The effect of cervical spine manipulation on elbow proprioception, electrical activity of the triceps and biceps muscles and balance

By

Hannah Lenka McKay

Dissertation submitted in partial compliance with the requirements for the

Master's Degree in Technology: Chiropractic

Durban University of Technology

Declaration

I, Hannah Lenka McKay, declare that this dissertation represents my own work in conception and execution. It is being submitted for the Chiropractic Degree of Master's in Technology at the Durban University of Technology. This dissertation has not been previously submitted for any degree or examination to any other University.

_____ Date:_____

Hannah McKay

Approved for Final Submission

_____ Date:_____

Dr Grant Matkovich

MTech: Chiropractic

Dedication

To the Creator, who moulded our anatomy and breathed our physiology into life, thank you for allowing my hands to facilitate healing and for a career that is a constant reminder that we are fearfully and wonderfully made.

To my dear parents, Lionel and Debra McKay. You have supported, guided, encouraged, loved and believed in me. Thank you for the incredible opportunities that you have so selflessly given me.

For you formed my inward parts;

You knitted me together in my mother's womb.

I praise you, for I am fearfully and wonderfully made.

Psalm 139:13

Acknowledgements

My supervisor, Dr Matkovich, thank you for your commitment, guidance and time that you have invested into this dissertation. Your input and assistance was invaluable.

Thank you, Dr Korporaal, for helping me conceptualise this study and for always making time in your busy schedule to lend a helping hand or a word of advice. You are so appreciated.

Dr Joshua Korten, my love, thank you for patiently introducing my analytical brain to Innate and for fueling my passion for Chiropractic. Thank you for the time that you put into helping me with this thesis. I am so excited to take on this chiropractic life-mission with you.

Sarah, my sweet sister, and Joshua, my beloved brother, thank you for your continual love, support and humour. You are both so precious to me.

Thank you Brad and Kim Woods, for opening up your hearts and your home to me. Your warmth, love and hospitality is greatly appreciated. You will always hold a special place in my heart.

Professor Glenda Matthews, thank you for your time, patience and skill dedicated to conducting my statistics.

Mr Gideon Burger, from Axiology Labs, thank you for your assistance with the Biopac electromyography and goniometer used in this study.

Dr Richard Steele, thank you for agreeing to proof-read my dissertation at such short notice.

Thank you to all the people who were participants in this study. The time that you so willingly gave, made this study possible.

Lastly, thank you to my tribe – to all of my dear friends and family who walk alongside me. You are greatly appreciated and I hold you all close to my heart.

Abstract

Objectives

The purpose of this study was to determine the effect of cervical spine manipulation (CSM) on joint position sense (JPS) of the elbow; electrical (muscular) activity of the biceps and triceps brachii muscles and balance.

Background

Balance is a complex process requiring constant communication between the visual, the vestibular and the somatosensory (nervous) systems. JPS and electrical activity of muscles play an important role in maintaining balance. Many of the tracts relaying information regarding JPS, electrical activity and balance pass through the cervical spine. It is thought that cervical spine fixations have a negative effect on the surrounding neurology and thus affect somatosensory integration. Therefore, correction of cervical spine fixations with CSM may improve and restore normal function, including, but not limited to, elbow JPS, electrical activity of the biceps and triceps brachii muscles and balance.

Methods

Institutional Research Ethics Committee (IREC) approval of the study was obtained (IREC reference number: REC 115/16). A quantitative, descriptive, pre-test post-test randomised control trial investigation design was utilised. A pilot study was performed to validate the experimental procedures. Potential participants were assessed through a telephonic interview, a case history and a physical examination, to screen them against the inclusion criteria. Eighty-one participants between the ages of 18-35 years were randomly allocated to either the control (n = 20) or the intervention group (n = 61). The intervention group was further stratified into three subgroups, namely upper cervical spine fixations only (C0-C3); lower cervical spine fixations only (C4-C7) and both upper and lower cervical spine fixations. Each participant completed two pre-tests for static balance (eyes open and closed) and dynamic balance (eyes open and closed) [Biosway Biopac balance system]; one pre-test for electrical activity of biceps and triceps brachii muscles at rest and then during an active movement; and one pre-test of the ipsilateral elbow for JPS [Biopac AcqKnowledge sEMG machine and goniometer]. All tests were performed on the dominant arm. The intervention group then received CSM to correct the fixated segments. The control group underwent a 20 second rest period instead of the CSM. The electrical activity of the biceps and triceps brachii muscles was recorded during the intervention period. The pre-tests were then repeated as post-tests

immediately following the intervention. Analysis was by paired sample t-tests (pre and post outcomes for intra-analysis). Independent t-tests were conducted to determine mean differences between the control group and intervention group. An ANOVA test was conducted for mean differences from pre- and post-intervention readings between the control group and the three intervention subgroups. If the null-hypothesis was rejected, then post hoc tests were conducted to detect where the differences lay. A p-value < 0.05 was considered statistically significant. The effect size (Cohen's d), was also used to determine the magnitude of the effect of interest.

Results

There was no statistically significant improvement in elbow JPS immediately following CSM. The combined intervention group showed a statistically significant increase in the electrical activity of biceps ($p < 0.001$) and triceps brachii ($p = 0.004$) muscles during the CSM. The group that received upper CSM only had the greatest increase during CSM in both muscles ($p = 0.04$ for biceps and $p = 0.024$ for triceps. This group also had a sustained increased electrical activity that was statistically significance for a 10% level of significance ($p = 0.09$), during the rest period. There was a statistically significant improvement in dynamic balance for the combined intervention group ($p = 0.012$). Of the subgroups, the lower CSM only group had the greatest improvement in dynamic balance ($p = 0.035$) followed by the upper CSM only group ($p = 0.074$, significant for a 10% level of significance). Comparison of the four groups indicated two trends in the outcomes. The first trend was that the upper CSM only group had the greatest effect size for elbow JPS improvement and increased electrical activity for the biceps and triceps brachii muscles during the intervention and rest period, as well as a statistically significant difference in dynamic balance at a 10% confidence interval ($p = 0.074$). The second trend was in the lower CSM only group, which had the greatest effect size in decreasing electrical activity during the active movement as well as the greatest statistically significant improvement in dynamic balance ($p = 0.035$).

Conclusion

This preliminary study indicates that there is no immediate improvement in elbow JPS following CSM as a once off intervention. CSM has an immediate effect on increasing electrical activity of the biceps and triceps brachii muscles during the CSM. CSM also improves dynamic balance. Upper CSM has the greatest effect on electrical activity during the CSM and rest period. Lower CSM has the greatest effect in improving dynamic balance.

Table of Contents

List of Figures

List of Tables

List of Appendices

Abbreviations and Symbols

BNN	Basal nuclei neuron
BBPBS	Biosway Biopac balance system
CN	Cerebellar neuron
CI	Contraindications
CP	Contact point
CSM	Chiropractic spinal manipulation
CSP	Cervical spine position
DUT CDC	Durban University of Technology Chiropractic Day Clinic
DCML	Dorsal column-medial lemniscus
FFA	Forward-feed activation
HVLA	High velocity low amplitude
I	Indicated
IREC	Institutional Research Ethics Committee
IH	Indifferent hand
JPS	Joint Position Sense
LCN	Local circuit neuron
LMN	Lower motor neuron
MCTSIB	modified clinical test for sensory integration and balance
PP	Participant position
PCML	Posterior column-medial lemniscus
RP	Researcher position
SCP	Segmental contact point
SIJ	Sacro-iliac joint
SMI	Sensorimotor integration
TMS	Trans-crania stimulation
UMNs	Upper motor neurons
V	Vector

%	percentage
<	less than
>	greater than
P	p-value
=	equal to

Definitions

Afferent neurons: Nerves conducting towards the central nervous system.

Efferent neurons: Nerves conducting away from the central nervous system.

Joint position sense: The brain's ability to register where a joint is in relation to its surroundings.

Kinaesthesia: The perception of limb movement in the absence of visual cues.

Manipulation: A thrust of high velocity and low amplitude, in the plane of movement that was limited, with the goal of removing the spinal fixation.

Proprioception: The sense of orientation. It is a specialised variation of the sense of touch. Proprioceptive sensations allow a person to register where their head and limbs are at any point in time. It encompasses joint position sense (JPS) and kinaesthesia.

Somatosensory integration: The process by which incoming sensory or afferent information is coordinated and integrated with the motor system so that movement is controlled.

Somatosensory system: part of the sensory nervous system that consists of sensory neurons and pathways that respond to changes in the body.

Spinal fixation: A spinal fixation is described as an altered alignment, function or restricted movement within a spinal motion segment.

Spinal motion segment: Two adjacent vertebrae and the connecting tissue binding them together

Sway index: A measurement of the amount of sway. The higher the sway index, the more unstable a person is.

Chapter 1: Introduction

1.1 Introduction

Balance is a complex process that requires optimal communication between many systems and body parts to occur optimally (Derrickson and Tortora 2011; Walker et al. 2014). The eyes, vestibular system and the nervous system work together to control balance (Waugh, Grant and Ross 2010). For this study, the nervous system component of balance was investigated. Joint position sense is a vital component of balance as it allows the body to gauge where the joints of the body are placed in relation to its surroundings (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011; van Neckel 2017). Muscle tone, which is affected by the electrical activity of muscles, is directly linked to joint position sense (JPS) (Gilman 2002; Pickar and Kang 2006; CNS Clinic-Jordan 2016).

The receptors all over the body, called proprioceptors, send afferent sensory information from muscles and joints to the central nervous system to inform the CNS about the placement of limbs and joints in relation to its surroundings. In the spinal cord, this information is propagated along spinal tracts to higher processing centres in the cerebrum and cerebellum. Once this information has been processed, command signals are generated and sent back down the spinal cord in somatic motor pathways to instruct movement in response to the sensory stimuli received (Derrickson and Tortora 2011, Haavik and Murphy 2012).

Information regarding JPS, muscle activity and balance from all areas below must pass through the cervical spinal cord before the tracts can reach the higher processing centres. The cervical spine plays a protective role in housing the spinal cord as it passes through this region (Derrickson and Tortora 2011). The cervical spine can become fixated when there is altered alignment, function or restricted movement within a spinal motion segment. This affects the joint itself, as well as the surrounding soft tissue structures and the spinal neurology (Leach 2004; Gatterman 2005: Hieronymus cited in Gatterman 2005; Haavik 2012). When this occurs, the proprioception of the cervical joints is disrupted which results in neural integration of postural activities and sensorimotor integration in the cervical region being disrupted according to the proprioceptive insult hypothesis. This altered sensorimotor integration and proprioception is not restricted to affecting the cervical neurology but can influence vertical or horizontal components of the nervous system and therefore the tracts in the cervical spine may present with altered function (Fall 2004; Gatterman 2005; Haavik

and Murphy 2007, 2011, 2012). Many of these tracts relay sensory and motor information concerning coordination of balance. JPS and muscular activity, are important components of balance, relay information in the cervical tracts and therefore all three of these functions may be impaired by a cervical fixation (Gatterman 2005).

Chiropractic cervical spinal manipulation (CSM) has been shown to correct the proprioceptive disturbances that present in the case of fixations (Haavik-Taylor et al. 2010; Haavik-Taylor and Murphy 2010; Barker 2011; Haavik and Murphy 2011; Holt 2014). When the cervical spine is biomechanically aligned through CSM the proprioceptive insult is removed, which removes the interference from the cervical tracts and allows normal function to resume, including relaying of information concerning balance, JPS and muscular activity (Suter and McMorland 2002; Gatterman 2005; Dunning and Rushton 2009; Nolan 2010; Haavik-Taylor et al. 2010; Haavik-Taylor and Murphy 2007, 2010, 2011; Holt 2014).

1.2 Aim

The aim of this study was to determine the effect of CSM[1] on elbow proprioception[2] and electrical activity[3] of the triceps brachii and biceps brachii muscles and balance.

1.3 Objectives

- The first objective was to determine the effect of CSM on JPS[4] of the elbow joint.
- The second objective was to determine the effect of CSM on electrical activity of the triceps brachii and biceps brachii muscles.
- The third objective was to determine the effect of CSM on static and dynamic balance.
- The fourth objective was to determine the relationship between elbow joint proprioception, muscular activity and balance.

1.4 Rationale

Although there has been research conducted on the effects of CSM on local neurophysiology, there is a deficit in research that studies the effect of CSM on global neurophysiology. Research has shown that CSM improves balance (Nolan 2010; Barker 2011; Holt 2014); upper limb JPS; and alters electrical activity of upper limb muscles

[1]Cervical spine manipulation (CSM) included the following groups: upper (C0-C3), lower (C4-C7) and both upper and lower cervical spine. The participants were divided into these groups according to the levels of the fixations that they presented with.
[2] Joint position sense (JPS)
[3] Also referred to as muscular activity
[4] As a component of proprioception

(Haavik-Taylor and Murphy 2010; Haavik-Taylor and Murphy 2007; Haavik and Murphy 2012; Plaugher, 1993; Barker 2011; Holt 2014). However, there is a lack of research that investigates whether CSM delivered to correct fixations at any level of the cervical spine will result in an improvement in balance, JPS and a change in muscle electrical activity in the upper limb. Therefore, this study may provide evidence of the effects of CSM to all three of these neurophysiological functions, as well as information regarding which levels of the cervical spine have the greatest influence on each of these functions that are so closely related. This research thus contributes to the chiropractic studies that investigate the neurophysiological effects of chiropractic manipulation.

1.5 Benefits

Participants have the chance to have their balance and proprioception checked. Based on the current research that has been conducted, it is hypothesised that CSM could improve a person's balance. Every participant also received one free treatment voucher which they could redeem at the DUT Chiropractic Day Clinic at any time for any complaint after their assessment.

1.6 Conclusion

The introduction will be followed by Chapter 2: The Literature Review, which will present the body of literature available on this topic. The Methodology will follow in Chapter 3 where the materials and methods used to structure the design of this research will be discussed. Chapter 4: Results, will present the results obtained and Chapter 5: Analysis and Discussion will analyse and further explain these results and how they relate back to the Aims and Objectives. In Chapter 6: Conclusion and Recommendations, conclusions will be drawn, and recommendations based on the research outcomes will be presented, thereby concluding the research project.

Chapter 2: Literature Review

2.1 Introduction

This chapter will cover the current literature regarding this study. The anatomy and neurology of the body parts being investigated will be described with a focus on the receptors, the ascending and descending spinal tracts and the higher processing centres of the CNS that are concerned with JPS, balance and electrical activity of muscles. Lastly, the effects of fixation and manipulation on the somatosensory system concerning balance, JPS and electrical activity of muscles will be addressed.

2.2 Anatomy of the cervical spine

Because the cervical spine is the area that received the intervention in this study, this chapter will begin with a brief overview of the anatomy of the cervical spine.

The cervical spine sits between the head and the thoracic spine. It consists of seven cervical vertebrae and forms a lordotic curve. The cervical spinal cord is protected by the cervical vertebrae (Gatterman 2005; Tortora and Derrickson 2011).

2.2.1 The cervical facet joints

The superior and inferior articular facets between two adjacent vertebrae form the facet joints (Gatterman 2005). These joints can also be referred to as the zygapophyseal joints. There are left and right facet joints between each pair of vertebrae. They are classified as synovial planar joints. These small joints allow movement to occur within the spine as well as determine the direction and limitations of the movement that occurs (Gatterman 2005). The six movements of the cervical spine are lateral flexion, rotation, flexion and extension. Normal cervical range of motion includes approximately 20º-45º of lateral flexion on either side, 80º-90º flexion, 70º extension and 90º rotation to both sides. However, pure uniplanar movement hardly occurs in the cervical spine as most movements are coupled with another one or two movements (Swartz et al 2005). Facet joints are of great interest to those who treat spinal conditions as aberrant motion of these joints can cause spinal dysfunction (Gatterman 2005).

The cervical facet joints lie approximately 45º to the horizontal plane. The upper cervical spine lies at approximately 35º to the horizontal plane and the lower cervical facet joints lie at 65º to the horizontal plane (Gatterman 2005).

2.2.2 Articular capsule

Facet joints are surrounded by a capsule posterolaterally. The ligamentum flavum is a ligament that covers the anterior and medial aspects of the facet joints (Gatterman 2005). In the cervical spine the capsules are longer and looser than in the rest of the spine to compensate for the greater amount of movement that occurs in the cervical spine. There are inferior and superior protrusions of the joint capsule which are known as recesses (Gatterman 2005).

2.2.3 Innervation of the facet joints

The capsules of the facet joints are richly supplied by sensory innervation. This supply is derived at the level of the joint as well as from the level above (Gatterman 2005). In addition to this rich sensory innervation, Wyke also states that there are three different types of sensory receptors in the facet joint capsule (Wyke 1987; Gatterman 2005). These are:

- Type I - extremely sensitive static and dynamic mechanoreceptors that fire continually, even when the joint is still.
- Type II - less sensitive dynamic mechanoreceptors which do not fire when the joint is not moving
- Type IV - slow conducting nociceptive mechanoreceptors

Type III sensory receptors are nociceptive fibres that are found in extremity joints. Wyke did not find these receptors on the facet joint (Wyke 1987; Gatterman 2005).

The three types of mechanoreceptors situated in the cervical facet joints function to ensure proper alignment of the vertebrae in the cervical spine.

The natural contours of the spinal column are related to the functioning of the nervous system and therefore to one’s health. When the normal lordotic curve of the cervical spine is compromised, there is a disruption in the proper biomechanical functioning of the spine. Because the brachial plexus originates in the cervical spine, an abnormal cervical curve can result in a compromised neurological state of the upper limb (Leach 1983; Morningstar 2002; Rohrbach et al. 2011).

2.2.4 Cervical spine nerves

Spinal nerves are peripheral nerves that are associated with the spinal cord. They are parallel bundles of axons and their associated neuroglial cells wrapped in several layers of connective tissue. The function of spinal nerve roots is to connect the CNS to sensory receptors, muscles and glands of the body (Tortora and Derrickson 2011).

The first pair of cervical nerves exits the spinal cord between the occipital bone (C0) and C1. The remaining cervical spinal nerves exit the spinal cord through the intervertebral foramina between adjacent vertebrae. Spinal nerves C1-C7 emerge from the vertebral canal above their corresponding vertebrae. Spinal nerve C8 emerges from the spinal canal between C7 and T1 (Tortora and Derrickson 2011) (Figure 1).

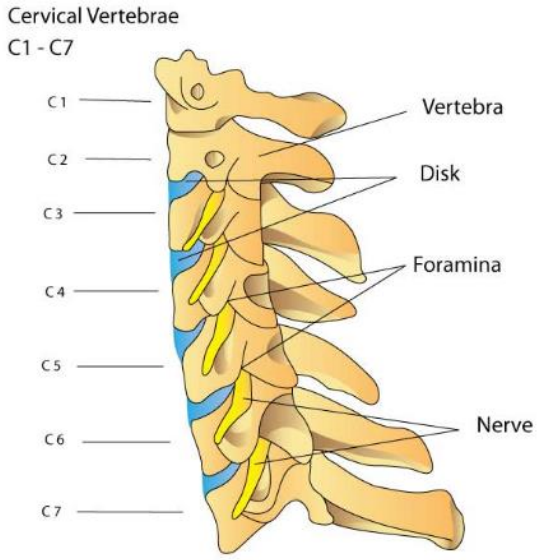


Figure 1: Lateral cervical spine
Source: Tran (2012)

2.2.5 The brachial plexus

The anterior rami or nerve roots of spinal nerves C5-C8 and T1 form the brachial plexus. These nerve roots unite and divide to eventually form the principal nerves of the brachial plexus (Tortora and Derrickson 2011). The brachial plexus innervates the upper limbs and shoulders. The five important nerves that arise from the brachial plexus include the axillary, musculocutaneous, radial, median and ulnar nerves (Tortora and Derrickson 2011).

2.3 Anatomy of the biceps and triceps brachii muscles

For this study, the electrical activity of the biceps and triceps brachii muscles was investigated. These muscles were chosen as they are two of the main movers of the elbow joint, in which JPS was being tested. A brief overview of these muscles' anatomy is discussed below.

2.3.1 Biceps brachii muscle

The biceps brachii muscle has two proximal attachments, namely the long and the short head. The long head attaches to the supraglenoid tubercle of the scapular. The short head attaches to the coracoid process of the scapula where it partly blends with the

origin tendon of the coracobrachialis (Karunaharamoorthy 2018a). The biceps brachii muscle attaches distally to the radial tuberosity and via the bicipital aponeurosis to the fascia on the medial side of the forearm (Karunaharamoorthy 2018a). The actions of the biceps brachii muscle include weak flexion of the arm at the shoulder as well as flexion and supination of the forearm at the elbow. The biceps brachii muscle is innervated by the musculocutaneous nerve which is supplied by nerve roots C5,6 and 7 (Karunaharamoorthy 2018a) (Figure 2).

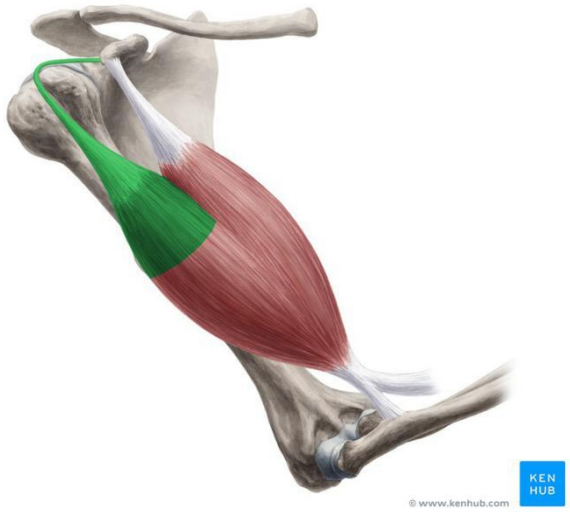


Figure 2: Biceps brachii muscle
Source: Koh (2018a)

2.3.2 Anatomy of the triceps brachii muscle

The triceps brachii muscle is a large three-headed muscle of the arm. The long head attaches to infraglenoid tubercle of the scapula (Karunaharamoorthy 2018b). The medial head attaches to the dorsal humerus, distally from the radial sulcus. It is connected to the medial intermuscular septum. The lateral head attaches to the dorsal humerus, proximally from the radial septum. The three heads join distally to form a thick tendon which attaches to the olecranon process of the ulnar, the capsule of the elbow joint and the antebrachial fascia (Karunaharamoorthy 2018b). The action of the triceps brachii muscle is extension of the elbow joint. The radial nerve supplies the triceps brachii muscle. Its originates from nerve roots C6-C8 (Karunaharamoorthy 2018b) (Figure 3).

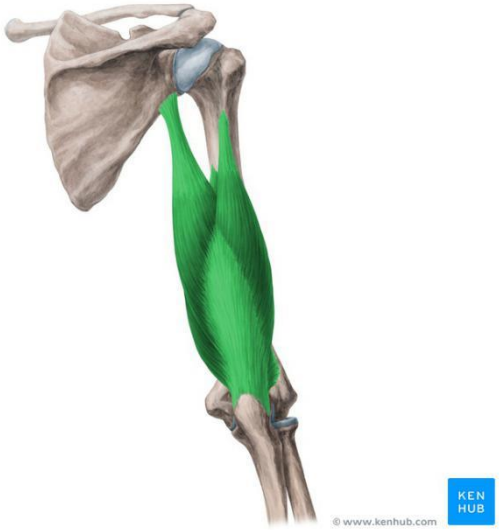


Figure 3: Triceps brachii muscle
Source: Koh (2018b)

2.4 Anatomy of the elbow joint

The elbow joint is a synovial hinge joint formed by the trochlea and the capitulum of the humerus, the head of the radius and the trochlear notch of the capitulum. The joint surfaces are covered with hyaline cartilage and are surrounded by a capsule and synovial membrane. Synovial fluid fills the synovial space and helps to reduce friction during movement. The main ligaments that contribute to joint stability are the anterior, posterior, medial and lateral strengthening ligaments. The only movements that occur at the elbow are flexion and extension. The biceps brachii is the main flexor of the forearm, aided by brachialis. The triceps brachii muscle extends the forearm (Waugh, Grant and Ross 2010).

2.5 Introduction to balance

The three main systems controlling balance are the visual, the vestibular and the somatosensory (proprioceptive) systems (Walker et al. 2014). Balance requires ongoing modification of limb and axial muscles as well as joint position to adjust to the effects of gravity, loads applied to the body, and changes in body positions, so as to allow an individual to maintain an upright posture and optimal balance (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011; Walker et al. 2014).

There are two types of balance, namely, static and dynamic balance. Static balance refers to the maintenance of the body position in relation to the force of gravity, whereas dynamic balance refers to the maintenance of the body position in response to movement (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011).

For a person to balance optimally, there needs to be effective function in three main systems, namely, the eyes (visual system), ears (vestibular system) and the nervous system (proprioception). When one of these systems is dysfunctional, the body relies more on the other two systems to ensure the person can remains balanced, and often the other two systems become enhanced in the body's effort to maintain optimal balance (Walker et al. 2014). When assessing balance, it is therefore important that each of the three sensory systems be isolated so that the dysfunctional system can be identified (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011; Walker et al. 2014).

For this study, the nervous system component of the balance triad is investigated. This nervous system component is known as proprioception.

2.6 Introduction to proprioception

Proprioception, also known as the sixth sense or the sense of orientation, is a specialised variation of the sense of touch. Proprioceptive sensations allow one to register where one's head and limbs are at any point in time. It encompasses joint position sense (JPS), which is the brain's ability to register where a joint is in relation to its surroundings, and kinaesthesia, which is the perception of limb movement in the absence of visual cues (Gilman 2002; Waugh, Grant and Ross 2010; Derrickson and Tortora 2011). Proprioception is a primitive, unconscious function that is vital in maintaining balance and performing movement (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011; van Neckel 2017).

Specialised sensory receptors called proprioceptors, all over the body generate nervous impulses in response to movement of the body. These nerve impulses are propagated along afferent nerves to the spinal cord and up to the brain where they are interpreted (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011).

2.6.1 Proprioceptors

Proprioceptive sensations arise in receptors knows as proprioceptors (Waugh, Grant and Ross 2010). Proprioceptors are embedded in muscles and tendons and inform us of the degree to which muscles are contracted as well as the amount of tension in tendons and the position of the joints (Derrickson and Tortora 2011). The hair cells in the inner ear which monitor the position of the head, are also a type of proprioceptor (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011). Proprioceptors adapt slowly and slightly (Derrickson and Tortora 2011). Therefore, the brain continually receives nervous impulses relaying information about the position of different body parts

(Waugh, Grant and Ross 2010; Derrickson and Tortora 2011). Adjustments are then made to ensure optimal coordination (Derrickson and Tortora 2011). Proprioceptors also allow one to gauge the muscular effort needed to perform a task (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011).

The three main types of proprioceptors are: muscle spindles which are embedded in skeletal muscles; tendon organs which are situated in tendons; joint kinaesthetic receptors in synovial joint capsules (Derrickson and Tortora 2011) (Figure 4).

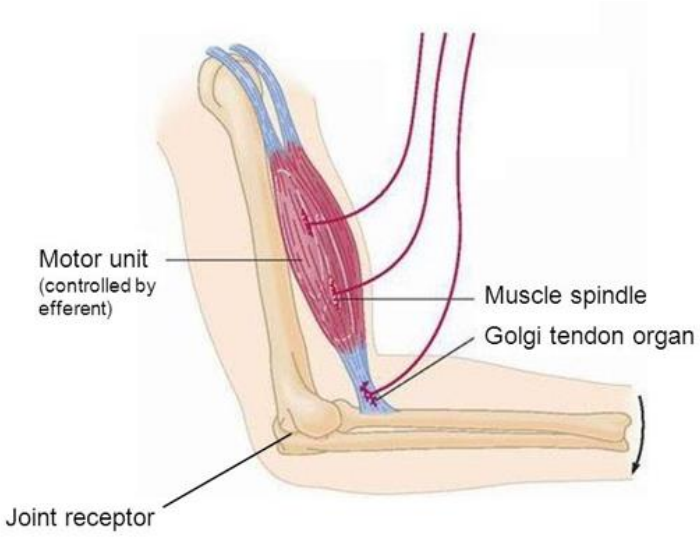


Figure 4: Proprioceptors
Source: Bisley (2018)

2.6.1.1 Muscle spindles

A muscle spindle is a type of proprioceptor that is embedded within skeletal muscles. Muscle spindles are encapsulated within the belly of the muscle (CNS Clinic-Jordan 2016) and monitor changes in the length of the muscles and participate in stretch reflexes. Muscle spindles are the major receptors that are responsible for posture and movement (Raff et al. 2008). At rest, all skeletal muscles have a small degree of contraction present, which is referred to as muscle tone. The brain sets an overall level of muscle tone depending on how vigorously a muscle spindle responds to the stretching of a skeletal muscle (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011; CNS Clinic-Jordan 2016).

A muscle spindle consists of several sensory nerve endings that are slowly adapting. These nerve endings wrap around 3-10 specialised intrafusal muscle fibres. The muscle spindles lie parallel to the skeletal muscle fibres and are thus directly affected by increased tension of the skeletal muscle fibres (Derrickson and Tortora 2011).

The main function of muscle spindles is to detect muscle length. Stretching of the intrafusal muscle fibres can stimulate the sensory nerve endings. Nerve impulses are propagated into the CNS, allowing information from muscle spindles to be quickly sent to the somatic sensory areas of the cerebral cortex in the brain, allowing conscious perception of limb positions and movement. At the same time, the impulses from the muscle spindles are sent to the cerebellum where the input is used to coordinate the movement of the joints by coordinating the muscle contractions (Derrickson and Tortora 2011).

