The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction

By

Daniel James Fenton

Dissertation submitted in partial compliance with the requirements for the Master's Degree in Technology: Chiropractic

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

Daniel Fenton

Date

Approved for final examination by:

Supervisor

Dr L. O'Connor

(M.Tech Chiropractic)

Date
Dedication

It is with deep gratitude that I dedicate this dissertation to my family: Elizabeth, Neville, Devlin, Keenu and most significantly, Tammy. None of this would have been possible without you. I am deeply grateful for the sacrifices that you have all made for me to be able to achieve at this level.

To those we have lost along the way; I am haunted by your absence, but I am eternally grateful for the part you have played in my life. You are deeply missed.

Thank you.

“Honour carries on”
Clan Fenton
Acknowledgements

Dr Laura O’Connor, your guidance and supervision have been invaluable in this process. Thank you for your time and effort. It is greatly appreciated.

Mr Gideon Burger, thank you for your time and guidance with the Biopac Systems over the last few years. Your insight has been immeasurable.

Dr Charmaine Korporaal, thank you for everything you do for the profession, the programme and for all of us individually. Your contribution, guidance and support to chiropractic are simply inspiring.

Dr Andrew Jones, thank you for inspiring me to become the practitioner I am today. Your time and care have been acknowledged, absorbed and put into practice.

The National Research Fund, for their financial support of this research project.

Mrs Twiggs, Dr Basdav and all the clinicians, thank you for all your help and guidance with this research project. Your contribution to the DUT Chiropractic Clinic is irreplaceable and this project would not have run so smoothly without you.

Ms Tonya Esterhuizen, thank you for the speedy analysis of my statistics. Your input was invaluable.

To all the research participants, this study would not have been possible without you. I am deeply grateful for your participation.

To all my fellow chiropractic students; it has been a joy to spend the last few years with you and to teach you a thing or two. Thank you for your wonderful and unique insights into life and our profession.

Elizabeth Dugmore, your eternal, maternal support has been a constant light in the sometimes-dark times. Thank you for being there for me always.

Dr Neville Dugmore, thank you for your steadfastness and gentle informative care. You are a true inspiration and were the spark that lit this particular fire.
Dr Devlin Fenton, thank you for your support. Though you were far away, I appreciate the feedback, critique and deep discussion over the years always.

Keenu, thank you for lending me something so precious to the both of us. I hope you are proud of what we have achieved. I will always be proud of you and the great young man you have become.

Tammy Fenton, words cannot express my gratitude. Thank you, my Earth and Mars, my moon and stars. The land is now truly at the end of our toes...
Abstract

Objective: The effects of spinal manipulation are well documented, however there is a gap in the current literature regarding the neurophysiological mechanisms responsible for these effects. Further evidence is required to reveal the specific neurophysiological mechanisms of spinal manipulative therapy and its effect on muscle activity. The objectives of this study were to investigate the short-term effects of a single cervical spine manipulation on grip strength and muscle activity of the forearm flexors and extensors in an asymptomatic sample when compared to a control.

Methods: A randomised, controlled, pre-test, post-test, repeated measures design allowed for 46 participants, aged 18-35 years old, with joint dysfunction at C7 to be allocated to either a cervical spine manipulation or a control group. Force output and muscle activity of the forearm flexors and extensors were measured before and immediately after the intervention and again at 5, 10 and 15-minutes. IBM SPSS was used to analyse the data with significance set at (p=0.05). Repeated measures ANOVA testing and Post hoc contrast studies were used to determine significance within, and between, groups.

Results: In the treatment group there was a statistically significant change in muscle activity over time in the Extensor carpi radialis (p=0,013) and Extensor digitorum (p=0,021). Similarly, force output increased within the treatment group over time (p=0,012). A statistically significant beneficial treatment effect was identified between the groups in the Extensor carpi radialis (p=0,001) and Flexor digitorum superficialis (p=0,019) muscles only.

Conclusion: Though statistical significance was not detected in all muscle groups, this study showed a trend of a treatment effect following cervical spine manipulation (C7) with most values lying just outside the parameters set for significance. Specific muscles of the forearm were affected more than others. Future studies are required with a larger sample to validate the trends observed in this study.
**Key indexing terms:** spinal manipulative therapy, muscle activity, grip strength, force output.
Table of Contents

Dedication .......................................................................................................................... II
Acknowledgements ............................................................................................................. III
Abstract ............................................................................................................................... V
   Table of Contents ............................................................................................................... VII
List of Tables ........................................................................................................................ XI
List of Figures ....................................................................................................................... XII
List of Appendices ............................................................................................................... XIII
List of Abbreviations .......................................................................................................... XIV
Definitions ........................................................................................................................... XVII
Chapter One ........................................................................................................................ 1
   Introduction......................................................................................................................... 1
      1.1 Introduction ................................................................................................................ 1
      1.2 Aims and Objectives ................................................................................................. 3
         1.2.1 Aim of the study ............................................................................................... 3
         1.2.2 Study Objectives ............................................................................................. 3
      1.3 The Hypothesis ........................................................................................................ 4
      1.4 Study Rationale ....................................................................................................... 4
      1.5 Delimitations of The Study ................................................................................... 5
      1.6 Flow of Dissertation .............................................................................................. 5
Chapter Two ........................................................................................................................ 6
   Literature Review ............................................................................................................. 6
      2.1 Introduction ............................................................................................................. 6
      2.2 Overview of The Anatomy Relevant to This Study .............................................. 6
         2.2.1 The Cervical Spine and Brachial Plexus ....................................................... 6
         2.2.2 Spinal Cord Tracts ........................................................................................... 8
         2.2.2.1 The Corticospinal Tract ............................................................................ 9
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2.2.2 The Reticulospinal Tract</td>
<td>9</td>
</tr>
<tr>
<td>2.3 Muscles of The Forearm, Motor Unit Recruitment and Electromyography</td>
<td>10</td>
</tr>
<tr>
<td>2.3.1 Forearm Flexors</td>
<td>10</td>
</tr>
<tr>
<td>2.3.2 Forearm Extensors</td>
<td>10</td>
</tr>
<tr>
<td>2.3.3 Motor Unit Recruitment Patterns</td>
<td>10</td>
</tr>
<tr>
<td>2.3.4 Electromyography</td>
<td>11</td>
</tr>
<tr>
<td>2.3.4.1 Intramuscular Electromyography</td>
<td>11</td>
</tr>
<tr>
<td>2.3.4.2 Surface Electromyography</td>
<td>12</td>
</tr>
<tr>
<td>2.4 Spinal Manipulative Therapy</td>
<td>13</td>
</tr>
<tr>
<td>2.4.1 Theories of Spinal Manipulative Therapy</td>
<td>15</td>
</tr>
<tr>
<td>2.4.2 The Effect of SMT On Muscle Activity</td>
<td>18</td>
</tr>
<tr>
<td>2.4.2.1 The Effect of SMT On Muscle Activity of Muscles Related to The Spine</td>
<td>18</td>
</tr>
<tr>
<td>2.4.2.2 The Effect of SMT On Muscle Activity of Muscles in The Extremities</td>
<td>21</td>
</tr>
<tr>
<td>2.5 Grip Strength and SMT</td>
<td>25</td>
</tr>
<tr>
<td>2.6 Use of Control Groups in Research</td>
<td>28</td>
</tr>
<tr>
<td>Chapter Three</td>
<td>30</td>
</tr>
<tr>
<td>Methodology</td>
<td>30</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>30</td>
</tr>
<tr>
<td>3.2 Study design and approval</td>
<td>30</td>
</tr>
<tr>
<td>3.3 Study Population</td>
<td>30</td>
</tr>
<tr>
<td>3.4 Sample Strategy</td>
<td>31</td>
</tr>
<tr>
<td>3.4.1 Sample Size</td>
<td>31</td>
</tr>
<tr>
<td>3.4.2 Sample Characteristics and Recruitment</td>
<td>31</td>
</tr>
<tr>
<td>3.4.2.1 Inclusion Criteria</td>
<td>32</td>
</tr>
<tr>
<td>3.4.2.2 Exclusion Criteria</td>
<td>32</td>
</tr>
</tbody>
</table>
5.4 Force Output ................................................................. 54

Chapter Six .................................................................................................. 56

Conclusion and Recommendations .............................................................. 56
  6.1 Conclusion .......................................................................................... 56
  6.2 Limitations ......................................................................................... 56
  6.3 Recommendations ............................................................................. 57

References .................................................................................................. 59

Appendices ................................................................................................. 67
List of Tables

Table 2.1: The effects of spinal manipulative therapy on muscle activity................................................................. 18
Table 2.2: The effects of spinal manipulative therapy on extremity muscle activity................................................ 20
Table 2.3: The effects of spinal manipulative therapy on grip strength................................................................. 25
Table 3.1: Screening questions................................................................. 30
Table 4.1: Baseline demographic characteristics................................. 43
Table 4.2: Mean muscle activity measured at the five time points for the investigated forearm muscles......................... 44
List of Figures

Figure 2.1: Lateral and posterior views of the cervical spine .................. 7
Figure 2.2: The Brachial plexus ......................................................... 8
Figure 2.3: Schematic illustrating the sensory pathways that may
modulate γ motor neuron discharge .............................................. 17
Figure 3.1: Lateral flexion manipulation of the C7 vertebral segment ...... 33
Figure 3.2: Electrode placement and setup ........................................ 35
Figure 3.3: Electrode placement protocol and location .......................... 36
Figure 4.1: Consort flow diagram ....................................................... 42
Figure 4.2: Mean muscle activity of the ED for both groups over time ....... 45
Figure 4.3: Mean muscle activity of the ECR per group ....................... 46
Figure 4.4: Mean muscle activity of the FDS per group ....................... 46
Figure 4.5: Mean force output of grip strength per group ..................... 47
List of Appendices

Appendix A: Typical and atypical vertebrae.....................................................64
Appendix B: Muscles of the forearm flexor and extensor compartment……. 65
Appendix C: IREC approval........................................................................66
Appendix D: Department of Health - Trial application and registration……. 67
Appendix E: Permission to use the DUT Chiropractic day clinic…………..68
Appendix F: Permission to conduct research at DUT...............................69
Appendix G: Advertisement........................................................................70
Appendix H: Case history form....................................................................72
Appendix I: Physical examination form........................................................76
Appendix J: Cervical spine regional examination form...............................77
Appendix K: Letter of Consent.....................................................................79
Appendix L: Letter of Information.................................................................81
Appendix M: Peak amplitude data measures from tested muscles.............85
Appendix N: Peak amplitude force output....................................................86
Appendix O: Letter requesting permission to conduct the study using
DUT students and place advertisements on campus.........................87
Appendix P: Letter requesting permission to conduct research at the
DUT Chiropractic Day Clinic.................................................................88
Appendix Q: Application for approval of amendment: change of
treatment position..............................................................................89
Appendix R: Approval of amendment: treatment position change............91
Appendix S: Application for approval of amendment: sample size
Amendment.......................................................................................92
Appendix T: Approval of sample size amendment....................................93
**List of Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ach</td>
<td>Acetylcholine</td>
</tr>
<tr>
<td>AchE</td>
<td>Acetylcholinesterase</td>
</tr>
<tr>
<td>AP</td>
<td>Action potential</td>
</tr>
<tr>
<td>cm</td>
<td>centimetres</td>
</tr>
<tr>
<td>CN</td>
<td>Cranial nerves</td>
</tr>
<tr>
<td>CNS</td>
<td>Central nervous system</td>
</tr>
<tr>
<td>C/S</td>
<td>Cervical spine</td>
</tr>
<tr>
<td>CSM</td>
<td>Cervical spine manipulation</td>
</tr>
<tr>
<td>DUT</td>
<td>Durban University of Technology</td>
</tr>
<tr>
<td>DJD</td>
<td>Degenerative joint disorder</td>
</tr>
<tr>
<td>FCR</td>
<td>Flexor carpi radialis</td>
</tr>
<tr>
<td>FCU</td>
<td>Flexor carpi ulnaris</td>
</tr>
<tr>
<td>FDS</td>
<td>Flexor digitorum superficialis</td>
</tr>
<tr>
<td>ECR</td>
<td>Extensor carpi radialis</td>
</tr>
<tr>
<td>ECU</td>
<td>Extensor carpi ulnaris</td>
</tr>
<tr>
<td>ED</td>
<td>Extensor digitorum</td>
</tr>
<tr>
<td>GTO</td>
<td>Golgi tendon organ</td>
</tr>
<tr>
<td>HVLA</td>
<td>High-Velocity Low-Amplitude</td>
</tr>
<tr>
<td>Hz</td>
<td>Hertz</td>
</tr>
<tr>
<td>IVD</td>
<td>Intervertebral disc</td>
</tr>
<tr>
<td>IVF</td>
<td>Intervertebral foramen</td>
</tr>
<tr>
<td>L/S</td>
<td>Lumbar spine</td>
</tr>
</tbody>
</table>
LSM : Lumbar spine manipulation
min : minimum
max : maximum
mm : millimetres
ms : milliseconds
mVs : millivolts
MS : Muscle spindle
MVC : maximum voluntary contraction
MVIC : maximum voluntary isometric contraction
n : sample number
N : Newtons
p : p value
PA : Posterior to anterior
RCT : Randomised clinical trial
ROM : Range of motion
SC : Spinal cord
sEMG : Surface electromyography
SM : Spinal manipulation
SMT : Spinal manipulative therapy
SP : Spinous process
Std : Standard
T/S : Thoracic spine
TSM : Thoracic spine manipulation
TVP : Transverse process
VB : Vertebral body
VC : Vertebral column
% : percentage
\( \alpha \) : alpha
\( \gamma \) : gamma
< : less than
> : greater than
\( \pm SD \) : standard deviation
Definitions

Afferent neuron:
A sensory nerve conveying impulses to the central nervous system (CNS) (Taber’s Cyclopedic Medical Dictionary 2013: 58).

Asymptomatic:
Without symptoms (Taber’s Cyclopedic Medical Dictionary 2013: 221).

Efferent neuron:
A nerve that conveys impulses from the brain or CNS towards the periphery (Taber’s Cyclopedic Medical Dictionary 2013: 769).

Inhibition:
The limitation or depression of reflex activity (Taber’s Cyclopedic Medical Dictionary 2013: 1252).

Isometric contraction:
A muscular contraction in which there is a change in muscle tension but not in muscle length (Taber’s Cyclopedic Medical Dictionary 2013: 560).

Joint Dysfunction:
Disturbances in function without structural change affecting quality and range of joint motion represented by decreased, increased or aberrant joint motion (Bergmann and Peterson 2011: 37).

Joint fixation:
Chiropractic term typically referring to a partial loss of joint movement in one or more directions usually in a position it may normally occupy during any phase of normal movement; the immobilisation of an articulation in a position of movement when the joint is at rest, or in a position of rest when the joint is in movement (Bergmann and Peterson 2011: 37, 39; Haldeman 2005: 274).
Joint manipulation:

A specific manual procedure that involves a directed high-velocity low-amplitude (HVLA) thrust to move a joint past normal physiological range of motion (ROM), into the paraphysiologic space without exceeding the anatomical limit: commonly associated with an audible pop or cavitation (Bergmann and Peterson 2011: 85; Haldeman 2005: 275).

Motion palpation:

Manual procedure used to assess the active and passive segmental joint range of motion, joint play and end feel (Bergmann and Peterson 2011: 67).

Motor Neuron:

Neural structures that transfer impulses from the CNS to muscle tissue to stimulate contraction or glands to secrete (Taber’s Cyclopedic Medical Dictionary 2013: 1612).

Muscle inhibition:

The inability to fully activate a muscle due to ongoing reflex inhibition (Taber’s Cyclopedic Medical Dictionary 2013: 1252).

Nociceptive:

Stimulus-response process involving the stimulation of pain sensitive nociceptors and the transmission of impulses along the peripheral nerves to the CNS (Taber’s Cyclopedic Medical Dictionary 2013: 1628).

Pathological:

The physical, biochemical and functional changes caused by disease (Taber’s Cyclopedic Medical Dictionary 2013: 1752).

Placebo:

A method used as an inactive control as a test of a treatment that is suspected of being useful in the treatment of a certain condition (Taber’s Cyclopedic Medical Dictionary 2013: 1814).
Proprioception:

Awareness of posture, movement and equilibrium together with understanding of position, weight and the resistance of objects in relation to the human body (Taber’s Cyclopedic Medical Dictionary 2013: 1920).

Spinal Manipulative Therapy (SMT):

A conservative treatment modality used primarily by Chiropractors and other manual therapy practitioners in the treatment of neuromuscular skeletal conditions characterised by a manual thrust to elicit movement of a joint past the normal physiological range of motion while not exceeding the anatomical limit. This type of joint manipulation is commonly associated with a cavitation or audible crack (Haldeman 2005: 150; Bergmann and Peterson 2011: 88).

Sensory Neuron:

Neural structures capable of transmission of afferent information or sensation (Taber’s Cyclopedic Medical Dictionary 2013: 1600).

Somatic:

Relating to the structures of the body such as skeletal muscle as opposed to visceral structure such as visceral muscle or internal organs (Taber’s Cyclopedic Medical Dictionary 2013: 2165).

Visceral:

Pertaining to the viscera, such as the internal organs and glands (Taber’s Cyclopedic Medical Dictionary 2013: 2476).
Chapter One

Introduction

1.1 Introduction

Chiropractors and other manual therapy practitioners use spinal manipulative therapy (SMT) in the treatment of spinal (Maigne and Vautravers 2003: 336) and extremity musculoskeletal pain disorders (Brantingham et al. 2013). This is done by assessing joint motion and congruency, identifying joints that are hypermobile or hypomobile. When a joint is hypomobile, it is referred to as a fixation or restriction. The origin of joint fixation is complex and varied and can result in mechanical, neurophysiological, inflammatory and vascular effects (Bergmann and Peterson 2011: 38-46).

