5
MT	22.1	15.8	6.5	97.4	52.3	7.3	63.5	58.6	7.0
PD	17.7	12.7	5.4	70.8	56.6	4.6	62.3	84.0	5.4
UT	18.7	9.6	5.7	76.1	32.6	5.7	46.7	24.7	5.8
Bi	22.6	16.3	7.0	89.3	70.4	5.9	41.6	27.2	4.8
CP	24.1	11.5	8.2	80.1	28.9	6.2	50.5	28.8	6.3
LT	19.8	15.1	6.0	90.4	43.8	6.6	56.9	31.2	6.6
SA	21.6	13.5	6.5	68.9	28.8	5.1	42.3	21.8	5.5
IS	17.0	10.3	4.6	89.9	49.1	6.4	50.5	30.7	6.3

Appendix 13: : Descriptive outcomes regarding the activation magnitude mean for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases.

Table 4.7: Descriptive outcomes regarding the activation magnitude mean for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases.

MUSCULATURE	ADJUSTMENT PHASES					
	PRELOAD		THRUST		RESOLUTION	
	Mean	SD	Mean	SD	Mean	SD
AD	15.7	10.8	82.3	26.1	48.5	31.9
SP	25.8	13.6	80.7	45.2	55.1	30.1
Tri	19.6	12.5	88.4	36.6	62.3	23.7
MT	25.4	17.4	102.0	59.6	70.3	66.2
PD	21.9	16.0	79.6	76.3	80.8	124.6
UT	22.9	10.8	82.1	32.8	54.7	29.8
Bi	25.6	18.3	89.0	66.1	49.9	41.5
CP	27.3	12.7	81.2	28.3	53.1	27.5
LT	22.6	17.2	95.4	45.6	59.6	31.5
SA	23.7	14.4	70.5	28.3	45.2	21.4
IS	20.2	12.0	93.6	48.8	56.3	31.4

Appendix 14: Descriptive outcomes regarding the activation magnitude maximum for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases

Table 4.8: Descriptive outcomes regarding the activation magnitude maximum for participants (n=20) across the 11 investigated muscles during preload, thrust and resolution adjustment phases.

MUSCULATURE	ADJUSTMENT PHASES					
	PRELOAD		THRUST		RESOLUTION	
	Mean	SD	Mean	SD	Mean	SD
AD	61.9	30.4	143.2	57.7	115.7	82.2
SP	83.5	38.8	127.4	67.4	105.7	57.8
Tri	60.4	36.6	156.6	65.3	142.8	70.4
MT	91.4	70.7	171.7	127.1	143.2	145.6
PD	79.2	64.9	158.8	191.3	196.5	295.4
UT	88.8	52.3	151.5	75.9	125.9	78.9
Bi	83.2	70.2	147.5	114.2	120.7	144.7
CP	88.0	50.2	130.6	42.7	98.0	45.1
LT	80.8	62.4	162.0	74.7	115.3	51.9
SA	71.0	32.6	109.5	39.7	85.2	36.1
IS	76.5	52.3	160.5	86.8	124.7	72.3

Appendix 15: Descriptive outcomes regarding the maximum force output for participants (n=20) across the 11 investigated muscles during the preload, thrust and resolution adjustment phases.

Table 4.3: Descriptive outcomes regarding the maximum force output for participants (n=20) across the 11 investigated muscles during the preload, thrust and resolution adjustment phases.

MUSCULATURE	ADJUSTMENT PHASES							
	PRELOAD			THRUST			RESOLUTION	
	Mean	SD	Mean Rank	Mean	SD	Mean Rank	Mean	SD
AD	1.9	1.4	6.5	1.9	1.4	6.0	1.9	1.4
SP	1.9	1.4	6.0	1.9	1.4	6.0	1.9	1.4
Tri	1.9	1.4	6.0	1.9	1.4	6.0	1.9	1.4
MT	1.9	1.4	6.0	1.9	1.4	6.0	1.9	1.4
PD	1.9	1.4	6.0	1.9	1.4	6.0	1.9	1.4
UT	1.9	1.4	6.0	1.9	1.4	6.0	1.9	1.4
Bi	1.9	1.4	6.0	1.9	1.4	6.0	1.9	1.4
CP	1.9	1.4	6.0	1.9	1.4	6.0	1.9	1.4
LT	1.9	1.4	6.0	1.9	1.4	6.0	1.9	1.4
SA	1.9	1.4	6.0	1.9	1.4	6.0	1.9	1.4
IS	17.0	1.9	6.0	1.9	1.4	6.0	1.9	1.4

Appendix 16: Descriptive outcomes regarding the high activation time percentage for participants (n=20) across the 11 investigated muscles during the preload, thrust and resolution adjustment phases.

Table 4.4: Descriptive outcomes regarding the high activation time percentage for participants (n=20) across the 11 investigated muscles during the preload, thrust and resolution adjustment phases.