Muscle spindles are not entirely sensory in nature. In addition to their sensory nerve endings located in the mid region of the muscle spindle, they also contain gamma motor neurons. These motor neurons terminate near the two ends of the intrafusal fibres and are responsible for adjusting the tension in a muscle spindle to variations in muscle length.

Extrafusal muscle fibres surround the muscle spindles. They are ordinary skeletal muscle fibres responsible for muscle contraction. They are supplied by large-diameter A fibres called alpha motor neurons. The cell bodies of both the gamma and alpha motor neurons are located within the anterior grey horn of the spinal cord (Derrickson and Tortora 2011). Some of these afferents synapse on second-order neurons which relay information up the spinal cord to the cerebellum and cerebral cortex (CNS Clinic-Jordan 2016). Because the firing rate of these neurons is constantly changing with the degree and velocity of stretch, the CNS is continually informed of the status of the muscle movement and tone, which is constantly changing (CNS Clinic-Jordan 2016).

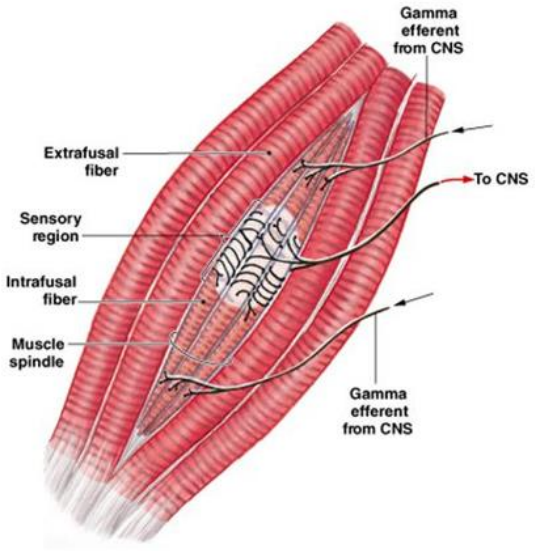


Figure 5: Muscle spindles
Source: Martini (2006)

2.6.1.2 Tendon organs

Tendon organs are proprioceptors that are situated at the junction of a tendon and muscle. They protect tendons and their associated muscles from damage related to excessive stretch by initiating tendon reflexes (Derrickson and Tortora 2011). Each tendon organ is composed of a thin capsule of connective tissue that encloses a few bundles of collagen. One or more sensory nerve endings entwine among and around the collagen fibres of the tendon and then penetrate the capsule (Derrickson and Tortora 2011). When tension increases in a muscle, the tension in the tendon increases and the tendon organ generates nerve impulse that propagate into the CNS. These impulses provide information regarding changes in muscle tension. The resulting reflex is muscle relaxation which causes a decrease in muscle tension (Derrickson and Tortora 2011).

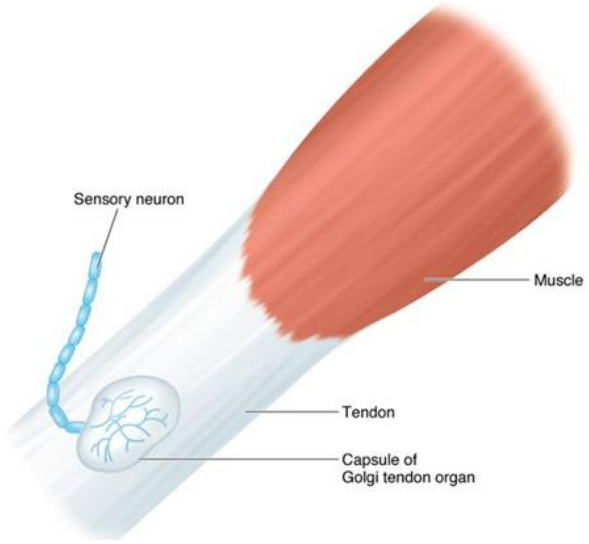


Figure 6: Golgi tendon organs
Source: Anon (2018)

2.6.1.3 Joint kinaesthetic receptors

Joint kinaesthetic receptors are proprioceptors that are located within and around the articular capsules of synovial joints (Waugh, Grant and Ross 2010; Raff et al. 2008; Derrickson and Tortora 2011). Free nerve endings and Ruffini corpuscles are in the joint capsules and respond to pressure. Small Pacinian corpuscles are present in the connective tissue outside of the articular capsule which respond to acceleration and deceleration of joint movement (Derrickson and Tortora 2011) The term kinaesthesia refers to the sense of movement within a joint (Raff et al. 2008). Receptors similar to tendon organs are situated in the joint ligaments and they adjust reflex inhibition of adjacent muscles when strain is placed on the joint excessively (Derrickson and Tortora 2011).

The receptors work together to generate information which allows the body to register where every joint is situated in space. This gives rise to joint position sense (JPS) (Waugh, Grant and Ross 2010; Raff et al. 2008; Derrickson and Tortora 2011).

2.6.2 Introduction to JPS

JPS is the component of proprioception that allows the brain to register and interpret the placement of joints in space.

When a limb is moved through space, there is ongoing monitoring of sensorimotor inputs. This is required to ensure that there is congruency between motor outputs, current intentions and proprioceptive feedback from the actual movement that occurred (Haavik and Murphy 2012). If there is a breakdown in this congruency, then goal-directed actions will be disrupted or impaired, and the intended movement will not be coordinated. This monitoring is an automatic process but can become conscious if there is incongruency between expected and realised sensorimotor states (Haavik and Murphy 2012).

Motor commands therefore interact with afferent signals to generate sensation. This is known as sensorimotor integration (SMI) and it is an important component of proprioception and JPS (Smith et al. 2009; Haavik and Murphy 2012). Normally, there is integration of intention, action and sensory feedback. When individuals are functioning optimally, there is congruence between motor intention and sensory experience (including JPS) (Haavik and Murphy 2012).

The main source of the afferent impulses for JPS arises from muscle spindles. Other sources that contribute to proprioception include mechanoreceptors in joint capsules (Gilman 2002; Pickar and Kang 2006) and golgi tendon organs (Gilman 2002). Although extensive research has been conducted on JPS of extremity joints including the ankle, knee and hip joints (Adachi et al. 2007; Bennell et al. 2005; Ribeiro et a. 2007; Tsauo and Cheng 2008), recently there has been more focus on JPS of the spine (Allison 2003; Jull et al. 2007; Learman et al. 2009; Strimpakos et al. 2006.) However, minimal research has been conducted on the effect of the spine on limb JPS (Knox et al. 2006a, 2006b; Knox and Hodges 2005; Haavik and Murphy 2012).

Because the main source of afferent impulses for JPS arise from muscle spindles, the tone of the muscles surrounding a joint has a direct effect of the JPS of that joint (Gilman 2002; Pickar and Kang 2006). Therefore, it is important that the tone of muscle involved with movement of a specific joint be considered when studying JPS of that joint. For this study, the elbow JPS along with the electrical activity of the ipsilateral

biceps and triceps brachii muscle were investigated due to the effect of muscle electrical activity and tone on JPS.

2.7 Muscle tone and its relation to JPS

At rest all muscles are partially contracted. This small degree of tension is called the resting potential. This tone is ultimately controlled by the brain, however, proprioceptors in muscles play an important role in regulating muscle tone (Derrickson and Tortora 2011; CNS Clinic-Jordan 2016). The brain relies on input from these proprioceptors as well as proprioceptors located in tendons and joints, to provide the information needed to conduct coordinated, smooth muscle movements and ensure accurate JPS. These receptors constantly supply the brain with input regarding the tone and position of muscles (Gilman 2002; Pickar and Kang 2006; CNS Clinic-Jordan 2016). Posture and movement are both largely dependent on controlled and monitored tone in the large postural muscles. The spinal cord plays an important role in this regulation of muscle tone (CNS Clinic-Jordan 2016).

The resting potential of muscles is important in producing effective movements. If muscles were to relax completely, having no resting tone, they would over-lengthen, and the time required to take up slack when a contraction was required would be too long (Derrickson and Tortora 2011; CNS Clinic-Jordan 2016).

The main regulator of muscle tone is the muscle spindle as discussed above (CNS Clinic-Jordan 2016). The spindle's afferents that directly excite large alpha motor neurons that innervate skeletal muscle fibres is an important reflex activation mechanism in maintaining a pre-set muscle tone. This is crucial for optimal proprioception, JPS and ultimately balance (Derrickson and Tortora 2011; CNS Clinic-Jordan 2016). The small gamma motor neurons in the anterior horn of the spinal cord can adjust the stretch sensitivity of the muscle spindles. This is a crucial capability as it allows the CNS to maintain the spindles "in tune" with the muscles. If there is a breakdown in this communication, then goal-directed actions of the muscles could be impaired due to the break down in proprioceptive feedback. The result is uncoordinated movements because of decreased JPS and ultimately decreased proprioception (Derrickson and Tortora 2011; CNS Clinic-Jordan 2016). The electrical activity of the biceps and triceps brachii muscles were investigated in this study.

2.8 Introduction to the role of the central nervous system in movement

The three main components of the CNS are the spinal cord, brain stem and the cortex. These three function in parallel, allowing some extent of control of movement by one

component in a way that is independent of the other two (Kandel et al. 1991). Afferent neurons send sensory information from sensory receptors such as proprioceptors, all around the body, to the CNS for interpretation or processing. Once the information has been processed, then the CNS sends command signals to the body to respond in a certain way to the sensory information that was received. These efferent and afferent neurons travel up and down the spinal cord in tracts or pathways (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011).

Interactions between sensory and motor systems allow individuals to engage with their environments and therefore numerous activities of daily living are directly dependent on appropriate SMI (Chen et al. 2009). Appropriate SMI is reliant on strong feedback connections between various CNS structures that are associated with all neuroanatomical subsystems. The CNS makes use of all the peripheral afferent information to build and maintain an internal frame of reference (Lackner and DiZio 2005; Sainsburg and Kalakanis 1999). Continuous adjustments are made as this information is continuously processed and compared to actual movements that take place. Thus, error adjustments occur continuously to motor learning and frequent movements. A disturbance or breakdown at any point in SMI loops has the potential to greatly affect any related neuroanatomical subsystems in either an adaptive or maladaptive manner. The human central nervous system (CNS) adapts to its ever-changing surroundings and changes in the functioning of the CNS can result when there is both increased (hyperafferentation) and decreased (deafferentation) afferent input (Bertolasi et al. 1998; Brasil-Neto et al. 1993; Tinazzi et al. 1997; Haavik and Murphy 2012). These plastic changes may occur in a manner that is positive for the individual subjectively. This is known as adaptive neuroplasticity. However, there is also research indicating that plastic changes can occur in a manner that has negative outcomes for the individual. This is known as maladaptive neural plastic changes (Haavik 2010; Barker 2011; Zabihhosseinian *et al* 2015).

An important component of healthy SMI is early sensory integration of afferent input (Haavik and Murphy 2012). In typical SMI there is a sensory filtering process that takes place. It allows the individual's CNS to attenuate (suppress) the processing of multiple afferent peripheral inputs which are mainly proprioceptive. This surround-like inhibition allows for the contrast between stimuli to remain high by suppressing the processing of input from the general surrounding areas. This inhibition is important as it allows the body to perceive stimuli as separate and thus process them correctly (Haavik and Murphy 2012; Tinazzi et al. 2000). The ability of the CNS to gate sensory information is believed to be important in the maintenance of the internal representation of posture or

activity at any given time and therefore to avoid any undesirable reactions to external or internal disturbances (Ivanenko et al. 2000; Paulus and Brumagne 2008). In individuals with cervical fixations, this important filtering process has been found to be altered (Haavik-Taylor and Murphy 2007, 2010); Tinazzi et al. 2000).

Therefore, sensory input influences motor output at all levels of the motor system. Sensory input to the spinal cord triggers reflex responses directly. It also allows one to determine the exact parameters of a voluntary response before it is initiated. Proprioception is integral to feedback as well as feed-forward mechanisms, allowing flexibility in the way in which motor output is controlled (Kandel et al. 1991). This afferent input is relayed to the CNS via ascending spinal tracts in the spinal cord and the motor output is sent down the spinal cord via descending tracts.

2.8.1 Ascending somatosensory tracts

Somatic sensory pathways are afferent pathways that relay information from somatic sensory receptors (muscle spindles, tendon organs and joint kinaesthetic receptors) to the primary somatosensory area in the cerebral cortex as well as to the cerebellum. The pathways to the cerebral cortex consist of thousands of sets of three order type neurons namely; a first order neuron, a second-order neuron and a third order neuron (Derrickson and Tortora 2011). Impulses are relayed from one region of the CNS to the other via these three neurons. The places where these neurons synapse with each other are known as relay stations (Derrickson and Tortora 2011). Somatic sensory impulses ascend to the cerebellum via the spinocerebellar tracts. They reach the cerebral cortex via three main ascending pathways, namely the posterior column-medial lemniscus (PCML) pathway; the anterolateral (spinothalamic) pathway and the trigeminothalamic pathway (Derrickson and Tortora 2011).

2.8.1.1 Posterior column-medial lemniscal pathway to the cortex

Sensations of touch, pressure, vibration and conscious proprioception from the neck, trunk, limbs and posterior head ascend via the posterior column-medial lemniscus pathway to reach the cerebral cortex (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011). First order neurons in the PCML pathway extend from these areas of the body into the spinal cord and ascend to the medulla oblongata on the ipsilateral side of the body (Raff et al. 2008). The cell bodies of these first-order neurons are situated in the dorsal root ganglia of the spinal nerves. Their axons form the posterior (dorsal) columns in the spinal cord. These consist of two parts, namely the gracile fasciculus and the cuneate fasciculus (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011).

Afferents that enter the spinal cord below the level of T6 vertebra carry proprioceptive information that arise from the lower limbs and lower trunk, ipsilaterally, along axons in the gracile tract of the spinal cord (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011). On the other hand, afferent nerves carrying proprioceptive information from the upper limbs, upper trunk, neck and posterior head, enter the spinal cord superior to the level of T6 and propagate along axons in the cuneate tract of the spinal cord, ipsilaterally. Both tracts synapse in the caudal aspect of the medulla (Raff et al 2008; Derrickson and Tortora 2011; Bisley 2018).

First-order neurons synapse with second-order neurons whose cell bodies are in the gracile nucleus or the cuneate nucleus of the medulla (Raff et al. 2008; Derrickson and Tortora 2011; Bisley 2018). From there, the second order neurons decussate in the medulla and cross over to the opposite side before entering the medial lemniscus, which is a thin projection tract that extends from the medulla to the ventral posterior nucleus of the thalamus. Here, the second-order neurons synapse with the third-order neurons, which relay the information to the primary somatosensory area of the cerebral cortex (Waugh, Grant and Ross 2010 2006; Derrickson and Tortora 2011).

2.8.1.2 Anterolateral (spinothalamic) pathway to the cortex

Information regarding pain, temperature, itch and tickle from the limbs, trunk, neck and posterior head are propagated along this tract (Raff et al. 2008; Derrickson and Tortora 2011).

There is an interaction between the anterolateral tract and the dorsal column-medial lemniscus system that plays a role in regulating pain perception. This is demonstrated when an injured individual rubs a wound in an effort to decrease the experience of pain (Bisley 2018).

2.8.1.3 Trigeminothalamic pathway to the cortex

The trigeminothalamic pathway transports nerve impulses for most somatic sensations (thermal, tactile and pain) from the head to the cerebral cortex (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011).

2.8.1.4 Dorsal (posterior) and ventral (anterior) spinocerebellar tract

There are two major routes that proprioceptive impulses travel along from the trunk and the lower limbs on one side of the body to reach the cerebellum on the same side, namely, the dorsal and ventral spinocerebellar tracts. The proprioceptive input from golgi tendon organs, muscle spindles and joint capsules informs the cerebellum of the

actual movements. These sensory impulses are critical for maintenance of posture, balance and coordination, especially of fine skilled movements (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011). These impulses are not consciously perceived as they are not sent to the primary somatosensory cortex of the cerebrum (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011).

2.8.2 Cerebral cortex processing

Once the somatic information reaches the cerebrum it is processed and organised in various centres of the brain. This will be discussed below.

2.8.2.1 The primary somatosensory cortex

Precise localisation of somatic sensations occurs when nerve impulses arrive at the primary somatosensory cortex. Each region receives sensory input from a specific part of the body (Raff et al. 2008). The somatic sensory map demonstrates this (Gatterman 2005; Waugh, Grant and Ross 2010; Derrickson and Tortora 2011) (Figure 7).

Somatosensory input from the left side of the body is sent to the somatosensory cortex of the right cerebral hemisphere and vice versa (Raff et al. 2008). The size of the somatosensory areas allocated to various body parts differs proportionally according to the number of specialised sensory receptors within the corresponding body part (Gatterman 2005; Raff et al. 2008).

2.8.2.2 The Motor Cortex

The primary motor cortex is situated in the cerebral cortex (Waugh, Grant and Ross 2010). It functions as a major control area for voluntary movement execution (Gatterman 2005). The premotor area sits adjacent to the primary motor cortex and transmits impulses to the descending motor pathways (Waugh, Grant and Ross 2010). Just like the somatic sensory representation in the somatosensory cortex, different muscles are mapped unequally in the primary motor area, in proportion to the complexity and skill required of those muscles (Gatterman 2005; Derrickson and Tortora 2011). This is referred to as the motor homunculus. The somatosensory and somatic motor representation are similar but not identical for parts of the body (Gatterman 2005; Waugh, Grant and Ross 2010; Derrickson and Tortora 2011).

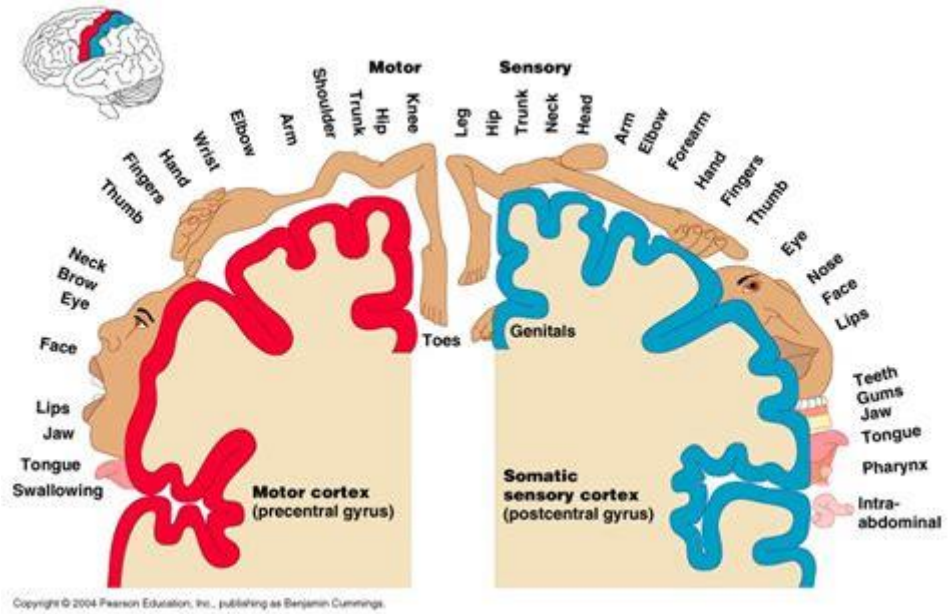


Figure 7: The homunculus
Source: Cummings (2014)

2.8.2.3 The basal nuclei

The basal nuclei are responsible for influencing movement. This is accomplished through their effect on upper motor neurons (UMNs). There are four main functions of basal nuclei:

1. Initiate and terminate movements (Derrickson and Tortora 2011).
2. Suppress unwanted movements by means of the basal nuclei through their inhibitory effects on the thalamus and superior colliculus (Derrickson and Tortora 2011).
3. Influence muscle tone by means of impulses sent by the globus pallidus to the reticular formation reduce muscle tone (Derrickson and Tortora 2011).
4. Influence cortical functions, including cognitive, limbic, sensory and linguistic functions (Derrickson and Tortora 2011).

2.8.2.4 Introduction to the cerebellum: modulation of movement

The cerebellum is positioned above the brainstem and beneath the occipital lobes of the cerebral cortex. The cerebellum plays a vital role in coordinating movements, balance, equilibrium, muscle tone and controlling posture (Raff et al. 2008; Bailey 2017: 1). The sensory information received from the muscles, joints, skin, eyes, ears, viscera and parts of the brain that are involved in movement control allows the cerebellum to be informed of actual movements (Raff et al. 2008; Bailey 2017: 1).

The cerebellum also receives information in the form of nerve impulses from the eyes and proprioceptors in skeletal muscles and joints (Raff et al. 2008). The information that

is received from the ears, eyes and proprioceptors is coordinated and efferent nerve impulses are sent to the cerebrum and the skeletal muscles (Raff et al. 2008). The cerebellum sends out corrective feedback if a discrepancy exists between the intended movement and the actual movement that is carried out (Derrickson and Tortora 2011).

2.8.3 Descending somatomotor pathways

Once the information has been processed and the brain has decided what to do with this information, neurological instructions are sent from the brain to the involved muscles and joints via specific pathways called somatic motor pathways (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011).

2.8.3.1 Direct motor pathways

Voluntary movements are controlled by nerve impulses that are propagated via direct motor pathways from the cerebral cortex to the lower motor neurons (LMNs). The direct motor pathways descend from the primary motor area and the premotor area of the cerebral cortex. The two pathways that make up the direct motor pathways are the corticospinal and the corticobulbar pathways (Derrickson and Tortora 2011).

2.8.3.2 Corticospinal pathways

This pathway conducts impulses from the frontal and parietal cortex to muscles of the limbs and trunk. It is responsible for control of distal muscles utilised in fine independent movements (Kandel et al. 1991). In the medulla oblongata, the corticospinal tract forms the pyramids which are the ventral bulges of the medulla oblongata. Approximately 90% of the axons in this tract decussate in the medulla oblongata and then descend contralaterally in the spinal cord, whereas the other 10% decussate in the spinal cord (Derrickson and Tortora 2011). Because of the decussation that occurs, most of the muscles in the body are controlled by the contralateral side of the cerebral cortex (Derrickson and Tortora 2011).

The corticospinal tract is divided into two parts, namely the lateral and the anterior corticospinal tracts (Derrickson and Tortora 2011). The lateral tracts function in innervating distal motor neurons whereas the medial fibres which are fewer, innervate axial motor neurons (Kandel et al. 1991).

2.8.3.3 Lateral corticospinal tract

Those axons that decussate in the medulla form the lateral corticospinal tract which is situated in the lateral white matter of the spinal cord. These distal muscles are

responsible for highly skilled and precise movements of the hands and feet (Derrickson and Tortora 2011).

2.8.3.4 Anterior corticospinal tract

The axons that decussate in the spinal cord form the anterior corticospinal tract in the anterior white column of the spinal cord. The decussation occurs so that at each level of the spinal cord, some of the axons of these neurons decussate. They terminate in skeletal muscles of the trunk and proximal parts of the limbs (Derrickson and Tortora 2011).

2.8.3.5 Corticobulbar pathways

This pathway conducts impulses to skeletal muscles of the head (Derrickson and Tortora 2011).

2.8.3.6 Indirect motor pathways

These pathways are also known as extrapyramidal pathways. They include all somatic motor tracts that do not form the corticospinal and corticobulbar tracts. The UMNs that form the indirect motor pathways descend from various nuclei situated in the brain stem. They descend as six motor tracts of the spinal cord before terminating on local circuit neurons or LMNs.

The medial system consists of three main parts: the vestibulospinal tracts (medial and lateral), the reticulospinal tracts (medial and lateral) and the tectospinal tract. They are involved directly in influencing the activity of spinal motor units. The first two pathways are responsible for relaying information that controls posture and balance. This is mediated by motor neurons and axial muscles. The vestibulospinal pathway originates in the vestibular nuclei and the reticulospinal pathway originates in the reticular formation. The tectospinal pathway terminates within the cervical spine and therefore does not extend into the thoracic spinal cord. It is responsible for coordinating head and eye movements (Kandel et al. 1991). All these pathways descend in the ventral columns of the spinal cord ipsilaterally and terminate mostly on interneurons and long propriospinal neurons in the intermediate zone. Some terminate directly on motor neurons responsible for innervation of the axial muscles.

The rubrospinal tract descends in a lateral pathway and is therefore anatomically separate from the above-mentioned medial tracts.

The six indirect motor tracts and their functions are explained below.

2.8.3.6.1 Rubrospinal tract

The rubrospinal tract is the main lateral descending pathway from the brain stem (Kandel et al. 1991). Nerve impulse from the red nucleus of the mid-brain are conducted along this tract. The rubrospinal fibres descend through the medulla to the dorsal portion of the spinal cord's lateral column (Derrickson and Tortora 2011). The lateral and medial systems have different roles in motor function. The medial system is important in maintaining balance and posture which both rely on axial and proximal muscle control (Kandel et al. 1991). The lateral pathways control distal muscles used in precise, voluntary movements (Kandel et al. 1991).

2.8.3.6.2 Tectospinal tract

This tract is responsible for reflexively moving the head, eyes and trunk in response to auditory or visual stimuli (Derrickson and Tortora 2011).

2.8.3.6.3 Medial and lateral vestibulospinal tract

The vestibular nucleus receives information about head movements from the inner ear. These impulses are then conducted along the vestibulospinal tract to ipsilateral skeletal muscles of the trunk and proximal parts of limbs. Both vestibulospinal tracts originate in the vestibular nuclei and are responsible for relaying information for the reflex control of balance and posture from the vestibular labyrinth in response to head movement (Kandel et al. 1991; Derrickson and Tortora 2011).

2.8.3.6.4 Medial and lateral reticulospinal tract

Impulses from the reticular formation are conveyed to ipsilateral skeletal muscles of the trunk and proximal parts of the limbs via this tract. This allows for maintenance of posture as well as regulation of muscle tone in response to ongoing movements (Derrickson and Tortora 2011). Both reticulospinal tracts originate from several nuclei that are located in the reticular formation of the medulla and the pons. The reticulospinal systems are important in posture maintenance and have both excitatory and inhibitory connections with spinal interneurons and motor neurons. They maintain posture via integrating information from inputs such as the vestibular nuclei and the cerebral cortex (Kandel et al. 1991). The cortico-reticulospinal pathway is formed by axons originating from the primary motor and premotor cortex synapse and synapsing with reticulospinal neurons. The importance of this pathway is largely related to the suppression of spinal reflexes and activity by motor cortical areas (Kandel et al. 1991) (Figure 8).

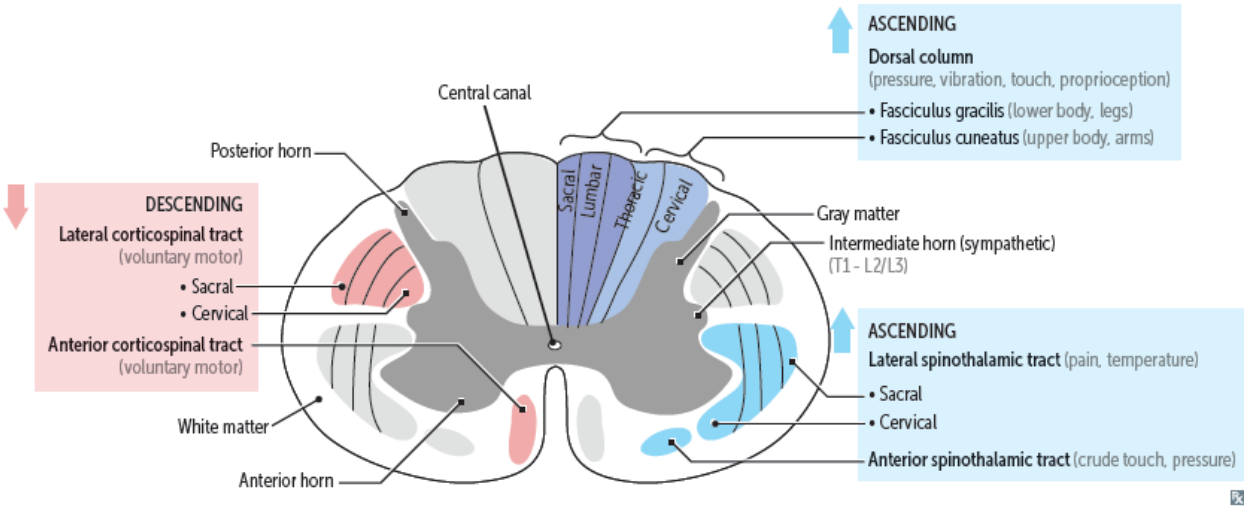


Figure 8: Cervical spinal tracts
Source: Studyblue (2018)

2.8.4 The brain stem and it's relation to the spinal tracts

The brain stem is situated beneath the cerebrum. It consists of three parts, namely the midbrain, the pons and the medulla oblongata.

The brainstem is responsible for the flow of messages between the cerebrum and the spinal cord as well as between the cerebrum and the cerebellum (Bailey 2017: 1; Chaves et al. 2018). The most superior part of the brainstem is the midbrain. It gives rise to many tracts, including the tectospinal and tectobulbar tracts and transmits primary motor pathways such as the corticospinal tract (Chaves et al. 2018). Important nuclei in the midbrain include the red nucleus which gives rise to the rubrospinal tract which is an accessory motor pathway that mediates swinging of the arms in adults (Chaves et al. 2018). The pons sits just below the midbrain. It is responsible for transmitting bundles of the corticospinal tract from the cerebral cortex to the spinal cord. The posterior area of the pons houses the pontine reticular formation and ascending spinal tracts (Chaves et al. 2018).