SMT is utilised to correct the joint fixation. It is characterised as a mechanical input that is directed and applied to the tissues of the vertebral column, providing not only mechanical but also neurophysiological effects (Cardinale et al. 2015: 121). It is proposed to do this by activating mechanoreceptors within and around the joint, whether the SMT is compressive or distractive in nature. When a joint is distracted it results in forceful stretching of the joint capsule and surrounding musculature which in turn sends a volley of afferent information to the spinal cord which may then influence pain-producing mechanisms together with other mechanical and neurophysiological systems controlled by the central nervous system (CNS) (Pickar 2002: 359).

The effect of SMT was suspected to result from the mechanical changes to the biomechanics of the cervical spine (Naidu et al. 2016: 51). However modern theories indicate that the mechanical stimulus results in a cascade of neurophysiological mechanisms that are responsible for the effects of spinal manipulation. The exact mechanisms are still not clearly understood despite the growing body of evidence supporting the various postulations (Bialosky et al. 2009: 531). The mechanisms proposed are both biomechanical and neurophysiological. The neurophysiological mechanisms, whether supraspinal, peripheral or spinal cord mediated have undergone much study, yet still require further explanation in order to validate the effects of spinal manipulative therapy.
The current evidence explaining the neurophysiological effects of spinal manipulation, does not explain these mechanisms (Haavik-Taylor and Murphy 2007: 391; Metcalfe and Murphy 2007: 153). Haavik-Taylor and Murphy (2007: 400) suggest that SMT modifies nerve transmission not only at the spinal level, but also at a cortical level. However, further research is necessary to understand these effects.

Dunning and Rushton (2009), Suter and McMorland (2002), Harvey and Descarraeus (2013) and Metcalfe et al. (2006: 152) have investigated the effect of SMT on muscle activity of both spinal and extremity muscles. They found significant improvements in muscle activity and strength, together with a reduction in fatigue and muscle inhibition. Botelho, Bruno and Andrade (2012), Fernández-Carnero et al. (2008), Humphries (2013), and Naidoo (2002) assessed changes in grip strength following cervical spine manipulation (CSM), and reported statistically significant improvements in grip strength after SMT. However, these studies are limited in some cases by small sample populations, the lack of a control group, indirect measurement tools and disparity around the type of intervention used. This leads to further hypothesising around the mechanisms responsible for the effect of SMT. Though these studies make use of different treatment periods and range from single to multiple interventions, few assess the short term effects of SMT therefore the magnitude of this effect and its sustainability are yet to be explored (Haavik-Taylor and Murphy 2007: 391; Metcalfe et al. 2006: 153).

Grip strength has been used as an accepted index of the biomechanical functionality of the forearm and hand (Joghataei 2004: 880). Weakened grip strength has also been associated with increased mortality from all causes (including cancer and cardiovascular disease) (Gale et al. 2007: 231), indicating the importance of physical strength of the upper extremity. Joint dysfunction, when it occurs at C7/T1, has been identified as a significant predictor of hand weakness. It was estimated that 15% of all hand weakness in persons could be attributed to reduced cervical mobility (Chugh et al. 2013: 86).

This study aims to contribute to the body of knowledge by investigating whether there are changes in muscle activity and force output of the forearm flexors and
extensors, assessed by grip strength, following CSM at C7 in asymptomatic participants.

1.2 Aims and Objectives

1.2.1 Aim of the study

The aim of the study is to determine the effect of C7 cervical spine manipulation (CSM) compared to a control on grip strength measured in kilograms/force, and muscle activity of the forearm flexor and extensor muscles measured as peak amplitude (mV) and mean duration (RMS) in asymptomatic participants immediately post intervention and again at 5, 10 and 15-minute intervals.

1.2.2 Study Objectives

The objectives of the study were:

1) To determine the effect of CSM at the C7 on grip strength and muscle activity in asymptomatic participants, pre and immediately post intervention, then at 5, 10 and 15-minute intervals post intervention.

2) To determine the effect of a control on grip strength and muscle activity in asymptomatic participants pre and immediately post intervention, then at 5, 10 and 15-minute intervals post intervention.

3) To compare the results of CSM at the C7 and a control on grip strength and muscle activity in asymptomatic participants, pre and immediately post intervention, then at 5, 10 and 15-minute intervals post intervention.
1.3 The Hypothesis

The null hypothesis states that:

1. There will be no significant difference ($p < 0.05$) between the pre-intervention readings of grip strength and muscle activity and the post intervention measures immediately and at 5, 10 and 15-minute intervals following C7 CSM in asymptomatic participants.

2. There will be no significant difference ($p < 0.05$) between the pre-intervention readings of grip strength and muscle activity and the post intervention measures immediately and at 5, 10 and 15-minute intervals following a control in asymptomatic participants.

3. There will be no significant difference ($p < 0.05$) between the groups in terms of pre-intervention readings of grip strength and muscle activity and the post intervention measures immediately and at 5, 10 and 15-minute intervals following either C7 CSM or sham treatment in asymptomatic participants.

1.4 Study Rationale

Current evidence shows significant short term changes in both spinal and extremity muscles as a result of SMT, though detail on the sustainability, duration and magnitude of these changes is lacking (Haavik-Taylor and Murphy 2007: 391; Metcalfe et al. 2006: 153). The neurophysiological mechanisms responsible for the effects of SMT, whether supraspinal, peripheral or spinal cord mediated mechanisms, though well documented in the literature, are not clearly understood (Bialosky et al. 2009: 531) and the way they generate pain relief and restored function are often hypothesised (Haavik-Taylor and Murphy 2007: 391; Metcalfe et al. 2006: 153). The results of this study may provide details and further scientific evidence to understand the magnitude of the effect of SMT and the neurophysiological mechanisms of SMT on muscle activity as an expression of motor unit recruitment and the generation of force.
1.5 Delimitations of The Study

This study was conducted on asymptomatic participants to allow for the investigation to occur without the influence that pain has on a person neuromuscular system. Thus, the results of this study are not applicable to a symptomatic population.

The inclusion criteria for this study were limited to asymptomatic participants between the ages of 18 - 35 years, whom had a C7 joint fixation, to allow for a homogenous sample at lower risk for any potential degenerative disorders associated with advanced age.

Only three forearm flexors and three forearm extensors were chosen for examination in this study. This was due to limitations in forearm diameter, electrode size and shape (Mogk and Keir 2003) and equipment limitations. The MP150 Data Acquisition System was only able to capture three pairs of wireless EMG Transmitter and Receivers.

1.6 Flow of Dissertation

The subsequent chapters will be structured as follows:

Chapter Two will outline a review of the current literature, the mechanisms of cervical spine dysfunction and the theories behind the effects of SMT.

Chapter Three details the methodology of the study.

Chapter Four will present the results.

Chapter Five provides a discussion of the results in terms of the current literature.

Chapter Six will provide a conclusion along with any limitations related to the study and recommendations stemming from the investigation.
Chapter Two

Literature Review

2.1 Introduction

Spinal manipulation has been used as a healing modality since the time of Hippocrates. It has been shown to reduce pain, increase range of motion and improve functional ability as defined by the ability to perform integrated biopsychosocial activities or tasks of normal daily life (Bialosky et al. 2009; Maigne and Vautravers 2003; Pickar 2002.) However further clarification is required on the mechanism through which it does this (Haldeman 2005).

This chapter provides the reader with a brief outline of the relevant anatomy followed by a review of the literature related to SMT and its effects. The following databases and sources were used to find literature for this review: the Durban University of Technology Library, Summon, Google Scholar, Medline, PubMed, eMedicine and Ebscohost. Key terms included: chiropractic manipulation, spinal manipulative therapy, surface electromyography, muscle activity, neurophysiology of manipulation, grip strength, effects of spinal manipulation, mechanical effects of manipulative therapy, electromyography.

2.2 Overview of The Anatomy Relevant to This Study

2.2.1 The Cervical Spine and Brachial Plexus

The cervical spine is a complex region of the spine. It consists of seven articulating cervical vertebral, as seen in Figure 2.1, and 76 joints with its many contributing vascular, neurological and other crucial structures. It is the most mobile region of the entire spine. The cervical lordosis assists with weight bearing, increasing strength and shock absorption. The seven cervical vertebrae
Several spinal ligaments support the cervical spine, permitting smooth motion while reducing resistance and preserving energy within the normal range of motion parameters of the spine. Additionally, they serve a protective function by limiting excessive motion and absorbing disproportionate stress, thereby preserving the integrity of the spinal cord (Cramer and Darby 2014: 32; Moore et al. 2014: 466). Between each vertebra, from C2 – C7, are the intervertebral discs (IVD), which contribute to approximately 25% of total vertebral column height (Tortora and Derrickson 2014: 215). There are two intervertebral foramen (IVF) per segment, except for between C1 and C2. The IVF is of great biomechanical and functional significance as it allows the nerve root to exit the spinal canal, forming an anatomical boundary between the peripheral and central nervous systems (CNS). The IVF is also often a common site of nerve root compression (Cramer and Darby 2014: 49, 50; Moore et al. 2014: 464).

Once the spinal nerve leaves through the IVF, it divides into three branches or rami. The posterior branch, or dorsal ramus innervates the skin and deep muscles on the posterior of the trunk, while the meningeal branch returns to the vertebral canal to supply the spinal cord, the meninges, blood vessels and vertebral bodies and ligaments. The anterior, or ventral ramus, does not innervate structures.
directly; instead it develops bilateral networks of nerve axons from cervical spinal nerves C5-C8 and thoracic spinal nerve T1, forming the brachial plexus (Tortorra and Derrickson 2014: 450). The structure of the brachial plexus is complex, as seen in figure 2.2, and supplies almost the entirety of the shoulder and upper limb by terminating in five large branches. These are the axillary, the musculocutaneous, the radial nerve supplying the musculature on the posterior aspect of the arm and forearm, the median nerve supplying the musculature of the anterior forearm and hand and the ulnar nerve supplying the musculature of the anteromedial aspect of the forearm and hand. (Tortorra and Derrickson 2014: 451; Moore et al. 2014: 693).

Figure 2.2: The Brachial Plexus (Tortorra and Derrickson, 2014: 454).

2.2.2 Spinal Cord Tracts

Spinal tracts, or fasciculi, are bundles of arranged fibres with the same origin, course and function, clustered together in the dorsal, ventral or lateral aspects of the white matter of the spinal cord. The dorsal funiculus is comprised of two ascending tracts, the fasciculus gracilis and fasciculus cuneatus. Short tracts, connecting to various spinal segments, run adjacent to the grey matter whereas the lateral funiculi are made up of long ascending and descending tracts. The ascending tracts principally convey sensation from sensory nerve endings to the
brain while the descending tracts, which originate in the higher centres, send signals primarily of motor information to the spinal cord (Siegel 2015: 136-139; Cramer and Darby 2014: 358). The two spinal tracts that are of specific relevance to this study, and are discussed below, are the corticospinal tract and the reticulospinal tract.

### 2.2.2.1 The Corticospinal Tract

The corticospinal tract is the largest voluntary motor pathway with approximately 40% of the fibres originating in the motor cortex of the precentral gyrus. These fibres are supplemented by the medial motor areas, the lateral premotor cortex, the cingulate gyrus, the parietal lobe and the somatic sensory cortex. The corticospinal tract synapses on dendrites of alpha and gamma motor neurons which supply limb musculature, specifically the upper limb muscles and are generally responsible for rapid movement (Snell 2010: 172). The corticospinal tract allows for fractionalisation which can be characterised by the selective activation of smaller groups of neurons and allows for fine and skilled movements of the hand. This is observable in the index finger, which can flex and extend independently of the other fingers of the hand despite sharing tendons that arise from musculature devoted to all four fingers. In addition, the lateral corticospinal tract synapses on Renshaw cells, allowing for co-contraction of protagonists and antagonists to stabilise and steady the joint during specific hand movements required during grip strength. This co-contraction is attained by inactivation of inhibitory internuncials by the Renshaw cells (FitzGerald et al. 2012: 187-189).

### 2.2.2.2 The Reticulospinal Tract

The origin of the partially crossed reticoluspinal tracts is the reticular formation of the medulla oblongata and pons. The reticulospinal tracts act on motor neurons supplying limb musculature; the medullary reticulospinal is thought to act on flexor motor neurons, while the pontine reticulospinal tract acts on extensor motor neurons - both exerting reciprocal inhibition. The reticulospinal tracts are
responsible for reflex activity and the control of voluntary movement (FitzGerald et al. 2012: 192; Snell 2010: 172). Together, the reticulospinal tracts and corticospinal tract allow for voluntary motor control of the body and limbs.

2.3 Muscles of The Forearm, Motor Unit Recruitment and Electromyography

2.3.1 Forearm Flexors

The forearm flexors are contained within the anterior compartment of the forearm. They are arranged in three layers, a superficial layer responsible for flexion and adduction at the wrist, an intermediate layer responsible for flexion of the middle four phalanges and a deep layer responsible for flexion of the distal phalanges and pronation of the upper limb (Moore et al. 2014: 746, 747). Appendix B details the anatomy and nerve supply of these muscles.

2.3.2 Forearm Extensors

The forearm extensors are enclosed in the posterior compartment of the forearm and are innervated by the radial nerve and its branches. The forearm extensors are arranged into three functional groups: the first group is made up of muscles that extend, abduct and adduct the hand at the wrist. The second group comprises muscles that extend the four medial digits. The third and last group is comprised of muscles that extend or abduct the thumb. (Moore et al. 2014) The anatomy and nerve supply of these muscles are detailed in Appendix B.

2.3.3 Motor Unit Recruitment Patterns

Muscle tone is a representation of a low-level contraction that is demonstrative of a resting muscle and is a summation of the resting volley of the CNS activity directed to the muscle. Upon the initiation of muscle contraction, motor unit recruitment occurs, based upon a principle of size whereby the smallest motor units and muscle fibres are recruited first, followed in succession by larger motor units and muscle fibres as the synaptic drive increases (Snell 2010: 124-126).
The recruitment of muscle fibres responds to exertional demand of the muscle and results in the firing rate of muscle fibres moving from slower to higher frequencies as measured by electromyography (Criswell 2011: 28).

Motor neurons specific to skeletal muscle include alpha motor neurons which can be divided into tonic and phasic neurons that project to slow extrafusal muscle fibres and clusters of fast extrafusal muscle fibres respectively; beta motor neurons which project to both extrafusal and intrafusal muscle fibres; and gamma motor neurons. The latter can be divided into static and dynamic types that directly innervate neuromuscular spindles of skeletal muscle, specifically the contractile portion. The alpha and gamma neurons are enclosed tightly into pools specific to the skeletal muscle they innervate. They receive both inhibitory and excitatory input from adjacent interneurons that have formed proprioceptive neurons and local reflex circuits that assist in the modulation of motor neurons. Additionally, alpha neurons receive afferent fibres from muscle spindles, which form the sensory arc of the stretch reflex of myotatic reflex (Cramer and Darby 2014: 355).

2.3.4 Electromyography

Electromyography is an electrodiagnostic technique used to measure the muscle activity of skeletal muscle and is comprised of two methods; intramuscular electromyography and surface electromyography (Merletti; 1999. Kent; 1997).

2.3.4.1 Intramuscular Electromyography

Intramuscular electromyography is characterised by the use of either intramuscular wire electrodes or needle electrodes that are inserted directly into the skeletal muscle in order to increase the specificity of the electromyographic data of the muscles that are evaluated. Intramuscular electromyography, though more specific, results in varying levels of tissue damage and can lead to difficulties in reproducing electrode insertion depth and location leading to inferior reliability (Merletti; 1999. Kent; 1997).
2.3.4.2 Surface Electromyography

Surface electromyography (sEMG) is a non-invasive, valid and dependable indicator for approximating muscle recruitment and/or evaluating muscle function in symptomatic and asymptomatic individuals (Lee et al. 2012). It is safe and accurate and has been used in several studies to assess muscle changes associated with spinal manipulation (Haavik-Taylor and Murphy 2007; Grindstaff et al. 2014; Suter and McMorland 2002; Keller and Colloca 2000; Dunning and Rushton 2009).

The sEMG allows for the amplification and recording of action potentials, measured in millivolts, which is interpreted by the software and displayed on a screen as a waveform. The baseline measurement visible when the muscle is resting can be provoked and changed by contracting the muscle, displaying visible peaks and troughs as the muscle goes through the contraction cycle. sEMG allows for highly specific muscle activity analysis and though it is often used for research purposes it also has significant ability when it comes to diagnosing certain muscle pathologies such as muscular dystrophy and muscle atrophy (Lee et al. 2012: 1219, 1222; Criswell 2011: 5, 6; Moore et al. 2014: 36; Tortora and Derrickson 2014: 307).

The sEMG signal can be assessed by various means. In this study the integrated sEMG signal was used and is defined as the area under the curve of the rectified sEMG signal, measured in millivolts. Root Mean Square (RMS) analysis was used as it more easily establishes the maximum value of the sEMG signal. The sEMG RMS is considered the most accurate analysis of the signal as the waveform is easily examinable and provides a good measurement of the power and amplitude of the signal (Suter and McMorland 2002: 542; BIOPAC® System, Inc. 2016).