MUSCULATURE	ADJUSTMENT PHASES								
	PRELOAD			THRUST			RESOLUTION		
	Mean	SD	Mean Rank	Mean	SD	Mean Rank	Mean	SD	Mean Rank
AD	1.4	2.0	4.67	60.2	20.3	6.2	22.9	22.2	5.1
SP	4.1	5.5	7.4	52.4	28.1	5.8	30.6	27.6	6.2
Tri	2.3	4.9	4.3	57.0	25.6	5.6	33.2	21.7	7.8
MT	4.7	9.0	6.7	63.4	33.2	7.7	30.3	24.5	6.4
PD	4.6	6.6	6.5	38.1	34.9	3.9	27.8	30.7	6.2
UT	3.2	3.1	6.3	53.8	29.3	6.1	24.5	21.0	5.8
Bi	4.7	10.4	5.7	53.2	35.7	5.7	19.7	23.6	5.2
CP	3.8	5.3	7.1	58.4	26.7	6.6	29.1	26.3	5.8
LT	5.3	9.9	6.1	60.2	31.5	6.4	34.3	26.8	6.6
SA	3.5	6.2	6.1	49.6	35.2	5.7	22.4	22.4	5.0
IS	2.7	4.5	5.1	60.2	30.5	6.6	29.4	24.6	6.2

Appendix 17: Descriptive outcomes regarding the moderate activation time percentage for participants (n=20) across the 11 investigated muscles during the preload, thrust and resolution adjustment phases.

Table 4.5: Descriptive outcomes regarding the moderate activation time percentage for participants (n=20) across the 11 investigated muscles during the preload, thrust and resolution adjustment phases.

MUSCULATURE	ADJUSTMENT PHASES								
	PRELOAD			THRUST			RESOLUTION		
	Mean	SD	Mean Rank	Mean	SD	Mean Rank	Mean	SD	Mean Rank
AD	11.1	16.1	4.0	22.6	11.0	5.6	29.7	18.8	4.9
SP	24.3	22.8	7.8	35.2	19.6	7.4	36.6	19.5	7.0
Tri	14.6	19.1	5.7	25.7	15.0	6.5	36.8	15.3	6.9
MT	14.7	19.3	6.5	21.2	14.5	4.3	34.7	20.1	6.3
PD	13.2	17.7	5.3	29.9	24.3	6.9	27.8	22.3	4.7
UT	14.4	14.0	5.6	29.9	20.5	6.1	35.4	19.7	5.9
Bi	21.3	23.1	6.8	24.8	19.0	6.0	35.8	21.6	6.6
CP	25.4	21.8	7.4	27.5	15.5	6.4	38.3	22.0	6.6
LT	16.3	21.3	5.8	21.8	16.1	5.1	28.1	18.4	5.2
SA	20.0	21.0	6.4	31.4	19.4	7.2	33.9	18.0	6.2
IS	12.3	15.3	4.9	21.3	13.3	4.7	32.3	19.6	5.9

Appendix 18: Descriptive outcomes regarding the low activation time percentage for participants (n=20) across the 11 investigated muscles during the preload, thrust and resolution adjustment phases.

Table 4.6: Descriptive outcomes regarding the low activation time percentage for participants (n=20) across the 11 investigated muscles during the preload, thrust and resolution adjustment phases.

MUSCULATURE	ADJUSTMENT PHASES								
	PRELOAD			THRUST			RESOLUTION		
	Mean	SD	Mean Rank	Mean	SD	Mean Rank	Mean	SD	Mean Rank
AD	87.5	16.9	7.9	17.2	19.8	7.1	47.4	30.8	7.6
SP	71.6	25.7	4.4	12.4	14.0	4.6	32.8	32.5	5.5
Tri	83.2	22.6	6.4	17.3	15.0	7.0	30.1	21.9	4.8
MT	80.6	23.8	5.5	15.5	23.9	4.6	35.0	30.0	5.3
PD	82.2	22.6	6.6	32.0	33.1	7.2	44.5	35.6	6.4
UT	82.5	15.6	6.4	16.3	21.2	6.0	40.1	29.9	6.3
Bi	74.0	28.8	5.1	22.1	26.9	6.4	44.4	32.8	6.7
CP	70.8	23.8	4.4	14.1	16.7	5.3	32.5	32.5	5.2
LT	78.4	29.2	6.1	18.0	26.3	5.8	37.6	30.1	5.8
SA	76.5	25.8	5.9	19.0	20.9	5.7	43.7	33.4	6.4
IS	85.0	18.4	7.5	18.5	25.0	6.5	38.4	32.0	6.3

Appendix 19: IREC ethical clearance letter

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 2022

Mr B Hardy
2 Jackalberry Lane
Simbithi
Ballito

Dear Mr Hardy

Muscle recruitment patterns of selected upper extremity muscles in Chiropractors within the eThekwini Municipality while performing a simulated sacroiliac joint manipulation
Ethical Clearance number 039/22

The Institutional Research Ethics Committee acknowledges receipt of your gatekeeper permission letter.

Please note that FULL APPROVAL is granted to your research proposal. You may proceed with data collection.

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 Standard Operating Procedures (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

Prof J K Adam
Chairperson: IREC