The most inferior portion of the brain stem is the medulla oblongata. The medulla oblongata ends inferiorly at the origin of the first pair of cervical spinal nerves, just after the medulla oblongata exits the skull though the foramen magnum and becomes the spinal cord (Bailey 2017: 1; Chaves et al. 2018; Peters 2018: 1).

2.8.4.1 Medulla oblongata and it's relation to the spinal tracts

The basilar portion of the medulla contains the pyramids which transmit the corticospinal tracts. The basilar portion also contains the olives which transmit ascending pathways to the opposite cerebellar lobe. This pathway contributes to motor learning via a feed forward system (Bailey 2017: 1; Chaves et al. 2018). The posterior part of the medulla

contains the gracile and the cuneate tubercles along with their nuclei (Chaves et al. 2018). It also houses the medullary reticular formation and some ascending tracts (Chaves et al. 2018) and is also the site of decussation of many of the tracts of the spinal cord.

The medulla oblongata is of importance as this is the most inferior portion of the brain stem and the only portion of the brainstem that extends through the foramen magnum and into the most superficial region of the cervical spine (at C1). It therefore is closely related to the functioning of the upper cervical spine (Bailey 2017: 1; Peters 2018: 1). Because the medulla oblongata is involved in important processes such as coordination of movement, balance, equilibrium and muscle tone, as well ensuring a communication link between the cerebrum and the cerebellum as well as between the cerebral cortex and the spinal cord, the medulla and its anatomical link to the upper cervical spine is of special interest.

It is proposed that fixations of the upper cervical spine could have a direct effect of the functioning of the medulla oblongata and the tracts that occur here due to their position adjacent to the upper cervical spine (Cagnie et al. 2005; Syndicated 2013; Bailey 2017: 1; Chaves et al. 2018).

2.9 Fixation

A spinal fixation is described as an altered alignment, function or restricted movement within a spinal motion segment. A spinal motion segment consists of two adjacent vertebrae and the connecting tissue binding them together (Leach 2004; Gatterman 2005: Hieronymus cited in Gatterman 2005; Haavik 2012).

When a fixation exists, there is an effect on the surrounding soft tissue structures as well as the joints of the cervical spine and the neurology.

Because there are many spinal tracts relaying information concerning movement, balance, JPS and muscle activity throughout the cervical spine, a fixation in the cervical spine can cause an interruption in the information relayed by theses tracts and therefore affect function relating to the signals being relayed by these tracts. This was confirmed by Haavik and Murphy (2007, 2011) who found that fixated spinal joints represent a state of altered afferent input which may be responsible for ongoing central neural plastic changes. Literature demonstrates that maladaptive neural plastic changes can occur with musculoskeletal dysfunction (Falla 2004). In cases where the individual is experiencing pain with the musculoskeletal dysfunction, many researchers have hypothesised that the maladaptive neuroplastic changes that are present, rather than the pain itself, is responsible for the individual’s symptoms and functional disturbances.

In those suffering with neck pain, changes in the way the CNS processes proprioception information has been suggested as the most important factor responsible for how they present clinically (Paulus and Brumagne 2008). Pain is a symptom that is considered a component of the vertebral fixation, but it need not be present for a fixation to exist (Gatterman 2005). Therefore, patients that have spinal fixations may present with maladaptive neural plastic changes even when they do not experience any pain.

In individuals with cervical impairments such as cervical fixations, the sensory filtering process (surround-like inhibition) that aids optimal postural control, has also been found to be altered (Haavik-Taylor and Murphy 2007, 2010; Tinazzi et al. 2000).

2.10 Manipulation

The neurobiological effects of spinal manipulation are not limited to relieving symptoms such as pain, inflammation, range of movement, general spinal dysfunction and muscle spasm (Korr 1975; Pickar 2002; Leach 2004; Gatterman 2005; Nolan 2010). The neurobiological effects are far reaching and include effects of the spinal tracts and spinal cord and therefore on any function mediated by these neurological structures (Coote 1978; Lantz 1995; Mootz 2001; Gatterman 2005; Nolan 2010).

Haavik-Taylor and Murphy (2010) demonstrated that CSM can increase the surround-like inhibition of proprioceptive afferent input (the sensory filtering process), thereby improving the ability to filter sensory information and enhance sensory integration of afferent input (Haavik-Taylor et al. 2010; Haavik-Taylor and Murphy 2010) which is believed to be important in the maintenance of posture. Many studies support these findings as they concluded that CSM improves JPS and proprioception in the elbow (Haavik-Taylor and Murphy 2010), upper limb in general (Barker 2011) and in the ankle (Holt 2014). In a study conducted by Nolan (2010) it was concluded that CSM improves balance. Nolan (2010) and Holt (2014) focused on upper CSM in their studies. On the other hand, conclusions in Barker's (2011) study suggest that involvement of the entire cervical spine can lead to changes in upper limb proprioception. Thus, there is a deficit in literature that investigates whether CSM at either the upper or the lower cervical spine can influence both global and local proprioceptive changes.

2.10.1 Effects of manipulation on JPS

Current literature shows that a link exists between upper limb proprioception and the cervical spine (Leach 2004; Gatterman 2005; Waugh, Grant and Ross 2010; Haavik and Murphy 2010; Derrickson and Tortora 2011; van Neckel 2017). Haavik and Murphy (2011) demonstrated that those individuals presenting with cervical dysfunction have

reduced elbow JPS compared to individuals with no history of neck complaints. Furthermore, the study demonstrated that CSM of fixated/dysfunctional segments of the cervical dysfunction group improved the accuracy of the JPS of the elbow joint and that cervical fixations can impair the manner in which proprioceptive information from the upper limb is processed. Furthermore, studies suggest that improving function of the spine with manipulation may lead to better processing and integration of such proprioceptive input (Haavik and Murphy 2011).

Other studies confirm the strong link between cervical spine function and accurate proprioceptive processing and sensorimotor integration (Karlberg et al. 1995; Falla 2004; Michaelson et al. 2003; Takayama et al. 2005a, 2005b; Stapley et al. 2006; Sterling et al. 2003). These studies are all related to significant cervical injury, however there is one study that demonstrated that changes in the position of the head and neck in participants without any history of neck pain or cervical injury led to a reduced accuracy of elbow JPS (Knox and Hodges 2005). The researchers of this study investigated movement execution and discovered that accuracy of such execution depends on the ability of the CNS to integrate somatosensory, vestibular as well as visual information regarding the body position (Knox and Hodges 2005). They noticed that by placing the participants' heads in full flexion and rotation could overload the computational capacity of the CNS and result in inaccurate JPS (Knox and Hodges 2005). Barker (2011) demonstrated that minor postural changes in the neck has also been shown to effect joint position sense at the elbow joint (Barker 2011).

Altered musculoskeletal function of the cervical spine may impair proprioception in the upper limb as well as spinal stability (Karlberg et al. 1995; Falla 2004; Michaelson et al. 2003; Takayama et al. 2005a, 2005b Stapley et al. 2006; Stapley et al. 2006; Sterling et al. 2003; Barker 2011; Haavik and Murphy 2011; Zabihhosseinian et al. 2015). This conclusion is supported by Haavik (2010) who concluded that CSM can improve elbow JPS (Haavik 2010). In a study conducted by Nolan (2010) and Holt (2014), it was concluded that CSM improved global proprioception.

2.10.2 Effects of manipulation on balance

When performing movements that affect the whole body such as throwing a ball for example, the CNS will activate the postural trunk muscles before the movement is initiated to ensure balance is maintained during the movement. This is known as feed-forward activation (FFA). A study by Radebold et al. (2001) demonstrated the link between delayed muscle activation and impaired motor control. Marshall and Murphy (2006) conducted a study that evaluated the delays in the FFA of muscles relating to

balance. It was found that all the individuals who had delayed FFA and therefore impaired balance, presented with a sacroiliac joint dysfunction. Chiropractic manipulation to the fixated SIJ improved the CNS activation times of these muscles associated with balance. Subsequent work by Marshall and Murphy (2006) demonstrated that participants who were treated with manipulation and/or exercise, had FFA times that continued to improve at one year follow ups.

In a study conducted by Holt (2014) it was determined that CSM was effective in improving sensorimotor function related to balance in older adults over a 12-week period. Holt (2014) noted that the test group improved in ankle JPS and choice stepping reaction time which shows an improvement in balance. Nolan (2010) concluded that CSM as an intervention increased a patient's ability to maintain their centre of movement (COM) within their base of support (BOS). Therefore, neurological effects of CSM include improvement in global JPS and balance (Haavik 2008).

2.10.3 Effects of manipulation on electrical activity of muscles

Spinal manipulation has been used in the treatment of neuromuscular disorders for over 2000 years (Symons et al. 2000; Pickar and Kang 2006; Dunning and Rushton 2009). There have been numerous studies that have shown that spinal manipulation affects local muscle electrical activity (Symons et al. 2000; Colloca and Keller 2001; Keller and Colloca 2000; Dishman and Bulbulian 2000; Lehman and McGill 2001; DeVocht et al. 2005).

A study conducted by Herzog et al. (1999) demonstrated an ipsilateral reflex contraction of the deltoid muscle following manipulation of the cervical, thoracic, lumbar and pelvic spine. Another study conducted by Suter and McMorland (2002) concluded that CSM results in an immediate increase in elbow flexor torque (Dunning and Rushton 2009). Dunning and Rushton (2009) conducted a study that investigated the nature (excitatory or inhibitory) and the magnitude of the change in resting electromyographic activity of the biceps brachii muscle bilaterally, following CSM of C5/C6. This was the first study that investigated the effects of CSM on a muscle more distal than the deltoid and was the first study to investigate contralateral upper limb muscle activity (Herzog et al. 1999; Suter and McMorland 2002; Dunning and Rushton 2009). Apart from these three studies, there is a gap in the literature regarding the effects of spinal manipulation on extremity muscles that are unconnected to the vertebral column by an origin or insertion (Dunning and Rushton 2009).

There is conflicting evidence regarding whether the neurophysiological response that occurs in muscles post spinal manipulation is excitatory (Herzog et al. 1999; Suter et al.

1999; Keller and Colloca 2000; Symons et al. 2000; Suter et al. 2000; Colloca and Keller 2001; Dishman et al. 2000 Suter and McMorland 2002; Dunning and Rushton 2009) or inhibitory (Dishman and Bulbulian 2000; Lehman and McGill 2001; DeVocht et al. 2005; Dunning and Rushton 2009) in nature.

Haavik and Murphy concluded that spinal fixations result in altered function and sensorimotor inhibition and that high velocity, low amplitude spinal manipulation applied to correct cervical fixations can correct altered somatosensory processing and early SMI of input received from the upper limb (Haavik-Taylor and Murphy 2007, 2010). The degree to which an individual can successfully execute more challenging tasks is proportionate to the degree to which the CNS is disturbed, how the CNS processes, interprets and transforms the information from afferent input to motor commands (Persson et al. 1996; Michaelson et al. 2003; Paulus and Brumagne 2008). It is possible that the changes in cortical somatosensory processing, SMI and motor control that have been documented following CSM actually reflect alterations in central processing of proprioceptive afferent input.

2.11 Proprioceptive insult hypothesis

The proprioceptive insult hypothesis suggests that the highly innervated soft tissue around the spinal joints may become irritated in the presence of a fixation. The resultant irritation may lead to reflex changes in postural tone and neural integration of postural activities as well as somatosensory reflexes. This may result in reflex muscle spasm; however, a spasmed muscle need not be present for a fixation to be present. This is a positive feedback cycle in that a spasmed muscle may result from, and contribute to, proprioceptive irritation (Korr 1975; Coote 1978). It has been demonstrated that spinal cord segments in the vicinity of a spinal fixation have a lower firing threshold (Coote 1978; Lantz 1995; Mootz 2001; Gatterman 2005). Spinal manipulation has been shown to reduce the muscle spasm as measured by electromyography (England and Deibert 1972; Grice 1975; Gatterman 2005).

During a spinal manipulation, there is depolarisation of the motor neuron pools at the level that the manipulation is delivered. As a result, these receptors are excited and there is an afferent bombardment of the spinal nerve roots and dorsal root ganglions. This is known as the bombardment theory and supports the proprioceptive insult hypothesis (Beck 2011; Crossman and Neary 2014).

These theories were supported in studies conducted by Haavik and Murphy (2007 2011). They proposed that altered afferent feedback from a fixated segment alters the afferent “milieu” into which afferent feedback is received from the spine and limbs and

processed, thus altering SMI of the afferent input. SMI can be described as the process by incoming sensory or afferent information is coordinated and integrated with the motor system so that movement is controlled.

The proprioceptive insult hypothesis may explain the way in which fixations in the cervical spine can affect the afferent input relating to balance, JPS and electrical activity of muscles as well as the relaying of this information via the cervical spinal tracts. Thus, sensory input to the higher processing centres in the brain is impaired at the level of the cervical spine fixation. This results in impaired motor output to muscles and joints responsible for maintaining JPS, electrical activity of muscles and balance. CSM delivered to the fixated segments corrects these fixations which in turn restore the transmission of neural impulses regarding these three functions.

2.12 Motor systems degeneration model

The Eastern European manual medicine movement theorised a model of somatic and peripheral “blockages” and how they affect integrated function of the motor system from the cortex to the periphery (Lewit 1991; Janda 1983; Dvorak 1985; Gatterman 2005). This model is called the motor systems degeneration model (Gatterman 2005) and describes two types of nervous system integration, namely vertical and horizontal integration. Vertical integration refers to the relationship between four structures, namely the central nervous system (CNS) structures, the spinal cord, peripheral nerves and musculoskeletal structures. Horizontal integration, on the other hand, refers to the relationship between any anatomically adjacent or related structures of the four components of the vertical system (Gatterman 2005).

The motor system degeneration model argues that a lesion in any of the four vertical levels leads to some form of functional alterations vertically and horizontally throughout the motor system. These alterations may be subtle and gradual but with time, if not corrected, will worsen with recruitment of other areas of the motor system (vertical and horizontal), leading to recurrence of the lesion (Cyriax 1975; Gatterman 2005).

According to the motor systems degeneration model, disturbances in the spinal neurology could affect the integrated function of the motor system via vertical as well as horizontal integration. Therefore, any disturbances that occur in the cervical spinal tracts as per the proprioceptive insult hypothesis theory, will not only have local cervical disturbances, but will affect vertical and horizontal systems as well.

2.13 Combination of the two models

The proprioceptive insult hypothesis and the motor systems degeneration model do not occur in isolation and therefore one may feed into the other one. In the case of cervical spine fixations, the proprioceptive insult hypothesis states that there will be a lowered firing threshold detected in the spinal cord segments in the vicinity of the fixated segment (Coote 1978; Lantz 1995; Mootz 2001; Gatterman 2005). However, according to the motor systems degeneration model, the effects of the changes in this spinal cord segment will not be isolated to the fixated level. Because spinal tracts relay afferent and efferent information from all over the body, and many of these tracts pass through the cervical spinal cord, the changes in the firing rate of the spinal cord will lead to functional alterations in any four of the vertical systems as well as horizontally throughout the motor system.

2.14 Conclusion of literature: The effect of CSM on JPS, electrical activity and balance

The four vertical systems include the CNS, spinal cord, the peripheral nerves and the musculoskeletal structures.

According to the proprioceptive insult hypothesis, a fixation in the cervical spine may interrupt the information relayed in the cervical tracts. Many of these tracts are involved in relaying information regarding proprioception (JPS), electrical activity of muscles and balance (posterior columnar-media lemniscus and spinocerebellar tracts as afferents and corticospinal, rubrospinal, vestibulospinal and reticulospinal tracts as efferents).

Therefore, the motor systems degeneration model may explain how a disturbance in the cervical tracts could result in impaired function of proprioception (JPS), electrical activity of muscles and balance as these functions relate vertically with the cervical spinal tracts. For this study, the lesion that is being investigated as causing interference in the CNS is a cervical fixation. The musculoskeletal structures studied as a component of the vertical system consists of the biceps and triceps brachii muscle and the ipsilateral elbow joint, innervated by the brachial plexus (C5-T1 nerve roots). Elbow JPS and electrical activity of the biceps and triceps muscles are two functions of the musculoskeletal systems that are being tested. Balance is tested as a function of the overall integration of the vertical system.

Cervical spine fixations may impair balance, elbow JPS and electrical activity of the biceps and triceps brachii muscles. CSM applied to correct cervical spine fixations, may,

therefore, improve balance, elbow JPS and electrical activity of the biceps and triceps brachii muscles.

Chapter 3: Methodology

3.1 Introduction

In this chapter, the study procedure will be discussed. This will include an explanation of the study design, the advertising, recruitment of the participants, the sample size, allocation of the participants into the various groups and the methodology.

The intervention will be explained, and the specifics of the measurement tools used to collect and record the data for this study will be discussed. The setup and procedure for data collection will also be covered, as well as the validity and reliability of all the equipment used.

The methods used for statistical analysis will be discussed and the ethics surrounding this study will be explained.

3.2 Study design

This study used a quantitative, descriptive, pre-test post-test randomised control trial investigation design. A pilot study was performed to validate the experimental procedures.

3.3 Advertising and recruitment

Participants were recruited by means of advertisements (Appendix B) placed around the Durban University of Technology (DUT) Ritson and Steve Biko campuses and at various sports events and wellness days attended by the chiropractic students of the Durban University of Technology.

Individuals who responded to the advertisements were interviewed telephonically using the telephonic screening interview (Appendix C).

Participants who were suitable to be included in the study after the telephonic screening interview, were invited to attend an appointment at the Durban University of Technology Chiropractic Day Clinic (DUT CDC).

Only individuals who read the letter of information and signed the informed consent form (Appendix A) were then included in the study. Participants then underwent a case history evaluation (Appendix E), a physical examination (Appendix D), and a regional examination of the cervical spine (Appendix F).

3.4 Sample population

The participants included both males and females between the ages of 18-35 years who responded to the advertisements and who met the inclusion criteria.

3.5 Sample size

A sample size of 80 participants was used in this study with 20 participants in the control group and 60 participants in the intervention group (20 participants in each intervention subgroup: B1: fixations present in the upper cervical spine (C0-C3); B2: fixations present in the lower cervical spine (C4-C7); B3: fixations present in both the upper and lower cervical spine) (Matthews 2016).

A sample size calculation for one-way analysis of variance using GPower 3.1.9.2 software was done. The values used were: power = 0.80, level of significance = 0.05 and effect size = 0.04. The sample size obtained was 76. This was then rounded up to 80 participants in total (20 in each of the four subgroups).

3.6 Sample characteristics

3.6.1 Inclusion criteria

1) All participants were required to read the letter of information and sign the informed consent form (Appendix A).
2) The participants had to be between the ages of 18 and 35 years.

This age range was chosen so as to obviate the necessity for consent of a parent and to decrease the prevalence of spinal degeneration associated with ageing (Giles 2014). The increased incidence of pathology in older individuals could have influenced the results of the study (Walker et al. 2014)

3) All the participants were required to present with at least one fixation in the cervical spine.

3.6.2 Exclusion criteria

Participants were excluded if they:

1) Had received CSM during the 4 weeks preceding the initial appointment.
2) Had previously been diagnosed with vestibular disease and were suffering with vestibular disease at the time of the initial appointment.
3) Had been diagnosed with peripheral neuropathies and were still experiencing symptoms at the time of the initial appointment.

4) Presented with contraindications to CSM.

Contraindications or conditions that required modification to high-velocity, low amplitude CSM included: atherosclerosis of major blood vessels, vertibrobasilar insufficiency, aneurysms, tumours, fractures, severe sprains, late stages of osteoarthritis, uncarthrosis, blood clotting disorders, osteopenia (osteoporosis), space occupying lesions, diabetic neuropathy, malingering hysteria hypochondriasis, Alzheimer's disease (Bergmann and Peterson 2011).

5) Presented with any neck pain or shoulder joint or elbow joint pain at the time of the initial appointment, on the participants' dominant side.
6) Had undergone any surgery or trauma (requiring surgical or emergency room intervention only) to the neck, dominant shoulder and dominant elbow.

3.7 Allocation

The participants were randomly allocated to either the control or the intervention group, using the hat method – 60 participants in the intervention group and 20 participants to the control group. The intervention group was then further stratified into three subgroups of 20 participants each according to purposive sampling based on the levels of fixations that they presented with. Motion palpation was utilised as a tool to locate these fixated levels.

Motion palpation is a diagnostic tool used by chiropractors, physiotherapists, osteopaths and medical doctors to assess joint motion. There are two main types of motion palpation, including active motion palpation and passive motion palpation. Active motion palpation is an assessment technique where the clinician palpates bony landmarks while guiding the participant through motions of the spine. Passive motion palpation is an assessment technique whereby one vertebra is moved in physiological ranges in relation to another vertebra; or whereby spinal segmental mobility is assessed trough the translatory motions that are associated with physiological motions of that spinal segment (Huijbregts 2002).

The stratification (Table 1) was utilized to monitor the patients that were in each group.

Table 1: Stratification table

Table 1: Stratification Table				
	Control Group	Intervention Groups		
Location of fixation	Participants could present with fixations at any level in the cervical spine	Participants presented with fixations in the upper cervical spine: C0-C3	Participants presented with fixations in the lower cervical spine: C4-C7	Participants presented with fixations in both the upper and lower cervical spine.
Number of participants	20	20	20	20
Code	A1	B1	B2	B3

3.8 Procedure

3.8.1 Pilot study

Before the data collection for this study commenced, a pilot study was performed. This was done to allow the researcher to run through the test procedures in an effort to detect any areas that needed to be changed or adapted to allow for more accurate and efficient data collection.

The first eight participants to respond to the advertisements were placed in the pilot study. The procedure for data collection during the pilot study was the same as that used in the main study.

The results of those included in the pilot study were not included in the main results.

3.8.2 Study procedure

1. People responded to the advertisement or word of mouth recruitment. If they were found to be eligible to be included in the study after the initial telephonic screening process (Appendix C) then an initial consultation was scheduled at their convenience at the DUT CDC.
2. If a participant was found to eligible to be included in the study, they read and signed the letter of consent (Appendix: A).
3. The participants' completed fa questionnaire, listing possible diseases that may result in vestibular dysfunction as well as some of the contraindications to manipulation (Appendix M). The purpose of the questionnaire was to screen for any known neurological pathology.
4. Participants were randomly placed into either the control or test group using 'the hat' method. A tin was filled with 60 pieces of paper that read "intervention" and

20 pieces of paper that read “control”. As the participant arrived for their appointment, the DUT CDC receptionist would draw a single piece of paper out of the tin without looking and then read the word on the paper. The researcher was then handed the piece of paper. If the paper read “intervention” then the participant fell into the intervention group. If the paper read “control”, then the participant fell into the control group. The piece of paper was then discarded.

5. A case history was taken (Appendix E) and a physical examination (Appendix D) was performed.
6. Participants were divided into subgroups based on the level of the fixations found by the researcher during the cervical regional examination (Appendix G). Fixations were identified using motion palpation (see section 3.9.1). The data collection process was only completed when each subgroup had a minimum of 20 participants. When a subgroup was filled with 20 participants, but there was still another subgroup that had not yet been filled, then the study continued until there all subgroups were filled with a minimum of 20 participants each. If participants presented with fixation levels that qualified them for a subgroup that had reached the minimum requirement of 20 participants, then that individual was still included in the study and the subgroup gained an extra participant, above the minimum requirement of 20. This happened in the case of group B2 (the lower CSM group) as they had 21 participants at the end of the study.
7. The participant was then set up for data collection.

3.8.3 Data collection

1. The participant was set up for the balance on the biosway biopac balance system (BBPBS) machine and the pre-test was performed (see section 3.10.1).
2. The participant was set up for the data collection of JPS of the elbow (see section 3.10.2) and the electrical activity of triceps and biceps brachii muscles (see section 3.10.3). The pre-tests for the JPS and electrical activity was then performed simultaneously.
3. The intervention sub-groups then received CSM to the corresponding fixated levels (see section 3.9.2).
4. The control group was allocated a 20 second period of rest in place of the intervention. No placebo was given.
5. The elbow JPS and electrical activity post-tests were performed with the same method as the pre-test data collection.
6. Balance post-tests were conducted with the same method as the pre-test data collection.

7. The participant was thanked for partaking in the study.
8. A free treatment voucher was issued (Appendix I).
9. Participants were treated by any of the chiropractic students in the clinic if they chose to redeem their voucher.
10. All readings obtained from the BBPBS, goniometer and the sEMG machine were captured on an excel spreadsheet on the researcher's laptop. The spreadsheet and files were safely stored, and confidentiality was ensured as only the researcher and the research supervisor had access to the files.

3.9 Intervention

3.9.1 Motion palpation

Participants were screened for fixations in the cervical spine using motion palpation as a means of assessing motion and joint play and identifying fixated segments. Passive and active range of motion testing was also done to gauge the symmetry of the movements in the cervical spine (as per the cervical spine regional exam: Appendix F).

3.9.2 Chiropractic cervical spine manipulation (CSM)

The participants in the intervention group received diversified CSM as per Bergmann and Peterson (2011). A thrust of high velocity and low amplitude, delivered in the plane of movement that was limited, was used to remove the fixation in the cervical spine. The plane of drive and the nature of the CSM (flexion, left or right lateral flexion, extension, left or right posterior-anterior rotation or left or right anterior-posterior) was in line with the nature of the fixation. The aim of the CSM was to remove the fixation and allow the joint segment to return to its optimal functional state (Bergmann and Peterson 2011).

Inter-examiner reliability in detecting cervical spine dysfunction has been found to be poor to excellent depending on factors such as examiner experience, incorporation of a patient's subjective report of tenderness and the motion palpation tests employed (Vaughan 2002; Van Trijffel et al. 2005).

The procedure for the CSM intervention that was applied is explained below.

3.8.2.1 Supine: loss of posterior to anterior rotation and lateral fixations: index - articular pillar contact/ thumb web contact

As per Bergman (2011), Byfield (2012) and Szaras (1984).

Indicated (I): Loss of movement as noted by a hard end-feel or the lack of separation of the transverse processes on motion palpation when the participant's head was rotated away from the side being tested or laterally flexed to the contralateral side.

Participant position (PP): supine.

Researcher position (RP): standing at the head of the chiropractic table.

Contact point (CP): the index of the contact hand / thumb / thumb web of the contact hand.

Segmental contact point (SCP): the transverse process.

Indifferent hand (IH): Contact was made to the side of the cranium contralateral to the side of the fixation, with the fingers expanded so as to provide maximum support for the head and cervical spine.

Vector (V): Posterior to anterior or lateral to medial, depending on the nature of the fixation present.

Cervical spine position (CSP): For fixations in the PA direction, the participant was rotated until skin and joint slack were removed and then slight lateral flexion was applied, and an impulse thrust was imparted in the posterior-anterior direction.

For fixations in lateral fixation, the participant's head was laterally flexed over the contact point until resistance was felt and then a very small amount of rotation (in the posterior-anterior direction) was applied in order to lock up the joint and reach the end of the elastic barrier. When the elastic barrier was reached an impulse thrust was applied into the point of fixation, in the lateral to medial direction.

When rotating the participant's head, any form of extension was avoided. To ensure this, the indifferent hand remained in contact with the head piece of the chiropractic table to ensure that the head was fully supported at all times.

3.9.2.1 Supine: loss of extension of C0-C1 (close jam jar)

As per Bergman and Peterson (2011), Byfield (2012) and Szaras (1984).

Indicated (I): Loss of extension, unilaterally, and/or hypertonic anterior cervical musculature.

Participant position (PP): Supine.

Researcher position (RP): At the head of the chiropractic table, 45 to 90 degrees to the fixation, in a fencer stance.

Contact point (CP): The hypothenar aspect of the caudal hand was cupped over the mastoid process and ear, with the fingers pointing somewhere between the eye and the vertex of the head. In some cases, an index contact was also used.

Segmental contact point (SCP): The posterior supramastoid groove, just posterior to the ear.

Indifferent hand (IH): A broad contact was used to cradle the head and stabilise the neck.

Vector (V): posterior to anterior and superior to inferior.

Cervical spine position (CSP): The participant's head was slightly rotated away from the point of contact and the cranium was extended through both the contact and indifferent hands. The skin and joint slack was then removed, and an impulse thrust was imparted in order to maximise extension of the C0-C1 joint complex.

3.10 Measurement Tools

3.10.1 Biosway Biopac Balance System

3.10.1.1 Introduction

The BBPBS measures the sway index, which is a measurement of the amount of sway (Biodex Medical Systems n.d.: 4.5). The higher the sway index, the more unstable the participant is and the greater the likelihood of injury and the risk of future injury (Emery 2003: 496; Koenig 2014).

3.10.1.2 Set up

The modified clinical test for sensory integration and balance (MCTSIB) was the specific programme used to measure the sway index (Biodex 2017). From this measurement, the researcher was able to gauge the degree of steadiness and postural control (Biodex 2017).

The participants' ability to maintain an upright posture while standing on a fixed platform was assessed. Both static and dynamic balance was tested, and the sway index scores were compared. Participants normally produce higher sway index scores on the dynamic surface as opposed to the static surface (Biodex 2017). If the sway index for the dynamic balance was significantly higher than the static balance score, then this could have indicated a musculoskeletal or sensory dysfunction (Koenig 2014).