Many factors can influence the quality of the sEMG signal. Extrinsic factors include those controlled for by the experimenter, such as electrode placement with respect to optimum muscle motor points, electrode configuration, shape and inter-electrode distance, as well as skin preparation, perspiration and ambient temperature. Intrinsic factors are highly variable within individuals and include
anatomical variance of muscle fibres, motor unit predominance, number of active motor units, blood flow to the muscle and subcutaneous fat composition. Not only can these factors vary within individuals, they may also vary within a day, based on the normal internal and external changes that occur as time passes (Halaki and Ginn 2012: 175). There is a discussion in the literature around normalising the raw sEMG data. This is achieved by dividing the sEMG amplitude by a reference sEMG value, usually the MVIC of the same muscle (Halaki and Ginn 2012: 177). However, it is commonly accepted that the raw data can be used effectively as long as all the data were collected within a single collection session over a short period of time and no changes were made to the sEMG setup or electrode placement of the participant, as was done in this study. Within these boundaries the raw data can be effectively used for comparisons such as comparing signals from a specific muscle, before and after interventions, within the same session (Halaki and Ginn 2012; Merletti 1999).

2.4 Spinal Manipulative Therapy

Spinal manipulative therapy has existed since the time of Hippocrates. Today it is a procedure predominantly used by the chiropractic and osteopathic professions and growing in popularity with physiotherapists and other health care professionals (Maigne and Vautravers 2003; Haldeman 2005). SMT refers to a group of techniques used to assess joint motion and congruency, identifying joints that are hypermobile, hypomobile or fixed and then correcting the aberrant joint motion (Leach 2004). Motion palpation is a manual examination technique designed to assess active, passive and accessory joint movement and to identify dysfunction (Bergmann and Peterson 2011: 3-5, 67; Vernon 2010; Leach 2004). The reliability of motion palpation is inconsistent with many studies reporting contrasting levels of reliability based on clinical experience and clinician confidence (Holt et al. 2018; Cooperstein and Young 2016; Walker et al. 2015).

A joint fixation may result from intradiscal derangement, posterior joint derangement, inter-capsular adhesions, muscle spasm and tissue fibrosis resulting in motion segment dysfunction (Leach 2004). As a result, the physiological changes in the connective tissue, muscles, ligaments and/or nerves
produce abnormal joint movement, reduced joint play and end feel and cause palpable changes to the soft tissue like bogginess, swelling and muscle hypertonicity (Morris 2006; Leach 2004). Altered biomechanics within one component of the vertebral motion segment impact the functioning of adjacent spinal structures and segments (Cardinale et al. 2015; Bergmann and Peterson 2011: 112).

Spinal joint manipulation is characterised by the manual application of a low amplitude direct thrust of controlled velocity and varying direction in order to move a joint past its physiologic range of motion but not beyond its anatomical limit. It is typically performed using a high velocity-low amplitude (HVLA) thrust, which was used in this study. When applied, it results in biochemical changes within the joint cavity, often resulting in a cracking or popping noise referred to as a cavitation, caused by changes in intra-articular pressure and gapping of the joint. An audible cavitation is not always necessary for manipulation to be considered successful (Cardinale et al. 2015; Bergmann and Peterson 2011: 84, 85; Evans and Lucas 2010; Pickar 2002). The HVLA targets movement into the paraphysiologic space, which is found between the physiological zone (which occurs at the limits of both active and passive range of motion) and the pathological zone (which is where the anatomical limit of a joint occurs) (Vernon and Mrozek 2005: 68, 69). The HVLA SMT moves the joint beyond the elastic barrier of end play into the paraphysiologic space, separating the articular surfaces and producing the cavitation (Bergmann and Peterson 2011: 68; Vernon and Mrozek 2005: 68, 69). This manoeuvre brings about the effects of SMT which are associated with analgesia (Maigne and Vautravers 2003: 336).

During this procedure, there is distraction of the facet joints, which possibly decreases intradiscal pressure and forcefully stretches the local muscles, inducing relaxation by means of mechanisms still to be determined (Cardinale et al. 2015: 121). It is hypothesised that spinal joint dysfunction is capable of chronically altering both proprioceptive and nociceptive input. The recurring altered afferent input, resulting from pain, inflammation, mechanical trauma or dysfunction, drives a segmental spinal cord response which can result in pathological somatovisceral and somatosomatic reflexes because of over-sensitisation of spinal neuron pools. These pathological reflexes are then
hypothesised to become the source of somatic or visceral dysfunction such as referred pain (Leach 2004; Maigne and Vautravers 2003), distorted sympathetic activity, hypertonicity and hyperesthesia. Though the sample used in this study was asymptomatic, the onset of symptoms is undetermined once a segmental fixation has occurred. SMT has been shown to be able to reduce and resolve local and distant visceral and somatic dysfunction or “Type O” conditions (Pollard 2005) by reducing and removing the neurogenic reflexes that arise from spinal joint dysfunction (Bergmann and Peterson 2011: 45; Morris 2006; Leach 2004).

2.4.1 Theories of Spinal Manipulative Therapy

Joint dysfunction was originally purported to result in direct nerve root compression which resulted in an inability of the spinal nerve to function optimally, resulting in ill health. Modern day research has shown this to be unlikely. However, due to the numerous other vascular, neurological and lymphatic structures that occupy the IVF it is possible that joint dysfunction presents mechanical stresses to the area, altering neurological function (Vernon 2010: 23, 27, 28).

Prolonged local inflammation or spinal motion segment fixation can result in an interruption of neural vascularity and cause a disruption to neural blood supply resulting in neuroischaemia (Ammendolia, 2014). Pressures applied to spinal motion segments can result in a variety of neurophysiological variations, including altered nerve conduction and alterations to intraneural protein composition. Spinal joint injury, trauma or hypomobility can result in the initiation of an inflammatory cascade, resulting in vascular congestion and local ischemia (Vernon and Mrozek 2005: 68, 69; Bergmann and Peterson 2011: 44, 46).

In addition, the biomechanical changes that occur as a result of joint manipulation are thought to stimulate mechanoreceptors within the joint and adjacent tissues which relay the information along type I and type II afferent fibres to the spinal cord. The interneuron upon which the afferent neuron synapses, relays an inhibitory or an excitatory stimulus to the motor neuron, which results in a decrease or increase of the motor neuron pool excitability (Haavik-Taylor and
There is growing evidence suggesting that spinal dysfunction influences neural processing, inhibiting neural input to certain muscles. There is current evidence explaining the neurophysiological effects of spinal manipulation, however, the exact mechanisms responsible for pain relief and restored function after spinal manipulation are not well understood and are often hypothesised and misrepresented in the literature (Haavik-Taylor and Murphy 2007: 391; Metcalfe et al. 2006: 153). Haavik-Taylor and Murphy (2007: 400) suggest that SMT of dysfunctional joints may modify nerve transmission in neuronal circuitries – this occurs not only at the spinal level - but also at a cortical level and potentially even in deeper brain structures, having an even more substantial effect than previously identified.

The neurophysiological theory for the effects of joint manipulation is characterised by peripheral mechanisms, spinal cord mechanisms and supraspinal mechanisms (Bialosky et al. 2009: 533):

- **Peripheral mechanisms of SMT:**

These may directly affect the short term inflammatory response and pain relating to musculoskeletal injury by interacting with nociceptors and inflammatory mediators. Several studies (Degenhardt et al. 2007; Teodorczyk-Injeyan et al. 2006), investigating the effect of SMT, showed changes in blood and serum levels, circulating cytokines, serotonin and endorphin levels and altered acute inflammation responses that were unobserved in control groups, suggesting peripheral nervous system mediation of musculoskeletal pain as a result of SMT.

- **Spinal cord mechanisms:**

Pickar (2002) suggests that SMT may exert an effect on the spinal cord by flooding the CNS with sensory input from proprioceptors and furthermore proposing the associated neuromuscular responses resulting from SMT as evidence for a spinal mechanism of manual therapy (MT). Further evidence of a
spinal mechanism of SMT is supplied by studies producing evidence of hypoalgesia, motor neuron pool activity and altered muscle activity (Dishman and Burke 2003; Vicenzino et al. 2001; Herzog et al. 1999). The current evidence indicates that spinal manipulation may influence proprioceptive neurons in paraspinal tissues and in addition may affect pain processing and motor control systems by altering the central facilitated state of the spinal cord (Bialosky et al. 2009. Pickar 2002: 368). Korr (1976) suggested that SMT produced a cascade of impulses in muscle spindle and small-diameter afferents silencing facilitated \( \gamma \) motor neurons. Korr proposed that the \( \gamma \) motor neuron discharge would be elevated in the muscles of the vertebral segments responding to SMT and that the increased background \( \gamma \) gain would reduce joint mobility by the stretch reflex being sensitised to abnormally small muscle length changes. His theory proposes that SMT stimulates muscles spindle afferents, and that the barrage of these impulses would reduce the \( \gamma \) gain by an undetermined pathway (Pickar 2002: 360). The barrage of high frequency muscle spindle discharge, together with the smaller diameter Group III and IV neurons, may affect the descending input to \( \gamma \) motor neurons as seen in Figure 2.3 below.

![Figure 2.3](image_url)

Figure 2.3: Schematic illustrating the sensory pathways that may modulate \( \gamma \) motor neuron discharge (Pickar 2002).
• Supraspinal mechanisms:

Supraspinal structures such as the amygdala, periaqueductal grey and the anterior cingulate cortex, which are instrumental in central pain processing, have been shown to have decreased activity in response to SMT (Bialosky et al. 2009). Malisza et al. (2003) found support for a supraspinal mechanism of action by noting a trend of decreased activation of the supraspinal regions in rats having undergone lower extremity MT. Decreased activation was noted in regions responsible for pain processing implying a supraspinal mechanism (Bialosky et al. 2009: 4). SMT may alter central corticospinal facilitatory and inhibitory neural processing together with cortical motor control of the upper limb musculature and may affect sensorimotor integration revealing additional information about the mechanisms responsible for pain relief and improved functional ability following SMT (Haavik-Taylor and Murphy 2007). However Grindstaff et al. (2014) suggest that SMT does not acutely change spinal reflex excitability but rather the manual therapy may improve functional ability and impairment through undetermined mechanisms.

In addition, aspects such as expectation, placebo and psychosocial factors may also play a role in the mechanisms of SMT, however these require further investigation (Bialosky et al. 2009).

2.4.2 The Effect of SMT On Muscle Activity

2.4.2.1 The Effect of SMT On Muscle Activity of Muscles Related to The Spine

Herzog, Scheele and Conway (1999) were the first researchers to examine the effect of SMT on neuromuscular reflexes and muscle activity of muscles surrounding the spine, using sEMG. They observed consistent asynchronous reflex responses in target-specific areas, following SMT in asymptomatic individuals. They postulated that the evoked responses to SMT were most likely of multi receptor origin and that they were responsible for the observed functional
improvements, inhibition of muscle hypertonicity and pain reduction seen following SMT. In addition to this study, Table 2.1 highlights other studies investigating local muscle effects following SMT.

Table 2.1: The effects of spinal manipulative therapy on muscle activity

<table>
<thead>
<tr>
<th>Author</th>
<th>Design</th>
<th>Sample size</th>
<th>Intervention</th>
<th>Outcomes</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvey and Descarreaux, 2013</td>
<td>RCT</td>
<td>n=60, low back pain</td>
<td>1: L/S SMT 2: Control</td>
<td>Muscle activity of PS, kinematics, pain intensity</td>
<td>Significant increase in PS muscle activity and pain in control during task when compared to group receiving SMT</td>
</tr>
<tr>
<td>Lalanne et al. 2009</td>
<td>RCT</td>
<td>n=27, chronic low back pain</td>
<td>1: L/S SMT. 2: Control.</td>
<td>Trunk and pelvic angles and muscle activity of PS muscles in trunk flexion-extension</td>
<td>Significant decrease in muscle of PS muscles at full flexion following SMT</td>
</tr>
<tr>
<td>DeVocht et al. 2005</td>
<td>RCT</td>
<td>n=16, non-specific spinal pain</td>
<td>1. Activator SMT 2. SMT</td>
<td>Resting muscle activity of paraspinal muscles</td>
<td>Significant decrease in muscle activity in cases with LBP. Increases in muscle activity normally followed by decrease in activity to pre-intervention levels</td>
</tr>
<tr>
<td>Lehman and McGill, 2001</td>
<td>Analytical cohort</td>
<td>n=14, LBP</td>
<td>1. L/S SMT</td>
<td>Muscle of RA, EO and ES during flexion /extension, lateral flexion and axial twist pre and post SMT</td>
<td>No significant changes following SMT</td>
</tr>
<tr>
<td>Keller and Colloca, 2000</td>
<td>RCT</td>
<td>n=40, low back pain</td>
<td>1: Manually assisted SMT. 2: Control.</td>
<td>Muscle activity of PS muscles during trunk extension - maximum voluntary contraction</td>
<td>Significant increase in muscle activity of PS muscles post manually assisted SM</td>
</tr>
<tr>
<td>Herzog, Scheele and Conway, 1999</td>
<td>Pre-test, post-test ED.</td>
<td>n=10, asymptomatic</td>
<td>1. SMT - 11 clinically relevant treatments</td>
<td>sEMG readings of 16 back and proximal upper limb muscles</td>
<td>Consistent reflex responses in target areas post SMT</td>
</tr>
</tbody>
</table>

(RCT=randomised clinical trial, ED=experimental design, HVLA=high velocity, low amplitude, SMT=spinal manipulative therapy, MVC=maximum voluntary contraction, L/S=lumbar spine, PS=paraspinal muscles, RA=rectus abdominus, EO=external oblique, ES=erector spinae)
In a low back pain (LBP) population (n=16), DeVocht, Pickar and Wilder (2005), assessed the effect of both manual and activator SMT on resting sEMG levels of the paraspinal muscles in participants with non-specific spinal pain. They found a reduction in paraspinal muscle activity following the intervention. In some cases, there was an increase in resting sEMG activity recorded during and after the intervention, which then decreased shortly after to a lower than pre-intervention level. The authors propose that the findings of this study are consistent with the assumption that muscle hypertonicity is associated with LBP and can be alleviated with SMT.

These findings were supported by Lalanne, Lafond and Descarreaux (2009) in a placebo-controlled trial (n=27), using participants with LBP and assessing the effect of SMT on the paraspinal muscles. The reduction in paraspinal muscle activity following lumbar SMT was proposed by the authors to modulate stabilising neuromuscular responses. Contributing to these findings, Keller and Colloca (2000) in a placebo controlled randomised clinical trial (n=40) found a significant increase in muscle activity when assessed during maximum voluntary contraction following SMT involving a mechanical force, manually assisted activator, when compared to a sham. The authors suggested that the mechanical input of the SMT stimulated the somatosensory system improving the functional ability of the trunk musculature, inhibiting nociception and improving spinal range of motion. These studies support that SMT modulates sensory inflow from paraspinal structures, resulting in improved physiological functioning (Lalanne et al. 2009: 203, 207; Pickar 2002).

Lehman and McGill’s (2001) and Harvey and Descarreux’s (2013) studies assessed the effect of SMT on trunk muscles during tasks. Lehman and McGill (2001), in a cohort study (n=14) reported that there had been no significant changes detected post-intervention, although a trend of decreased muscle activity was noted in those participants who were in the greatest amount of pain or had the more severe dysfunction. In contrast, Harvey and Descarreux (2013), in a placebo controlled clinical trial (n=60), found significant increases in paraspinal muscle activity and increased reporting of pain in the control group during the last 30 minutes of the trunk flexion/extension task compared to the group receiving lumbar SMT. They proposed that neuromuscular changes in the
trunk resulting from the SMT, reduced sensitisation or fatigue related to repetitive muscle activity, adding to the commonly held supposition that SMT may reduce muscle fatigue.

2.4.2.2 The Effect of SMT On Muscle Activity of Muscles in The Extremities

Spinal manipulation of lower cervical spine dysfunction results in a pronounced neurological effect as shown by the immediate effects on muscle strength (Metcalfe et al. 2006: 157). Several studies, as seen in Table 2.2, have investigated the effect of SMT on the muscle activity of extremity muscles.

Table 2.2: The effects of spinal manipulative therapy on extremity muscle activity

<table>
<thead>
<tr>
<th>Author</th>
<th>Study design</th>
<th>Sample size</th>
<th>Intervention</th>
<th>Outcome measures</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christiansen et al. 2018</td>
<td>RCT - crossover trial.</td>
<td>n=11, subclinical pain</td>
<td>1.SMT</td>
<td>MVC of the plantar flexors, Soleus V-waves, and H-Reflex</td>
<td>SMT increased muscle strength and corticospinal excitability.</td>
</tr>
<tr>
<td>Niazi et al. 2015</td>
<td>RCT</td>
<td>n=10, subclinical low back pain</td>
<td>1: L/S SM 2: Control</td>
<td>sEMG V-wave, H-reflex, M-wave and max MVC of ankle plantar flexors</td>
<td>Significant increase in motor neuron pool excitability, cortical drive and preventing fatigue.</td>
</tr>
<tr>
<td>Cardinale et al. 2015</td>
<td>RCT - crossover trial.</td>
<td>n=27, asymptomatic participants</td>
<td>1: L/S SM 2: Lumbar stretching. 3: Sham</td>
<td>Force fluctuation task, modified Sorensen’s test, sit and reach. sEMG of PS and gastrocnemius muscles.</td>
<td>No significant improvement superior to the other modalities for force output and sEMG parameters post L/S SM.</td>
</tr>
<tr>
<td>Grindstaff et al. 2014</td>
<td>RCT</td>
<td>n=75, history of knee joint injury and current quadriceps inhibition.</td>
<td>1: Lumbopelvic SM 2: SM positioning (no thrust) 3: Grade IV patella mobilisation 4: Grade I patella mobilisation 5: Control</td>
<td>sEMG H-reflex of quadriceps over time (pre, post 0, 30, 60, 90 min)</td>
<td>No significant differences in H-reflex between groups across time.</td>
</tr>
<tr>
<td>Study</td>
<td>Design, Duration</td>
<td>Sample</td>
<td>Intervention 1</td>
<td>Intervention 2</td>
<td>Outcome Measures</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>------------------</td>
<td>--------</td>
<td>----------------</td>
<td>----------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Fryer and Pearce, 2012</td>
<td>RCT - crossover</td>
<td>n=14,</td>
<td>1: HVLA</td>
<td>2: Control</td>
<td>Motor evoked potentials and H reflex measured from gastrocnemius muscle.</td>
</tr>
<tr>
<td></td>
<td>study.</td>
<td>asymptomatic</td>
<td>manipulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>lumbo sacral joint.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dunning and Rushton, 2009</td>
<td>RCT – placebo</td>
<td>n=54,</td>
<td>1. HVLAT</td>
<td>2. Sham</td>
<td>Resting sEMG activity of the biceps brachii muscle</td>
</tr>
<tr>
<td></td>
<td>controlled,</td>
<td>asymptomatic.</td>
<td></td>
<td>3. Control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>single blinded.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suter and McMorland, 2002</td>
<td>RCT</td>
<td>n=16,</td>
<td>SMT - C5/6,</td>
<td>sEMG activity</td>
<td>SMT significantly increase elbow flexor strength.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>chronic</td>
<td>C6/C7.</td>
<td>of biceps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>neck pain.</td>
<td></td>
<td>muscle, cervical spine ROM and PPT.</td>
<td></td>
</tr>
<tr>
<td>Naidoo, 2002</td>
<td>RCT</td>
<td>n=120,</td>
<td>1. C4-C5 SMT</td>
<td>Force measures</td>
<td>Statistically significant improvement in grip strength in all four groups.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cervical</td>
<td>2. C5-C6 SMT</td>
<td>from a handheld</td>
<td>No statistical improvement in dynamic electrical contractibility in group 1.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>spine joint</td>
<td>3. C6-C7 SMT</td>
<td>dynamometer</td>
<td>Statistically significant improvement in dynamic electrical contractibility in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fixation.</td>
<td>4. C7-T1 SMT</td>
<td>before and after intervention.</td>
<td>groups 2, 3 and 4.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sEMG readings</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>for muscle</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>activity.</td>
<td></td>
</tr>
</tbody>
</table>

(RCT= randomised clinical trial, HVLA=high velocity, low amplitude, SMT=spinal manipulative therapy, SM=spinal manipulation, MVC=maximum voluntary contraction, L/S=lumbar spine, LBP=Low back pain, PS=paraspinal muscles, TF=tibiofibular, FL=fibularis longus)

Suter and McMorland (2002) reported that participants (n=16) with chronic neck pain showed significant inhibition of the biceps muscle together with increased pain pressure sensitivity and a reduction in cervical spine range of motion. They then investigated the effect of SMT on the cervical spine (C/S) at C5/C6 or C6/C7 to determine its effect on the biceps muscle. Post-intervention they found a significant reduction in biceps inhibition and increased biceps force output during an elbow flexion procedure. The authors indicated that SMT altered sensory input resulting in altered efferent pathways at a specific segment level. This study highlighted that SMT effects can occur in muscles distal to the spine, supporting a neurophysiological effect however the small sample and lack of control group lower the reliability of the findings. Similar findings were found by Dunning and Rushton (2009) in a placebo-controlled, single blinded study (n=54) where they
found increased resting electromyographic activity of the biceps brachii bilaterally following C/S SMT, irrespective of the presence of a cavitation, when compared to the control group. Though this study improved on some of the shortcomings in the Suter and McMorland study (2002) neither of these studies assessed how long the effect persisted following the SMT.

In contrast Naidoo (2002: 45-47) assessed the effect of cervical spine manipulation (CSM) on grip strength, in four different groups (n=30) where each group received either C4/C5, C5/C6, C6/C7 or C7/T1 SMT. No significant between-group effects were found, but within-group improvements occurred in grip strength and forearm flexor muscle activity in all groups. The absence of a control group and the use of a broad electromyographic contact over the entire flexor component of the forearm - as opposed to assessing each individual muscle - make it difficult to clearly determine the effect of the CSM on grip strength. The degree of specificity regarding the multiple specific levels of manipulation in this study is unreliable. The trend of treatment effect suggests the need for further investigation.

Further evidence of the spinal cord effects of SMT was found by Niazi et al. (2015). It was reported that SMT produced significant increases in motor neuron excitability and cortical drive, improving soleus muscle maximum voluntary contraction (MVC) in subclinical LBP participants (n=18) when compared to a control group. They suggest further that SMT may reduce muscle fatigue in the short term suggesting significant clinical relevance of SMT as a treatment therapy in sports players and athletes. The small sample, lack of a control group and subjectivity of a maximal voluntary contraction are drawbacks in this study suggesting further examination in this area.

Similarly, Christiansen et al. (2018) showed that a single session of SMT increased ankle plantar flexor muscle strength and corticospinal excitability to these muscles in elite asymptomatic Taekwondo athletes (n=11) when compared to a control. The MCV of participants in the treatment group increased over time in direct contrast to participants in the control group whose MVC decreased over time, suggesting the increased MVC was as a result of increased cortical drive to the muscle. The decrease in MCV force in the control group correlated with
participant fatigue. This was not seen in the treatment group. Neuromuscular fatigue is a common predisposing factor to musculoskeletal injury and has been shown to decrease power and muscle strength (Christiansen et al. 2018: 746). Christiansen et al. (2018) suggest that SMT may even be of benefit to asymptomatic individuals in improving muscle performance, supporting the findings of Harvey and Descarreux’s (2013) study.

In contrast, Fryer and Pearce (2012) in a randomised, controlled crossover trial (n=14), assessing motor evoked potentials and H-reflex of the gastrocnemius muscle following lumbar SMT, found that there was a significant reduction in spinal reflex and corticospinal excitability in asymptomatic individuals. This suggests that HVLA SMT precipitates an immediate dampening of motor neuron excitability, supporting the Lalanne et al. (2009) study findings.

Furthermore, Cardinale et al. (2015) in a randomised controlled, cross over trial, examined the effect of lumbar SMT compared to L/S stretching and a control on muscle activity of the gastrocnemius and soleus muscles during a force fluctuation task, a modified Sörensen’s Test and a sit and reach task. They found that L/S SMT did not produce any significant change in muscle activity when compared to L/S stretching or a control. The results of this study suggested that the neuromuscular effects SMT are negligible and transient in nature and that further study using less indirect measures such as the Sörensen’s Test and a sit and reach test is is necessary to explain the effects of SMT on neuromuscular function.

Unique to the above studies Grindstaff et al. (2014) using a randomised, placebo controlled clinical trial (n=75) examined the effect of lumbopelvic manipulation and patella mobilisation techniques on quadriceps neuromuscular excitability in individuals with a history of knee joint injury. The study found no significant changes following lumbopelvic manipulation, lumbopelvic positioning or patella mobilisation suggesting that SMT directed at these areas may not have an immediate effect on the spinal reflex excitability of the quadriceps muscle.

Cervical spine manipulation (CSM) has been associated with changes in upper extremity muscle function (Suter and McMorland 2002: 543,544; Naidoo 2002: 45-47) and significantly improved active cervical range of motion with substantial
effect sizes, suggesting a significant clinical effect (Martinez-Segura et al. 2006: 514,515; Naidu 2016: 51).

Evidence suggests that increased muscle tone associated with spinal dysfunction may be reduced by SMT. Increases in muscle activity as a result of SMT can be attributed to improved motor fibre recruitment and proprioception. It is possible that the alteration in corticospinal excitability may result in changes to motor recruitment strategies (Fryer and Pearce 2012: 92). Determining the clinical significance of the changes in sEMG magnitude is difficult due to the lack of correlation between sEMG data and other clinical outcomes measures. Though some studies have identified decreased muscle activity, increased muscle activity has yet to be established as a discriminating factor between asymptomatic and symptomatic populations (Lehman and McGill 2001: 299).

The current literature is conflicting as to the exact effects of SMT on muscle activity, warranting further investigation into the specifics of these effects (Grindstaff et al. 2014; Fryer and Pearce 2012; Lehman and McGill 2001).

2.5 Grip Strength and SMT

Reduced muscle strength and power together with neuromuscular fatigue are detrimental to functional ability and are predisposing factors to injury. These physiological factors, mediated by neuromuscular mechanisms, can be adequately investigated by measuring MVC (Christiansen et al. 2018: 738). Grip strength, often independently assessed (i.e. not in conjunction with muscle activity) is commonly utilised by investigators when assessing the effect of SMT, as seen in Table 2.3. It is an accepted index of the biomechanical functionality of the forearm and hand (Joghataei 2004: 880) and is simple to measure. Joint dysfunction in the cervical spine, specifically at C7/T1 was found to be a significant predictor of hand weakness and it was estimated that 15% of all hand weakness could be attributed to cervical spine dysfunction (Chugh et al. 2013: 86; Coetzee 2003).
Table 2.3: The effects of spinal manipulative therapy on grip strength.

<table>
<thead>
<tr>
<th>Author/s</th>
<th>Study design</th>
<th>Sample Size</th>
<th>Intervention</th>
<th>Outcome measures</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chugh et al. 2013</td>
<td>RCT</td>
<td>n=20, 4-week history of shoulder impingement.</td>
<td>1. Cervicothoracic mobilisation – one-month duration.</td>
<td>Force measurements from a handheld dynamometer before and after intervention – at one month.</td>
<td>Improvement in grip strength measurements in both groups. Significant improvement of grip strength in cervicothoracic mobilisation group.</td>
</tr>
</tbody>
</table>

(RCT=randomised clinical trial, SMT=spinal manipulative therapy, C/S=cervical spine)

Though not HVLA SMT - but considered under the broad definition of SMT – Chugh et al. (2013) showed in a randomised clinical trial of participants with shoulder impingement (n=20) that manual cervicothoracic mobilisation
techniques significantly improved hand grip strength when compared to standard hand grip exercise techniques. Chugh et al. (2013) propose that the reversal of abnormal spinal biomechanics adversely affecting neuromuscular function may have led to the improvement in grip strength following cervicothoracic mobilisation. Spinal mobilisation has been shown to produce neurophysiological changes, increasing sensory input to the CNS. In turn, Golgi tendon and muscle spindles afferents are stimulated, resulting in increased motor unit recruitment and muscle strength (Pickar 2002).

These findings were supported by Botelho, Bruno and Andrade (2012) who in a randomised clinical trial, assessing HVLA SMT to the C/S, reported statistically significant increases in grip strength in judo athletes over a series of three visits where SMT was applied, compared to a sham. In addition, the improvements in grip strength were progressive from the first to the third intervention. The authors attributed the effect to inducing vertebral motion and the concomitant nerve root responses resulting in increased muscle strength. The progressive treatments this study lend more weight to the long term effect of spinal manipulation. Further research is required to establish the immediate and short term effect of SMT.

Humphries et al. (2013) demonstrated a marginal increase in both grip strength and free throw accuracy following lower cervical spinal manipulation of 24 asymptomatic basketball players. Though no performance improvements were detected between pre- and post-intervention measurements, the SMT group showed preliminary changes indicative of a positive effect. The SMT group also demonstrated less variation in motor tasks post SMT compared to the control. The authors recommended further evaluation with a larger sample size.

In participants with lateral epicondylitis (n=10) Fernández-Carnero, Fernández-de-las-Peñas, and Cleland (2008) found following CSM there had been an immediate increase in pain pressure threshold and pain-free grip strength on the affected side when compared to a manual contact intervention. The researchers suggest that the reduction in pain was a plausible reason for the increase in pain-free grip strength. SMT has been linked to the activation of the endogenous opioid system and changes to circulating endogenous cannabinoids and is thereby proposed to bring about pain relief (Bialosky et al. 2009). In addition to the pain-
relieving effects, other studies (Humphries et al. 2013; Botelho, Bruno and Andrade 2012; Haavik-Taylor and Murphy 2008; Fernández-Carnero et al. 2008; Suter and McMorland 2002) have reported that spinal manipulation alters muscle activity of extremity muscles, which may also have played a role in the findings of this study.

Many studies have examined symptomatic individuals or individuals that have a history of cervical spine dysfunction. In many cases the immediate effect of CSM is clearly observed (Metcalf et al. 2006: 152. Keller and Colloca 2000) and more specifically, its effect on grip strength (Botelho, Bruno and Andrade 2012: 43; Naidoo 2002: 45-47; Humphries et al. 2013). However, the duration and magnitude of this effect requires further examination. As such the importance of clearly identifying the duration of the effect of cervical spine manipulation on force output and muscle activity in the forearm flexor and extensor group - in contrast to a control - is necessary to provide further evidence of the effect of cervical spine manipulation.

2.6 Use of Control Groups in Research

There is little consensus amongst academics and clinicians regarding the appropriate and most effective placebo or control in clinical trials examining the effects of SMT. Randomised clinical trials of chiropractic treatment may be significantly complicated by non-specific treatment factors such as general manual contact or ‘hands-on effect’ or the general expectation of benefit (Ruddock et al. 2016). Though these are regarded in most instances as beneficial to the patients’ health, they detract from analysing the treatment effect in an RCT and are regarded as a weakness of the study as they can produce a beneficial treatment effect, thereby reducing the statistical significance of the manipulation and control groups (Vernon et al. 2005: 662-663).

A light touch in the affected area may elicit afferent stimulation, however, studies examining joint manipulation have been criticised for lacking a control to minimise any non-specific treatment factors (Chaibi et al. 2015: 1, 3, 4). It is for this reason that for the purposes of this study a control procedure that lacked physical contact
was used to observe the time taken to deliver the intervention in the treatment group only.
Chapter Three

Methodology

3.1 Introduction

This chapter will detail the methodology used in this study together with the ethical considerations taken into account to ensure the well-being and safety of participants.

3.2 Study design and approval

This study was done using a quantitative approach and a randomised controlled pre-test, post-test experimental design. Though it is not a given, randomisation attempts for both groups to be largely the same in baseline characteristics and pre-test measures within the limits of uncontrolled variation. Pre-test measures also serve to control for participant differences on an individual physiological level while post-test measures allow for the testing of the intervention (Crano et al. 2015: 83, 84).

The study was approved by the Institutional Research Ethics Committee (IREC) of DUT (IREC 46/17, Appendix C) and was registered on the South African Clinical Trials register (DOH-27-0717-5719, Appendix D). The study was conducted at the Durban University of Technology (DUT) Chiropractic Day Clinic (CDC) after permission was obtained from the Clinic Director (Appendix E) and the Institutional Research Ethics Committee (Appendix F).

3.3 Study Population

For this study, participants who were healthy and free from symptoms were recruited from the eThekwini Municipality.
3.4 Sample Strategy

3.4.1 Sample Size

In consultation with a biostatistician a power analysis was conducted using G-Power (Crano et al. 2015). A 90% power, 0.25 effect size and a probability of 0.05, resulted in a sample size of 26 participants required for the study. To account for other assumptions that were difficult to control for in this sample estimation, such as sampling errors resulting from a sample that deviates from the population, due to the potential of a largely student targeted population due to the location of the study, a sample of 46 participants was selected (Esterhuizen 2018).

3.4.2 Sample Characteristics and Recruitment

Study participants were recruited through advertisements (Appendix G), placed, after permission was obtained from the relevant authorities, (Appendix F) at the Durban University of Technology campuses, sports clubs and gyms and other areas of communal gathering. In addition, word of mouth was used to inform and recruit participants for the study.

Potential participants contracted the researcher either telephonically or in person and were screened for eligibility using the questions in Table 5.1.

Table 3.1: Screening questions

<table>
<thead>
<tr>
<th>Questions to be asked.</th>
<th>Response required for inclusion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Would you be willing to answer a few questions?</td>
<td>Yes.</td>
</tr>
<tr>
<td>2. Are you between the ages of 18 and 35 years of age?</td>
<td>Yes.</td>
</tr>
<tr>
<td>3. Do you have any pain of the head, neck and/or upper limb?</td>
<td>No.</td>
</tr>
<tr>
<td>4. Are you currently undergoing, or have you had manual/manipulative cervical spine treatment in the last three months?</td>
<td>No.</td>
</tr>
</tbody>
</table>
Those who were eligible and agreed to participate were scheduled for an appointment at the DUT Chiropractic Day Clinic (CDC). At this appointment, a full case history (Appendix I), physical examination (Appendix J) and cervical spine orthopaedic examination (Appendix K) were conducted to ensure the participant met the study inclusion and exclusion criteria.

### 3.4.2.1 Inclusion Criteria

1. **Age:** 18-35 years of age, to reduce the contamination by degenerative joint disease (DJD), as the incidence of DJD and osteoarthritis increases over the age of 35 (Neogi and Zhang 2013).
2. Participants were required to be asymptomatic with regard to pain in the head, neck and upper limbs.
3. Participants were required to have a joint fixation at C7 as determined by motion palpation, according to the techniques outlined by Bergmann and Peterson (2011: 51).

### 3.4.2.2 Exclusion Criteria

1. Contraindications to cervical spine manipulation such as a history of head and/or cervical trauma, cervical fracture, cervical surgery, patients with neurological deficits and/or systemic disorders affecting the cervical region (Bergmann and Peterson 2011: 92).
2. Any participant that presents with ‘red flags’ to cervical spine manipulation such as hypertension, fever and/or significant loss of body mass (Peuntedura et al. 2012: 67).
3. Any individual currently receiving treatment for head, neck, arm and/or wrist pain or dysfunction.
3.4.3 Sample Allocation

Participants were randomly allocated by the reception staff at the DUT CDC into two groups of 23 using the hat method. In total, 46 pieces of paper, 23 indicating the treatment group and 23 the control group were deposited into a sealed container, which was kept at the DUT CDC reception. The sealed container was mixed well before each drawing and the member of staff made sure not to look into the container when drawing to prevent any influence on the piece of paper being drawn. This allowed for a simple random sample (Crano et al. 2015: 224, 225).