The MCTSIB (Biodex 2017) had four test components, each 30 seconds long. The procedure can be set up for unilateral or bilateral stance. For the purpose of this study the participants were positioned for bilateral stance. The foot placement was noted on a grid pad that is divided into 1.8cm intervals. This allowed the foot position to be recorded in the anterior-posterior (HPX) and medial-lateral (HPY) directions. The third metatarsal was also being recorded in relation to the Y-axis. The test time for this study was set to 30 seconds. The stability of the platform can be adjusted to be more or less stable and thus the difficulty of the test can be adjusted. At level eight the surface is most stable and at level 1 it is least stable. For the purpose of this research, the platform was fixed for the first test and for the second test a foam pad was attached to the fixed, stable platform to allow investigation of balance on an unstable surface of foam (Arnold and Schmitz 1998; Hinman 2000).

The participants were allocated time to familiarise themselves with the BBPBS before the pre-testing commenced. The participant's chosen foot position on the BBS platform was determined and recorded. It was then explained to the participant that there would be four balance tests, with each being 30 seconds long. The participant was told that the first and second test would be performed on a stable surface and the second two would be performed on a foam mat. The patient was instructed to open his/her eyes during the first and third test and to close their eyes for the second and forth tests. Before each test commenced there was a three second count down, indicated by three beeps. For the tests that required the eyes to be closed, the participant was instructed to close his/ her eyes when they heard the second beep of the countdown. The balance tests were all done bare-foot with no socks on.

3.10.1.3 Procedure

The pre-tests of the BBPBS were then commenced. The first two tests evaluated static balance and the subsequent two tested dynamic balance.

1) First test: eyes open on a stable platform.

2) Second test: eyes closed on a stable platform.

3) Third test: eyes open on a foam mat.

4) Fourth test: eyes closed on a foam mat.

Between each test the participant was allowed a 10-60 second break, during which they were able to centre their weight to the target. No uniform time was given as it was necessary that the participant felt relaxed and balanced when they started the test. Therefore, the participant indicated when they were ready to commence the next test.

The sway index was measured for each pre-test. These results were saved on the BBPBS machine as well as recorded manually on the data collection sheet.

Four post-readings were taken with the BBPBS as performed in the pre-testing.

Figure 9: Biosway Biopac Balance System

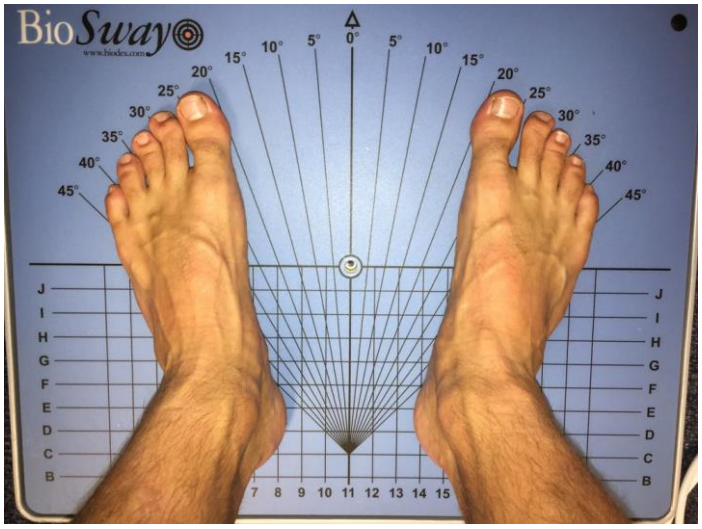


Figure 10: Static balance on firm surface

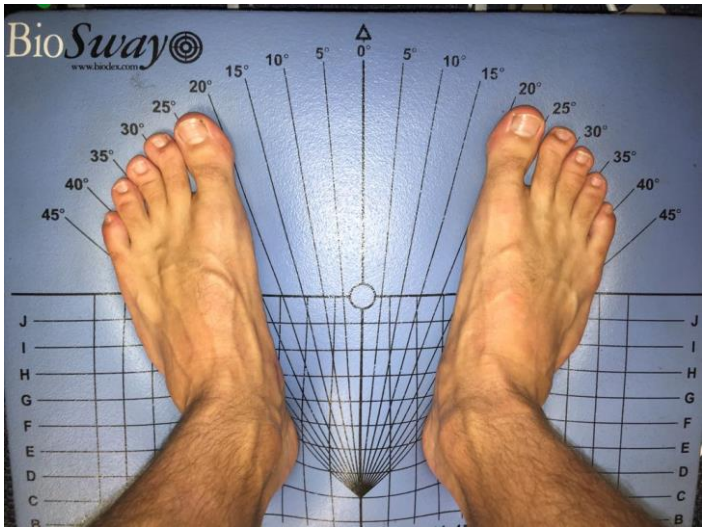


Figure 11: Dynamic balance on foam pad (superior view)

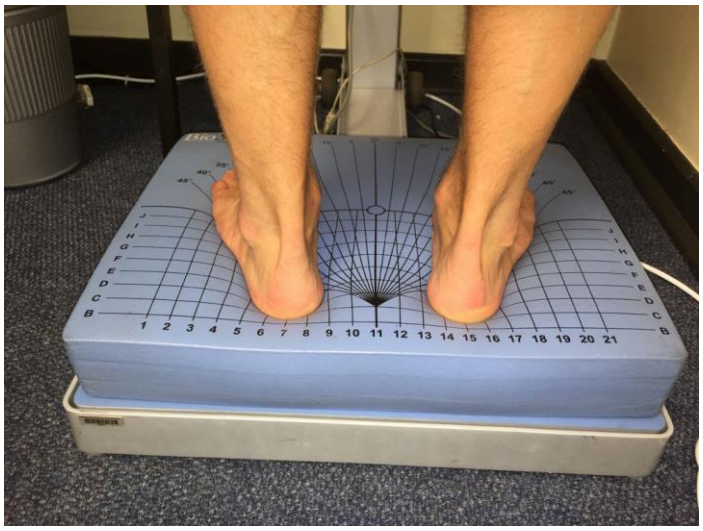


Figure 12: Dynamic balance on foam pad (posterior view)

3.10.2 Goniometer

3.10.2.1 Introduction

The goniometer used is a dual-axis device that provides simultaneous measurements around two orthogonal rotational axes. The X/Y plotting feature can be utilised to inspect motion resulting from two degrees of freedom. For this study, only one axis and one plane of movement was tested (elbow flexion and extension). (Used with a MP3X or MP45 unit.)

SS20L and SS21L dual-axis goniometers measure limb angular movement (e.g., wrist flexion/extension and radial/ulnar deviations).

One MP3X/45 channel is required for each output. To measure both axes simultaneously, twin-axis goniometers require two MP3X/45 channels. For the purpose of the study, two channels were connected because the goniometer was a twin-axis goniometer. However, only one connection was actually required.

The goniometer was set up with the sEMG equipment that was used to conduct this study, namely the BioPac-Bionomadix complete wireless research system (BIOPAC Systems Inc 2018). The system that was used includes the MP150 Data Acquisition System and AcqKnowledge software.

3.10.2.2 Set up

Once the BBPBS tests were complete, the goniometer was set up. The steps for the setup of the goniometer was as follows:

For this study, joint position sense of elbow was studied as a pre-test, post-test evaluation. The participant was positioned in a supine position. The shoulder of the dominant arm was abducted and slightly extended so that the dominant upper limb was relaxed on the table next to the participant. The participant's skin was cleaned appropriately with water and a cloth if the patient reported that he/she had applied any substance to the skin (including creams) that day.

The goniometer was placed on the lateral aspect of the elbow of the dominant upper limb. Two straps were used to position the two ends of the goniometer so that it lay flush with the arm and forearm during the test. It was ensured that there was no torque in the goniometer when it was set up. Once the goniometer was secured it was calibrated before the test commenced.

The goniometer remained attached to the participant for the duration of the upper limb tests, including the intervention/control period. Only once all upper limb post-tests were complete were the straps and the goniometer removed.

3.10.2.3 Procedure

The researcher asked the participant to close his/her eyes for the duration of the JPS test. The researcher moved the participant's forearm passively through 40º to a given elbow angle which was uniform for all participants. The participant was then informed that was the joint position that he/she would be required to reproduce on their own. The researcher passively extended the elbow joint back to the resting position. The participant was then asked to actively reproduce the same angle that was demonstrated passively by the researcher previously. The start of this movement was marked as F3 on the graph. When the participant reached this position, he/she was asked to say

“here” so that the researcher could mark the point on the graph as F4. See Table 2 below for the markers used and their definition.

Once the JPS pre-tests were complete, the intervention was applied, after which the post-test for the JPS was conducted.

During the goniometer procedure, certain markers were used to mark specific points on the graph as it was recorded in real-time. This allowed for easier data capturing. The markers used are shown in Table 2.

Table 2: sEMG markers

Marker	When the marker was used
F1	As the participant was told that the test had commenced, the marker was used. The 20 second time frame allocated to rest was also started at this point.
F2	Once the 20 seconds allocated to rest was complete. The participant was then informed that the researcher was going to show them the elbow angle passively.
F3	When the participant was instructed to move their elbow to the position previously denoted by the researcher.
F4	When the participant informed the researcher that his/her elbow angle had been reached
F5	When the participant was instructed to flex the elbow actively until he/she felt the resistance of the bands and then extend back down.
F6	Once the participant had completed the above-mentioned movement and the arm was completely extended on the table once again.
F7	For the intervention group (A1, A2, A3): This marked the beginning of the time allocated to the participant receiving their first CSM. For the control group (B1): This marked the beginning of the time allocated to a 20 second interval during which the control group was instructed to relax on the table (no intervention/placebo received).
F8	For the intervention group (A1, A2, A3) participants who presented with second fixation in their cervical spine: This marked the beginning of the time allocated to the participant receiving their second CSM.
F9	This marked the end of the test period.

Figure 13: Biopac AcqKnowledge System

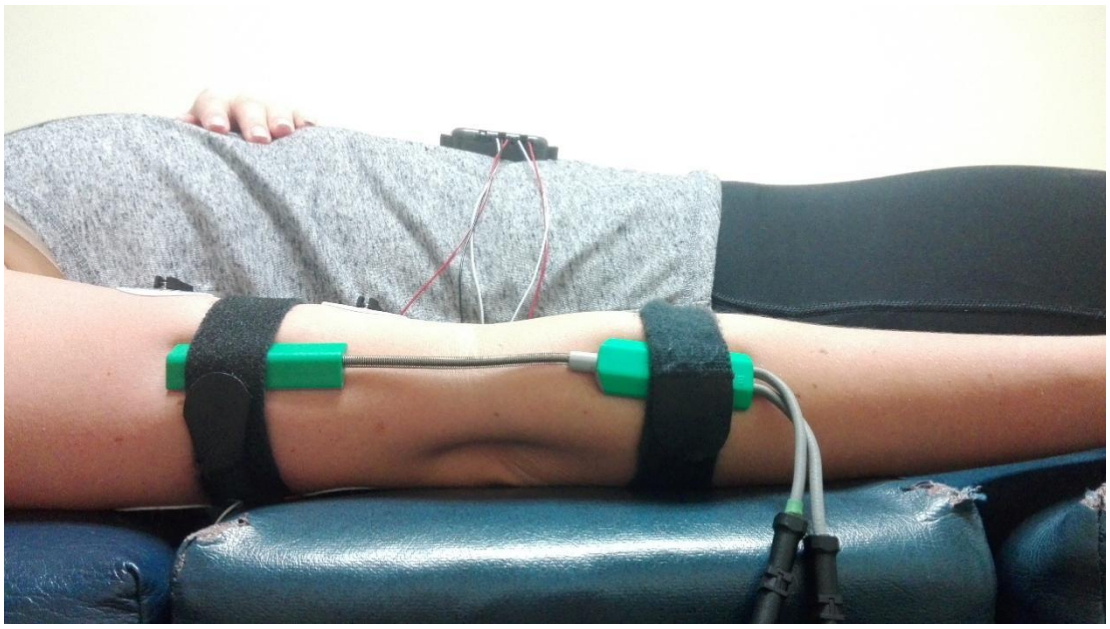


Figure 14: Goniometer set up at rest

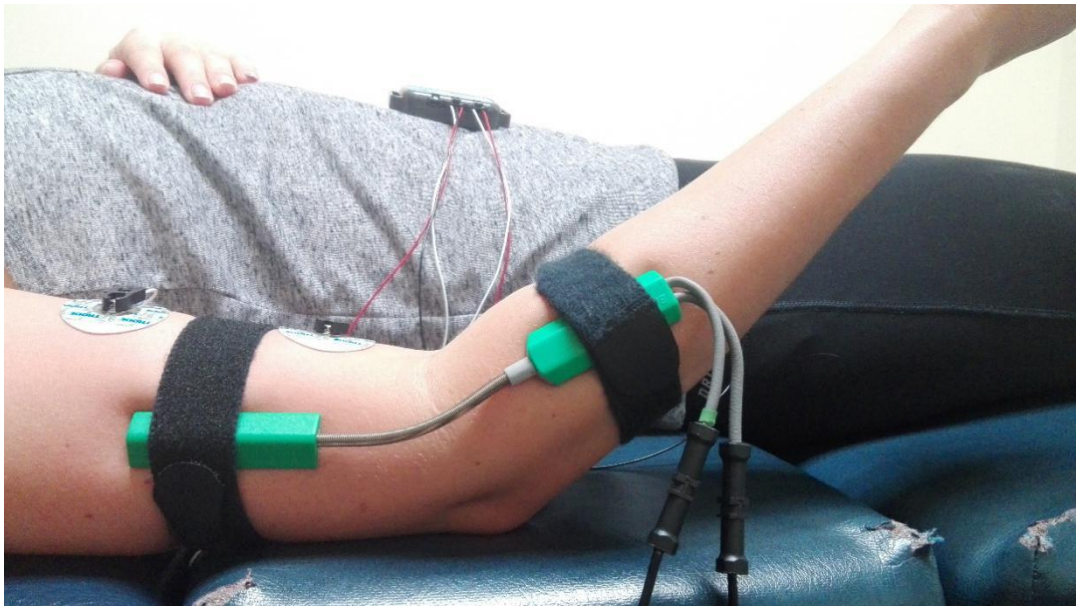


Figure 15: Goniometer set up during active movement

3.10.3 sEMG machine: Biopac AcqKnowledge

3.10.3.1 Introduction

The sEMG machine used in this study had the following specifications:

LabMate Biopac-Bionomadix complete wireless research system with four channel EMG recording. Included MP150 System with AcqKnowledge, BioNomadix 2Ch EMG Amplifier x2, Electro Leads, electrodes and two transmitters.

The electrodes that were used in this study were the Vitatrode midi-ACF 35mm round, Ag/AgCl solid gel, disposable, diagnostic electrocardiography.

There were two main issues of concern (variables) when considering the reliability of the sEMG signal. These were the signal to noise ration and the distortion of the signal. Noise refers to the electrical signals that are not part of the wanted sEMG signal. The signal to noise ratio should be as high as possible. The distortion of the signal refers to the alteration of the relative contribution of any frequency component of the signal. Ideally, the distortion of the should be minimised (De Luca 2002).

Noise can emanate from various sources such as:

- Inherent noise in the electronic components of the detection and recording equipment. This was minimised by using high quality electronic components, intelligent design of circuits and construction techniques (De Luca 2002).
- Ambient noise. This noise radiates from all electromagnetic equipment (De Luca 2002).

- Motion artefacts. The two main sources are from the interface between the surface of the electrodes and the skin; and the from the movement of the cable that connects the electrode to the amplifier. Most of the energy of these noise sources are in the frequency of 0 - 20Hz. Proper design of the electronics circuit was ensured to minimise these sources (De Luca 2002).
- Inherent instability of the signal. The amplitude of the EMG machine is particularly unstable between 0 - 20Hz as the signal is quasi-random in nature. Thus, these components of the signal were considered as unwanted noise and were removed from the signal (De Luca 2002).

3.10.3.2 Set up

The participant remained in the same supine position as described in the set up for the goniometer above. The surface EMG pads were then placed on the skin superficial to the biceps and triceps muscles, on either side of the goniometer straps so that one electrode was positioned at the belly of the muscles and the other one was positioned superficial to the distal muscle attachment. A neutral electrode was placed on the anterior fore-arm of each participant (See Table 3 for electrode placement).

The biceps and triceps brachii muscles are superficial muscles which makes it easily accessible for electromyographic data extraction.

Table 3: sEMG electrode placement

Electrode	Colour of lead attached	Placement of electrode
A1	White	In the muscle belly of the biceps brachii, just proximal to the proximal goniometer strap.
A2	Red	In the distal portion of the biceps brachii muscle close to the musculo-tendinous junction, just distal to the proximal goniometer strap.
A3	black (neutral electrode)	Superficial to the belly of the forearm muscles, just distal to the distal goniometer strap.
B1	white	Superficial to the belly of the triceps brachii muscle, just proximal to the proximal goniometer strap.
B2	Red	Superficial to the distal attachment of the triceps brachii muscle, close to its musculo-tendinous portion, just distal to the proximal goniometer strap.

All five electrodes were connected to the transmitter which was synchronised to the first amplifier. The settings of the transmitter and the amplifier were checked to ensure that they were corresponding to the template set up on the software. The electrodes remained on the participant and readings were taken for the duration of all upper limb tests as well as during the period of intervention or the control time. Once all three pre- and post-

intervention tests of the upper limb were complete, the electrodes were disconnected and then removed from the participant's skin.

3.10.3.3 Procedure

1. The participant was instructed to relax the upper limb completely for the first 20 seconds. The marker F1 was used to mark the start of this time. F2 indicated the end of the 20 second rest.
2. The JPS test was conducted.
3. The participant was then asked to actively move the arm through its full comfortable ROM: from the extended supported position, into full comfortable flexion and then extended back into the supported anatomical position. F5 was used to mark the start of the active movement and F6 was used to mark the end.
4. Full flexion was naturally limited due to the goniometer straps that were positioned over the arm and forearm. The participant was encouraged to flex the elbow as far as it was comfortable and no further as the investigation required data on the active muscular contraction of the involved muscles and was not concerned with the ROM readings taken from the goniometer at this point. Forceful flexion also caused the straps and thus the goniometer to shift out of calibrated alignment and therefore participants were instructed to stop flexion when they felt the resistance of the goniometer straps to movement.
5. Once the pre-tests were complete, the test groups (B1, B2, B3) received their allocated CSM of the fixated level and the control group was allocated a 20 second time of rest (A1). F7 was used to mark the start of the intervention/ control time. F8 was used to mark the start on the second intervention time-frame if the participant was receiving two manipulations (those that presented with a second fixation). F9 was used to mark the end of the control/intervention time.
6. During the intervention/control time, the sEMG reading of the biceps brachii and triceps brachii muscles were taken.
7. The sEMG tests (20 seconds of resting and active movement tests) were then performed as post-tests and the data was recorded electronically.
8. The data that was captured and interpreted from the EMG readings was the root mean square (RMS)/linear envelope, the duration of activity, and the peak amplitude.

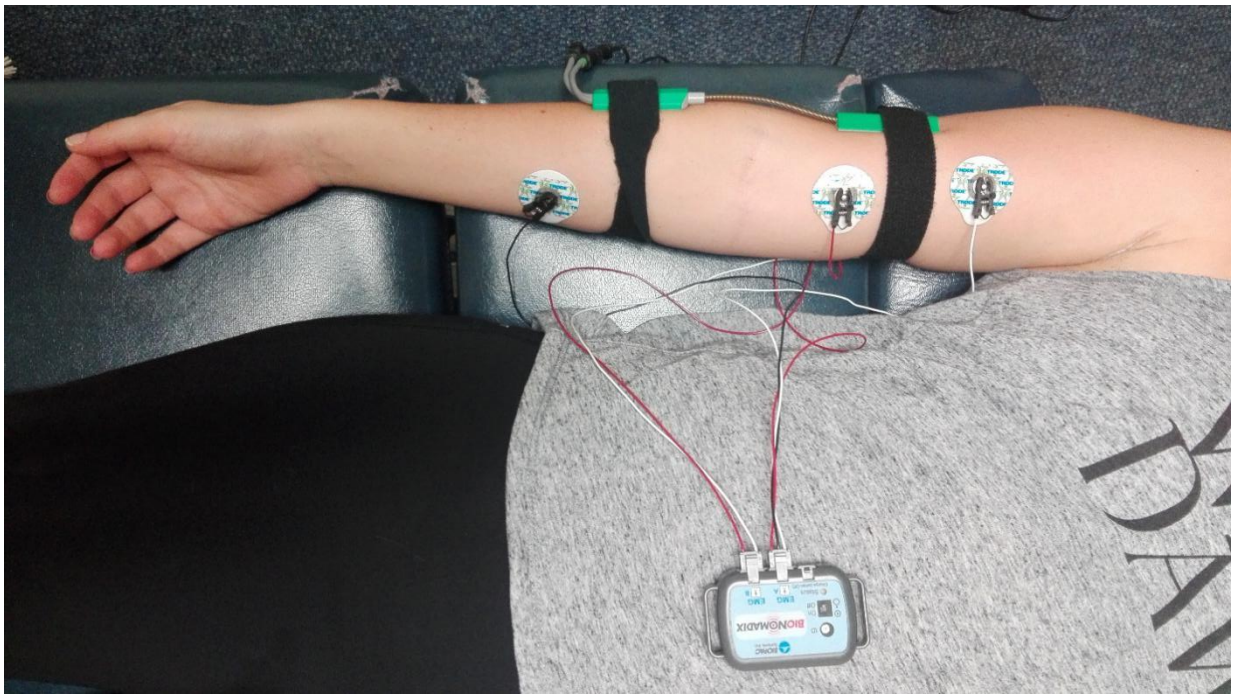


Figure 16: sEMG set up showing the biceps brachii electrodes and the neutral electrode

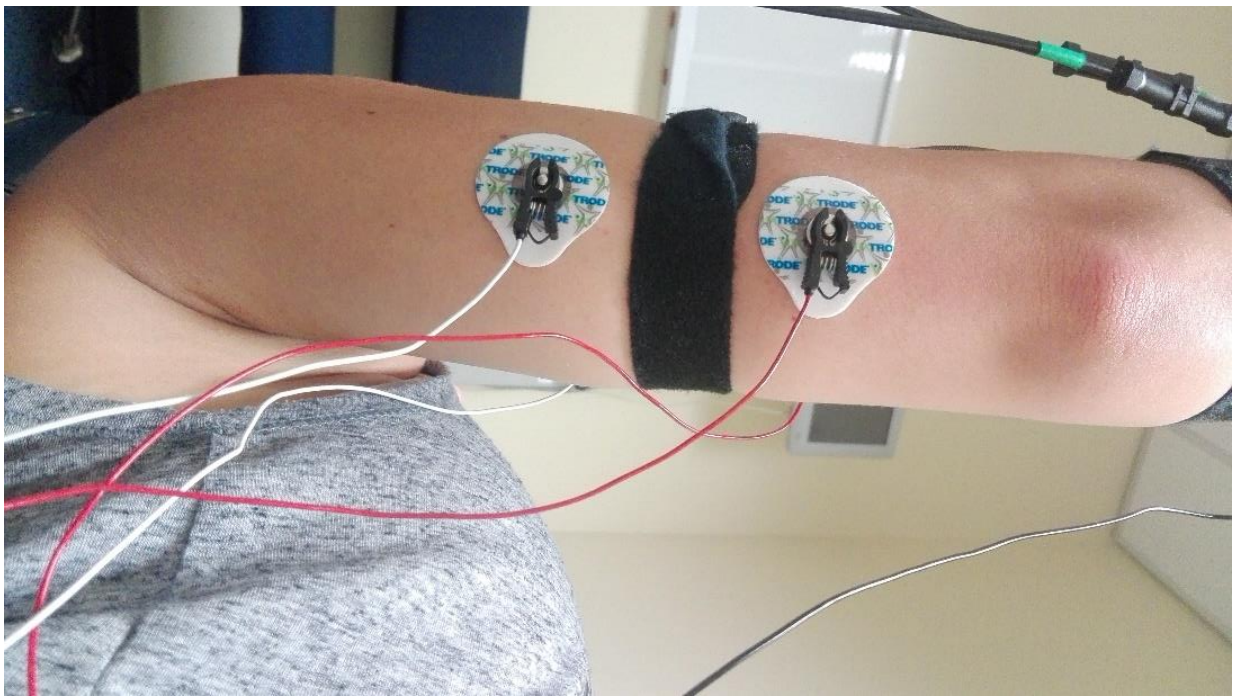


Figure 17: sEMG set up showing the triceps brachii electrodes

3.10.4 Validity and reliability

BIOPAC equipment was used for all the data collection for JPS, electrical activity and balance.

BIOPAC data acquisition and analysis systems record, display and analyse data for a vast array of life science applications. There are over 3 020 BIOPAC citations in peer-

reviewed journal publications and more than 30 700 BIOPAC scholarly references. Over 97% of the top 100 Universities in the United States rely on BIOPAC systems for teaching systems needs and life science research (BIOPAC Systems Inc 2018). Applications include animal studies, biology, biomechanics, electromyography, exercise physiology and evoked responses, to name a few (BIOPAC Systems Inc 2018).

Hinman (2000) stated that the test-retest reliability of the stability indices produced by the Balance System is comparable to other balance measures and acceptable for clinical testing.

3.11 Statistical analysis

All readings obtained from the BBPBS, goniometer and the EMG machine were captured on an SPSS spreadsheet and submitted to a statistician for analysis. Data was analysed by the statistician using the latest version of SPSS (version 23 released in August 2014).

Statistical analysis included statistics using frequency, cross-tabulations and bar charts. Descriptive and inferential statistics using Pearson's correlations were utilised with a significance level (p-value) of 0.05 (Cortinhas and Black 2012: 489). The testing of hypotheses were performed using Fisher's Exact tests for nominal data and ordinal data. A *p* value of less than 0.05 was considered as statistically significant. Odds ratio calculations were also included in the statistical analysis.

In a meeting with the biostatistician at DUT, Professor Glenda Matthews, on 6 May 2016, it was decided that the main statistics considered would be the paired T-test, analysis of variance on differences and multiple comparisons including Tukey's test and Duncan's multiple range test. General descriptives were also investigated.

Paired sample t-tests were conducted on the pre- and post-tests readings of variables measured for intra-analysis of the groups. The paired t-test indicates whether the mean of the pre-intervention data differed from the mean of the post-intervention data. A p-value < 0.05 was considered statistically significant. The null-hypothesis is that there is no difference in the mean values pre- and post-intervention. The alternative hypothesis states that there is a difference between the mean readings pre- and post-intervention.

Independent t-tests were conducted to determine whether the mean difference for the control group (A) is equal to the mean difference of the intervention groups combined (B1, B2, B3).

A one-way analysis of variance (ANOVA) test was conducted to analyse whether the mean differences from pre- and post-intervention readings for the four groups A1, B1,

B2 and B3 are the same or not. ANOVA testing was thus used as an inter-group analysis. If the null-hypothesis was rejected, then post hoc tests were conducted to detect where the differences lie. These included Tukey's test and Duncan's multiple range test.

The above-mentioned tests were used to analyse the data for the first three objectives.

The effect size (Cohen's d), is a measure that reflects the magnitude of the effect of interest. This measurement was used to analyse objective 4. In this study the effect size is a measure of the difference between two means scaled by the standard deviation. Guidelines for the interpretation of the effect size are provided in Table 7 (Cohen 1998).

Table 4: Effect size interpretation

Effect size (Cohen's d)	Interpretation
0. 2	Small
0.5	Medium
0.8	large

For the paired sample test, Cohen's d = $\frac{difference\ between\ means}{standard\ deviation\ of\ differences}$

For the independent two sample test Cohen's d = $\frac{difference\ between\ means}{pooled\ standard\ deviation}$

3.12 Ethics

Institutional Research Ethics Committee (IREC) approval was obtained from DUT before commencement of the data collection procedure (REC 115/16). See Appendix J.

Each participant was required to read and sign a letter of information and informed consent before they could participate in the study (Appendix A). Participants were allowed to withdraw from the study at any given point in time. During the screening process, it was established whether the participants had fixations in the cervical spine. Only those who presented with fixations could partake in the study as per the inclusion criteria. The participants were properly informed with regards to the research procedure. All data collected was coded and safely stored in the clinic. The data will be stored for five years before it will be shredded as per DUT Chiropractic Clinic protocol. Once the research procedure was complete all participants had the opportunity to have one free treatment. No care was withheld from patients needing it.

Chapter 4: Results

4.1 Introduction

This chapter describes the results obtained from the primary data collected over the duration of the study. Measurements included:

1. Elbow joint position sense – measured in degrees. It was measured using a goniometer connected to the sEMG machine (Biopac AcqKnowledge).
2. Electrical activity of biceps and triceps brachii muscles – measured in hertz using the sEMG machine (Biopac AcqKnowledge).
3. Balance – in terms of the sway index which was expressed as a decimal fraction. It was measured using the Biosway Biopac balance system.

4.2 Demographics

The participants included both males and females between the ages of 18-35 years who responded to the advertisements and who met the inclusion criteria. The following tables summarise the age and gender distribution of the sample and the individual groups.

4.2.1 Age

Table 5: Age distribution

Group	N	Minimum (years)	Maximum (years)	Mean	Std. Deviation
A1	20	20	34	25.45	4.006
B1	20	19	33	24.50	3.832
B2	21	20	33	25.05	3.383
B3	20	20	35	26.15	4.320

The mean age for the control group was 25.45 years; for the upper CSM group it was 24.5 years; for the lower CSM group it was 25.05 years and for the group that received both upper and lower CSM the mean age was 26.15 years.

4.2.2 Gender

Table 6: Gender distribution

Group	Gender	Frequency	Percent
A1	f	14	70.0
	m	6	30.0
B1	f	12	60.0
	m	8	40.0
B2	f	15	71.4
	m	6	28.6
B3	f	9	45.0
	m	11	55.0

Table 5 shows that the gender percent distribution of the entire sample was 50 females (61,73%) and 31 males (38,27%). The distribution between the groups was 14 (70%) females and 6 (30%) males for group A1; 12 (60%) females and 8 (40%) males for group B1; 15 (71,4%) females and 6 (28,6%) males for group B2 and 9 (45%) females and 11 (55%) males for group B3.