Group allocation:

Group 1: Experimental group (n = 23)

Group 2: Control group (n = 23)

3.5 Intervention

3.5.1 Cervical Spinal Manipulation

Group 1, the experimental group, received a high velocity – low amplitude (HVLA) manipulation delivered to the C7 vertebral segment with the participant lying in the supine position, as illustrated in Figure 3.1. The technique utilised was the supine lateral flexion index push manipulation applied to the side of greatest restriction according to the technique outlined by Bergmann and Peterson (2011).
Outline of the procedure:

- The patient lay supine on the adjusting table.
- The researcher stood at the head of the table on the side of adjustable contact, angled approximately 45 to 90 degrees to the participant’s head.
- Using the ventrolateral surface of the index finger of the hand corresponding to the side of segmental contact, the researcher made contact with the posterior articular pillar of the C7 vertebrae.
- The researcher’s indifferent hand supported the participant’s head, making thenar contact with the participant’s cheek and using the fingers to support the occiput and upper cervical spine.
- Rotating the participant’s head away from the side of dysfunction to establish the adjustable contact, the researcher then laterally flexed the
participant’s head toward the side of contact minimalizing rotation and thrust with a medioinferior vector to induce lateral flexion.

Confirmation of the adjustment was assessed post-intervention by using motion palpation evaluating for improved joint motion (Bergmann and Peterson 2011: 85, 180). A cavitation was not required but was produced by every manipulation. Thereafter, the participant returned to sit in the chair in the same position as prior to the intervention.

3.5.2 Control Group

The participants in group 2 received no intervention. After recording the pre-measurements, they lay supine on the chiropractic table for a period of 90 seconds timed with a stopwatch, the approximate time taken for the intervention in group 1. Thereafter, the participant was made to sit in the chair, in the same position as for the pre-measurements to record the post measurements. There was no interaction or help from the researcher during this period. All participants were given clear instructions and had no direct contact with the researcher at any time.

3.6 Measurement Tools

3.6.1 Muscle Activity

To measure the muscle activity of the forearm muscles the Biopac Bionomadix MP150 Data Acquisition System was used, together with the Bionomadix Dual-Channel wireless EMG Transmitter and Receiver pair to monitor muscle signals for the duration of the data collection period with a data sampling rate of 2000 Hz. The system has an internal high pass and low pass filter from 5.0 Hz to 500 Hz to ensure quality amplification of the sEMG waveform and elimination of any artefact or noise interference (Biopac Systems Inc 2015). The same research consultation room was used throughout the study. The room was sealed from outside interference and noise by closing and locking the door. In addition, all other electronic devices were removed and stored away from the data acquisition
system, to prevent noise interference. All participants followed the same pre-manipulative protocol to control for any extraneous environmental factors.

The EL-Check, a Biopac electrode impedance checker, was used to determine the impedance between each pair of electrode leads to obtain the cleanest sEMG signal. To improve biopotential measurement results, the skin was lightly abraded, shaved where necessary and all impedance was limited to 5kΩ (Biopac Systems Inc 2015; Mogk and Keir 2003).

Disposable 35 mm round pre-gelled Ag/AgCl sEMG electrodes were placed on the muscle bellies of the Flexor Carpi Radialis (FCR), Flexor Carpi Ulnaris (FCU), Flexor Digitorum Superficialis (FDS), Extensor Carpi Radialis (ECR), Extensor Carpi Ulnaris (ECU) and Extensor Digitorum (ED) according to the technique outlined by Mogk and Keir (2003). Electrode placement was determined by using manual palpation and an anatomical atlas to determine a position on a line between origin and insertion on the muscle in the supinated hand and verified by using the Biopac EL-Check to ensure optimal signal quality (Mogk and Keir 2003: 65; Kong et al. 2010: 1224, 1225). Figure 3.2 illustrates the electrode placement.
Electrode Placement Protocol:

- A landmark electrode and its partner were placed on the muscle belly of the FCR, a position defined as one-third of the distance from the proximal end of a line from the medial epicondyle to the distal head of the radius, with the forearm in supination (Mogk and Keir 2003: 63, 65, 66). This point was confirmed by manual palpation and EL-Check.

- The electrodes for FDS were placed slightly medially on the line between the oblique line of the radius and the middle phalynx at a position approximately ¼ from the oblique line of the radius.

- The electrodes placed on the FCU were placed on a line from the medial epicondyle of the humerus to the pisiform and the palmar aponeurosis, approximately 1/3 of the distance from the medial epicondyle of the humerus (Kong et al. 2010: 1224, 1225).

- An inter-electrode placement, following the technique outlined by Mogk and Keir (2003), began from the FCR landmark electrode with an equidistant spacing determined by the diameter of the participant’s forearm with an approximate distance of 3 cm between each pair of remaining electrodes.

- A ground electrode was placed over the anterior distal end of the forearm between the styloid processes of the ulnar and radius (Kong et al. 2010: 1224). The remaining grounding electrodes for each wireless EMG transmitter were placed above the elbow on the biceps or triceps muscles.

- New electrodes were used for each participant as reusing electrodes is both unhygienic and can lead to motion artefacts due to a reduction in electrode adhesive (Reaz et al. 2006: 14). This resulted in the electrodes being placed as illustrated by Figure 3.3.

![Figure 3.3: Electrode placement protocol and location (Mogk and Keir 2003: 65)](image-url)
3.6.2 Force Output

The handheld dynamometer has been identified in many studies as a reliable and valid measuring tool (Humphries et al. 2013: 156; Incel et al. 2002: 235). Its advantage is the ability to assign numerical values to the magnitude of the maximum voluntary contraction of the participant (Naidoo 2002: 27, 28).

Dynamometer readings in this study were made using the TSD121C Isometric Hand Dynamometer, which connected to the MP150 data acquisition unit via the DA100C module. The maximum voluntary contraction of the grip strength was recorded in kilograms/force for the FCR, FCU, FDS, ECR, ECU and ED.

All dynamometer grip strength measurements were taken with the participant seated with back straight and hips flexed to 90 degrees, shoulder and arm adducted and in the neutral position. The medial aspect of the upper arm was held comfortably against the torso with the elbow flexed at 90 degrees to reduce fatigue throughout the session (Ngo and Wells 2016: 68). The participant’s forearm rested against the chair’s armrest. In the case of taller or shorter participants, a cushion was used either to sit on or to rest the forearm on.

Measurements were taken with the dominant arm only as the evidence shows that dominant arm grip strength is significantly stronger in right-handed individuals and shows no significant difference between sides in left-handed individuals (Incel et al. 2002: 234; Naidoo 2002: 28). The researcher demonstrated the use of the handheld dynamometer allowing all participants to practice with the device until they were satisfied in its use. Once beginning the study, the participant was asked to squeeze the dynamometer (Biopac Systems Inc 2015; Botelho, Bruno and Andrade 2012: 40; Ngo and Wells 2016: 67, 68) once as forcefully as they could for duration of 1-2 seconds, which was assessed using a stopwatch. Readings were taken before, and immediately after, the interventions and again at 5, 10 and 15-minute intervals.

All readings were recorded, analysed and exported to an Excel sheet, which enabled the comparison of grip strength pre- and post-manipulation (Naidoo 2002: 28).
3.7 Research Procedure

Once the participant met the inclusion criteria and had been preliminarily included in the study, an appointment was made at the CDC where they were informed about the details of the study, both verbally and through a Letter of Information (Appendix M). They were given a Letter of Consent to complete and sign (Appendix L). Participants were free to ask any questions pertaining to the study and the field of research and were made aware that they were free to withdraw from the study at any time without any consequence. Participants were made aware that all personal details would remain confidential and would only be available to the researcher and the research supervisors and that all other information and data would be coded.

The researcher performed a case history after which the researcher used motion palpation to identify a C7 cervical spine fixation. If a fixation was not found the participant was excluded from the study, thanked and was free to leave. If a C7 cervical spine fixation was found, a full case history (Appendix I), physical examination (Appendix J) and cervical spine regional examination (Appendix K) of the individual was performed.

On being included in the study, the electrode placement sites on the forearm were lighted abraded and shaved, if necessary, and the surface electromyography electrodes were placed to obtain signals from the muscles outlined in section 3.6.1. The operating technique of the handheld dynamometer was then demonstrated to the participant. The researcher explained the procedure to the participant and initiated the surface electromyography recording, which ran for the duration of the data collection period and recorded the baseline handheld dynamometer measurement and all electrode measurements with the participant seated in a chair as detailed in section 3.6.2.

The participant then lay supine on the adjusting table and the researcher either delivered the cervical spine manipulation at the level of C7 (Supine Lateral Flexion) to the treatment group or waited 90 seconds timed on a stopwatch. Once the intervention had been delivered to the treatment group or after observing 90
seconds in the control group, the participant sat up and returned to the chair and original position. The researcher then recorded the post intervention measurements.

The researcher recorded the sEMG and handheld dynamometer measurements again at 5, 10 and 15-minute intervals, according to a stopwatch that was started at the beginning of the session. During the time intervals between the post-measures, the participant was asked to remain seated in the chair to maintain the electrode placement though the dynamometer was taken from them and put aside to minimise any chance of fatigue.

Event markers were placed on the electromyography recording to note each of the post measurements. Once all the measurements had been taken the study was complete and the participant was free to leave. On average, each research participant was with the researcher for one hour and thirty minutes. Each participant was thanked for their participation and offered a free treatment voucher for the DUT CDC, in return for their participation in the study.

3.8 Data Storage and Analysis

All physiological data was coded and stored on a password protected hard drive until the research was complete. Upon completion of the trial, the physiological data was copied on to a password protected external flash drive and exported into an Excel spreadsheet.

The muscle activity readings were converted using RMS whereby the mean duration and peak amplitude of the muscle activity during the MVC was recorded. 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: 542; BIOPAC® System, Inc. 2016). Thereafter the data was journaled and exported from the AcqKnowledge system into a Microsoft Excel spreadsheet, where the participants’ identity was hidden with a system of coding. The force output for the grip strength MVC was recorded in force/kilograms and entered into the same spreadsheet per participant.
IBM Statistical Package for the Social Sciences (SPSS) Statistics version 25 (Esterhuizen 2018) was used for data analysis. A \( p \) value of less than 0.05 was considered as statistically significant. Descriptive statistics such as mean, standard deviation, count and percentage described the participants per group. Baseline characteristics per group were compared using independent sample t-tests for continuous normally distributed variables and categorical variables were compared using Pearson’s chi square tests.

Outcome measurements were tested for normality using Kolmogorov-Smirnov tests and were found to be plausibly normally distributed. Repeated measures ANOVA tests were used to assess effects of time and interactions between the time and treatment group. Initially, intra-group comparisons were done per group to assess changes over time for each outcome. Simple contrasts were used to compare each subsequent time point to the baseline if the overall time effect was statistically significant.

Then, intra and inter-group comparisons were achieved using repeated measures analysis of variance (ANOVA) testing for within and between group effects of time (5 levels) and treatment group (2 levels). A statistically significant time by group interaction effect signified a significant treatment effect. Where the interaction was significant, simple contrasts were examined to assess at which time point relative to baseline the treatment effect was significant. Profile plots were generated to show the trends between and within groups (Esterhuizen 2018).

### 3.9 Ethical Considerations

All participant personal and demographic data will be stored in the Durban University of Technology Chiropractic Day Clinic where it will remain secure for the next five years, where after it will be shredded and disposed of.

Participant autonomy was maintained throughout the duration of the study and they were made aware of the details of the study verbally and in writing through the letter of information and letter of consent. They were informed that they could
drop out of the study at any stage, for any reason with no consequence. No participants were coerced into participating in the study.

Non-maleficence was adhered to in the study as the well-being of all participants was protected by only making use of procedures and equipment that have been validated and proven to be safe. All demographic and physiological data together with the signed letter of informed consent were kept safe in the participant’s file at the DUT CDC. All research data were coded as to ensure the participant’s confidentiality.

The study made use of a control group. This group did not receive an active treatment therefore all participants were offered a free treatment voucher from the researcher at the end of the study. If the participant required or sought out further treatment, an appropriate practitioner would be recommended to them. At the start of the study, all participants were made aware that the study made use of a control and that a random drawing would determine whether they received an intervention or not.

All participants were treated equally and fairly and without discrimination with regard to their race, sex, nationality and religion in accordance with the ethical principle of justice.

Confidentiality applied to all participants as all data were coded ensuring that no participant names or details were published in the study.

Participants were made aware that they may feel some delayed onset muscle stiffness or soreness after the treatment session and that if this presents it should resolve naturally over a period of 24 hours with no exacerbating complications to the participant (Paanalathi et al. 2014: 1)

Permission to conduct the study was obtained from the DUT CDC director, Dr Korporeaal (Appendix E) and Professor Moyo; Director: Research and Postgraduate Support (Appendix F).

In line with the ethical principle of beneficence it was anticipated that the study would contribute to the growing body of knowledge regarding SMT and its effect on muscle activity
Chapter Four
Data Analysis

4.1 Introduction

This chapter will present the results of the study in the form of graphs and cross-tabulations.

4.2 Consort Flow Diagram

Figure 4.1 shows the flow of the participants through the research, which resulted in 23 participants per group.
4.3 Demographic Characteristics of The Participants

Table 4.1 shows the sex, race and mean age of the participants per group. There were no significant differences found between the groups for sex or race using Pearson’s chi square tests, or for age assessed using independent students t-test.

Table 4.1: Baseline demographic characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group1 (n=23) n (%)</th>
<th>Group 2 (n=23) n (%)</th>
<th>Total (n=40) n (%)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>13 (56.5)</td>
<td>13 (56.5)</td>
<td>26 (56.5)</td>
<td>1.000</td>
</tr>
<tr>
<td>Male</td>
<td>10 (43.5)</td>
<td>10 (43.5)</td>
<td>20 (43.5)</td>
<td></td>
</tr>
<tr>
<td><strong>Race</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>19 (82.6)</td>
<td>20 (87.0)</td>
<td>39 (84.8)</td>
<td>0.388</td>
</tr>
<tr>
<td>White</td>
<td>2 (8.7)</td>
<td>2 (8.7)</td>
<td>4 (8.7)</td>
<td></td>
</tr>
<tr>
<td>Indian</td>
<td>2 (8.7)</td>
<td>0 (0.0)</td>
<td>2 (4.3)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>0 (0.0)</td>
<td>1 (4.3)</td>
<td>1 (2.2)</td>
<td></td>
</tr>
<tr>
<td><strong>Age (Mean ± SD)</strong></td>
<td>21.52 (± 1.59)</td>
<td>21.70 (± 2.70)</td>
<td>21.61 (± 2.20)</td>
<td>0.792</td>
</tr>
</tbody>
</table>

4.4 Muscle Activity

4.4.1 Mean Muscle Activity

Table 4.2 shows the mean muscle activity of the MVC per group for each of the muscles assessed in this study. At baseline measures, using independent student t-tests, no statistically significant differences between the groups for mean muscle activity were found for the FCR \(p=0.931\), FCU \(p=0.897\), FDS \(p=0.552\), ECR \(p=0.241\) and ECU \(p=0.140\) and ED \(p=0.248\), making the groups comparable for mean muscle activity.

Repeated measure ANOVA was used to assess within- and between-group effects over the five time-measurements. The within-groups comparisons for the muscle activity of the FCR, FCU, and ECU revealed no significant differences
between the groups. Similarly, no significant treatment effect was seen in these
muscles when assessing between-group comparisons as seen in Table 4.2.

However, a trend of a treatment effect can be seen.

Table 4.2: Mean muscle activity measured at the five time points for the investigated forearm muscles

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre (±SD)</th>
<th>Post 1 (±SD)</th>
<th>Post 2 (±SD)</th>
<th>Post 3 (±SD)</th>
<th>Post 4 (±SD)</th>
<th>p value within</th>
<th>p value between</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCR</td>
<td>0.12 (0.05)</td>
<td>0.13 (0.04)</td>
<td>0.13 (0.05)</td>
<td>0.12 (0.05)</td>
<td>0.12 (0.04)</td>
<td>0.379</td>
<td>0.261</td>
</tr>
<tr>
<td></td>
<td>0.12 (0.08)</td>
<td>0.12 (0.07)</td>
<td>0.12 (0.07)</td>
<td>0.13 (0.10)</td>
<td>0.14 (0.10)</td>
<td>0.156</td>
<td></td>
</tr>
<tr>
<td>FCU</td>
<td>0.23 (0.16)</td>
<td>0.26 (0.15)</td>
<td>0.25 (0.15)</td>
<td>0.24 (0.12)</td>
<td>0.25 (0.15)</td>
<td>0.53</td>
<td>0.374</td>
</tr>
<tr>
<td></td>
<td>0.22 (0.18)</td>
<td>0.23 (0.19)</td>
<td>0.22 (0.17)</td>
<td>0.21 (0.18)</td>
<td>0.23 (0.17)</td>
<td>0.252</td>
<td></td>
</tr>
<tr>
<td>FDS</td>
<td>0.26 (0.13)</td>
<td>0.28 (0.12)</td>
<td>0.29 (0.15)</td>
<td>0.28 (0.15)</td>
<td>0.27 (0.13)</td>
<td>0.063</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>0.23 (0.11)</td>
<td>0.24 (0.10)</td>
<td>0.22 (0.10)</td>
<td>0.22 (0.09)</td>
<td>0.24 (0.10)</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>ECR</td>
<td>0.30 (0.15)</td>
<td>0.35 (0.24)</td>
<td>0.34 (0.18)</td>
<td>0.34 (0.21)</td>
<td>0.33 (0.18)</td>
<td>0.013</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>0.26 (0.10)</td>
<td>0.25 (0.10)</td>
<td>0.24 (0.10)</td>
<td>0.24 (0.11)</td>
<td>0.26 (0.12)</td>
<td>0.186</td>
<td></td>
</tr>
<tr>
<td>ECU</td>
<td>0.26 (0.14)</td>
<td>0.29 (0.10)</td>
<td>0.28 (0.11)</td>
<td>0.27 (0.10)</td>
<td>0.27 (0.10)</td>
<td>0.270</td>
<td>0.179</td>
</tr>
<tr>
<td></td>
<td>0.21 (0.08)</td>
<td>0.22 (0.10)</td>
<td>0.21 (0.08)</td>
<td>0.20 (0.09)</td>
<td>0.22 (0.09)</td>
<td>0.132</td>
<td></td>
</tr>
<tr>
<td>ED</td>
<td>0.28 (0.13)</td>
<td>0.31 (0.14)</td>
<td>0.32 (0.14)</td>
<td>0.31 (0.14)</td>
<td>0.31 (0.14)</td>
<td>0.021</td>
<td>0.105</td>
</tr>
<tr>
<td></td>
<td>0.32 (0.13)</td>
<td>0.33 (0.12)</td>
<td>0.32 (0.13)</td>
<td>0.32 (0.16)</td>
<td>0.34 (0.16)</td>
<td>0.614</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.2 shows that the ED muscle in the treatment group, for within-group comparisons, had significant increases in muscle activity ($p=0.021$) from baseline to immediately post intervention ($p=0.011$), 5-minutes post ($p=0.001$), 10-minutes post ($p=0.008$) and 15-minutes post ($p=0.010$), assessed using Post hoc contrasts.