4.2.3 Fixations

The levels of the fixations that the participants presented with were recorded. Some participants presented with two fixations, in which case both the fixations were identified. The tables below summarise the frequency and the percentage of the various levels of fixations that each group presented with.

Table 7: Fixation distribution

Fixations			
Group	**Levels**	**Frequency**	**Percent**
A1 (control)	C0	1	3.7
	C1	4	14.8
	C2	5	18.5
	C3	2	7.4
	C4	0	0
	C5	4	14.8
	C6	1	3.7
	C7	10	37.0
	Total	**27**	**100.0**
B1 (upper only)	C0	1	4.3
	C1	14	60.9
	C2	3	13.0
	C3	5	21.7
	Total	**23**	**100.0**
B2 (lower only)	C4	3	12.5
	C5	8	33.3
	C6	1	4.2
	C7	12	50.0
	Total	**24**	**100.0**
B3 (upper and lower)	C0	2	5.0
	C1	8	20.0
	C2	8	20.0
	C3	2	5.0
	C4	2	5.0
	C5	5	12.5
	C6	0	0
	C7	13	32.5
	Total	**40**	**100.0**

Table 6 shows that Group A1 included participants who could present with fixations of any levels of the cervical spine. One participant (5%) presented with a C0 fixation. Four participants (20%) presented with C1 fixations. Five participants (25%) presented with C2 fixations. Two participants (10%) presented with C3 fixations. Three participants (15%) presented with C5 fixations. One participant (5%) presented with a C6 fixation. Four participants (20%) presented with C7 fixations. There were no C4 fixations detected in group A1.

4.3 Analysis of the primary data

4.3.1 Objective 1: To determine the effect of CSM on joint position sense of the elbow joint

To compare the differences between the elbow JPS pre- and post-intervention, the absolute values of the differences between the given elbow angle and the participants' actively placed position was calculated pre- and post-intervention. The absolute difference for the post-intervention JPS was then subtracted from the absolute difference of the pre-intervention JPS to determine whether there was an improvement in JPS following the intervention. If this pre-post intervention difference was calculated as a positive value, then it demonstrated an improvement in the JPS accuracy compared to the pre-intervention JPS; whereas if the difference was negative then it demonstrated a decrease in JPS accuracy compared to the pre-intervention JPS reading.

4.3.1.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3)

4.3.1.1.1 Paired t-test

Table 8: Paired sample statistics for JPS (2 groups)

	Paired Samples Statistics				
Group2		Mean	N	Std. Deviation	Std. Error Mean
A1 (control)	JPS Pre	7.0571	20	5.55784	1.24277
	JPS Post	6.3026	20	6.04816	1.35241
B's (combined intervention)	JPS Pre	6.0896	61	4.28868	.54911
	JPS Post	5.6783	61	4.57407	.58565

Table 9: Paired t-test for JPS (2 groups)

Paired T-Test								
		Paired Differences						effect
Group2		Mean	Std. Deviation	Std. Error Mean	t	df	p-value	size
A1 (control)	JPS difference	.75448	6.55190	1.46505	.515	19	.613	0.115
B's (combined intervention)	JPS difference	.41124	5.71857	.73219	.562	60	.576	0.0725

Tables 8 and 9 show that when comparing the mean difference between the pre- and post-intervention JPS scores, there was an improvement in both group A1 (0,75448)

and the combined intervention groups (B1, B2, B3) (0,41124). However, neither of the changes was of statistical significance as the p-value for both was greater than 0.05. A1 had a p-value = 0.613 and the intervention groups combined had a p-value = 0.576. The effect size for group A1 was 0.115 and for the combined intervention groups it was 0.0725.

4.3.1.1.2 Independent t-test

Table 10: Group statistics for JPS

Group Statistics					
	Group2	N	Mean	Std. Deviation	Std. Error Mean
JPS	A	20	.7545	6.55190	1.46505
	B's	61	.4112	5.71857	.73219

Table 11: Independent t-test for JPS

Independent T-Test							
	Levene's Test for Equality of Variances		t-test for Equality of Means				
JPS	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	.011	.916	.225	79	.823	.34323	1.52790

Tables 10 and 11 show that there was no statistically significant difference between group A1 and the intervention group combined (B1, B2, B3) as the p-value was greater than 0.05 (p = 0.823).

4.3.1.2 Comparison across all 4 groups (A1, B1, B2, B3)

4.3.1.2.1 Paired samples statistics for JPS (4 groups)

Table 12: Paired samples statistics for JPS (4 groups)

Paired Samples Statistics					
Group 4		Mean (^{o})	N	Std. Deviation	Std. Error Mean
A1 (control)	JPS pre	7.0571	20	5.55784	1.24277
	JPS post	6.3026	20	6.04816	1.35241
B1 (upper)	JPS pre	5.6973	20	4.24585	.94940
	JPS post	4.2363	20	3.16115	.70685
B2 (lower)	JPS pre	6.3170	21	3.62444	.79092
	JPS post	6.7052	21	6.08551	1.32797
B3 (upper and lower)	JPS pre	6.2431	20	5.09738	1.13981
	JPS post	6.0422	20	3.68792	.82464

Table 13: Paired t-test for JPS(4 groups)

Paired T-Test									
	Paired Differences								Effect size
				95% Confidence Interval of the Difference					
Group 4	Mean (°)	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	P-value	
A1 (control)	.75448	6.55190	1.46505	-2.31191	3.82086	.515	19	.613	0.1151
B1 (upper)	1.46098	4.63348	1.03608	-.70755	3.62952	1.410	19	.175	0.3153
B2 (lower)	-.38822	6.55220	1.42981	-3.37074	2.59430	-.272	20	.789	0.0608
B3 (upper and lower)	.20094	5.89040	1.31713	-2.55585	2.95773	.153	19	.880	0.0342

Tables 12 and 13 show that when comparing the mean difference between the pre- and post-intervention JPS scores, there was an improvement in group A1 (0,75448), B1 (1,46098), and B3 (0,20094), with group B1 demonstrating the greatest mean improvement of the groups. The mean JPS scores for group B2 worsened (-0,38822), as indicated by the negative reading. However, none of these changes were statistically significant as all p-values were greater than 0.05. Group A1 had a p-value = 0.613; group B1 had a p-value = 0.175; group B2 had a p-value = 0.789; group B3 had a p-value = 0.880. Group B1 has the highest effect size of 0.3153.

4.3.1.2.2 JPS ANOVA

Table 14: ANOVA for JPS

ANOVA					
JPS difference of absolute differences					
	Sum of Squares	df	Mean Square	F	P-value
Between Groups	38.120	3	12.707	.357	.784
Within Groups	2741.398	77	35.603		
Total	2779.518	80			

Table 14 shows that there was no statistically significant difference between the means for group A1, B1, B2 and B3, as the p-value was greater than 0.05 (p = 0,784).

4.3.1.3 Conclusion

4.3.1.3.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3)

Both groups improved in elbow JPS. Neither of the improvements were of statistical significance, however, the combined intervention group had the lower of the two p-values.

4.3.1.3.2 Comparison across all 4 groups (A1, B1, B2, B3)

The group that received upper CSM only demonstrated the greatest improvement in JPS, although none of the results were of statistical significance.

4.3.2 Objective 2: To determine the effect of CSM on muscular activity of the triceps brachii and biceps brachii muscles

For electrical activity readings at rest the median value was taken, for the active period the mean value was taken, and to measure the electrical activity during the intervention the maximum value for electrical activity was taken.

For the control group (A1) vs the intervention groups combined (B1, B2, B3), the difference between the electrical activity of the biceps and triceps brachii muscles pre- and post-intervention was calculated by subtracting the post intervention value from the pre-intervention value. This was done for the rest period and the active movement. Therefore, a positive value indicated a decrease in electrical activity post-intervention and a negative value indicated an increase in electrical activity post-intervention

4.3.2.1 Rest period

4.3.2.1.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3)

4.3.2.1.1.1 Paired T-Test

Table 15: Paired samples statistics for the rest period (2 groups)

Group 2		Mean (Hz)	N	Std. Deviation	Std. Error Mean
A1 (control)	Biceps Pre	.0043905	20	.00352170	.00078748
	Biceps Post	.0042760	20	.00295307	.00066033
	Triceps Pre	.0052835	20	.00323209	.00072272
	Triceps Pre	.0051845	20	.00317717	.00071044
B's (combined intervention)	Biceps Pre	.0050138	61	.00494495	.00063314
	Biceps Post	.0067370	61	.01169717	.00149767
	Triceps Pre	.0059285	61	.00455188	.00058281
	Triceps Post	.0066267	61	.00676250	.00086585

Table 16: Paired t-test for the rest period (2 groups)

Paired Differences										
					95% Confidence Interval of the Difference					
Group 2	Muscles	Mean (Hz)	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	P-value	Effect size
A1 (control)	Biceps	.00011450	.00132796	.00029694	-.00050700	.00073600	.386	19	.704	0.0863
	Triceps	.00009900	.00147571	.00032998	-.00059165	.00078965	.300	19	.767	0.0671
B's (combined intervention)	Biceps	-.00172328	.00831126	.00106415	-.00385189	.00040533	-1.619	60	.111	0.2090
	Triceps	-.00069820	.00539719	.00069104	-.00208048	.00068409	-1.010	60	.316	0.1304

Tables 15 and 16 show that when comparing the change in the electrical activity of biceps and triceps brachii muscles at rest, the combined intervention groups (B1, B2, B3) had an increase in electrical activity of both muscles (biceps brachii = -0.00172328; triceps brachii = -0.00069820) and the control group (A1) had a decrease in electrical activity of both muscles (biceps brachii = 0.00011450; triceps brachii = 0.00009900).

However, none of the changes were of statistical significance as all p-values were greater than 0.05. Both muscles of the combined intervention group had a lower p-value (biceps p-value = 0,111; triceps p-value = 0.316) and a higher effect size (biceps = 0.2090; triceps = 0.1304) when compared to the changes in the muscles of the control group (A1) (biceps brachii p-value = 0,704; triceps brachii p-value = 0,767 and biceps effect size = 0.0863; triceps effect size = 0.0671). The intervention group (B's combined)

showed the largest effect size = 0.2090 for the difference in biceps pre- and post-intervention.

4.3.2.1.1.2 Independent t-test

Table 17: Independent t-test for the rest period

Group Statistics					
	Group2	N	Mean (Hz)	Std. Deviation	Std. Error Mean
Biceps	A1 (control)	20	.00011450	.001327956	.000296940
	B's (combined intervention)	61	-.00172328	.008311257	.001064147
Triceps	A1 (control)	20	.00009900	.001475708	.000329978
	B's (combined intervention)	61	-.00069820	.005397189	.000691039

Table 18: Independent t-test for the rest period

Independent T-Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	P-value	Mean Difference	Std. Error Difference	Lower	Upper
Biceps	Equal variances assumed	2.290	.134	.981	79	.330	.001837779	.001873871	-.001892069	.005567626
Triceps	Equal variances assumed	2.635	.109	.650	79	.518	.000797197	.001226233	-.001643560	.003237953

Tables 17 and 18 show that there was no significant difference between the electrical activity of the muscles in the control and the combined intervention group as the p-value was greater than 0.05. The biceps brachii muscle demonstrated p = 0.330 and the triceps brachii muscle demonstrated p = 0,518. (Equal variance option was used, since p-value > 0.05 for Levene's test for equal variances.)

4.3.2.1.2 Comparison across all 4 groups (A1, B1, B2, B3)

4.3.2.1.2.1 Paired t-test

Table 19: Paired t-test for the rest period (4 groups)

Paired T-Test										
group	**Test**	**Paired differences**					**t**	**df**	**p-value**	
		Mean (Hz)	**Std. deviation**	**Std. Error mean**	**95% confidence interval of the difference**					**effect size**
					lower	**upper**				
A1 (control)	Biceps	.00011450	.0013279 6	.0002969 4	-.0005070 0	.0007360 0	.386	19	.704	.0861
	Triceps	.00009900	.0014757 1	.0003299 8	-.0005916 5	.0007896 5	.300	19	.767	.0671
B1 (upper)	Biceps	-.0016195 0	.0040493 5	.0009054 6	-.0035146 6	.0002756 6	-1.789	19	.090	.4000
	Triceps	-.0012430 0	.0064284 7	.0014374 5	-.0042516 2	.0017656 2	-.865	19	.398	.1934
B2 (lower)	Biceps	.00027095	.0013351 7	.0002913 6	-.0003368 1	.0008787 2	.930	20	.363	.2029
	Triceps	-.0000076 2	.0015097 2	.0003294 5	-.0006948 4	.0006796 0	-.023	20	.982	.0050
B3 (upper and lower)	Biceps	-.0039210 0	.0137975 7	.0030852 3	-.0103784 6	.0025364 6	-1.271	19	.219	.2842
	Triceps	-.0008785 0	.0068840 5	.0015393 2	-.0041003 3	.0023433 3	-.571	19	.575	.1277

Table 19 shows that there was a decrease in the mean electrical activity of the biceps and triceps brachii muscles in the control group as demonstrated by the positive mean values (biceps brachii = 0,00011450; triceps brachii = 0.00009900). However, neither of these differences were statistically significant as $p > 0,05$ (biceps brachii $p = 0,704$; triceps brachii $p = 0,767$).

There was an increase in the mean electrical activity of the biceps and triceps brachii muscles post-intervention in the group that received upper CSM only as demonstrated by the negative mean values (biceps brachii = -.00161950; triceps brachii = -.00124300). The increase in the biceps brachii electrical activity post-intervention was statistically significant at a 10% level of significance as $p = 0,090$. However, the triceps brachii muscle difference was not statistically significant ($p = 0,398$).

There was a decrease in the mean electrical activity of the biceps brachii muscle post-intervention in the group that received lower CSM only as demonstrated by the positive mean value (biceps brachii = 0,00027095). The triceps brachii muscle on the other hand demonstrated a mean increase in the electrical activity of the muscle post-intervention, as demonstrated by the negative value (-.00000762). However, neither of these

differences were statistically significant as p > 0,05 (biceps brachii: p = 0,363; triceps brachii: p = 0,982).

There was an increase in the mean electrical activity of both the biceps and triceps brachii muscles post-intervention in the group that received both upper and lower CSM as demonstrated by the negative mean values (biceps brachii = -0,00392100; triceps brachii = -0,00087850). However, neither of these differences were statistically significant as p > 0,05 (biceps brachii p = 0,219; triceps brachii p = 0,575).

4.3.2.1.2.2 ANOVA

An ANOVA test was performed to test whether the means of the change in electrical activity of the biceps brachii and triceps brachii muscles at rest in the four groups (A1, B1, B2, B3) post-intervention were the same or not.

Table 20: ANOVA for the rest period

ANOVA						
		Sum of Squares	df	Mean Square	F	P-value
Biceps	Between Groups	.000	3	.000	1.484	.225
	Within Groups	.004	77	.000		
	Total	.004	80			
Triceps	Between Groups	.000	3	.000	.379	.768
	Within Groups	.002	77	.000		
	Total	.002	80			

Tables 20 shows that the p-value between the four groups for the biceps brachii electrical activity was 0.225. The p-value between the four groups for the triceps brachii electrical activity was 0.768. Therefore, the null-hypothesis was not rejected for both muscles because p > 0.05. This indicates that there was no statistically significant change of electrical activity of the biceps brachii and triceps brachii muscles at rest post cervical spine manipulation.

4.3.2.1.3 Conclusion

For both biceps and triceps brachii muscles, the combined intervention group had an increase in electrical activity during the rest period and the control group had a decrease in electrical activity. Although neither of these values were of statistical significance, the p-value for the combined intervention group was much lower than that of the control group.

When the four groups were compared, the group that received upper CSM only had the greatest increase in electrical activity of both the biceps and the triceps brachii muscles during the rest period. This increase in the biceps muscle was significant at a 10% level of significance (p = 0.090).

4.3.2.2 Active period

4.3.2.2.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3)

4.3.2.2.1.1 Paired T-Test

Table 21: Paired sample statistics for the active movement (2 groups)

Paired samples statistics					
Group 2		Mean (Hz)	N	Std. Deviation	Std. Error Mean
A1 (control)	Pre Biceps	.0328370	20	.01552087	.00347057
	Post Biceps	.0350605	20	.01472483	.00329257
	Pre Triceps	.0140590	20	.00642498	.00143667
	Post Triceps	.0145820	20	.00755294	.00168889
B's (combined intervention)	Pre Biceps	.0351689	61	.02663151	.00340982
	Post Biceps	.0340410	61	.02342176	.00299885
	Pre Triceps	.0159341	61	.00875887	.00112146
	Post Triceps	.0157670	61	.00805747	.00103165

Table 22: Paired t-test for the active movement (2 groups)

Paired T-test										
					95% Confidence Interval of the Difference					
Group 2		Mean (Hz)	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	P-value	effect size
A1 (control)	Biceps	-.00222350	.00711736	.00159149	-.00555453	.00110753	-1.397	19	.178	.3124
	Triceps	-.00052300	.00374153	.00083663	-.00227409	.00122809	-.625	19	.539	.1398
B's (combined intervention)	Biceps	.00112787	.00871462	.00111579	-.00110405	.00335979	1.011	60	.316	.1305
	Triceps	.00016705	.00513411	.00065736	-.00114786	.00148196	.254	60	.800	.0328

A paired t-test was performed to determine whether the mean of the electrical activity of the biceps and triceps muscles of the pre-intervention rest period equals the mean of the electrical activity of the biceps and triceps muscles of the post-intervention rest period. The mean electrical activity of both biceps and triceps brachii muscles increased in the control group (A1), as indicated by the negative mean values in Table 22. The

combined intervention group (B1, B2, B3) had a mean electrical decrease for both muscles, as indicated by the positive mean values in able. However, none of the changes were of statistical significance as all p-values were greater than 0,05. For group A1 (control) the biceps had a p-value = 0,178 (effect size=0,3124) and for triceps brachii, the p-value = 0,539 (effect size = 0.1398). The combined intervention group had a p-value = 0,316 for biceps brachii (effect size = 0.1305) and the p-value = 0,800 for triceps brachii (effect size = 0.0328).

4.3.2.2.1.2 Independent t-test

Table 23: Independent t-test for the active movement

Independent T-Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	P-value	Mean Difference	Std. Error Difference	Lower	Upper
Biceps	Equal variances assumed	.654	.421	-1.556	79	.124	-.003351369	.002153701	-.007638204	.000935466
Triceps	Equal variances assumed	.720	.399	-.554	79	.581	-.000690049	.001246077	-.003170303	.001790205

An independent t-test was performed to determine whether the mean of the electrical activity of the biceps and triceps muscles of the pre-intervention active period equals the mean of the electrical activity of the biceps and triceps muscles of the post-intervention active period. Table 23 shows that for the biceps brachii muscle the p-value was 0.124 and for the triceps brachii muscle the p-value was 0.581. Therefore, the null-hypothesis was not rejected for both the muscles as the p-value > 0.05.

4.3.2.2.2 Comparison across all 4 groups (A1, B1, B2, B3)

4.3.2.2.2.1 Paired t-test

Table 24: Paired t-test for the active movement (4 groups)

Paired T-Test										
group	**Test**	**Paired differences**					**t**	**df**	**P-value**	
		Mean (Hz)	**Std. deviation**	**Std. Error mean**	**95% confidence interval of the difference**					**effect size**
					lower	**upper**				
A1 (control)	Biceps	-.00222350	.00711736	.00159149	-.00555453	.00110753	-1.397	19	.178	.3124
	Triceps	-.00052300	.00374153	.00083663	-.00227409	.00122809	-.625	19	.539	.1398
B1 (upper)	Biceps	.00137050	.00909990	.00203480	-.00288838	.00562938	.674	19	.509	.1507
	Triceps	.00009500	.00666717	.00149082	-.00302533	.00321533	.064	19	.950	.0143
B2 (lower)	Biceps	.00207810	.01036406	.00226162	-.00263957	.00679576	.919	20	.369	.2005
	Triceps	.00021524	.00427643	.00093319	-.00173137	.00216185	.231	20	.820	.0504
B3 (upper and lower)	Biceps	-.00011250	.00642423	.00143650	-.00311913	.00289413	-.078	19	.938	.0174
	Triceps	.00018850	.00441920	.00098816	-.00187975	.00225675	.191	19	.851	.0427

Table 24 shows that there was an increase in the electrical activity of both muscles for group A1. The biceps had a p-value = 0,178 (effect size=0,3124) and for triceps brachii, the p-value = 0,539 (effect size = 0.1398). Neither of these values are of statistical significance as p > 0.05. This group had the greatest effect size for both muscles.

There was a decrease in the mean active electrical activity of both the biceps and triceps brachii muscles post-intervention in group B1 as demonstrated by the positive mean values in Table 24. However, neither of these differences were statistically significant as p > 0,05 (biceps brachii p = 0,509; triceps brachii p = 0,950).

There was a decrease in the mean active electrical activity of both the biceps and triceps brachii muscles post-intervention in group B2 as demonstrated by the positive mean values in Table 24. However, neither of these differences were statistically significant as p > 0,05 (biceps brachii p = 0,369; triceps brachii p = 0,820).

There was an increase in the mean active electrical activity of the biceps brachii muscle as demonstrated by the negative mean values in the above table and a decrease in the triceps brachii muscles post-intervention in group B3 as demonstrated by the positive

mean values in the above table. However, neither of these differences were statistically significant as p > 0,05 (biceps brachii p = 0,938; triceps brachii p = 0,851).

When comparing effect sizes, it is evident that the group that received lower CSM only had the greatest effects sizes of the groups that demonstrated a decrease in electrical activity readings (0.2 for biceps and 0.05 for triceps). These are considered small effect sizes.

4.3.2.2.2.2 ANOVA

Table 25: ANOVA for the active movement

ANOVA						
		Sum of Squares	df	Mean Square	F	P-value
Biceps	Between Groups	.000	3	.000	1.033	.383
	Within Groups	.005	77	.000		
	Total	.006	80			
Triceps	Between Groups	.000	3	.000	.102	.959
	Within Groups	.002	77	.000		
	Total	.002	80			

An ANOVA test was performed to test whether the means of the change in electrical activity of the biceps brachii and triceps brachii muscles during an active movement in the four groups (A1, B1, B2, B3) post-intervention were the same or not.

Table 26 shows that the p-value between the four groups for the biceps brachii electrical activity was 0.383. The p-value between the four groups for the triceps brachii electrical activity was 0.959. Therefore, the null-hypothesis was not rejected for both muscles because p > 0.05. This indicates that there was no statistical significance in the change of electrical activity of the biceps brachii and triceps brachii muscles during an active movement post CSM.

4.3.2.2.3 Conclusion

4.3.2.2.3.1 Control group compared to the intervention groups combined

During the active period, the control group experienced an increase in electrical activity for both muscles and the combined intervention group experienced a decrease in electrical activity for both muscles. These changes were not statistically significant.

4.3.2.2.3.2 Comparison across all four groups

When the four groups were compared, none of the changes were of statistical significance. The group that received lower CSM only, had the greatest decrease in electrical activity for the biceps and triceps brachii muscles during the active movement, by comparison of effects sizes.

4.3.2.3 Intervention period

4.3.2.3.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3)

4.3.2.3.1.1 Independent t-test

Table 26: Sample descriptive statistics for the intervention period (2 groups)

Descriptive Statistics						
Group2		N	Minimum (Hz)	Maximum (Hz)	Mean (Hz)	Std. Deviation
A1 (control)	Biceps Maximum	20	.00361	.28234	.0290115	.06520659
	Triceps Maximum	20	.00320	.08085	.0150500	.01666022
	Valid N (listwise)	20				
B's (combined intervention)	Biceps Maximum	61	.01375	1.00564	.1699520	.20956241
	Triceps Maximum	61	.01441	1.89028	.2345470	.32792589
	Valid N (listwise)	61				

Table 27: Independent t-test for the intervention period

Independent T-Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	P-value	Mean Difference	Std. Error Difference	Lower	Upper
Biceps	Equal variances assumed	13.681	.000	-2.950	79	.004	-.14094047	.04777444	-.23603310	-.04584783
	Equal variances not assumed			-4.615	78.932	.000	-.14094047	.03053745	-.20172456	-.08015638
Triceps	Equal variances assumed	8.583	.004	-2.980	79	.004	-.21949705	.07366782	-.36612917	-.07286493
	Equal variances not assumed			-5.207	60.936	.000	-.21949705	.04215155	-.30378607	-.13520803

An independent t-test was performed to determine whether the mean difference of the electrical activity of the biceps and triceps brachii muscles during the intervention for the

control group (A1) was equal to the mean difference of the intervention groups combined (B1, B2, B3). Tables 26 and 27 show that the p-value for the biceps brachii muscle electrical activity was less than 0.001 and for the triceps brachii muscle p=0.004. Equal variances were not assumed for both muscles as $p < 0.05$. The null hypothesis for the electrical activity of both the biceps and triceps muscles during the intervention period was thus rejected. This means that there is a difference between the means of the two groups.

4.3.2.3.2 Comparison across all 4 groups (A1, B1, B2, B3)

4.3.2.3.2.1 ANOVA

Table 28: Descriptive statistics for the intervention period (4 groups)

Descriptive Statistics						
Group4		N	Minimum (Hz)	Maximum (Hz)	Mean (Hz)	Std. Deviation
A1 (control)	Biceps Maximum	20	.00361	.28234	.0290115	.06520659
	Triceps Maximum	20	.00320	.08085	.0150500	.01666022
	Valid N (listwise)	20				
B1 (upper)	Biceps Maximum	20	.01723	1.00564	.1891990	.25265897
	Triceps Maximum	20	.02011	1.57719	.2781695	.37322592
	Valid N (listwise)	20				
B2 (lower)	Biceps Maximum	21	.01375	.75931	.1864886	.22790914
	Triceps Maximum	21	.02234	.58797	.1691886	.14588209
	Valid N (listwise)	21				
B3 (upper and lower)	Biceps Maximum	20	.03135	.45124	.1333415	.13441489
	Triceps Maximum	20	.01441	1.89028	.2595510	.41292085
	Valid N (listwise)	20				

Table 29: ANOVA for the intervention period

ANOVA						
		Sum of Squares	df	Mean Square	F	P-value
Biceps Maximum	Between Groups	.339	3	.113	3.253	.026
	Within Groups	2.676	77	.035		
	Total	3.015	80			
Triceps Maximum	Between Groups	.866	3	.289	3.518	.019
	Within Groups	6.317	77	.082		
	Total	7.183	80			

Tables 28 and 29 show that the p-value between the four groups for the biceps brachii electrical activity was 0.026. The p-value between the four groups for the triceps brachii electrical activity was 0.019. Therefore, the null-hypothesis was rejected for both muscles because $p < 0.05$. This indicates that there was a statistically significant

difference between the means of the electrical activity of the biceps brachii and triceps brachii muscles during the intervention.

The group that received upper CSM only had the highest electrical activity readings in both muscles during the intervention (Biceps brachii = 0.1891990; triceps brachii = 0.2781695).

4.3.2.3.2.2 Post hoc tests

Table 30: Multiple comparisons for the intervention period

Multiple Comparisons								
Dependent Variable		(I) Group4	(J) Group4	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
							Lower Bound	Upper Bound
Biceps Maximum	Tukey HSD	A1 (control)	B1	-.16018750*	.05894981	.040	-.3149917	-.0053833
			B2	-.15747707*	.05824380	.041	-.3104273	-.0045268
			B3	-.10433000	.05894981	.296	-.2591342	.0504742
		B1 (upper)	A1	.16018750*	.05894981	.040	.0053833	.3149917
			B2	.00271043	.05824380	1.000	-.1502398	.1556607
			B3	.05585750	.05894981	.779	-.0989467	.2106617
		B2 (lower)	A1	.15747707*	.05824380	.041	.0045268	.3104273
			B1	-.00271043	.05824380	1.000	-.1556607	.1502398
			B3	.05314707	.05824380	.798	-.0998032	.2060973
		B3 (both upper and lower)	A1	.10433000	.05894981	.296	-.0504742	.2591342
			B1	-.05585750	.05894981	.779	-.2106617	.0989467
			B2	-.05314707	.05824380	.798	-.2060973	.0998032
Triceps Maximum	Tukey HSD	A1 (control)	B1	-.26311950*	.09057628	.024	-.5009759	-.0252631
			B2	-.15413857	.08949150	.319	-.3891463	.0808692
			B3	-.24450100*	.09057628	.042	-.4823574	-.0066446
		B1 (upper)	A1	.26311950*	.09057628	.024	.0252631	.5009759
			B2	.10898093	.08949150	.618	-.1260268	.3439887
			B3	.01861850	.09057628	.997	-.2192379	.2564749
		B2 (lower)	A1	.15413857	.08949150	.319	-.0808692	.3891463
			B1	-.10898093	.08949150	.618	-.3439887	.1260268
			B3	-.09036243	.08949150	.744	-.3253702	.1446453
		B3 (both upper and lower)	A1	.24450100*	.09057628	.042	.0066446	.4823574
			B1	-.01861850	.09057628	.997	-.2564749	.2192379
			B2	.09036243	.08949150	.744	-.1446453	.3253702
* The mean difference is significant at the 0.05 level.								

Post hoc tests were conducted to determine where the differences in electrical activity of the biceps and triceps brachii muscles during the intervention were.