![Extensor digitorum](image)

Figure 4.2: Mean muscle activity of ED for both groups over time

Within- and between-group differences were found for the ECR muscle, as seen in Figure 4.3. There was a significant effect for within-group comparisons in the ECR muscle ($p=0.013$) for the treatment group where there were significant increases in muscle activity from baseline to immediately post intervention ($p=0.02$), 5-minutes post ($p=<0.001$) and 15-minutes post ($p=0.024$). Between-group comparisons showed a significant treatment effect ($p=0.001$) where the treatment group had a significant increase in muscle activity when compared to the control group from baseline to the immediate post intervention ($p=0.019$), at 5-minutes post ($p=<0.001$) and 10-minutes post ($p=0.020$), using Post hoc contrasts.
A similar result occurred in the FDS muscle where a significant treatment effect ($p=0.019$) was observed. The intervention group had an increase in mean muscle activity from baseline to the 5-minutes post ($p=0.002$) and 10-minutes post ($p=0.028$) when compared to the control group, using Post hoc contrasts, as seen in Figure 4.4.

Figure 4.3: Mean muscle activity of the ECR per group

Figure 4.4: Mean muscle activity of the FDS per group
4.4.2 Peak Amplitude Muscle Activity

There were no significant differences in peak amplitude of the muscle activity during the MVC for any of the investigated muscles observed at baseline, between or within the groups over the duration the study. These results are found in Appendix M.

4.5 Force Output

4.5.1 Mean Force Output

Figure 4.5 shows the mean force output of the MVC for the two groups measured by the handheld dynamometer. There was no significant difference between the groups at baseline ($p=0.501$) (independent student $t$-tests), allowing the groups to be compared. Using repeated measures ANOVA, within- and between-group effects were assessed. A significant within-group effect was only observed in the treatment group ($p=0.012$) with significant increases for force output from baseline to the 5-minutes post ($p=0.008$) and the 15-minutes post reading ($p=0.004$). There was no significant treatment effect seen over the five time points, when the two groups were compared ($p=0.069$). However, a trend of a treatment effect can be seen in Figure 4.5.

![Figure 4.5: Mean force output of grip strength per group](image-url)
4.5.2 Peak Amplitude Force Output

There were no significant differences in peak amplitude of the MVC observed at baseline between, or within, the groups over the duration of the study. These results can be seen in Appendix N.
Chapter Five
Discussion of Results

5.1 Introduction

This chapter discusses the results of this study in the context of the current literature.

5.2 Discussion of the Demographic Data

5.2.1 Age, Sex and Race

Age is an important factor when performing sEMG studies as it has been shown to be associated with decreases in strength and muscle mass (Billot et al. 2010, Hairi et al. 2010). Older individuals require a greater level of muscle activity to produce the equivalent force produced by younger individuals (Billot et al. 2010), thus affecting the quality and reliability of the muscle activity recordings. Increased age is also a predisposing factor to degenerative joint disorders with the incidence rate of osteoarthritis increasing sharply after 50 years of age (Neogi and Zhang 2013). This study controlled for age by limiting the sample population to people between 18 and 35-year-old, to reduce the risk of poor sEMG data and DJD. When the groups were compared for age there was no difference between them, thus negating the effect that age could potentially have had on the results.

There is little reference to sex and race and its association with sEMG readings in the literature. However, women and men have different upper body strength with 90% of women reportedly having weaker grip strength than 95% of men (Leyk et al. 2007) There was no statistically significant difference ($p=1.000$) between the groups in terms of sex, adding to the consistency and homogeneity of the study. Similarly, no differences between the groups were observed for race. However, there was a predominant representation of black individuals with few white or Indian individuals. This made the sample similar to the racial demographic of the South African population.
5.3 Muscle Activity

The results of this study indicate that CSM may have an effect on forearm flexor and extensor muscle activity. Statistically significant time effects were identified within the experimental group in the ECR ($p=0.013$) and ED ($p=0.021$) muscles and in the ECR ($p=0.001$) and FDS ($p=0.019$) when comparing the treatment group to a control. The significance observed in these muscles echo the results produced by Suter and McMorland (2002), Dunning and Rushton (2009) and Niazi et al. (2015).

Suter and McMorland (2002) showed that SMT of the cervical spine at C5, C6 and C7 significantly increased muscle activity of the biceps brachii muscle during elbow flexion. It was observed that individuals with chronic neck pain suffered from significant inhibition of the biceps brachii muscle activation, and it was proposed that SMT of the cervical spine decreased the muscle inhibition and increased short term elbow flexor strength. HVLA type SMT has been thought to activate proprioceptors and mechanoreceptors within and around the joint, changing sensory input and affecting the efferent pathways at a specific vertebral level (Pickar, 2002). In addition, it has been proposed that the effects of SMT can be widespread throughout the body and that the change in afferent input as a result of the SMT may improve the excitatory function of extremity muscles not directly connected to the spine (Suter and McMorland 2002: 543, 544).

Similarly, Dunning and Rushton (2009) demonstrated significant increases in the resting muscle activity of the biceps brachii muscle post C5/C6 HVLA SMT. Though the resting mean muscle activity change was greater for the right biceps, both left and right showed significant changes post manipulation, compared to a control. Dunning and Rushton (2009: 511) postulate that the SMT directly activates the mechanosensitive afferents in the IVD, facet joints and paraspinal muscles, changing the afferent input and thereby altering alpha motor neuron excitatory capacity, resulting in subsequent muscle activity increases.

The increased muscle activity of the ECR and FDS in this study are likely to be ascribed to increased modulation in afferent neurons and/or an increase in the descending drive. Spinal manipulation may influence muscle activity by
increasing the excitability of low-threshold motor neurons in the extremity muscle or improving the efficacy of synaptic input from primary afferents in the muscle to low-threshold motor neurons (Niazi et al. 2015: 1171).

Harvey and Descarreux (2013) proposed that the neuromuscular changes resulting from the SMT may reduce sensitisation or fatigue related to repetitive muscle activity, supporting the supposition that SMT may reduce muscle fatigue. Though this study made use of repeated measurements over time, the participants were asked to squeeze the dynamometer five times, for one second only over the study session, limiting any chance of muscle fatigue affecting the forearm muscles.

No significant differences were found in the FCR, FCU or ECU. Grindstaff et al. (2014) suggest that the reason for an absence of significant muscle activity may lie in the possibility of pain-free joint dysfunction limiting the participant’s performance. Even though all participants were asymptomatic with regards to pain in the cervical spine and upper extremity, a limitation of this study is that no regional examination for the shoulder, elbow or wrist was performed, overlooking any potential upper limb joint dysfunction which may have influenced forearm muscle activity. Further studies should include a neuromuscular skeletal assessment of the entire upper extremity in order to exclude potential upper limb joint dysfunction.

This study aimed to assess the effect of SMT on grip strength and selected to use asymptomatic participants to remove the effect that the pain experience has on muscles and function. It has been suggested that symptomatic samples that have greater levels of pain and dysfunction may respond differently to SMT (Grindstaff et al. 2014). Thus, the effect that SMT has on grip strength may be more evident in a population with pain, such as neck pain. Cardinale et al. (2015) suggest that the neuromuscular changes brought about by SMT are nominal and transient in nature and through the current evidence, and supported by this study, there is clear physiological effects of SMT. Yet the detailed mechanism remains unclear. Cardinale et al. (2015) suggest that though a definitive answer on the effect of SMT on neuromuscular function is lacking, evidence of a limited cause
and effect relationship between SMT and neuromuscular function can be observed using sEMG and further studies should explore this relationship.

It is also necessary to consider the effect of crosstalk in this study, although every effort was made to reduce it. Crosstalk, a signal contamination that occurs when the pick-up area of electrodes overlaps, can contaminate and distort muscle signals, impacting the quality of the data (Mogk and Keir 2003). Forearm muscle crosstalk is understood to be larger than that of other extremities due to the greater quantity of muscles present in a smaller volume (Kong et al. 2010).

Studies show that crosstalk in the forearm can range between 4% to 50%, twice as high as that of lower limb muscles which range between 9% to 24% (Kong et al. 2010: 1223, 1227, 1228. Winter et al. 1994: 24-26). A possible reason for the lack of significant change in the FCR, FCU and/or the ECU may be related to crosstalk between muscles due to the differing forearm diameters of participants together with the relative size of the electrode differing between the upper and lower limbs.

Evidence-based literature (Dunning and Rushton 2009: 512; Suter and McMorland 2002) currently supports the notion that decreased muscle activity occurring in extremity muscles not directly connected to the spine can occur because of cervical spine dysfunction or lumbopelvic dysfunction. Although this study was completed using asymptomatic participants - and it is acknowledged that the results are not transferable to a symptomatic population - the results may still have clinical implications for manual therapy practitioners by adding to the evidence to show that SMT of the cervical spine may be beneficial to patients with cervical spine dysfunction before any strength training is initiated.

Criswell (2011) has reported a negative correlation between sEMG amplitude and skin fold thickness, as the subcutaneous fat can act as an insulator between the electrodes and the muscle, dampening the signal. The quality and amplitude of the sEMG signal therefore depends on the amount of subcutaneous fat of the individuals. Lean forearm volume and forearm diameter were not controlled for in this study and may have influenced the quality and magnitude of the data, as these factors varied greatly within the sample population.
Though a statistically significant beneficial treatment effect was only detected in the ECR and FDS, all other outcomes suggest positive trends of beneficial treatment effects. However, the sample size was too small to identify significance thus warranting further investigation.

5.4 Force Output

The results of this study indicate that cervical spine manipulation may have an effect on grip strength in healthy pain free young adults. A statistically significant overall time effect was identified within the CSM group ($p=0.012$). When comparing the groups, a statistically significant treatment effect was not observed ($p=0.069$). Although a treatment effect was not identified in the SMT group, the $p$-value marginally missed significance, adding to the positive trend seen in the forearm electromyography. Had the sample been larger a positive effect may have been observed.

These results are echoed in the Humphries et al. (2013) study on asymptomatic basketball players where a trend of improvement in grip strength (mean=0.7kg) was seen in those receiving SMT. Proprioceptive tasks increased as shown by improved free-throw accuracy (13.2%) but narrowly missed statistical significance ($p=0.058$).

Botelho, Bruno and Andrade (2012) found statistically significant increases in the grip strength of Judo athletes following three treatment sessions of SMT, compared to a control ($p=0.025$). The significant improvement in grip strength may be ascribed to inducing greater vertebral motion in the cervical spine and eliciting nerve root responses which may lead to increased muscle strength of the forearm flexors and extensors, due to the repeated treatments. In the current study only one treatment was administered, and the effect of that single treatment was observed over 15 minutes. Future studies should consider using repeated treatments. Contrary to the anatomical evidence presented in this dissertation which directed the intervention to C7 only, based on its association with the muscles of the forearm, the cervical spine interventions performed in Botelho, Bruno and Andrade (2012) were directed to primary cervical spine fixations with the majority delivered to C1 and C2 (n=27), representing 49.09% of total
manipulations, with C7 receiving the lowest number, making up 5.45% of total interventions. This contrasts with the 100% (n=46) of interventions directed to the C7 vertebral segment in this study.

Fernández-Carnero et al. (2008) identified a significant increase in pain-free grip strength ($p<0.001$) in participants with lateral epicondylalgia after cervical spine manipulation at the C5/C6 level. Pain-free grip force was defined as the maximum force the participant was able to generate by squeezing the dynamometer without pain on the affected side. Once pain was elicited, the participant was requested to release their grip. An MVC was examined on the unaffected arm, pre and post SMT interventions, and was found not to be significant ($p=0.9$). The authors suggested that, though still inconclusive, SMT stimulates the periaqueductal grey area by stimulating descending inhibitory mechanisms. However, future study is necessary to fully elucidate the mechanisms by which SMT achieves its effects.

The results of this study may be interpreted to show that manipulation of the C7 segment resulted in activation of mechanosensitive afferents in the joint and paraspinal muscles, resulting in changes in alpha motor neuron excitatory capacity (Dunning and Rushton 2009: 511) and subsequent excitatory function of the forearm muscle activity (Pickar 2002) and force output, specifically of the ECR and FDS, the muscles primarily responsible for gripping tasks (Moore et al. 2014: 752).

This study proposes that the digit dedicated flexors of FDS, as a primary agonist for a grip strength task (Long, Hallbeck and Jung 2010), may have naturally produced greater amplitudes compared to the wrist-dedicated flexors of FCR and FCU. Additionally, the ECR is the prime extensor involved in gripping tasks and has been noted as being indispensable when clenching the fist (Moore et al. 2014: 752). This may have resulted in greater muscle activity amplitudes detected in ECR over ECU and ED. As the prime flexor and extensor muscles responsible for gripping tasks, the increased muscle activity identified in ECR and FDS, together with the positive trends seen in all muscle groups, indicate that manipulation of C7 may have resulted in increased motor unit recruitment patterns, leading to an increase in muscle activity.
Chapter Six

Conclusion and Recommendations

6.1 Conclusion

The aim of this study was to determine the effect of C7 cervical spine manipulation compared to a control in terms of grip strength, measured in kilograms/force and muscle activity of the forearm flexor and extensor muscles measured as peak amplitude (mV) and mean duration (RMS) in asymptomatic participants immediately and again at 5, 10 and 15-minute intervals. The results of this study provided evidence to refute the null hypothesis that stated that there would be no statistically significant difference in muscle activity of the ECR and FDS between the two groups. This study showed that in these two muscles the mean activity increased in the treatment group in comparison to the control group over time. Indicating that following SMT, the ECR and FDS muscles improved their motor fibre recruitment. Similar results were not seen in the FCR, FCU and ECU, however a trend of a treatment effect was observed.

In terms of force output of grip strength, the study failed to supply evidence to refute the null hypothesis as no significant changes were observed between the treatment and control group. This indicates that SMT did not result in a change in force output of grip strength when compared to the control group. However, a trend of a treatment effect was observed. The findings in this study are supportive of previous studies, suggesting that SMT results in neurophysiological changes that may alter muscle function.

6.2 Limitations

The following limitations were identified during the course of this study:

1. The sample size (n=46) showed positive trends in all muscle groups and potentially could have shown a positive treatment effect had the sample size been larger.
2. The study was conducted using asymptomatic participants therefore it is acknowledged that the results of the study are not applicable to symptomatic individuals.

3. Lean forearm volume was not controlled for in this study, therefore the difference in the subcutaneous fat layer thickness of the forearm between participants may have affected sEMG data as it can act as an insulator between electrode and muscle.

4. Forearm diameter was not controlled for in this study. The differences in forearm diameter may have led to different levels of electrode interference between participants as much as crosstalk was controlled for.

5. In terms of the methodology - although much effort as was taken to ensure reproducibility - the exact sEMG electrode placement between participants could not be standardised or verified. In addition, although the same researcher delivered the C7 spinal manipulation to all participants, the magnitude of the HVLA could not be standardised between participants.

6. The operating technique of the handheld dynamometer was demonstrated to all participants, but maximum voluntary contraction is a subjective measure. It can improve with participant confidence, understanding of the muscles required for the task, the activation of neural pathways over time and participation.

7. The same researcher both assessed participants and conducted the sEMG study leading to a potential bias. This was done for convince sake only. Future studies should attempt to remove this potential bias.

8. A standardised warm-up or demonstration for the handheld dynamometer was not implemented and as such the sample may have had varying levels of understanding of the requirements of the device to produce a true MVC.

### 6.3 Recommendations

1. Future studies should make use of a larger sample size to further examine the positive trend found in this study.
2. Future studies should consider examining a symptomatic population which may yield different, yet more clinically relevant results.

3. Lean forearm volume should be controlled for in future studies by measuring skin fold thickness and making use of it as part of the participant inclusion criteria.

4. Forearm thickness should be controlled for by setting a minimum forearm diameter limit to reduce crosstalk and interference between electrodes.