Table 30 shows that the Tukey HSD test indicated a statistically significant difference in the maximum biceps brachii muscle electrical activity across the A1 and B1 groups (p = 0.04) as well as across the A1 and B2 groups (p = 0.041). In the triceps brachii muscle

there was a statistically significant relationship between group A1 and group B1 ($p = 0.024$) and between group A1 and group B3 ($p = 0.042$)

Therefore, the null-hypothesis was rejected for the relationship between A1 and B1 for both the biceps and triceps brachii muscle as well as between groups A1 and B2 muscles for the biceps brachii muscle and between groups A1 and B3 for the triceps brachii muscle because $p < 0.05$. This indicates that there was statistical significance in the electrical activity of both muscles during the intervention for group B1 in relation to group A1, the biceps brachii muscle for group B2 in relation to group A1, and the triceps brachii muscle for group B3 in relation to group A1.

Table 31: Homogenous subsets for the biceps brachii during the intervention period

Biceps				
			Subset for alpha = 0.05	
	Group4	N	1	2
Tukey HSD[a,b]	A1 (control)	20	.0290115	
	B3 (both upper and lower)	20	.1333415	.1333415
	B2 (lower)	21		.1864886
	B1 (upper)	20		.1891990
	Sig.		.291	.776
Duncan[a,b]	A1 (control)	20	.0290115	
	B3 (both upper and lower)	20	.1333415	.1333415
	B2 (lower)	21		.1864886
	B1 (upper)	20		.1891990
	Sig.		.079	.374
Means for groups in homogeneous subsets are displayed.				

Table 32: Homogenous subsets for the triceps brachii muscle during the intervention period

Triceps				
			Subset for alpha = 0.05	
	Group4	N	1	2
Tukey HSD[a,b]	A1 (control)	20	.0150500	
	B2 (lower)	21	.1691886	.1691886
	B3 (both upper and lower)	20		.2595510
	B1 (upper)	20		.2781695
	Sig.		.325	.622
Duncan[a,b]	A1 (control)	20	.0150500	
	B2 (lower)	21	.1691886	.1691886
	B3 (both upper and lower)	20		.2595510
	B1 (upper)	20		.2781695
	Sig.		.091	.259
Means for groups in homogeneous subsets are displayed.				

The Tukey HSD test and the Duncan's post-Hoc tests were run. As can be seen from Tables 31 and 32, both tests confirmed that there are significant differences in the electrical activity of the biceps brachii muscle during the intervention between groups A1, B1 and B2. A1 differs from group B1 and group B2. No differences exist between groups A1 and B3; and no significant difference between groups B1, B2 and B3.

When the homogenous subsets were run using the Tukey HSD test and the Duncan's test for the electrical activity of the triceps brachii muscle during the intervention, both tests confirmed that there are significant differences in the electrical activity of the group A1 when compared to groups B1 and B3. No differences exist between groups A1 and B2 or between groups B1, B2 and B3.

The Kruskal Wallis test, which is a nonparametric equivalent of the parametric one-way ANOVA test also gave a significant difference ($p < 0.001$) for the biceps and triceps variable when comparing all 4 groups.

The Mann-Whitney U test, which is the non-parametric equivalent of the independent samples test was also significant ($p < 0.001$) when comparing the maximum electrical activity of the biceps and triceps brachii muscles during the intervention for the control group (A1) and the combined intervention groups (B1, B2, B3).

4.3.2.3.3 Conclusion

4.3.2.3.3.1 Control compared to the combined intervention group

The combined intervention group experienced a statistically significant increase in electrical activity of the biceps ($p < 0.001$) and triceps ($p = 0.004$) brachii muscles during the CSM.

4.3.2.3.3.2 Comparison across the 4 groups

When the four groups were compared, the group that received upper CSM only (B1) had the greatest increase in electrical activity of both the biceps and triceps brachii muscles. Post hoc tests revealed a significant difference between the upper CSM group and the control group for both muscles. For the biceps brachii muscle there was also a statistically significant difference between the control group and the lower CSM (B2). For the triceps brachii muscle there was a statistically significant difference between the group that received both upper and lower CSM (B3) and the control group.

4.3.2.4 Overall conclusion of electrical activity

4.3.2.4.1 Control compared to the combined intervention group

The combined intervention group experienced a statistically significant increase in electrical activity of both the biceps and the triceps brachii muscle during the CSM. During the tests that followed, this group had an increase in electrical activity during the rest period and a decrease in electrical activity during the active movement. The control group had the opposite presentation: a decrease in electrical activity of both muscles during the rest period and an increase in electrical activity of both muscles during the active movement.

4.3.2.4.2 Comparison between the 4 groups

When the four groups were compared, the group that received upper CSM only showed the greatest increase in electrical activity of both muscles for the intervention period as well as for the rest period following. The group that received lower CSM only, showed the greatest decrease in electrical activity during the active movement.

The only readings that were statistically significant were those obtained during the intervention period. The group that received upper CSM only also had a statistically significant increase in electrical activity for a 10% level of significance.

4.3.3 Objective 3: To determine the effect of CSM on static and dynamic balance

Test 1 and 2 tested static balance whereas test 3 and 4 tested dynamic balance.

Only the static (test 2) and dynamic (test 4) tests performed with the eyes closed will be commented on as these tests eliminated the visual component of balance. The visual system and somatosensory (nervous system) are thus assessed. The individual kept their head and neck as still as possible to minimise the dependence on the nervous system for balance.

The smaller the sway index value, the better the participant’s balance. The post-intervention sway index values were subtracted from the pre-intervention sway index values to calculate the mean change in sway index. Therefore, a negative value indicated that balance had worsened, and a positive value indicated improved balance.

4.3.3.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3)

4.3.3.1.1 Paired T-Test

Table 33: Paired t-test for balance (2 groups)

Paired T-Test										
group	**Test**	**Paired differences**					**t**	**df**	**P-value**	
		Mean	**Std. deviation**	**Std. Error mean**	**95% confidence interval of the difference**					**effect size**
					lower	**Upper**				
A1 (control)	Test 1: static, eyes open	.00950	.04817	.01077	-.01305	.03205	.882	19	.389	.1972
	Test 2: static, eyes closed	-.02900	.14509	.03244	-.09690	.03890	-.894	19	.383	.1999
	Test 3: dynamic, eyes open	.06250	.09947	.02224	.01595	.10905	2.810	19	.011	.6283
	Test 4: dynamic, eyes closed	.08850	.29617	.06623	-.05011	.22711	1.336	19	.197	.2987
B's (combined intervention)	Test 1: static, eyes open	.01033	.07789	.00997	-.00962	.03028	1.036	60	.305	.1337
	Test 2: static, eyes closed	-.01557	.25671	.03287	-.08132	.05017	-.474	60	.637	.0612
	Test 3: dynamic, eyes open	.04623	.12115	.01551	.01520	.07726	2.980	60	.004	.3847
	Test 4: dynamic, eyes closed	.10639	.32061	.04105	.02428	.18851	2.592	60	.012	.3346

Table 33 shows that the combined intervention group showed a statistically significant improvement in dynamic balance ($p = 0.012$). The control group also improved in dynamic balance, but this was not statistically significant as $p > 0.05$ ($p = 0.197$). Both the control and the combined intervention group worsened in static balance. The control group had a p-value = 0.383 and the combined intervention group had a p-value = 0.637 for static balance. The null hypothesis was rejected for dynamic balance in the combined intervention group. The combined intervention group had the greatest effect size in dynamic balance (0.3346).

4.3.3.1.2 Independent t-test

Table 34: Group statistics for balance (2 groups)

Group Statistics					
	Group2	N	Mean	Std. Deviation	Std. Error Mean
Test 1 (static, eyes open)	A1 (control)	20	.00950000	.048174573	.010772162
	B's (combined intervention)	61	.01032787	.077888108	.009972550
Test 2 (static, eyes closed)	A1 (control)	20	-.02900000	.145091623	.032443473
	B's (combined intervention)	61	-.01557377	.256713359	.032868778
Test 3 (dynamic, eyes open)	A1 (control)	20	.06250000	.099465678	.022241202
	B's (combined intervention)	61	.04622951	.121149549	.015511610
Test 4 (dynamic, eyes closed)	A1 (control)	20	.08850000	.296173402	.066226386
	B's (combined intervention)	61	.10639344	.320608966	.041049772

Table 35: Independent t-test for balance

Independent T-Test								
	Levene's Test for Equality of Variances		t-test for Equality of Means					
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Effect size
Test 1 (static eyes open)	3.330	.072	-.045	79	.964	-.000827869	.018519370	.0116
Test 2 (static eyes closed)	1.150	.287	-.222	79	.825	-.013426230	.060491938	.0572
Test 3 (dynamic eyes open)	.003	.956	.543	79	.589	.016270492	.029968031	.1399
Difference for test 4 (dynamic eyes closed)	.005	.945	-.221	79	.826	-.017893443	.081141408	.0570

Tables 34 and 35 show that there was no statistically significant difference between the control group and the intervention group combined for static or dynamic balance as the p-value was greater than 0.05 (static balance = 0,825; dynamic balance = 0,826). (The equal variance case was used between the control and the combined intervention group.)

4.3.3.2 Comparison across all 4 groups (A1, B1, B2, B3)

4.3.3.2.1 Paired t-test

Table 36: Paired t-test for balance (4 groups)

Paired T-Test										
group	**Test**	**Paired differences**					**t**	**df**	**P-value**	
		Mean	**Std. deviation**	**Std. Error mean**	**95% confidence interval of the difference**					**effect**
					lower	**upper**				**size**
A1 (control)	1	.00950	.04817	.01077	-.01305	.03205	.882	19	.389	.1972
	2	-.02900	.14509	.03244	-.09690	.03890	-.894	19	.383	.1999
	3	.06250	.09947	.02224	.01595	.10905	2.810	19	.011	.628
	4	.08850	.29617	.06623	-.05011	.22711	1.336	19	.197	.2987
B1 (upper)	1	-.01050	.08319	.01860	-.04943	.02843	-.564	19	.579	.1261
	2	-.08700	.23508	.05257	-.19702	.02302	-1.655	19	.114	.3701
	3	.05150	.09571	.02140	.00671	.09629	2.406	19	.026	.5380
	4	.16350	.38672	.08647	-.01749	.34449	1.891	19	.074	.4228
B2 (lower)	1	.02095	.06480	.01414	-.00854	.05045	1.482	20	.154	.3234
	2	.03190	.31020	.06769	-.10930	.17311	.471	20	.643	.1028
	3	.07619	.14695	.03207	.00930	.14308	2.376	20	.028	.5184
	4	.14190	.28705	.06264	.01124	.27257	2.265	20	.035	.4942
B3 (upper and lower)	1	.02000	.08448	.01889	-.01954	.05954	1.059	19	.303	.2368
	2	.00600	.20786	.04648	-.09128	.10328	.129	19	.899	.0288
	3	.00950	.10962	.02451	-.04180	.06080	.388	19	.703	.0868
	4	.01200	.27223	.06087	-.11541	.13941	.197	19	.846	.0440

Table 36 shows that for the control group, static balance worsened, and dynamic balance improved. Neither of these changes were of statistical significance. Therefore, the null-hypothesis was not rejected for both static and dynamic balance in the control group.

In the group that received upper CSM only (B1), static balance worsened, and dynamic balance improved. The changes were not statistically significant for a 5% interval, but dynamic balance was significant for a 10% level of significance ($p = 0.074$). Therefore, the null hypothesis was rejected for dynamic balance.

In the group that received lower CSM only (B2), both static and dynamic balance improved. Only dynamic balance improvement was statistically significant ($p = 0.035$). This group also had the greatest effect size for improvement in static (0.1028) and dynamic (0.4942) balance.

In the group that received both upper and lower CSM (B3), both static and dynamic balance improved. Neither of these improvements were of statistical significance.

4.3.3.2.2 ANOVA

An ANOVA test was performed to test whether the means of the change in the balance tests, across the four groups (A1, B1, B2, B3) post-intervention are the same or not.

Table 37: ANOVA for balance

ANOVA						
		Sum of Squares	df	Mean Square	F	P-value
Test 1	Between Groups	.013	3	.004	.840	.476
	Within Groups	.395	77	.005		
	Total	.408	80			
Test 2	Between Groups	.161	3	.054	.987	.403
	Within Groups	4.195	77	.054		
	Total	4.357	80			
Test 3	Between Groups	.050	3	.017	1.265	.292
	Within Groups	1.022	77	.013		
	Total	1.073	80			
Test 4	Between Groups	.275	3	.092	.932	.429
	Within Groups	7.564	77	.098		
	Total	7.839	80			

Table 37 shows that the p-value between the four groups for static balance was 0.403. The p-value between the four groups for dynamic balance was 0.429. Therefore, the null-hypothesis was not rejected for both balance tests because $p > 0.05$. This indicates that there was no statistical significance between the four groups.

4.3.3.3 Conclusion

4.3.3.3.1 Control compared to the combined intervention group

When comparing the control group and the combined intervention group, both demonstrated an improvement in dynamic balance and a decrease in static balance scores. The combined intervention group was the only group that showed statistical significance for the improvement in dynamic balance.

4.3.3.3.2 Comparison between all 4 groups

When the four groups were compared, all groups improved in dynamic balance scores, but only the group that received lower CSM and the group that received both upper and lower CSM improved in static balance. The group that received lower CSM only was the only group that had a statistically significant improvement in dynamic balance for a 5% confidence interval. The group that received upper CSM only had a significant improvement in dynamic balance for a 10% level of significance.

4.3.4 Objective 4: To determine the relationship between elbow joint proprioception, muscular activity and balance

Tables 38 and 39 below show the comparison between the control group and the intervention group combined, as well as between the four groups (A1, B1, B2, and B3). The effect size was used to compare the relationship between JPS, muscular electrical activity and balance. The only time that the mean was used to compare the groups was for the electrical activity of the biceps and triceps brachii muscles during the intervention.

Table 38: Effect sizes of JPS, electrical activity and balance

Effect sizes										
Test	**Group**									
	B's combined		**A1 (control)**		**B1 (upper)**		**B2 (lower)**		**B3 (both upper and lower)**	
	Effect size	**comment**	**Effect size**	**comment**	**Effect size**	**comment**	**Effect size**	**comment**	**Effect size**	**Comment**
JPS (^{o})	0.0725	improved	0.115	improved	0.3153	improved	0.0608	worsened	0.0342	improved
Biceps at rest (Hz)	0.2090	Increased	0.0863	decreased	.4000	increased	.2029	decreased	.2842	increased
Triceps at rest (Hz)	0.1304	increased	0.0671	decreased	.1934	increased	.0050	increased	.1277	increased
Biceps during movement (Hz)	.1305	decreased	.3124	increased	.1507	decreased	.2005	decreased	.0174	increased
Triceps during movement (Hz)	.0328	decreased	.1398	increased	.0143	decreased	.0504	decreased	.0427	decreased
Static balance	.0612	worsened	.1999	worsened	.3701	worsened	.1028	improved	.0288	improved
Dynamic balance	.3346	improved	.2987	improved	.4228	improved	.4942	improved	.0440	improved

Table 39: Electrical activity during the intervention

Electrical activity during the intervention					
Muscle	**Intervention combined**	**control**	**Upper**	**Lower**	**Both**
Biceps	0.1699520	0.0290115	0.1891990	0.1864886	0.1333415
Triceps	0.2345470	0.0150500	0.2781695	0.1691886	0.2595510

There are two main trends noticed in the data, namely a trend in the group that received upper CSM only, and the group that received lower CSM only.

4.3.4.1 Trend 1: Upper CSM only (Group B1)

The group that received upper CSM only (group B1) had the highest electrical activity reading for both the biceps and the triceps brachii muscles during the intervention. This

group also had the greatest electrical activity for both muscles during the rest period and the greatest improvement in elbow JPS (when comparing effect sizes).

4.3.4.2 Trend 2: Lower CSM only (Group B2)

The second trend noted was in the group that received lower CSM only (B2). This group had the highest effect size for the lowered electrical activity of both biceps and triceps brachii muscles during the active movement. This group also had the greatest improvements in both static and dynamic balance.

4.3.4.3 Conclusion

There is a relationship between upper CSM, electrical activity in the biceps and triceps brachii muscles during the intervention and at rest and the JPS of the involved elbow. Upper CSM may cause an increase in electrical activity of muscles during rest, which may improve JPS of the involved joints.

There is a relationship between lower CSM, electrical activity during an active movement and balance. Lower CSM may cause a decrease in electrical activity during an active movement and improve static and dynamic balance.

Chapter 5: Discussion of Results

5.1 Introduction

This chapter involves the discussion of the demographic data and the results obtained from the statistical analyses of the primary data (the sway index from three balance tests, the elbow JPS, and the electrical activity of the biceps and triceps brachii muscles). Each variable is discussed independently in terms of objective or subjective outcomes. Any significant correlations between variables will be discussed at the end of this chapter.

5.2 Demographics

5.2.1 Age

The age was evenly distributed across the four groups and therefore represented the population between the ages of 18-35 years accurately.

5.2.2 Gender

The gender distribution was not uniform across the groups. Therefore, the distribution was not representative of the South African population as per the 2011 census (Statistics South Africa 2011). However, this does not affect the data as the immediate effect of CSM was being investigated independent of the gender of the participants.

5.2.3 Fixations

The levels of the fixations that individuals present with depends largely on their daily activities and posture (Brim 2013). Because a wide variety of individuals were selected, and daily activity or posture was not a criterion for selection, there was no typical fixation distribution that was anticipated.

Table 6 shows that each one of the four subgroups had a different number of fixations present. This is because the number of fixations in each participant was unique to their presentation. The differing number of fixations in each subgroup does not create a bias as the nature of the study is to investigate the immediate neurological effects (JPS, electrical activity and balance) of correcting all cervical spine fixations in the intervention groups and compare the results to a control group who did not have their cervical spine fixations corrected.

5.3 Analysis of the primary data

5.3.1 Objective 1: To determine the effect of CSM on joint position sense of the elbow joint

5.3.1.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3)

5.3.1.1.1 Paired t-test

The JPS for both the control and the combined intervention group improved. However, neither of these improvements were of statistical significance as both demonstrated $p > 0.05$.

The mean improvement in the JPS accuracy of the control group may be due to the patient becoming more familiar with the elbow test position. The same elbow position (40 degrees of flexion) was used for both the pre-and post-intervention tests and therefore the participant may have become familiar with that position by the time the second test was performed and therefore the JPS for the control group improved.

The p-value for the intervention group was lower than that of the control group and therefore, improvement in the combined intervention group may be due to the correction of the cervical spinal fixation by CSM, which, according to the proprioceptive insult hypothesis (Coote1978; Lantz 1995; Mootz 2001; Gatterman 2005) and the motor systems degeneration model states that this neural disturbance in the cervical spine could improve elbow JPS (Lewit 1991; Janda 1983; Dvorak 1985; Gatterman 2005).

5.3.1.1.2 Independent t-test

The independent t-test demonstrated that there was no statistical significance between the JPS when the control was compared to the combined intervention group (B1, B2, and B3). This may be because this was a once off intervention, measuring the immediate effects of spinal manipulation. Most of the individuals who partook in this study, had never seen a chiropractor before, and all of them had not received spinal manipulation in the four weeks before the tests. These individuals may have been living with these spinal fixations for some time. A study by Haavik and Murphy (2011) demonstrated that elbow JPS improvements were only statistically significant once the individual had received multiple CSM over a duration of a couple of weeks. Therefore, a longer-term study may be beneficial to investigate the change in elbow JPS following multiple CSM over a course of a couple weeks.

5.3.1.2 Comparison across all 4 groups (A1, B1, B2, B3)

5.3.1.2.1 Paired t-test

While there was no statistical significance in the JPS accuracy tests of any of the groups, it is interesting to note that B1 demonstrated the lowest p-value and the greatest effect size (0.3153). Therefore, the upper CSM group had the greatest improvement in elbow JPS. This may be due to the anatomical link that exists between the medulla oblongata and the upper cervical spine (Cagnie et al. 2005; Syndicated 2013; Bailey 2017: 1; Chaves et al. 2018). The medulla plays an important role in motor learning and is the site of decussation of the cuneate fasciculus of the posterior columnar-medial lemniscus tract which relays proprioceptive information from the upper limb to the cerebral cortex (Bailey 2017: 1; Chaves et al. 2018). It also transmits the ascending spinocerebellar tract which relays information regarding JPS to the cerebellum. Many descending motor spinal tracts carrying impulses regarding isolated movement of the elbow joint also pass through the medulla into the spinal cord, such as the anterior corticospinal tract, the medial rubrospinal tract and the reticulospinal tract (Bailey 2017: 1; Chaves et al. 2018). It has been proposed that upper CSM can have an effect on the medulla oblongata and even the cerebellum (Cagnie et al. 2005; Syndicated 2013) Therefore, upper CSM may have had an effect on the tracts of the medulla oblongata as per the proprioceptive insult hypothesis and therefore, vertical integration of the motor systems degeneration hypothesis theory may explain why the upper CSM group demonstrated the greatest improvement in JPS (Gatterman 2005).

In the lower CSM group, JPS worsened. Due to the neuroanatomical link between the cervical spine and the elbow joint via the brachial plexus, it may have been expected that this group improved in JPS, however it appears that improvements in JPS are more notable when the processing centres of proprioception and JPS, namely the medulla, is influenced, rather than the neural tracts on the cervical spine in the region of the nerve roots that are neuroanatomically linked to a joint (Gatterman 2005; Cagnie et al. 2005; Syndicated 2013).

Due to the nature of the lower CSM technique, in general, more gross cervical spine rotation and lateral flexion is induced, to lock up these lower joints, when compared to upper CSM techniques (Gatterman 2005). This may play a role in negatively affecting the JPS in the elbow, as head and neck position are directly related to the vestibular system, proprioception and JPS of the upper limb as demonstrated by Knox and Hodges (2005) and Barker (2011).

5.3.1.2.2 ANOVA

ANOVA tests demonstrated that there was no statistical significance between group A1, B1, B2 and B3, as the p-value was greater than 0.05 ($p = 0.784$).

5.3.1.3 Conclusion

5.3.1.3.1.1 Control compared to the combined intervention group

There is no statistically significant improvement in elbow JPS immediately following CSM. The improvements that did occur may have been due to the neurological effects of the CSM on the spinal tracts as per the proprioceptive insult hypothesis and the motor systems degeneration model (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005). However, further investigation is recommended to verify this.

5.3.1.3.1.2 Comparison of the four groups

The upper CSM group had the greatest improvement in elbow JPS. This could be due to the effect that upper CSM has on the medulla (Gatterman 2005; Cagnie et al. 2005; Syndicated 2013; Bailey 2017: 1; Chaves et al. 2018). The group that received lower CSM only was the only group whose JPS worsened. This was probably due to the nature of the lower CSM requiring more neck rotation and lateral flexion to lock up the joints and therefore more head displacement, as there is a link between neck position and inaccurate elbow JPS (Gatterman 2005).

Although none of the results were of statistical significance, the p-value of the upper CSM group was remarkably lower and the effect size was remarkably higher than the other groups. Therefore, further testing is recommended.

5.3.2 Objective 2: To determine the effect of CSM on muscular activity of the triceps brachii and biceps brachii muscles

5.3.2.1 Rest Period

5.3.2.1.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3)

5.3.2.1.1.1 Paired t-test

Both triceps and biceps brachii muscles experienced an increase in electrical activity in the combined intervention group (B1, B2, and B3) and a mean decrease in electrical

activity in the control group. While there was no statistical significance between the control and combined intervention group, as all p-values > 0.05, the combined intervention group had remarkably lower p-values and a remarkably higher effect size for both muscles than the control group had.

This suggests that CSM may increase the electrical activity of the biceps and triceps brachii muscles for a state of rest immediately post-CSM. This supports the literature that states that the neurophysiological effects of spinal manipulation on muscles is excitatory (Herzog et al. 1999; Suter et al. 1999; Keller and Colloca 2000; Symons et al. 2000; Suter et al. 2000; Colloca and Keller 2001; Dishman et al. 2000 Suter and McMorland 2002; Dunning and Rushton 2009) This increase in electrical activity post-CSM is most likely due to the effect of the adjustment on the descending motor tracts in the cervical spine, namely the anterior corticospinal tract, the rubrospinal tract and the reticulospinal tract, which are all involved in the regulation on muscle tone or movement of the biceps and triceps brachii muscles as described by the proprioceptive insult hypothesis and the motor systems degeneration model (Kandel et al. 1991; Derrickson and Tortora 2011; Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005). It is possible that a fixation resulted in a decreased electrical activity of biceps and triceps brachii muscles and therefore correction of this fixation resulted in an immediate increase in the electrical activity (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005).

The compressive force that was exerted by the goniometer strap may have influenced the results and its effect needs to be considered. The strap also resulted in sub-optimal placement of the triceps brachii electrodes as the goniometer strap made it difficult to place the electrodes superficial to the triceps brachii muscle belly. The electrodes would have therefore been less sensitive to changes in the electrical activity of the triceps brachii muscle. Further research, conducted with better electrode placement and removal of the goniometer strap, would be advisable. This may produce clearer results and is identified as a limitation of this study.

5.3.2.1.1.2 Independent t-test

There was no statistically significant difference between the combined intervention group and the control group for biceps or triceps brachii muscles during the rest period. Better electrode placement may show a statistically significant difference in the trends discussed in the section above.

The p-value was lower for the biceps brachii muscle than it was for the triceps brachii muscle, indicating a greater difference between the two groups for the biceps brachii.

This may be due to the sub-optimal placement of the electrodes due to the goniometer strap as previously mentioned. Therefore, changes in electrical activity in the biceps brachii muscle would have been more easily detected than in the triceps brachii muscle.

5.3.2.1.2 Comparison across all 4 groups (A1, B1, B2, B3)

5.3.2.1.2.1 Paired t-test

Both groups that received upper CSM (B1 and B3) showed an increase in electrical activity of both muscles, whereas the group that had lower CSM only (B2) did not have a uniform presentation as the biceps brachii muscle had a decrease in electrical activity and the triceps had an increase in electrical activity. The group that received upper CSM only (B1) had the greatest increase in both biceps and triceps brachii electrical activity at rest. The biceps increase was significant for a 10% level of significance.

The main ascending tracts involved in relaying information regarding electrical activity from the biceps and triceps brachii muscles to the brain, is the cuneate gracile and the spinocerebellar tracts. The main descending tracts relaying electrical activity information from these muscles are the anterior corticospinal tract, rubrospinal tract, vestibulospinal tract, and the reticulospinal tract (Kandel et al. 1991; Derrickson and Tortora 2011). The cervical spine transmits all of these tracts. The medulla is also a site of decussation for the cuneate gracile and is the origin of the reticulospinal tract (Bailey 2017: 1; Chaves et al. 2018).

The biggest increase in electrical activity which was seen following upper CSM may be due to the stimulation of the medulla oblongata, as per the proprioceptive insult hypothesis and the motor systems degeneration model as discussed previously (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005). The upper CSM removes the blockage in the medullary – a vital centre for transmission of signals regarding muscle electrical activity (Bailey 2017: 1; Chaves et al. 2018).

While the lower cervical spine transmits all of the tracts mentioned above, it may be that the further away from the medulla oblongata the CSM is delivered, the less of an effect it has on medulla and therefore on electrical activity. This may explain why there is conflicting evidence regarding whether the neurophysiological response that occurs post spinal manipulation is excitatory (Herzog et al. 1999; Suter et al. 1999; Keller and Colloca 2000; Symons et al. 2000; Suter et al. 2000; Colloca and Keller 2001; Dishman et al. 2002; Suter and McMorland 2002; Dunning and Rushton 2009) or inhibitory (Dishman and Bulbulian 2000; Lehman and McGill 2001; Lehman et al. 2001; DeVocht et al. 2005; Dunning and Rushton 2009) in nature.

5.3.2.1.2.2 ANOVA

There was no statistical significance between the four groups for the biceps and triceps brachii muscle as the p-value was greater than 0.05. The reason for the biceps brachii muscle (p-value = 0.225) having a much lower p-value than the triceps brachii muscle (p-value = 0.768) may be due to the sub-optimal placement of the electrodes superficial to the triceps brachii muscle as previously discussed.

5.3.2.1.3 Conclusion

5.3.2.1.3.1 Control group compared to the intervention groups combined

During the rest period the combined intervention group had an increase in electrical activity, whereas the control group had a decrease of the biceps and triceps brachii muscle. Although the p-values were not statistically significant, this demonstrates a trend that CSM may have an excitatory effect on the electrical activity of these two muscles at rest (Herzog et al. 1999; Suter et al. 1999; Keller and Colloca 2000; Symons et al. 2000; Suter et al. 2000; Colloca and Keller 2001; Dishman et al. 2000 Suter and McMorland 2002; Dunning and Rushton 2009).

5.3.2.1.3.2 Comparison across all four groups

When the four groups were compared, it was noted that the group that received upper CSM only had the greatest increase in electrical activity for both muscles, when compared to all four groups. The biceps increase was significant for a 10% level of significance. The group that received lower CSM only had a decreased in biceps brachii and an increase in triceps brachii muscle electrical activity. Therefore, it appears that upper CSM tends to have an excitatory effect of muscle electrical activity, whereas the effects of lower CSM seems to be inconsistent. This is most likely due to the effect that upper cervical spine manipulation has on the medulla oblongata as an important centre involved in transmission of nervous impulses that regulate muscle electrical activity and movement (Gatterman 2005; Cagnie et al. 2005; Syndicated 2013; Bailey 2017: 1; Chaves et al. 2018).

5.3.2.2 Active period

5.3.2.2.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3).

5.3.2.2.1.1 Paired t-test

The electrical activity of both biceps and triceps brachii muscles increased in the control group (A1) and decreased in the combined intervention group (B1, B2, B3). Although, none of the changes were of statistical significance. An interesting trend was observed as CSM appears to cause a decrease in electrical activity during an active movement.

This is in contrast to the effects seen during the rest period where the combined intervention group experienced an increase in electrical activity and the control group experienced a decrease in electrical activity. A certain amount of resting muscle tone is necessary in order for a contraction to occur (CNS Clinic-Jordan 2016). If the muscle tone is too low, the contraction takes long to occur as the muscle requires time to take up the slack. Therefore, because the muscles of the CSM group already experienced an increase in electrical activity and therefore greater tone in the rest period, when the muscles were contracted to allow movement there was less slack that needed to be taken up and therefore less electrical activity required in the muscles of the intervention group during the active movement (CNS Clinic-Jordan 2016).

Research has shown that a decreased amplitude of muscle activity during movement may demonstrate more skilled control of movement and muscle recruitment (Osu et al. 2004; Chapman et al. 2008) Therefore the decrease in electrical activity post-CSM may indicate an improvement in muscle efficiency (Chapman et al. 2008).

5.3.2.2.1.2 Independent t-test

There was no statistical significance in the difference between the control and the combined intervention group for electrical activity of the biceps and triceps brachii electrical activity during the active movement. However, it is important to note that the biceps brachii muscle had a lower p-value ($p = 0.124$) than the triceps brachii muscle ($p = 0.581$) had. This may be due to the placement of the triceps brachii electrodes as discussed above.

5.3.2.2.2 Comparison across all 4 groups (A1, B1, B2, B3)

5.3.2.2.2.1 Paired t-test

There is no statistical significance between the four groups. The control group experienced an increase in the electrical activity for both muscles during the active movement. The group that received upper CSM only as well as the group that received lower CSM only experienced a decrease in the electrical activity. However, the group that received both upper and lower CSM experienced an increase in the electrical activity of biceps brachii and a decrease in electrical activity of triceps brachii. These findings correspond with the bulk of literature that states that there is conflicting evidence regarding whether the neurophysiological response that occurs post spinal manipulation is excitatory (Herzog et al. 1999; Suter et al. 1999; Keller and Colloca 2000; Symons et al. 2000; Suter et al. 2000; Colloca and Keller 2001; Dishman et al. 2000; Suter and McMorland 2002; Dunning and Rushton 2009) or inhibitory (Dishman and Bulbulian 2000; Lehman and McGill 2001; Lehman et al. 2001; DeVocht et al. 2005; Dunning and Rushton 2009) in nature.

The group that received lower CSM only had the greatest effect size for decrease in electrical activity for both muscles during the active movement. This may be due to the techniques used for lower CSM as it induced more head and neck rotation and lateral flexion (Gatterman 2005) and therefore may have had a greater effect on the cervical spinal tracts overall, specifically those tracts relaying information regarding muscle tone and movement i.e. the spinocerebellar tract, the anterior corticospinal tract, the rubrospinal tract, the vestibulospinal tract and the reticulospinal tract (Kandel et al. 1991; Derrickson and Tortora 2011).

5.3.2.2.2.2 ANOVA

There was no statistical significance between the four groups for the biceps brachii and triceps brachii electrical activity during the active movement. The biceps brachii had a p-value that was much lower than the triceps brachii muscle. This was most probably due to the sub-optimal placement of the triceps brachii electrodes.

5.3.2.2.3 Conclusion

5.3.2.2.3.1 Control group compared to the intervention groups combined

The control group experienced an increase in electrical activity and the intervention group experienced a decrease in electrical activity during the period of active movement. This was opposite to what occurred during the rest period. This decrease in

electrical activity during an active movement may be indicative of improved muscle efficiency post CSM (CNS Clinic-Jordan 2016).

5.3.2.2.3.2 Comparison across all four groups

When the four groups were compared, there was no trends seen in the changes. The control group experienced an increase in electrical activity of both muscles as discussed above. The group that received upper CSM only and the group that received lower CSM only experienced decreased electrical activity in both muscles. The group that received both upper and lower CSM however, experienced an increase in the electrical activity of the biceps brachii muscle and a decrease in the triceps brachii muscle. This inconsistency supports the bulk of research that concludes that it is unclear whether the effects of CSM on muscles is excitatory (Herzog et al. 1999; Suter et al. 1999; Keller and Colloca 2000; Symons et al. 2000; Suter et al. 2000; Colloca and Keller 2001; Dishman et al. 2000 Suter and McMorland 2002; Dunning and Rushton 2009) or inhibitory (Dishman and Bulbulian 2000; Lehman and McGill 2001; DeVocht et al. 2005; Dunning and Rushton 2009). The greatest effect size was seen in the group that received lower CSM only. This may be due to the technique used to manipulate the lower joints, as the neck was moved more (Bergman and Peterson 2011) and therefore the spinal tracts involved in muscle electrical activity may be been excited more.

5.3.2.3 Intervention period

5.3.2.3.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3).

5.3.2.3.1.1 Independent t-test

The electrical activity of both the biceps brachii and triceps brachii readings in the intervention group, increased significantly ($p < 0.001$ for biceps brachii and $p = 0.004$ for triceps brachii). This increase or spike noticed during the CSM was most likely due to the bombardment theory which states that during a spinal manipulation, there is depolarisation of the motor neuron pools at the level that the manipulation in delivered (Beck 2011; Crossman and Neary 2014). As a result, these receptors are excited and there is an afferent bombardment of the spinal nerve roots and dorsal root ganglions. Therefore, there is an excitatory effect of the spinal tracts which can result in a spike of nervous impulses sent along these tracts (Beck 2011; Crossman and Neary 2014). As per the motor systems degeneration hypothesis theory, these neural changes can affect any of the related vertical or horizontal systems. Due to the vertical relationship of the

cervical spine and the brachial plexus, this surge of neural stimulation was detected in the biceps and triceps brachii muscles (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005).

5.3.2.3.2 Comparison across all 4 groups (A1, B1, B2, B3)

5.3.2.3.2.1 ANOVA

When comparing the electrical activity during the intervention period across the 4 groups (A1, B1, B2 and B3), there was statistical significance. In both muscles, group B1 had the highest electrical activity during the intervention period, suggesting that upper CSM has the greatest effect on increasing the electrical activity in biceps and triceps brachii muscles. This was probably due to effects of upper CSM on the medulla oblongata (Cagnie et al 2005; Syndicated 2013) in line with the proprioceptive insult hypothesis and the motor systems degeneration model (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005).

5.3.2.3.2.2 Post hoc tests

Groups B1 and B2 were significantly higher than A1 readings for the biceps brachii muscle and B1 and B3 being significantly higher than A1 for the triceps muscle. The common group for both biceps and triceps brachii significance was group B1 (upper CSM). Therefore, upper CSM produces the greatest spike in electrical activity for both biceps and triceps brachii muscles. The reason for this was most likely due to anatomical link of the upper cervical spine and the medulla (Gatterman 2005; Cagnie et al 2005; Syndicated 2013; Bailey 2017: 1; Chaves et al. 2018)

5.3.2.3.3 Conclusion

5.3.2.3.3.1 Control compared to the combined intervention group

CSM at any level causes a statistically significant increase in the electrical activity of both biceps and triceps brachii muscles at the instant that the manipulation is delivered. This could be explained by the bombardment theory and the motor systems degeneration theory which do not occur in isolation but can feed into one another (Gatterman 2005; Beck 2011; Crossman and Neary 2014).

5.3.2.3.3.2 Comparison across the 4 groups

Upper CSM causes the greatest increase in electrical activity of these muscles. This is most likely due to the anatomical link between the upper cervical spine and the medulla oblongata (Cagnie et al. 2005; Syndicated 2013; Bailey 2017: 1; Chaves et al. 2018).

5.3.2.4 Overall conclusion of electrical activity

5.3.2.4.1 Comparison between the control and the intervention groups combined

The combined intervention group experienced a statistically significant increase in electrical activity in the biceps and triceps brachii muscle at the instant that the CSM was delivered. During the rest period, the electrical activity in both muscles increased and the during the active period the electrical activity decreased in both muscles post intervention. Although the results seen in both groups for the rest and active period are not statistically significant, they are clinically important trends as it demonstrates that CSM has an excitatory effect on the biceps and triceps muscles at rest and an inhibitory effect on both muscles during an active movement. This may be indicative of improved muscle efficiency and may be due to the removal of proprioceptive disturbance in the cervical tracts as per the proprioceptive insult hypothesis and the motor systems degeneration model (Gatterman 2005; Haavik and Murphy 2007, 2011; Beck 2011; Crossman and Neary 2014). This improvement in muscle efficiency may therefore explain why there is conflicting evidence regarding whether the neurophysiological response that occurs in muscles post spinal manipulation is excitatory (Herzog et al. 1999; Suter et al. 1999; Keller and Colloca 2000; Symons et al. 2000; Suter et al. 2000; Colloca and Keller 2001; Dishman et al. 2000 Suter and McMorland 2002; Dunning and Rushton 2009) or inhibitory (Dishman and Bulbulian 2000; Lehman and McGill 2001; DeVocht et al. 2005; Dunning and Rushton 2009) in nature.

5.3.2.4.2 Comparison between the four groups

Upper CSM has the greatest effect on the electrical activity of biceps and triceps brachii muscles during the intervention and during the rest period following the intervention. The effects were excitatory on both muscles for both the intervention and rest period. The increase in biceps brachii electrical activity for the group that received upper CSM only was statistically significant for a 10% interval. This excitatory effect of upper CSM may be due to the effects of upper CSM on the medulla oblongata (Cagnie et al 2005; Syndicated 2013). The group that received lower CSM only had the greatest effect size

of the three intervention groups for decrease in electrical activity during the active period, which may be indicative of improved muscle efficiency (CNS Clinic-Jordan 2016).

5.3.3 Objective 3: To determine the effect of CSM on static and dynamic balance

5.3.3.1 Control group (A1) compared to the intervention groups combined (B1, B2, B3)

5.3.3.1.1 Paired t-test

Both the control and the combined intervention groups worsened for static balance and improved in dynamic balance. The only statistically significant change was for the improvement in dynamic balance in the combined intervention group. This improvement may be due to the corrections of the fixations in the cervical spine and the effect that that has on modulation of proprioception in the involved spinal tracts as per the proprioceptive insult hypothesis and the motor systems degeneration model (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005). These results support the conclusions in studies conducted by Holt (2014) and Nolan (2010) who stated that CSM improves balance.

5.3.3.1.2 Independent T-Test

The independent samples test demonstrated that there was no statistical significance between the control and the combined intervention group for static or dynamic balance.

5.3.3.2 Comparison across all 4 groups (A1, B1, B2, B3)

5.3.3.2.1 Paired t-test

The group that received lower CSM only demonstrated the greatest improvement in both static balance and dynamic balance, with dynamic balance improvements having statistical significance for a 5% interval. The group that received upper CSM only had an improvement in dynamic balance that was statistically significant for a 10% confidence interval. However, the upper CSM only group worsened in static balance. The group that received both upper and lower CSM improved in both static and dynamic balance, but neither were of statistical significance. Therefore, CSM at any level of the cervical spine may improve dynamic balance, but only lower CSM may improve static balance. The overall improvement that was seen in the lower CSM only group may be because of the technique of the lower CSM. In order to lock up a lower cervical spine joint for

manipulation, more rotation and lateral flexion is needed than would be required to lock up an upper cervical joint (Gatterman 2005). Therefore, there is more gross movement in head and neck position in individuals receiving lower CSM, which could result in a more global excitation of the cervical tracts involved in balance (the gracile fasciculus of the posterior columnar-medial lemniscus tract, spinocerebellar tract, corticospinal tract, the medial rubrospinal tract, the vestibulospinal tract and the reticulospinal tract) (Kandel et al. 1991; Derrickson and Tortora 2011)) as per the proprioceptive insult hypothesis (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005). This greater head movement may also excite the vestibular system more than an upper CSM would (Derrickson and Tortora 2011). Which according to the motor systems degeneration model, would have a global effect on all neurology concerning balance (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005).

5.3.3.2.2 ANOVA

There was no statistical significance between the four groups, in the immediate change of sway index for both static and dynamic balance.

5.3.3.3 Conclusion

5.3.3.3.1 Comparison between the control and the combined intervention groups

CSM at any level may improve dynamic balance due to excitation of the cervical tracts involved in balance as per the proprioceptive insult hypothesis and the motor systems degeneration model (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005).

5.3.3.3.2 Comparison between the four groups

Lower CSM may have an immediate effect on improving dynamic balance. This may be due to the technique used to deliver the lower CSM having a greater effect on the cervical tracts more as per the proprioceptive insult hypothesis; and a greater effect on the vestibular system which would cause a greater global effect on balance neurology as per the motor system degeneration model (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005).

5.3.4 Objective 4: To determine the relationship between elbow joint proprioception, muscular activity and balance

5.3.4.1 Trend 1: Upper CSM only (Group B1)

The trend indicates that there is a relationship between the electrical activity in both muscles during the intervention, the electrical activity in the muscles during the rest period and the accuracy of the JPS. A higher electrical activity reading in the biceps and triceps brachii muscles during the intervention and the rest period, the better the JPS accuracy of the elbow. This has the greatest effect when upper CSM is delivered to the individual.

This trend may be explained by the relationship that exists between the spinothalamic tract (anterolateral tract) and the dorsal column-medial lemniscus system (DCML) (Bisley 2018). The DCML tract carries afferent information from the body to the cerebral cortex for processing (Waugh, Grant and Ross 2010; Derrickson and Tortora 2011). The cuneate fasciculus transports proprioceptive information regarding elbow JPS and the muscles involved in elbow movement, including the biceps and triceps brachii muscles, up the spinal cord and into the caudal medulla oblongata where the tract decussates (Raff et al. 2008). This may explain why the group that received upper CSM responded the best to JPS improvement as the medulla may have been rid of mechanical irritation and therefore proprioceptive insult would have been corrected post manipulation (Coote 1978; Janda 1983; Lewit 1991; Kandel et al. 1991; Lantz 1995; Mootz 2001; Gatterman 2005 Derrickson and Tortora 2011).

5.3.4.2 Trend 2: Lower CSM only (Group B2)

During the active period, the combined intervention group had a mean decrease in electrical activity of both biceps and triceps brachii muscles and the control group experienced a mean increase in electrical activity of both biceps and triceps brachii muscles.

The intervention group that demonstrated the highest effect size for the decrease in electrical activity of both biceps and triceps brachii during the active movement was the group that received lower CSM only (group B2). This group also had the greatest improvements in both static and dynamic balance when considering effect size. It was also the only group that demonstrated statistical significance for the improvements in dynamic balance for a 5% level of significance. Therefore, there appears to be a relationship between lower CSM, lowered electrical activity of the biceps and triceps brachii muscles during an active movement and improved static and dynamic balance.

This trend is most likely due to the technique used to manipulate the lower cervical spine having the greatest effect on the cervical spine overall as discussed under Objective 3. The lowered electrical activity during the active period may show improved muscle efficiency as discussed under Objective 2 (Osu et al. 2004; Chapman et al. 2008). Therefore, there appears to be a relationship between muscle efficiency and balance. Lower CSM may improve muscle efficiency and static and dynamic balance (Coote 1978; Janda 1983; Lewit 1991; Lantz 1995; Mootz 2001; Gatterman 2005).

5.3.4.3 Conclusion

The first trend noted that upper CSM may increase the electrical activity of the biceps and triceps brachii muscles during the intervention and for a rest period following the intervention, as well as improve elbow JPS. Therefore, there exists a relationship between upper CSM, augmented electrical activity of the biceps and triceps brachii muscles during intervention and a rest period following, and improved JPS of the elbow joint. This may be due to the effects of upper CSM on the medulla oblongata (Cagnie et al 2005; Syndicated 2013).

The second trend identified was that there is a link between lower CSM, decrease in electrical activity of the biceps and triceps brachii muscle during active movement, and an improvement in static and dynamic balance. This may be due to the nature of the lower CSM stimulating the cervical spine overall (Bergman and Peterson 2011).

Chapter 6: Conclusions, Recommendations and Limitations

6.1 Conclusions

For objective 1 it was concluded that there was no statistically significant improvement in JPS following CSM as a once off intervention. Although the combined intervention group demonstrated a lower p-value, further testing is needed to confirm whether the improvements in JPS were because of the CSM or because the patient had become familiar with the elbow position in the test. Of the four groups, the greatest improvement in JPS was noted in the upper CSM group which may be due the effects of upper CSM on the medulla.

For objective 2 it was concluded that CSM delivered to any level of the cervical spine causes a significant increase in electrical activity of the biceps and triceps brachii muscles during the manipulation. The electrical activity is also increased for a rest period following the manipulation, but during the active movement there is a decrease in electrical activity when compared to the pre-intervention electrical activity. This may indicate improvement in muscle efficiency. Upper CSM has the greatest effect on the electrical activity increase noted during the manipulation and during the rest period immediately following. This may be due to the effect of the upper cervical spine on the medulla oblongata. Lower CSM has the greatest effect on decreasing the electrical activity during the active movement. This may be due to the technique used to manipulate the lower cervical spine as it may have a greater stimulatory effect on the cervical spinal tracts overall.

For objective 3 it was concluded that CSM significantly improves dynamic balance. There were statistically significant improvements in dynamic balance following lower CSM. Lower CSM also resulted in the greatest effect in improving static balance. This may be due to the overall cervical stimulation during lower CSM technique as discussed above, and especially stimulation of the cervical tracts involved in balance neurology, namely the gracile fasciculus of the posterior columnar-medial lemniscus tract, spinocerebellar tract, corticospinal tract, the medial rubrospinal tract, the vestibulospinal tract and the reticulospinal tract.

Two trends were identified with regards to Objective 4. Firstly, there was a relationship between increased electrical activity of the biceps and triceps muscles during the manipulation and at rest, and between improved JPS of the elbow joint. Upper CSM had

the greatest effect on this relationship. The second trend noted was a relationship between decreased electrical activity in the biceps and triceps muscles during the active movement and improved static and dynamic balance. Lower CSM had the greatest effect on this relationship.

6.2 Clinical relevance

Due to the findings of this study, clinicians may consider CSM as a means of improving patients' muscle efficiency and balance. Although the improvements in JPS were not statistically significant after one appointment, the effects of CSM in improving elbow JPS should not be ruled out, as Heidi Haavik's study showed that improvements in elbow JPS may only be noted after multiple adjustments over a period of time (Haavik and Murphy 2011).

6.3 Limitations

- The straps securing the goniometer to the lateral aspect of the elbow joint applied a compressive force over the biceps and triceps brachii muscles which may have interfered with the electrical activity of the muscles. This compressive force may have also interfered with elbow JPS. The spinothalamic tract (anterolateral tract) and the DCML system have established interaction in the regulation of pain perception, for instance, in rubbing of an injury to decrease pain (Bisley 2018). Therefore, if excitation of one sensory stimulation (crude touch in rubbing) can hinder another sensory stimulation (pain), and there is interaction between the two tracts, then the excitation of the spinothalamic tract in the form of a compressive force being applied to skin, such as in the case of the goniometer strap being attached to the forearm, could possibly override the proprioceptive information transmitted along the DCML tract and result in lowered elbow JPS scores.

Further testing in the absence of a goniometer strap, may render statistical significance for the readings at rest and for the JPS improvement. Future studies should be conducted to investigate the effects of cervical spine manipulation on the electrical activity of biceps and triceps brachii muscles in the absence of any attached devices.

- The electrode placement over the triceps brachii muscles could be improved by ensuring that the electrodes are placed over the bulk of the muscle belly, rather than close to the musculotendinous junction. In this study, the electrode placement was a challenge due to the goniometer straps as mentioned above.

- A larger sample group would increase the validity of the study and minimise the possibility of incorrectly accepting the null hypothesis.

6.4 Recommendations

To improve the statistical significance, the following recommendations can be made:

- This study was conducted using participants that were asymptomatic for neck pain, Future studies could be done on participants who present with neck pain in the presence of cervical spine fixations, to investigate the effect that neck pain has on elbow JPS, electrical activity of the biceps and triceps brachii muscles and balance.
- This study investigated the immediate effects of CSM. A prospective study investigating the long-term effects of CSM on elbow JPS, electrical activity of the biceps and triceps brachii muscles and balance, over a period of time where the participants receive regular CSM would be more beneficial in an effort to study the neuroplasticity of CSM.
- Questionnaires could be designed and incorporated into the study to give it more strength in terms of subjective data.

References

Adachi, N., Ochi, M., Uchio, Y., Iwasa, J., Ishikawa, M. and Shinomiya, R. 2007. Temporal change of joint position sense after posterior cruciate ligament reconstruction using multi-stranded hamstring tendons*. Knee Surgery, Sports Traumatology, Arthroscopy,* 15(1): 2-8.

Allison, G. T. 2003. Trunk muscle onset detection technique for EMG signals with ECG artefact. *Journal of Electromyography and Kinesiology*, 13: 209-16.

Anon. 2018. *Golgi Tendon Organ* (image). Available: https://www.bing.com/images/search?view=detailV2&ccid=cP6nNBEn&id=39819C26EC6464D7255FFC09E00EB31EB87977B4&thid=OIP.cP6nNBEnoogzoeCfKnQdhAHaFj&q=tendon+organs&simid=607987970404254119&selectedindex=8&mode=overlay&first=1 (Accessed 29 January 2018).

Arnold, B. L. and Schmitz, R. J. 1998. Examination of balance measures produced by the Biodex Stability System. *Journal of Athletic Training*, 33(4): 323-327.

Bailey, R. 2017. *ThoughtCo. Brainstem: it's function and location.* Available: https://www.thoughtco.com/brainstem-anatomy-373212 (Accessed 25 January 2018).

Barker, I. 2011. Alterations in neck muscle performance and proprioception with fatigue, altered posture and recurrent neck pain. Masters of Health Sciences, University of Ontario Institute of Technology.

Beck, R. W. 2011. *Functional neurology for practitioners of manual medicine.* Edinburgh: Elsevier Health Sciences UK.

Bennell, K., Wee, E., Crossley, K., Stillman, B. and Hodges, P. 2005. Effects of experimentally-induced anterior knee pain on knee joint position sense in healthy individuals. *Journal of Orthopaedic Research*, 23(1): 46-53.

Bergmann, T. F. and Peterson, D. H. 2011. *Chiropractic technique: principles and procedures.* 3rd ed. Edinburgh: Churchill Livingstone.

Bertolasi, L., Priori, A., Tinazzi, M., Bertasi, V. and Rothwell, J. C. 1998. Inhibitory action of forearm flexor muscle afferents on corticospinal outputs to antagonist muscles in humans. *Journal of Physiology*, 511(3): 947-56.

Biodex Medical Systems, Inc: Biosway Portable Balance System Operation Manual #950-460 and #950-461 (online). 2017. Available: http://www.biodex.com/physical-medicine/products/balance/biosway-portable. (Accessed 1 March 2018).

BIOPAC Systems Inc: Goniometers and Torsiometers – MP3X/45 (online). 2018. Available: https://www.biopac.com/product/goniometers-torsiometers-dsub9/. (Accessed 1 March 2018).

Bisley, J. 2018. *Ascending Sensory Pathways* (image). Available: https://www.bing.com/images/search?view=detailV2&ccid=mX93W5DQ&id=B9F4EA8AC057333C0196F373F060F329CA4424BE&thid=OIP.mX93W5DQZWlkUvZ3wAwEjwHaFj&q=tendon+organs&simid=608001173120355506&selectedIndex=16&ajaxhist=0 (Accessed 29 January 2018).

Brasil-Neto, J. P., Valls-Sole, J., Pascual-Leone, A., Amassian, V. E. and Cracco, R. et al. 1993. Rapid modulation of human cortical motor outputs following ischaemic nerve block. *Brain*, 116(3): 511-525.

Brim, J. 2013. *Chiro One Wellness Centre: The Cause of Subluxation: The Three Ts*. Available: https://www.chiroone.net/bewell/the-cause-of-subluxation-the-three-ts (Accessed 4 August 2018).

Byfield, D. 2012. *Technique skills in chiropractic*. Edinburgh: Churchill Livingstone

Chaves, C., Shahid, S. and Zehra, U. 2018. *Kenhub: Brainstem.* Available: https://www.kenhub.com/en/library/anatomy/the-brainstem (Accessed 29 January 2018).

Cagnie, B., Jacobs, F., Barbaix, E., Vinck, E., Dierckx, R. and Cambier, D. 2005.Changes in cerebellar blood flow after manipulation of the cervical spine using Technetium 99m-ethyl cysteinate dimer*. Journal of Manipulative and Physiological Therapeutics*, 28(2): 103-107.

Chapman, A. R., Vincenzino, B., Blanch, P. and Hodges, P. W. 2008. Patterns of leg muscle recruitment vary between novice and highly trained cyclists. *Journal of Electromyography and Kinesiology*, 18(3): 359-371.

Chen, J. L., Penhune, V. B. and Zatorre, R. J. 2009. The role of auditory and premotor cortex in sensorimotor transformations. *Annals of The New York Academy of Sciences*, 1169:15-34.

CNS Clinic-Jordan. 2016. *CNS Clinic: Muscle tone - spinal reflexes.* Available: http://humanneurophysiology.com/muscletone.htm. (Accessed 29 January 2018)

Cohen J.1988. *Statistical power analysis for the behavioral sciences (2nd ed.).* Hillsdale, NJ: Lawrence Earlbaum Associates.

Colloca, C. J. and Keller, T. S. 2001. Stiffness and neuromuscular reflex response of the human spine to posteroanterior manuipulative thrusts in patients with lower back pain. *Journal of Manipulative and Physiological Therapeutics*, 24: 489-500.

Cortinhas, C. and Black, K. 2012. *Statistics for business and economics.* Hoboken, N.J.: Wiley.

Coote, J. H. 1978. Somatic sources of afferent input as factors in aberrant in autonomic, sensory, and motor function. In: Korr, I. M. ed. *Neurobiologic mechanisms in manipulative therapy*. New York: Plenum Press.

Crossman, A. R. and Neary, D. 2014. *Neuroanatomy: an illustrated colour text*. London: Elsevier Health Sciences UK.

Cummings, B. 2014. *Homonculus brain sensory and motor.* Available: http://www.apsubiology.org/anatomy/2010/2010_Exam_Reviews/Exam_4_Review/12-09_MotorSensory.JPG (Accessed 29 January 2018).

Cyriax, J. 1975. Treatment of pain by manipulation. In: Goldstein M. ed. *The research status of spinal manipulative therapy*. NINCDS Monograph No. 15. Washington, D.C.: U.S. Government Printing Office.

De Luca, C. J. 2002. *DELSYS. Surface electromyography: detection and recording.* DelSys Incorporated.

Derrickson, B. and Tortora, G. J. 2011 *Principles of anatomy and physiology: organisation, support and movement, and control systems of the human body.* 13th ed. Asia: John Wiley & Sons Pte Ltd.

DeVocht, J. W., Pickar, J. G. and Wilder, D, G. 2005. Spinal manipulation alters electromyographic activity of paraspinal muscles: a descriptive study. *Journal of Manipulative and Physiological Therapeutics,* 28(9): 465-471.

Dishman, J. D. and Bulbulian, R. 2000. Spinal reflex attenuation associated with spinal manipulation. *Spine,* 2519-2525.

Dunning, J. and Rushton, A. 2009. The effects of cervical high-velocity low-amplitude thrust manipulation on resting electromyographic activity of the biceps brachii muscle. *Manual Therapy,* 14: 508-513.

Dvorak J., 1985. *Neurologic and biomechanical aspects of back pain.* In: Beurger, A. A. and Greenman, P.E. eds. *Empirical approaches to the validation of spinal manipulative therapy*. Springfield, IL: Charles C Thomas.

Emery, C. A. 2003. Is there a clinical standing balance measurement appropriate for use in sports medicine? A review of the literature. *Journal of Science and Medicine in Sport* (online), 6(4): 492-504.

England, R. and Deibert P., 1972. Electromyographic studies. Part 1. Consideration in the evaluation of osteopathic therapy. *Journal of The American Osteopathic Association*, 72: 162-169.

Falla, D. 2004. Unravelling the complexity of muscle impairment in chronic neck pain. *Journal of Manual Therapy*, 9(3): 125-133.

Gatterman, M. I. 2005. *Foundations of Chiropractic: Subluxation.* 2nd ed. St Louis, Missouri: Elsevier Mosby.

Giles, L. G. F. ed. 2014. *100 challenging spinal pain syndrome cases.* 2nd ed. Philadelphia: Churchill Livingstone.

Gilman, S. 2002. Joint position sense and vibration sense: anatomical organisation and assessment. *Journal of Neurology, Neurosurgery, and Psychiatry*, 73(5): 473-477.

Grice A. 1975. Muscle tone changes following manipulation. *Journal of The Canadian Chiropractic Association*, 18(4): 29.

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

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

Haavik, H. and Murphy, B. 2011. Subclinical neck pain and the effects of cervical manipulation on elbow joint position sense. *Journal of Manipulative and Physiological Therapeutics*, 34(2): 88-97.

Haavik, H. and Murphy, B. 2012. The role of spinal manipulation in addressing disordered sensorimotor integration and altered motor control*. Journal of Electromyography and Kinesiology,* 22(5): 768-776.

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

Huijbregts, P. A. 2002. Spinal motion palpation: a review of reliability studies. *Journal of Manual and Manipulative Therapy*, 10(1): 24-39.

Hinman, M. R. 2000. Factors affecting reliability of the Biodex Balance System: a summary of four studies. *Journal Of Sport Rehabilitation,* 9(3): 249-252.