5. Future studies should make use of a research assistant to deliver the intervention or conduct the sEMG study in order to remove any potential researcher bias.

6. Future studies should make use of a standardised dynamometer warm up in order to ensure that all participants are mentally and physiologically prepared for the use of the dynamometer.
References


## Appendices

### Appendix A: Typical and Atypical vertebrae

<table>
<thead>
<tr>
<th>Typical Vertebrae</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level</strong></td>
<td><strong>Structure</strong></td>
</tr>
<tr>
<td>C3 – C6</td>
<td>Small vertebral body with a posterior arch.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Atypical vertebrae</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C1 - Atlas</strong></td>
<td>Anterior and posterior arches separated by lateral masses that project laterally as transverse processes.</td>
</tr>
<tr>
<td><strong>C2 – Axis</strong></td>
<td>Two flat weight-bearing surfaces, which articulate with the Atlas</td>
</tr>
<tr>
<td><strong>C7 Vertebrae prominens</strong></td>
<td>Larger vertebral body with a posterior arch.</td>
</tr>
</tbody>
</table>

Appendix B - Muscles of the forearm flexor and extensor compartment

The muscles of the anterior aspect of the forearm that are relevant to this study are detailed in the table below.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Action</th>
<th>Origin</th>
<th>Insertion</th>
<th>Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Superficial Layer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexor carpi radialis (FCR)</td>
<td>Flexes and abducts the hand at the wrist</td>
<td>Medial epicondyle of the humerus</td>
<td>Base of the 2-metacarpal</td>
<td>Median nerve – C6 and C7.</td>
</tr>
<tr>
<td>Flexor carpi ulnaris (FCU)</td>
<td>Flexes and adducts the wrist</td>
<td>Humeral head: medial epicondyle of the humerus</td>
<td>Pisiform, hook of the hamate and 5th metacarpal</td>
<td>Ulnar nerve – C7 and C8</td>
</tr>
<tr>
<td><strong>Intermediate layer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexor digitorum superficialis</td>
<td>Flexes middle phalanges of medial four digits at proximal interphalangeal joint; acting more strongly, it flexes phalanges at metacarpophalangeal joints</td>
<td>Humeroulnar head: medial epicondyle of humerus, coronoid process of ulna and ulnar collateral ligament.</td>
<td>Shafts of middle phalanges; medial four digits</td>
<td>Median nerve – C7, C8 and T1</td>
</tr>
</tbody>
</table>


The muscles of the posterior compartment of the forearm that are relevant to this study are detailed in the table below.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Action</th>
<th>Origin</th>
<th>Insertion</th>
<th>Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Superficial layer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensor carpi radialis (longus)</td>
<td>Extension and abduction of the hand at the wrist. Active during fist clenching.</td>
<td>Lateral supracondylar ridge of humerus</td>
<td>Base of the 2-metacarpal</td>
<td>Radial nerve – C6 and C7</td>
</tr>
<tr>
<td>Extensor carpi ulnaris</td>
<td>Extension and adduction of the hand at the wrist. Active during fist clenching.</td>
<td>Lateral epicondyle of the humerus, posterior border of ulna</td>
<td>Base of 5th metacarpal</td>
<td>Posterior interosseus nerve – branch of radial nerve – C7 and C8</td>
</tr>
<tr>
<td>Extensor digitorum</td>
<td>Extension of digits at metacarpophalangeal and interphalangeal joints; extension of hand at the wrist</td>
<td>Lateral epicondyle of the humerus</td>
<td>Extensor expansions of medial four digits</td>
<td>Posterior interosseus nerve – branch of radial nerve – C7 and C8</td>
</tr>
</tbody>
</table>

Appendix C: IREC Approval

21 July 2017

IREC Reference Number: REC 46/17

Mr D J Fenton
17 Hillside Road
Seadown
4126

Dear Mr Fenton

The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction

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

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

Yours Sincerely,

[Signature]

Professor J K Adam
Chairperson: IREC
## Appendix D: Trial application and registration

### TRIAL APPLICATION

<table>
<thead>
<tr>
<th>Application ID:</th>
<th>4719</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOH Number</td>
<td></td>
</tr>
<tr>
<td>DOH-27-0717-6719</td>
<td></td>
</tr>
<tr>
<td>Page:</td>
<td>1/2</td>
</tr>
</tbody>
</table>

**Applicant Details**

- **Organisation:** Durban University of Technology
- **Applicant Type:** Academic Investigator
- **Contact Name:** Laura O’Connor
- **Address:** Chiropractic Programme
  Durban University of Technology
  PO Box 1334
  Durban
  4000
- **Telephone:** 0313732923
- **Fax:** 0865324209
- **E-mail:** lauraw@diut.ac.za
- **Responsible Contact person (for public):** L. O’Connor
- **Telephone:** 03137372923
- **Research contact person:** L. O’Connor
- **Telephone:** 0313732923

**Trial Application Details**

- **Issue Date:** 2017/04/18
- **Sponsors:** Durban University of Technology
- **Primary Sponsor:** Durban University of Technology
- **Funding Type:** Not Funded
- **Research Site Names:** Durban University of Technology Chiropractic Clinic
- **Primary Research Site Name:** Durban University of Technology Chiropractic Clinic
- **Total National Budget for Trial:** R 7040.00
- **Protocol / Grant Reference Number:** REC 17

**Study Descriptive Information**

- **Brief Title of Study:** The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction
- **Full Title of Study:** The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction
- **Anticipated Start Date:** 2017/05/22
- **Anticipated End Date:** 2018/01/31
- **Target Sample Size:** 70
- **Study Phase:** Other
- **Study Scope:** Single Site
- **Study Type:** Interventional
- **Disease Type Heading:** Muscle, Bone and Cartilage Diseases
- **Disease Type Condition:** Musculoskeletal Abnormalities
- **Intervention Name (Generic):** Cervical spine manipulation
- **Intervention Duration:** No. Type
Appendix E: Permission to conduct research at the DUT Chiropractic Day Clinic

MEMORANDUM

To : Prof Ross  
Chair : RHDC  
Prof Adam  
Chair : IREC

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

Date : 09.02.2017

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

Permission is hereby granted to:

Mr Daniel Fenton (Student Number: 21327075)

Research Title : The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction.

Mr Fenton, is requested to submit a copy of his RHDC / IREC approved proposal along with proof of his M.Tech. Chiropractic registration to the Clinic Administrators (Mrs Twiggs, Dr Basdav) 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 Charmaine Korporeal  
Clinic Director : Chiropractic Day Clinic : Chiropractic and Somatology

Cc: Dr Basdav  : Chiropractic Day Clinic
Mrs L. Twiggs  : Student Co-ordinator
Dr L. O’Connor  : Supervisor
Prof T. Puckree  : Co-supervisor
Appendix F: Permission to conduct research at DUT

27th June 2017

Mr Daniel James Fenton
O/o Department of Chiropractic and Osteopathy
Faculty of Health Sciences
Durban University of Technology

Dear Mr Fenton

PERMISSION TO CONDUCT RESEARCH AT THE DUT

Your email correspondence in respect of the above refers. I am pleased to inform you that the Institutional Research Committee (IRC) has granted full permission for you to conduct your research “The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction” at the Durban University of Technology.

The DUT may impose any other condition it deems appropriate in the circumstances having regard to nature and extent of access to and use of information requested.

We would be grateful if a summary of your key research findings can be submitted to the IRC on completion of your studies.

Kindest regards,
Yours sincerely

PROF SIBUSISO MOYO
DVC (ACTING): RESEARCH, INNOVATION AND ENGAGEMENT
DIRECTOR: RESEARCH AND POSTGRADUATE SUPPORT
Appendix G: Advertisement

Would you like to find out how strong your grip is? Would you like to see if that can be improved?

Research is being conducted at the Durban University of Technology Chiropractic Day Clinic.

**Participation in the study is free.**

**As part of the study you will receive a full medical examination free.**

If you are interested in participating in this study and are between the ages of 18 and 35, please contact the researcher via **phone, text message or WhatsApp** on **0844 306 176** or alternatively via email on **danielariesfenton@gmail.com**
Appendix G: Advertisement - ZULU

UNGATHANDA UKUTHOLA UKUTHI

UNGATHANDA UKUBONA UKUTHI KUNGENZIWA NCONO KANJANI?

UCWANINGO LUYENZIWA EMTHOLAMPILO WAKWA-CHIROPRACTIC OSE- DURBAN UNIVERSITY OF TECHNOLOGY

UKUBAMBA IQHAZA NOMA UKUBA YINGXENYE YALOLO CWANINGO KUMAHHALA.

NJENGOBAMBE IQHAZA KULOLUCWANINGO UZOTHOLA UKUHLOLWA NGOKWEZEMPITO MAHHALA.

Uma unentshisekelo yokuba yingxenye yalolucwachingo, luvulelekiyakubantu abaneminyaka ephakathi kuka 18 no 35 ungaxhumana nomcwaningi omkhulu ngokumfonela, ngokuthumela umyalezo noma Whatsapp enambeni 0844306176 noma usebenzise i-imeyili danielariesfenton@gmail.com
Appendix H: Case history form

CHIROPRACTIC PROGRAMME

CHIROPRACTIC DAY CLINIC
CASE HISTORY

Patient: ___________________________ Date: __________

File #: __________________________ Age: _________

Sex: ____________________________ Occupation: __________________________

Student: __________________________ Signature: __________________________

FOR CLINICIANS USE ONLY:
Initial visit
Clinician: __________________________ Signature: __________________________

Case History:

Examination:
Previous: ________________________ Current: __________________________

X-Ray Studies:
Previous: ________________________ Current: __________________________

Clinical Path. lab:
Previous: ________________________ Current: __________________________

CASE STATUS:

PTT: __________________________ Signature: __________________________ Date: __________

CONDITIONAL:
Reason for Conditional:

Signature: __________________________ Date: __________

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

Case Summary signed off: __________ Date: __________
**Student's Case History:**

1. **Source of History:**

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

3. **Present Illness:**

<table>
<thead>
<tr>
<th>Location</th>
<th>Complaint 1 (principle complaint)</th>
<th>Complaint 2 (additional or secondary complaint)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recent:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cause:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain (Character)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Progression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggravating Factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relieving Factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Associated S &amp; S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous Occurrences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Past Treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcome:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. **Other Complaints:**

5. **Past Medical History:**

- General Health Status
- Childhood Illnesses
- Adult Illnesses
- Psychiatric Illnesses
- Accidents/Injuries
- Surgery
- Hospitalizations
6. **Current health status and life-style:**

**Allergies**

**Immunizations**

**Screening Tests incl. x-rays**

**Environmental Hazards (Home, School, Work)**

**Exercise and Leisure**

**Sleep Patterns**

**Diet**

**Current Medication**

- Analgesics/week:
- Other (please list):

**Tobacco**

**Alcohol**

**Social Drugs**

7. **Immediate Family Medical History:**

**Age of all family members**

**Health of all family members**

**Cause of Death of any family members**

<table>
<thead>
<tr>
<th>Noted</th>
<th>Family member</th>
<th>Noted</th>
<th>Family member</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcoholism</td>
<td>Headaches</td>
<td>Anaemia</td>
<td>Heart Disease</td>
</tr>
<tr>
<td>Arthritis</td>
<td>Kidney Disease</td>
<td>CA</td>
<td>Mental Illness</td>
</tr>
<tr>
<td>DM</td>
<td>Stroke</td>
<td>Drug Addiction</td>
<td>Thyroid Disease</td>
</tr>
<tr>
<td>Epilepsy</td>
<td>TB</td>
<td>Other (list)</td>
<td></td>
</tr>
</tbody>
</table>

8. **Psychosocial history:**

**Home Situation and daily life**

**Important experiences**

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

General
Skin
Head
Eyes
Ears
Nose/Sinuses
Mouth/Throat
Neck
Breasts
Respiratory
Cardiac
Gastro-intestinal
Urinary
Genital
Vascular
Musculoskeletal
Neurologic
Haematological
Endocrine
Psychiatric
## Appendix I: Physical examination form

<table>
<thead>
<tr>
<th>Patient Name:</th>
<th>File no:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student:</td>
<td>Signature:</td>
<td></td>
</tr>
</tbody>
</table>

### VITALS:

- **Pulse rate:**
- **Respiratory rate:**
- **Blood pressure:** _R_ _L_  
  - **Medication if hypertensive:**
- **Temperature:**
- **Height:**
- **Weight:**  
  - **Any recent change:** _Y / N_  
  - **If Yes: How much gain/loss:**  
  - **Over what period:**

### GENERAL EXAMINATION:

- **General Impression**
- **Skin**
- **Jaundice**
- **Pallor**
- **Clubbing**
- **Cyanosis (Central/Peripheral)**
- **Oedema**
  - **Lymph nodes:**
    - Head and neck
    - Axillary
    - Epitrochlear
    - Inguinal
- **Pulses**
- **Urinalysis**

### SYSTEM SPECIFIC EXAMINATION:

- **CARDIOVASCULAR EXAMINATION**
- **RESPIRATORY EXAMINATION**
- **ABDOMINAL EXAMINATION**
- **NEUROLOGICAL EXAMINATION**

### COMMENTS

<table>
<thead>
<tr>
<th>Clinician:</th>
<th>Signature:</th>
</tr>
</thead>
</table>

---

Page 1
Appendix J: Cervical spine regional examination

CHIROPRACTIC PROGRAMME
REGIONAL EXAMINATION – CERVICAL SPINE

Patient: ___________________________  File No: ___________________________
Date: ___________________________  Student: ___________________________
Clinician: ___________________________  Sign: ___________________________

OBSERVATION:
Posture
Swellings
Scars, discoloration
Hair line
Body and soft tissue contours

Shoulder position
Left:
Right:
Shoulder dominance (hand):
Facial expression:

RANGE OF MOTION:
Extension (70°):
L/R Rotation (70°):
L/R Lat flex (45°):
Flexion (45°):

PALPATION:
Lymph nodes
Thyroid Gland
Trachea

MYOFASCIAL ASSESSMENT

<table>
<thead>
<tr>
<th>Tenderness</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger Points: SCM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scalenii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Cervicals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trapezius</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lev scapular</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ORTHOPAEDIC EXAMINATION:

<table>
<thead>
<tr>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adson’s test</td>
<td></td>
</tr>
<tr>
<td>Brachial plexus test</td>
<td>Hyper-abduction test</td>
</tr>
<tr>
<td>Cervical compression</td>
<td>Kemp’s test</td>
</tr>
<tr>
<td>Cervical distraction</td>
<td>Lateral compression</td>
</tr>
<tr>
<td>Costoclavicular test</td>
<td>Lhermitte’s sign</td>
</tr>
<tr>
<td>Dizziness rotation test</td>
<td>Shoulder abduction test</td>
</tr>
<tr>
<td>Doorbell sign</td>
<td>Shoulder compression test</td>
</tr>
<tr>
<td>Eden’s test</td>
<td></td>
</tr>
</tbody>
</table>
**NEUROLOGICAL EXAMINATION:**

<table>
<thead>
<tr>
<th>Dermatones</th>
<th>Left</th>
<th>Right</th>
<th>Myotomes</th>
<th>Left</th>
<th>Right</th>
<th>Reflexes</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>C1</td>
<td></td>
<td>C1</td>
<td>C2</td>
<td></td>
<td>C1</td>
<td>C2</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>C2</td>
<td></td>
<td>C2</td>
<td>C3</td>
<td></td>
<td>C2</td>
<td>C3</td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>C3</td>
<td></td>
<td>C3</td>
<td>C4</td>
<td></td>
<td>C3</td>
<td>C4</td>
<td></td>
</tr>
<tr>
<td>C5</td>
<td>C4</td>
<td></td>
<td>C4</td>
<td>C5</td>
<td></td>
<td>C4</td>
<td>C5</td>
<td></td>
</tr>
<tr>
<td>C6</td>
<td>C5</td>
<td></td>
<td>C5</td>
<td>C6</td>
<td></td>
<td>C5</td>
<td>C6</td>
<td></td>
</tr>
<tr>
<td>C7</td>
<td>C6</td>
<td></td>
<td>C6</td>
<td>C7</td>
<td></td>
<td>C6</td>
<td>C7</td>
<td></td>
</tr>
<tr>
<td>C8</td>
<td>C7</td>
<td></td>
<td>C7</td>
<td>C8</td>
<td></td>
<td>C7</td>
<td>C8</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>C8</td>
<td></td>
<td>T1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cerebellar tests: Left Right

Dysdiadochokinesis

**VASCULAR:**

<table>
<thead>
<tr>
<th></th>
<th>Left</th>
<th>Right</th>
<th></th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure</td>
<td></td>
<td></td>
<td>Subclavian arts.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carotid arts.</td>
<td></td>
<td></td>
<td>Wallenberg’s test</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MOTION PALPATION & JOINT PLAY:**

Left: Motion Palpation:  
Joint Play:  
Right: Motion Palpation:  
Joint Play:  

**BASIC EXAM: SHOULDER:**

Case History:

ROM: Active:
Passive:
RIM:
Orthopaedic:
Neuro:
Vascular:

**BASIC EXAM: THORACIC SPINE:**

Case History:

ROM:

Motion Palpation:
Orthopaedic:
Neuro:
Vascular:
Observ/Palpation:
Joint Play:
Appendix K: Letter of Consent

LETTER OF CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Daniel Fenton, about the nature, procedure, benefits and risks of this study - Research Ethics Clearance Number: REC 46/17
- I have received, read and understood the Letter of Information regarding this study.
- I am aware that the results of this study, including personal details regarding my name, sex, age, date of birth and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without consequence, withdraw my consent and participation in this study.
- I have had sufficient opportunity to ask questions and of my own free will declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research, which may relate to my participation, will be made available to me.