Holt, K. 2014. Effectiveness of chiropractic care in improving sensorimotor function associated with falls risk in older people. Degree of Doctor of Philosophy in Health Sciences, The University of Aukland.

Ivanenko, Y. P., Solopova, I. A. and Levik, Y. S. 2000. The direction of postural instability affects postural reactions to ankle muscle vibration in humans. *Neuroscience Letters*, 292: 103-106.

Janda, V. 1983. On the concept of postural muscles and posture*. Australian Journal of Physiotherapy*, 29:83.

Jull, G., Falla, D., Treleaven, J., Hodges, P. and Vicenzino, B. 2007. Retraining cervical joint position sense: the effect of two exercise regimes. *Journal of Orthopaedic Research,* 25(3): 404-412.

Kandel, E. R. Shwartz, J. H. and Jessel, T. M. 1991. *Principles of neural science.* 5th ed. New York: Elsevier Science Publishing Co., Inc.

Karlberg, M., Persson, L. and Magnusson, M. 1995. Reduced postural control in patients with chronic cervicobrachial pain syndrome. *Gait and Posture*, 3: 241-249.

Karunaharamoorthy, A. 2018a. *Kenhub: Biceps brachii muscle.* Available: https://www.kenhub.com/en/library/anatomy/biceps-brachii-muscle (Accessed: 29 January 2018).

Karunaharamoorthy, A. 2018b. *Kenhub: Triceps brachii muscle.* Available: https://www.kenhub.com/en/library/anatomy/triceps-brachii-muscle (Accessed: 29 January 2018)

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

Knox, J.J. and Hodges, P. W. 2005. Changes in head and neck position affect elbow joint position sense. *Experimental Brain Research*, 165(1): 107-113.

Knox, J., Cordo, P., Skoss, R., Durrant, S. and Hodges, P. 2006a. Illusory changes in head position induced by neck muscle vibration can alter the perception of elbow position. *Behavioural Neuroscience*, 120(6): 1211-1217.

Knox, J. J., Coppieters, M. W. and Hodges, P. W. 2006b. Do you know where your arm is if you think your head has moved? *Experimental Brain Research*, 173(1): 94-101.

Koenig, J. P. 2014. The relationship between postural stability sway, balance, and injury in adolescent female soccer players in the eThekwini district of KwaZulu-Natal. M. Tech, Durban University of Technology.

Koh, Y. 2018a. *Kenhub: Biceps brachii muscle.* (image) Available: https://www.kenhub.com/en/library/anatomy/biceps-brachii-muscle. (Accessed: 29 January 2018)

Koh, Y. 2018b. *Kenhub: Triceps brachii muscle.* (image) Available: https://www.kenhub.com/en/library/anatomy/triceps-brachii-muscle (Accessed: 29 January 2018)

Korr I. M., 1975, Proprioceptors and the behaviour of lesioned segments. In: Stark E.H., editor. *Osteopathic Medicine*. Acton: Publication Sciences Group.

Lackner, J. and DiZio, P. 2005. Vestibular, proprioceptive, and haptic contribution to spatial orientation. *Annual Review of Psychology*, 56: 115-147.

Lantz C. A., 1995. A review of the evolution of chiropractic concepts of subluxation. *Topics in Clinical Chiropractic*, 2(2):1-10.

Leach A. R., 2004. *The chiropractic theories: a textbook of scientific research.* 4th ed. Balitmore and Philadelphia, U.S.A: Lipponcott Williams and Wilkins.

Learman, K. E., Myers, J. B., Lephart, S. M., Sell, T. C., Kerns, G. J. and Cook, C. E. 2009. Effects of spinal manipulation on trunk proprioception in subjects with chronic lower back pain during symptom remission. *Journal of Manipulative and Physiological Therapeutics*, 32: 118-126.

Leach, R. A. 1983. An evaluation of the effect of chiropractic manipulative therapy of hypolordosis of the cervical spine. *Journal of Manual and Manipulative Therapy,* 6(1):17-23

Lehman, G. J. and McGill, S. M. 2001. Spinal manipulation causes variable spine kinematic and trunk muscle electromyographic responses. *Clinical Biomechanics*, 16(4): 207-212.

Lewit, K. 1991. *Manipulative therapy in the rehabilitation of the motor system.* 2nd ed. London: Butterworths.

Marshall, P. and Murphy, B. 2006. The effect of sacroiliac joint manipulation on feed-forward activation times of the deep abdominal musculature. *Journal of Manipulative and Physiological Therapeutics*, 29(3): 196-202.

Martini, F. H. 2006. *Fundamentals of anatomy & physiology* (image). Available: http://slideplayer.com/slide/4330964/14/images/49/Muscle+spindles.jpg (Accessed: 29 January 2018).

Michaelson, P., Michaelson, M., Jaric, S., Latash, M. L., Sjolander, P. and Djupsjobacka, M. 2003. Vertical posture and head stability in patients with chronic neck pain. *Journal Of Rehabilitation Medicine*, 35(5): 229-235.

Mootz, R. D. 2001. *Professional identity: the role of chiropractic theory. Topics in Clinical Chiropractic*, 8(1): 1-8.

Morningstar, M. 2002. Cervical curve restoration and forward head posture reduction for the treatment of mechanical thoracic pain using the Pettibon Corrective and Rehabilitative procedures*. Journal Of Chiropractic Medicine*, 3(1):113-115.

Nolan, J. H. 2010. The effect of cervical spine chiropractic manipulation on balance. Masters Degree in Technology: Chiropractic, University of Johannesburg.

Osu, R, Kamimura, N., Iwasaki, H., Nakano, E., Harris, C. M., Wada Y. and Kawato, M. 2004. Optimal impedence control for task achievement in the presence of signal dependent noise*. Journal of Neurophysiology*, 92(2): 1199-1215.

Paulus, I. and Brumagne, S. 2008. Altered interpretation of neck proprioceptive signals in persons with subclinical recurrent neck pain. *Journal of Rehabilitation Medicine*, 40(6): 426-432.

Persson, L. Karlberg, M. and Magnusson, M. 1996. Effects of different treatments on postural performance in patients with cervical root compression: a randomized prospective study assessing the importance of the neck in postural control. *Journal of Vestibular Research*, 6(6): 439-453.

Peters, L. 2018. *TeachMeAnatomy: The Medulla Oblongata.* Available: http://teachmeanatomy.info/neuro/brainstem/medulla-oblongata/ (25 January 2018).

Pickar, J. G. 2002. Neurophysiological effects of spinal manipulation. *The Spine Journal*, 357-371.

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

Plaugher, G. ed. 1993. *Textbook of clinical chiropractic a specific biomechanical approach.* PhiladelphiaP.A.: Lippincott, Williams and Wilkins,

Radebold, A., Cholewicki, J., Polzhofer, G. K. and Greene, H. S. 2001. Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain*. Spine*, 26(7): 724-730.

Raff, H., Strang, K. T. and Widmaier, E. P. 2008. *Vander's human physiology: the mechanisms of body function,* 11th ed. New York: McGraw-Hill

Ribeiro, F., Mota, J. and Oliveira, J. 2007. Effect of exercise-induced fatigue on position sense of the knee in the elderly. *European Journal of Applied Physiology*, 99(4): 379-385.

Rohrbach, T., Knowles, D. and Knowles, R. 2011. Restoration of the cervical curve and improvements in neurological function in a patient following network spinal analysis*. Vertebral Subluxation Research,* 3: (3): 99-103.

Sainsburg, R. G., Woolley, S. M., Dailey, V. M. and Goebel, J. A. 1999. Intersegmental dynamics are controlled by sequential anticipatory, error correction, and postural mechanisms. *Journal of Neurophysiology*, 81: 1045-1056.

Smith, J. L., Crawford, M., Proske, U., Taylor, J. L. and Gandevia, S. C. 2009 Signals of motor command bias joint position sense in the presence of feedback from proprioceptors. *Journal of Applied Physiology*, 106: 950-958.

Stapley, P. J., Beretta, M. V., Toffola, E. D. and Schieppati, M. 2006. Neck muscle fatigue and postural control in patients with whiplash injury. *Journal of Clinical Neurophysiology*, 117(3): 610-622.

Statistics South Africa. 2011. *STATS SA.* Available: http://www.statssa.gov.za/?page_id=595 (Accessed: 12 February 2018).

Sterling, M., Jull, G., Vincenzino, B., Kenardy, J. and Darnell, R. 2003. Development of motor system dysfunction following whiplash injury. *Pain*, 103(1-2):65-73.

Strimpakos, N., Sakellari, V., Gioftsos, G., Kapreli, E. and Oldham, J. 2006. Cervical joint position sense: an intra- and inter-examiner reliability study. *Gait and Posture*, 23(1): 22-31.

Studyblue. 2018. *Neurology: white matter tracts spinal cord*. (image) Available: https://www.bing.com/images/search?view=detailV2&ccid=zVoiwdiH&id=19488EF97562E01ACDFDC947AD1672CA699DD6A7&thid=OIP.zVoiwdiHzC_AT7hdmntZTAHaDF&q=White+Matter+Tracts+Spinal+Cord&simid=608003080135249538&selectedIndex=0&ajaxhist=0 (Accessed: 14 February 2018).

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

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

Swartz, E. E., Floyd, R. T., Cendoma, M. 2005. Cervical Spine Functional Anatomy and the Biomechanics of Injury Due to the Compressive Loading. *Journal of Athletic Training*, 40(3): 155-161. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1250253/ (Accessed 25 July 2018).

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

Syndicated. 2013. *The brain stem and chiropractic*. Available http://purechiropractic.co.uk/chiropractic/brain-stem (Accessed 10 February 2018).

Szaras Z, 1984. *The compendium of chiropractic technique*. Toronto: Canadian Memorial Chiropractic College.

Takayama, H., Muratsu, H., Doita, M., Harada, T., Kurosaka, M. and Yoshiya, S. 2005. Proprioceptive recovery of patients with cervical myelopathy after surgical decompression. *Spine*, 30(9): 1039-1044.

Takayama, H., Muratsu, H., Doita, M., Harada, T., Kurosaka, M. and Yoshiya, S. 2005. Impaired joint proprioception in patients with cervical myelopathy. *Spine,* 30(1): 83-86.

The John Hopkins University. 2018. *JHSPHOPEN coursework.* Available: http://ocw.jhsph.edu/index.cfm/go/viewCourse/course/StatisticalReasoning1/coursePage/lectureNotes/ (Accessed 5 February 2018).

Tinazzi, M. Priori, A., Bertolasi, L. Frasson, E., Mauguiere, F. and Fiaschi, A. 2000. Abnormal central integration of a dual somatosensory input in dystonia. Evidence for sensory overflow. *Brain*, 123(Pt 1): 42-50.

Tinazzi, M., Zanette, G., Polo, A., Volpato, D., Manganotti, P. and Bonato, C, et al. 1997. Transient deafferentation in humans induces rapid modulation of primary sensory cortex not associated with subcortical changes: a somatosensory evoked potential study. *Neuroscience Letters*, 223(1): 21-24.

Tran, P. 2012. *Orthoanswer: cervical spine anatomy*. Available: http://orthoanswer.org/spine-neck/cervical-radiculopathy/index.html (Accessed: 14 February 2018).

Tsauo, J. Y. and Cheng, P. F. 2008. The effect of sensorimotor training on knee proprioceptive and function for patients with knee osteoarthritis: a preliminary report. *Clinical Rehabilitation*, 22: 448-457.

Van Trijffel, E., Anderegg, Q., Bossuyt, P. M. and Lucus, C. 2005. Inter-examiner reliability of passive assessment of intervertebral motion in the cervical and lumbar spine: A systematic review. *Manual Therapy,* 10(4): 256-269.

Vaughan B., 2002. Inter-examiner reliability in detecting cervical spine dysfunction: a short review. *Journal of Osteopathic Medicine*, 5: 24-27.

Walker, B. R. Colledge, N. R. Ralston, S. H. and Penman, I. D. 2014. *Neurological disease: altered balance and vertigo*. 22nd ed. Edinburgh: Churchill Livingstone Elsevier.

Waugh, A., Grant, A, and Ross, J. S. eds. 2010. *Ross and Wilson anatomy and physiology in health and illness.* 11th ed. Edinburgh: Churchill Livingstone Elsevier.

Wyke, B. 1987. The neurology of low back pain. In: Jayson M. ed. *The lumbar spine and back pain.* 3rd ed. New York: Churchill Livingstone.

Zabihhosseinian, M., Holmes, M. W. R. and Murphy, B. 2015. *Neck muscle fatigue alters upper limb proprioception*. Faculty of Health Sciences, University of Ontario Institute of Technology.

Appendices

Appendix A: Letter of Information and Informed Consent

LETTER OF INFORMATION

Title of the Research Study: The effect of cervical spine manipulation on elbow proprioception, electrical activity of the triceps and biceps muscles and balance.

Principal Investigator/s/researcher: Hannah Lenka McKay, M.Tech Chiropractic

Co-Investigator/s/supervisor/s: Dr Grant Matkovich. M.Tech: Chiropractic. Clinician.

Brief Introduction and Purpose of the Study: Thank you for agreeing to participate in this research process. The aim of this study is to determine the effect that cervical spine manipulation (CSM) has on balance, joint position sense of the elbow and electrical activity within the triceps brachii and biceps brachii muscles. The biodex biosway portable balance system (BBPBS) will be used to assess balance, electromyography (EMG) machine will be used to assess the electrical activity if the triceps and biceps brachii muscles and a goniometer will be used to assess elbow joint position sense.

Outline of the Procedures: You will be required to attend an appointment at the Durban University of Technology during which you will be randomly allocated to either the test or control group to allow unbias allocation. A full patient history, physical exam and regional evaluation of the cervical spine, shoulder and elbow will be performed. Contraindications to CSM will also be evaluated for. You will then be screened in an effort to identify any fixations in their cervical spine. According to the levels of fixations that you present with, you will further be allocated to a subgroup. The researcher will then take the time to explain to you how the BBPBS, EMG and goniometer works. You will be allocated time to practise with the equipment. Two pre-tests for all measurements will then be taken. The intervention will then be performed and two post-tests for the stable platform (BBPBS) unstable platform (BBPBS), EMG and JPS will be done. The data will be recorded and securely filed.

Risks or Discomforts to the Participant: Transient muscle pain may be experienced in the neck region following CSM, however this usually subsides within 24 hours. You will be screened for risks or contraindications to CSM. Should any contraindications be detected, you will be excluded from the study. Should you wish to withdraw from the study you will not face any repercussions financially,

academically or institutionally. Autonomy is ensured when you sign the letter of information and informed consent.

Benefits: You will be given one free treatment following the completion of the research procedure. Due to the nature of the research investigating the effects of CSM on balance, elbow JPS and electrical activity of the biceps and triceps brachii muscles, there is a possibility that balance and upper limb proprioception may be improved with CSM.

Reason/s why the Participant May Be Withdrawn from the Study: If you take anti-inflammatory medication the day before the data collection takes place you may be withdrawn from the study. If you are involved in any accidents in the time between the telephonic screening and the data collection appointment, involving trauma to the neck, shoulder or elbow region will be excluded from the study. You may not receive any form of CSM for one month before as well as for the duration of the study. Chiropractic students who partake in the study must not receive CSM in any of their practical classes from one month before the study and for the duration of the study. If you do, you will be withdrawn from the study.

Remuneration: You will be issued with a voucher for one free treatment at the DUT Chiropractic Day Clinic.

Costs of the Study: You will not be expected to contribute to any of the costs of the study. The only requirement will be that you give up your time to attend two appointments - one for the initial consultation and a second one for the screening and data collection process.

Confidentiality: Standard clinical protocol applies to any information given by you. The files will only be accessible to the researcher, the supervisor and the co-supervisor for data collection purposes.

Research-related Injury: Should there be any adverse reactions, the researcher will report this to IREC

Persons to Contact in the Event of Any Problems or Queries: Please contact the researcher (0817999546), my supervisor, Dr Matkovich (0825683986) or the

Institutional Research Ethics administrator on 031 373 2900. Complaints can be reported to the

DVC: TIP, Prof F. Otieno on 031 373 2382 or dvctip@dut.ac.za.

General: Participation in the research is entirely voluntary. 20 participants will be included in each group. Therefore, a total 0f 80 participants will partake in the study.

CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, (name of ___

  researcher), about the nature, conduct, benefits and risks of this study - Research Ethics Clearance
  Number: _____,
- I have also received, read and understood the above written information (Participant Letter of

  Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may

  relate to my participation will be made available to me.

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

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

Full Name of Researcher	**Date**	**Signature**
Full Name of Witness (If applicable)		**DateSignature**
Full Name of Legal Guardian (If applicable)	**Date**	**Signature**

Please note the following:

Research details must be provided in a clear, simple and culturally appropriate manner and prospective participants should be helped to arrive at an informed decision by use of appropriate language (grade 10 level

- use Flesch Reading Ease Scores on Microsoft Word), selecting of a non-threatening environment for interaction and the availability of peer counselling (Department of Health, 2004)

If the potential participant is unable to read/illiterate, then a right thumb print is required and an impartial witness, who is literate and knows the participant e.g. parent, sibling, friend, pastor, etc. should verify in writing, duly signed that informed verbal consent was obtained (Department of Health, 2004).

If anyone makes a mistake completing this document e.g. a wrong date or spelling mistake, a new document has to be completed. The incomplete original document has to be kept in the participant's file and not thrown away, and copies thereof must be issued to the participant.

References:

Department of Health: 2004. *Ethics in Health Research: Principles, Structures and Processes*

http://www.doh.gov.za/docs/factsheets/guidelines/ethnics/

Department of Health. 2006. *South African Good Clinical Practice Guidelines*. 2nd Ed. Available at:

http://www.nhrec.org.za/?page_id=14

Appendix B: Advertisement

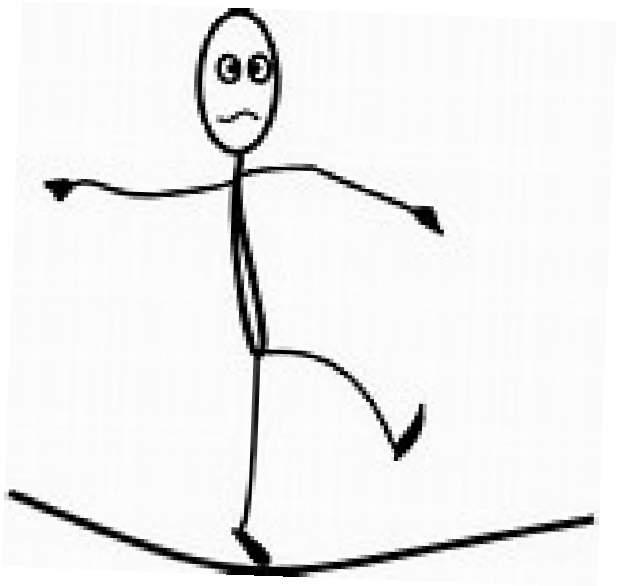
Would you like to be involved in a study that checks your balance?

Join me at the DUT Chiropractic Clinic, on Ritson campus, Berea, Durban.

[People eligible for participation must be between the ages of 18 and 35 years old.]

Contact Hannah McKay : 081 799 9546

Or the DUT Chiropractic Clinic: 031 373 2205



Appendix C: Telephonic interview

Question	Yes	No	Comment
1. Are you prepared to answer a few questions over the phone?			
2. How old are you?			
3. Do you have any elbow, shoulder or neck pain?			
4. Have you ever had surgery or trauma to the shoulder, elbow or neck?			
5. Do you have any known peripheral neuropathies?			
6. Do you have diabetes?			
7. Do you have anaemia?			
8. Are you on any chronic anti-inflammatory medication?			
9. Have you been adjusted in the last 4 weeks?			

Appendix D: Physical Examination

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC AND SOMATOLOGY

CHIROPRACTIC PROGRAMME

PHYSICAL EXAMINATION: SENIOR

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

Page 1

Appendix E: Case History

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:

Appendix F: Cervical spine regional

CHIROPRACTIC PROGRAMME

REGIONAL EXAMINATION – CERVICAL SPINE

Patient: _____ File No: _____

Date: _____ Student: _____

Clinician: _____ Sign: _____

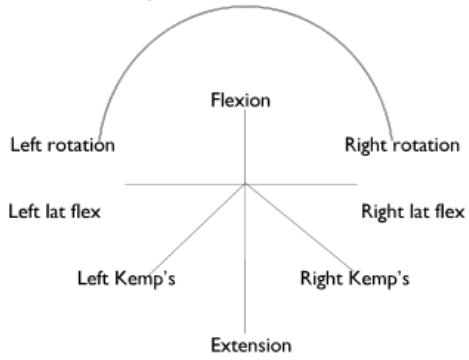
OBSERVATION:

Posture
Swellings
Scars, discolouration
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

Tenderness		Right	Left
Trigger Points:	SCM		
	Scalenii		
	Post Cervicals		
	Trapezius		
	Lev scapular		

ORTHOPAEDIC EXAMINATION:

	Right	Left		Right	Left
Adson's test			Halstead's test		
Brachial plexus test			Hyper-abduction test		
Cervical compression			Kemp's test		
Cervical distraction			Lateral compression		
Costoclavicular test			Lhermitte's sign		
Dizziness rotation test			Shoulder abduction test		
Doorbell sign			Shoulder compression test		
Eden's test					

Page 1 of 2

NEUROLOGICAL EXAMINATION:

Dermatones	Left	Right	Myotomes	Left	Right	Reflexes	Left	Right
C2			C1			C5		
C3			C2			C6		
C4			C3			C7		
C5			C4					
C6			C5					
C7			C6					
C8			C7					
T1			C8					
			T1					

Cerebellar tests:	Left	Right
Dysdiadochokinesis		

VASCULAR:	Left	Right		Left	Right
Blood pressure			Subclavian arts.		
Carotid arts.			Wallenberg's test		

MOTION PALPATION & JOINT PLAY:

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

BASIC EXAM: SHOULDER:

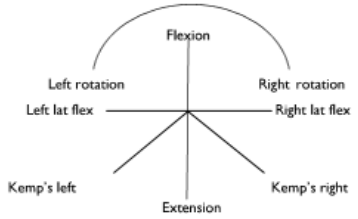
Case History:

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

BASIC EXAM: THORACIC SPINE:

Case History:

ROM:



Motion Palpation:	
Orthopaedic:	
Neuro:	
Vascular:	
Observ/Palpation:	
Joint Play:	

Appendix G: Stratification table

Table 1: Stratification Table				
	Control	Intervention		
Level of fixations: Upper = C0-C3 Lower = C4-C7	unspecified	Upper	Lower	Both
Number of participants	20	20	20	20

Appendix H: Data Collection Sheet

Electromyography reading			
Triceps Brachii		Biceps Brachii	
Pre intervention	**Electronic**	Pre intervention	**Electronic**
Post Intervention	**Electronic**	Post Intervention	**Electronic**

Proprioception			
Pre intervention	I	**Electronic**	**Angle requested: 40'**
Post Intervention	I	**Electronic**	**Angle requested: 40'**

Biosway			
Test readings			Mean
Pre intervention stable	Eyes open		**0,43**
	Eyes closed		**0,66**
Pre intervention unstable	Eyes open		**0,74**
	Eyes closed		**1,85**
Post intervention stable	Eyes open		**0,43**
	Eyes closed		**0,66**
Post intervention unstable	Eyes open		**0,74**
	Eyes closed		**1,85**

Fixation		Cavitation	
		Yes	No
#1			
#2			

Appendix I: Treatment Voucher

This is to certify
that ....., ID number:..... May receive one free treatment at the Durban University of Technology Chiropractic Clinic.

Thank you for participating in the research.

Date:

Researcher Name: Hannah McKay

Signature:

Appendix J: Ethical approval document

DUT
DURBAN
UNIVERSITY OF
TECHNOLOGY

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

P O Box 1334, Durban, South Africa 4001

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

www.dut.ac.za

10 May 2017

IREC Reference Number: **REC 115/16**

Ms H L McKay
567 Currie Road
College House
Berea
Durban
4001

Dear Ms McKay

The effect of cervical spine manipulation on elbow proprioception, electrical activity of the triceps and biceps muscles and balance

Your provisional approval letter dated 07 December 2016 refers.

Please be advised that ethics clearance has been granted for a period of 2 years, before the expiry of which you are required to apply for safety monitoring and annual recertification.

Please use the Safety Monitoring and Annual Recertification form to apply for recertification, this form can be found on http://www.dut.ac.za/research/institutional_research_ethics/

Please note that this form must be submitted to the IREC 3 months before ethics approval for the study expires.

Yours Sincerely

[redacted]

Professor J K Adam
Chairperson: IREC

DUT DURBAN UNIVERSITY OF TECHNOLOGY
2017 -05- 10
INSTITUTIONAL RESEARCH ETHICS COMMITTEE
P O BOX 1334 DURBAN 4000 SOUTH AFRICA

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

P O Box 1334, Durban, South Africa, 4001

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

www.dut.ac.za

14 February 2017

IREC Reference Number: **REC 115/16**

Ms H L McKay
567 Currie Road
College House
Berea
Durban
4001

Dear Ms McKay

The effect of cervical spine manipulation on elbow proprioception, electrical activity of the triceps and biceps muscles and balance

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.

[redacted]

Professor J K Adam
Chairperson: IREC

DUT DURBAN UNIVERSITY OF TECHNOLOGY
2017 -02- 14
INSITUTIONAL RESEARCH ETHICS COMMITTEE
P O BOX 1334 DURBAN 4000 SOUTH AFRICA

DUT
DURBAN
UNIVERSITY OF
TECHNOLOGY

Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
3rd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology

P O Box 1334, Durban, South Africa, 4001

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

www.dut.ac.za

7 December 2016

IREC Reference Number: **REC 115/16**

Ms H L McKay
567 Currie Road
College House
Berea
Durban
4001

Dear Ms McKay

The effect of cervical spine manipulation on elbow proprioception, electrical activity of the triceps and biceps muscles and balance

I am pleased to inform you that Provisional Approval has been granted to your proposal REC 115/16 subject to:

- Obtaining and submitting the necessary gatekeeper permission/s to the IREC.

Full approval is subject to meeting the above condition.

The Proposal has been allocated the following Ethical Clearance number IREC 131/16. Please use this number in all communication with this office.

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

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the IREC according to the IREC SOP's.

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

Yours Sincerely

[redacted]

Professor J K Adam
Chairperson: IREC

DUT DURBAN UNIVERSITY OF TECHNOLOGY
2016 -12- 07
INSTITUTIONAL RESEARCH ETHICS COMMITTEE
P O BOX 1334 DURBAN 4000 SOUTH AFRICA

Appendix K

Dear Professor Ross

I am a 5th year Chiropractic Masters student currently working on my dissertation which investigates the effect of cervical spine manipulation on elbow proprioception, electrical activity of the triceps and biceps muscles and balance.

Eighty asymptomatic participants will be used. All participants will be contacted telephonically prior to the study during which they will be interviewed in a screening process to determine whether they will meet the main inclusion criteria. They will then be required to sign a letter of information and informed consent should they wish to partake in the study. The participants will then be randomly placed in either the test or control group using the "hat method". A brief history and physical examination will be conducted. Three pre-readings will then be taken for each participant namely balance using the Biosway balance system, elbow joint position sense using the goniometer and electrical activity of the biceps and triceps muscles using the sEMG machine. The participant's cervical spine will then be screened for any fixations using motion palpation as a screening tool. According to the levels of fixations detected, the participant will be stratified into one of the following groups: lower cervical spine, upper cervical spine or fixations in both upper and lower cervical spine. There will also be an "unspecified" group which will be the control. The fixations will then be adjusted in the intervention groups using the diversified technique. The control group will receive no intervention. The readings for balance, joint position sense and electrical activity of the biceps and triceps muscles will then be redone to obtain the post-intervention readings.

I would like to request that you grant me permission to use the Biosway balance system, goniometer and the sEMG machine for the purpose of completion of my M.Tech Chiropractic dissertation.

Signed (Prof Ross): [redacted]

[redacted]

On this date: 07/02/2017

Signed (Hannah McKay): [redacted]

At: D.U.T.

On this date: 06-02-17

Appendix L: Permission from the Clinic Director

MEMORANDUM

To : Prof Ross
Chair : RHDC

Prof Adam
Chair : IREC

From : Dr Charmaine Korporaal
Clinic Director : FoHS Clinic

Date : 05.12.2016

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

---

Permission is hereby granted to :

Ms Hannah McKay (Student Number: 21208562)

Research title : "The effect of cervical spine manipulation on elbow proprioception, electrical activity of the triceps and biceps muscles and balance".

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

Thank you for your time.

Kind regards

[redacted]

Dr Charmaine Korporaal

Clinic Director : FoHS Clinic

Cc: Mrs L Twiggs : Chiropractic Day Clinic
Dr L O'Connor : Research co-ordinator
Prof T Puckree : Research supervisor

Appendix M: Contraindications questionnaire

Have you been diagnosed with any of the following conditions?	**Yes**	**No**	**Comments**
Vestibular disease			
Meniere's disease			
Vestibular neuronitis			
Benign positional vertigo			
Ototoxicity			
Ramsay Hunt syndrome			
Multiple Sclerosis			
Stroke/ Transient ischaemic attack			
Acoustic neuroma			
Vertiginous epilepsy			
Acoustic neuroma			
Atherosclerosis			
Vertibrobasilar insufficiency			
Aneurysms			
Tumours			
Fractures of the spine			

Severe neck sprains			
Late stages of osteoarthritis			
Uncarthrosis			
Blood clotting disorders			
Osteoporosis			
Space occupying lesions			
Malingering hysteria hypochondriasis			
Alzheimer’s disease			