__________________________  __________________  ____________
Full name of participant    Date                  Signature

I, Daniel Fenton, herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

__________________________  __________________  ____________
Full name of researcher      Date                  Signature

__________________________  __________________  ____________
Full name of witness (if applicable) Date                  Signature

__________________________  __________________  ____________
Full name of legal guardian (if applicable) Date                  Signature
Appendix K: Letter of Consent - ZULU

**INCWADI YEMVUME**

Isitatimende esimyelana nemvume yakho ukuba ube yingxenyeye yalolucwaningno:

* Ngalokhu ngiyisikhise ukuthi nginolwazi olupheleneyo mayelana nohlolo, nohlelo, nezinzuzo futhi nezindleko eziphathelene nocwaningno- izimiso zokuhle zocwaningno
  Inombolo: REC 46/17
* Ngitholile, ngafulana, ngaqonda kabanzi incwadi yolwazi ephathelene nocwaningno engiyiniwe.

* Ngiyazi ukuthi imiphumela yalolucwaningno, okubala iminingingwane ekhombisa mina njenge gama lami, ubulili, iminyaka, usuku lokuzalwa nohlalo lweni sami kuzoqhubhsha ngqunqo engakhombisi igama lami kufakwe embikweni walsolucwaningno.

* Mayelana nezimfuno zalolucwaningno, ngiyavuma ukuthi iminingingwena ehlanganiswe phakathi nocwaningno luqhubhsha ngendlela yeakhethile umcwaningi omkhulu.

* Ngingahoxa kunoma yisiphi isigaba ukuzimbakanya kwami noma ukuba yingxenyeye yalolucwaningno.

* Ngibe nethuba elaneleyo nelinginelisileyo lokubuzu imibuzo futhi nokuzikhethela ngaveza ngokusobana ukuzilungiselela kwami ukuthi ngibe yingxenyeye yalolucwaningno.

* Ngiyaqonda ukubaluleka kokutholakala kolwazi olusha oluza ngenxa yokuzebandakanya kwami ukuba umcwaningi omkhulu uzongazisa ngalo

Amagama apheleleyo omhlanganyeli  
____________________________  
Usuku  
____________________________  
Ukusayina

Mina, Daniel Fenton, lapha ngiyapheleleyo ukuthi umhlanganyeli obalulwe ngenhla unolwazi olwanele mayelana nohlolo, nohlelo futhi nezindleko zocwaningno olungenhla.

____________________________
____________________________
Amagama apheleleyo omcwaningi omkhulu  
Usuku  
Ukusayina

Amagama apheleleyo kafakazi (uma kunesidingo)  
____________________________
Usuku  
Ukusayina

Amagama apheleleyo omlondolozi osemthethweni (uma kunesidingo)  
Usuku  
Ukusayina
Appendix L: Letter of Information

Dear Participant

Welcome to my research study and thank you for agreeing to participate. The point of this study is to determine the effect of cervical spine manipulation on the muscle activity in the forearm. Current evidence shows that there are changes in muscle activity after cervical spine manipulation. The purpose of this study is to examine this effect in more detail, gaining knowledge into the short-term duration of this effect.

Title of the Research Study: The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction

Principal Investigator/s/researcher: Daniel Fenton
danielariesfenton@gmail.com

0844 306 176

Co-Investigator/s/supervisor/s: Dr Laura O’Connor (M. Tech: Chiropractic)

Brief Introduction and Purpose of the Study:
This study aims to determine the immediate and short-term effect of cervical spine manipulation (CSM) on grip strength and forearm muscle activity in asymptomatic participants with cervical spine dysfunction. Seventy participants with no head, neck, shoulder or arm pain will be recruited to participate in this study. Participants will have a baseline dynamometer and surface electromyography measurement recorded after which they will receive either an intervention treatment or not and undergo post intervention measurements. After this, measurements will be taken at timed intervals of 5, 10 and 15 minutes.

Outline of the Procedures:
Research study consultations will take place at the Durban University of Technology Chiropractic Day Clinic in Berea, Durban. You, as the participant, will be required to attend one consultation only for this study. A case history, physical and orthopaedic examination and cervical spine regional examination will be performed, after which the surface electromyography (sEMG) electrodes will be attached to your arm. Surface electromyography is a method of examining the activity of the muscles by attaching electrodes to the arm safely and without pain. The handheld dynamometer is a handle shaped device that you will have to simply squeeze. The sEMG recording will begin and baseline measurements will be taken. The researcher will allocate you to a random group. One group will receive an intervention,
the other will not. You will have equal chance of falling in either group. After this an intervention will either be delivered or not if you are in the control group. The researcher will then record the post intervention measurements. The researcher will then record the interval measurements at 5, 10 and 15-minute intervals. At this stage the consultation will be complete and you will be thanked for your participation and will be free to leave. The consultation is expected to last between two to three hours.

**Risks or Discomfort to the Participant:** This research study involves chiropractic manipulation. This form of treatment is relatively harmless but may result in short term muscle pain. In order to place the electrodes correctly, the forearm may need to be shaved. This may be uncomfortable.

**Benefits:** Those in the treatment group may benefit directly from improved range of motion and increased forearm muscle activity and all participants will benefit indirectly by adding to an evidence base used by chiropractors to better treat and manage their patients.

**Commitment to the study:** You may withdraw from this research study at any time, for any reason with no consequences whatsoever.

**Remuneration:** There are no financial rewards offered in this study. A free treatment voucher will be offered to you, should you choose to see the researcher for treatment again.

**Costs of the Study:** There are no personal costs involved in order for you to be included in this study.

**Confidentiality:** All patient information will be kept confidential and will be stored in the Chiropractic Day Clinic for 5 years, as an in-patient file, after which it will be shredded. No names will be used in the dissertation. The researcher and supervisor/s will have sole access to the data.

If you have any queries or concerns about the study, please do not hesitate to ask the researcher. You are not forced or coerced to participate in this study and are therefore optionally choosing to participate. You may withdraw from this study at any stage, for any reason with no consequence.

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

Dr Laura O’Connor on (031) 373 2923, lauraw@dut.ac.za
Institutional Research Ethics Administrator on 031 373 2375.
Complaints can be reported to: Director; Research and Postgraduate Support, Prof S. Moyo on 031 373 2577 or moyos@dut.ac.za
Appendix L: Letter of Information - ZULU

Incwadi yolwazi

Mhlanganyeli othandekayo

Ngiyakwamukela kucwaningo lwami futhi ngiyabonga ngokuba ube yingxenyeye yocwaningo lwami. Ingqikithi yalolucwaningo ukuthola mayelana nomthelela wokuluwa komqala ekusebenzeni kwemisipha yengalo. Ucwaningo lwakamumva luhluhla ukuthola kunoshihtsho emsipheni yengalo emva kokuluwa komqala. Inhluso yalolucwaningo ukucubungi kabanzi, nokuthola ulwazi emva kwesikhasha esincane emva kokuba ululile

Isihloko socwaningo: umthelela wokwelulwa komqala ekubambeni ngamandla, ukusebenza kwemisipha ebantwini abangenazo izimpawu zomqala ongasebenzi ngendlela

Umcwaningi omkhulu: Daniel Fenton – danielariesfenton@gmail.com 0844306176
Abalekeleli bacwaningo: Dr Laura O’Connor (M. Tech: Chiropractic)

Isingeniso ngamafuphi nenhlalo ngqangi:

Uheliso lokusebenza:
### Appendix M - Peak amplitude data measures from tested muscles

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre (±SD)</th>
<th>Post 1 (±SD)</th>
<th>Post 2 (±SD)</th>
<th>Post 3 (±SD)</th>
<th>Post 4 (±SD)</th>
<th>p value within</th>
<th>p value between</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCR</td>
<td>1</td>
<td>0.31 (0.14)</td>
<td>0.34 (0.17)</td>
<td>0.29 (0.12)</td>
<td>0.33 (0.17)</td>
<td>0.32 (0.17)</td>
<td>0.618</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.32 (0.28)</td>
<td>0.30 (0.21)</td>
<td>0.32 (0.31)</td>
<td>0.37 (0.37)</td>
<td>0.36 (0.30)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>p value</td>
<td>0.899</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCU</td>
<td>1</td>
<td>0.56 (0.33)</td>
<td>0.66 (0.36)</td>
<td>0.59 (0.34)</td>
<td>0.60 (0.28)</td>
<td>0.62 (0.37)</td>
<td>0.209</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.57 (0.40)</td>
<td>0.56 (0.43)</td>
<td>0.57 (0.45)</td>
<td>0.55 (0.39)</td>
<td>0.61 (0.41)</td>
<td>0.493</td>
</tr>
<tr>
<td></td>
<td>p value</td>
<td>0.976</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FDS</td>
<td>1</td>
<td>0.64 (0.31)</td>
<td>0.68 (0.28)</td>
<td>0.68 (0.33)</td>
<td>0.67 (0.32)</td>
<td>0.58 (0.34)</td>
<td>0.781</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.56 (0.25)</td>
<td>0.60 (0.25)</td>
<td>0.57 (0.23)</td>
<td>0.58 (0.26)</td>
<td>0.62 (0.29)</td>
<td>0.875</td>
</tr>
<tr>
<td></td>
<td>p value</td>
<td>0.454</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.580</td>
</tr>
<tr>
<td>ECR</td>
<td>1</td>
<td>0.70 (0.38)</td>
<td>0.76 (0.49)</td>
<td>0.78 (0.44)</td>
<td>0.78 (0.43)</td>
<td>0.75 (0.42)</td>
<td>0.227</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.69 (0.22)</td>
<td>0.60 (0.21)</td>
<td>0.58 (0.26)</td>
<td>0.59 (0.25)</td>
<td>0.51 (0.25)</td>
<td>0.535</td>
</tr>
<tr>
<td></td>
<td>p value</td>
<td>0.215</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECU</td>
<td>1</td>
<td>0.68 (0.43)</td>
<td>0.58 (0.17)</td>
<td>0.68 (0.20)</td>
<td>0.68 (0.23)</td>
<td>0.56 (0.16)</td>
<td>0.610</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.47 (0.19)</td>
<td>0.50 (0.22)</td>
<td>0.48 (0.18)</td>
<td>0.46 (0.20)</td>
<td>0.46 (0.19)</td>
<td>0.672</td>
</tr>
<tr>
<td></td>
<td>p value</td>
<td>0.291</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED</td>
<td>1</td>
<td>0.61 (0.30)</td>
<td>0.25 (0.27)</td>
<td>0.68 (0.30)</td>
<td>0.68 (0.31)</td>
<td>0.66 (0.25)</td>
<td>0.258</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.75 (0.30)</td>
<td>0.76 (0.28)</td>
<td>0.80 (0.37)</td>
<td>0.80 (0.41)</td>
<td>0.83 (0.40)</td>
<td>0.407</td>
</tr>
<tr>
<td></td>
<td>p value</td>
<td>0.124</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix N - Peak amplitude force output

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre (±SD)</th>
<th>Post 1 (±SD)</th>
<th>Post 2 (±SD)</th>
<th>Post 3 (±SD)</th>
<th>Post 4 (±SD)</th>
<th>p value within</th>
<th>p value between</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55.37 (26.80)</td>
<td>56.46 (21.04)</td>
<td>59.49 (22.69)</td>
<td>58.64 (25.47)</td>
<td>62.27 (28.49)</td>
<td>0.069</td>
<td>0.523</td>
</tr>
<tr>
<td>2</td>
<td>53.96 (21.35)</td>
<td>52.17 (21.71)</td>
<td>52.88 (24.50)</td>
<td>54.51 (22.79)</td>
<td>55.76 (23.84)</td>
<td>0.448</td>
<td></td>
</tr>
</tbody>
</table>
Appendix O: Letter requesting permission to conduct the study using DUT students and placing advertisements on campus.

Dear Prof Moyo

I hereby request permission to conduct a research study using DUT students as participants and to place the attached advertisement throughout DUT campuses in order to recruit participants for my Master’s research project.

Title: The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction.

The aim of the study is to determine the immediate and short-term effect of cervical spine manipulation on the maximum voluntary contraction of the forearm flexors and extensors.

The goal of the advertisement is to encourage individuals to become participants in the study thus adding to the growing body of evidence detailing the effects of chiropractic manipulation.

Please find the advertisement attached below.

Yours truly,

Dan Fenton
Student
21327075
Appendix P: Letter requesting permission to conduct research at the DUT Chiropractic Day Clinic

Dear Dr. Korporaal

I hereby request permission to use the Durban University of Technology Chiropractic Day Clinic in order to examine participants for my Master's research project.

The title of my Master's research is “The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction.” The aim of the study is to determine the immediate and short-term effect of cervical spine manipulation on the maximum voluntary contraction of the forearm flexors and extensors.

I intend to use the Chiropractic Day Clinic as a venue to interview, attain a case history and perform the physical and cervical regional examinations. Treatment and measurement recordings will be performed in the research laboratory.

Please don’t hesitate to contact me for any further information.

Yours truly,

Dan Fenton
Appendix Q: Application for approval of amendment: change of treatment position.

### APPLICATION FOR APPROVAL OF AMENDMENT

To be completed electronically by the principal investigator/researcher in accordance with the Standard Operating Procedures of the IREC.

| Title of the study: The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction |
| Institution: Durban University of Technology | Date: 23.08.2017 |
| Name and qualification of principal investigator/researcher: Daniel Fenton – registered for M.Tech Chiropractic | Name and qualification of supervisor(s): Dr L. O’Connor – M.Tech Chiropractic (Supervisor) Prof T. Puckree – PhD Exercise physiology (Co-Supervisor) |
| Name of qualification: M.Tech Chiropractic | Student Number: 21327075 |
| Ethical approval number: REC 46/17 | Research site: DUT Chiropractic Day Clinic |

Nature of amendment: Change of treatment positioning from seated to supine (page 8) and thus appendix G has been removed. The supine adjustment in the lateral flexion position will be more effective for the research.

Effect on risk benefit profile of participants: None

Please submit the following documentation:
- Amended proposal (changes to be underlined)
- Changes to letter of information and consent
- Any other relevant documentation

| Signature: | Date: |
| Researcher: | |
| Supervisor: | |
| Head of Department: | |
**TO BE COMPLETED BY THE CHAIRPERSON OF THE IREC.**

<table>
<thead>
<tr>
<th>Date received:</th>
<th>Review required:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expedited</td>
</tr>
</tbody>
</table>

**TO BE COMPLETED BY THE CHAIRPERSON OF THE IREC**

<table>
<thead>
<tr>
<th>The amendment is:</th>
<th>Yes</th>
<th>No</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approved – there are no evident grounds for concern or further investigation.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approved subject to minor changes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Needs to be re-submitted after recommendations are met</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approved however a site inspection is recommended.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denied (please see attached)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Signature:</strong></th>
<th><strong>Date:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chairperson of FRC</td>
<td></td>
</tr>
<tr>
<td>Chairperson of IREC</td>
<td></td>
</tr>
</tbody>
</table>
Appendix R: Approval of amendment: treatment position change

31 August 2017

Mr D J Fenton
17 Hillside Road
Seadowne
4126

Dear Mr Fenton

Application for Amendment of Approved Research Proposal

The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction

I am pleased to inform you that your application to change the treatment position from seated to supine has been approved. In addition, the removal of Appendix G from the proposal has been approved.

Yours Sincerely

[Signature]

Professor J K Adam
Chairperson: IREC
Appendix S: Application for approval of amendment: sample size amendment

APPLICATION FOR APPROVAL OF AMENDMENT

To be completed electronically by the principal investigator/researcher in accordance with the Standard Operating Procedures of the IREC.

Title of the study: The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction

<table>
<thead>
<tr>
<th>Institution: Durban University of Technology</th>
<th>Date: 23.05.2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name and qualification of principal investigator/researcher: Daniel Fenton – registered for M.Tech Chiropractic</td>
<td>Name and qualification of supervisor(s): Dr L. O’Connor – M.Tech Chiropractic (Supervisor)</td>
</tr>
<tr>
<td>Name of qualification: M.Tech Chiropractic</td>
<td>Student Number: 21327075</td>
</tr>
<tr>
<td>Ethical approval number: REC 46/17</td>
<td>Research site: DUT Chiropractic Day Clinic</td>
</tr>
</tbody>
</table>

Nature of amendment: When preparing the research proposal the power calculation for the sample was performed using a t-test, assuming a power of 80% and an effect size of 0.8 accounting for only two measurements. This calculation did not take into account the multiple repeat recordings that are being performed in this study and thus the sample calculation is inappropriate. Thus this amendment is to change the sample size based on the new power calculation.

Effect on risk benefit profile of participants: None

Please submit the following documentation:

- Amended proposal (changes to be underlined)
- Changes to letter of information and consent
- Any other relevant documentation

Signature: ___________________________ Date: ___________________________

Researcher: ___________________________

Supervisor: ___________________________

Head of Department: ___________________________

TO BE COMPLETED BY THE CHAIRPERSON OF THE IREC.

Date received: ___________________________ Review required: ___________________________
14 June 2018

Mr. D. J. Fenton
17 Hillside Road
Seadowne
4126

Dear Mr. Fenton,

Application for Amendment of Approved Research Proposal

The effect of cervical spine manipulation on grip strength and muscle activity in asymptomatic participants with cervical spine dysfunction

I am pleased to inform you that your application to reduce the sample size of your proposed study from 70 to 40 has been approved.

Yours Sincerely,

[Signature]

Professor J. R. Adam
Chairperson: IREC

2019-06-14

INSTITUTIONAL RESEARCH ETHICS COMMITTEE
P.O. BOX 1324 DURBAN 4000 SOUTH AFRICA