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How to cite this thesis
THE IMMEDIATE EFFECT OF SPINAL MANIPULATIVE THERAPY ON MOVEMENT TIME

A dissertation presented to the Faculty of Health Sciences, University of Johannesburg, as partial fulfilment for the Master’s Degree in Technology: Chiropractic by

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Supervisor: ___________________________ Date:_________________________

Dr. C. Yelverton
DECLARATION

I Hannah Morna Berry do hereby declare that this dissertation is my own, unaided work. It is being submitted in partial fulfilment for the Master’s degree in Technology, in the programme of Chiropractic, at the University of Johannesburg. It has not previously been submitted for any degree or examination in any other University or Technikon.

Signature of Candidate: ________________________________ Hannah Morna Berry

Signed at _________________________ on the __________ of __________ 2016.
ABSTRACT

Aim: The primary aim of this study was to explore the immediate effect that spinal manipulative therapy (SMT) had on a predefined motor task by measuring the time it took to complete a motor task in asymptomatic individuals, or by assessing the movement time (MT). Movement time is measured using Fitts' Law. This study also focused on assessing if there was any specific region receiving spinal manipulative therapy that yielded greater results.

Method: A total of 100 participants volunteered for this study. There were 52 female participants and 48 male participants that were selected. The participants were between the ages of 18 and 40 years of age. The participants were screened by means of an inclusion and exclusion criteria and those who were eligible, were invited to take part in the study. The participants were randomly allocated into 1 of 4 groups. Each group therefore consisted of 25 participants. Group 1 was the combination group and received SMT to dysfunctional vertebral segments located within the cervical, thoracic, lumbar and sacroiliac regions. Group 2 received SMT to dysfunctional vertebral segments located within the cervical spine only. Group 3 received SMT to dysfunctional vertebral segments located within the thoracic region and the 4th and final group received SMT to dysfunctional segments located within the lumbar and or sacroiliac regions.

Procedure: Due to the nature of the study design, the participants were only required for a single treatment. The participants were required to complete two objective tests, namely the Fitts’ Tapping Task (FTT) and the Generalised Fitts’ Law Model Builder (GFLMB), before any treatment was administered. The researcher then manipulated the dysfunctional vertebral segments that was assessed via motion palpation to the various regions according to each participant’s specific group. The participants were then required to redo the two tests immediately again following treatment.
**Results:** The results obtained from this study indicated that spinal manipulative therapy delivered to the cervical spine has a positive influence on movement time as all the participants in group 2 showed statistically significant results for all conditions for the two tests. Group 1, which was the combination group, showed statistically significant results or an improvement in movement time for 8 of the 9 conditions following SMT for the FTT. This indicates that SMT delivered to the cervical, thoracic and lumbar spine did not influence a motor task that was deemed more difficult, or that had a higher index of difficulty (ID). Group 1 also showed statistically significant results for all 4 conditions for the GFLMB test as the movement time improved for all conditions. Group 3 showed statistically significant results for conditions 1-3, 5-6 and 8-9, as the movement time for these conditions all improved following SMT for the FTT. Therefore for conditions that were more difficult to complete or that had higher indices of difficulty (ID>4.8), SMT delivered to the thoracic spine seemed to have no beneficial effect. Group 3’s results revealed statistically significant improvements in movement time for 3 of the 4 test conditions for the GFLMB following SMT. The 4th and final group showed statistically significant improvements in movement time for 8 of the 9 conditions for the FTT and 3 of the 4 conditions for the GFLMB.

**Conclusion:** The results indicate that SMT does in fact have an effect on improving the overall movement time, but with limitation. Group 2 which received SMT to dysfunctional segments located within the cervical spine was the only group that had statistically significant changes over all the various indices of difficulty for both tests. Condition 4 of the Fitts’ Tapping Task had an index of difficulty of ID=4.8 and did not produce statistically significant results for group 1, 3 and 4. Further research is required to ascertain which indices of difficulties are most improved with chiropractic treatment. The research also determined that SMT delivered to the cervical spine has the
DEDICATION

To my parents Bruce and Ronelle, thank you for viewing education with such a high regard. I am deeply appreciative of the endless amounts of encouragement you were always so willing to give me throughout the years.

To my siblings Bligh, Clyde, Camilla, Lloyd and Rebecca as well as their spouses Samantha, Charles, Debbie and Bernice. Thank you for all the support and encouragement you have all given me over the years.

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<tbody>
<tr>
<td>CNS</td>
<td>Central nervous system</td>
</tr>
<tr>
<td>CSF</td>
<td>Cerebrospinal fluid</td>
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<tr>
<td>DRG</td>
<td>Dorsal root ganglia</td>
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<tr>
<td>FTT</td>
<td>Fitts’ Tapping Task</td>
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<tr>
<td>GFLMB</td>
<td>Generalised Fitts’ Law model builder</td>
</tr>
<tr>
<td>ID</td>
<td>Index of difficulty</td>
</tr>
<tr>
<td>IVD</td>
<td>Intervertebral discs</td>
</tr>
<tr>
<td>IVF</td>
<td>Intervertebral foramen</td>
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<tr>
<td>MT</td>
<td>Movement time</td>
</tr>
<tr>
<td>PNS</td>
<td>Peripheral nervous system</td>
</tr>
<tr>
<td>SEP</td>
<td>Somatosensory evoked potential</td>
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<tr>
<td>SMI</td>
<td>Sensorimotor integration</td>
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<tr>
<td>SMT</td>
<td>Spinal manipulative therapy</td>
</tr>
<tr>
<td>TMS</td>
<td>Transcranial magnetic stimulation</td>
</tr>
<tr>
<td>TVP</td>
<td>Transverse process</td>
</tr>
<tr>
<td>VSC</td>
<td>Vertebral subluxation complex</td>
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<td>Z-Joints</td>
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1.1 General Introduction

Movement is a fundamental aspect to life. Without it, humans and animals alike, would not be able to survive. Humans require movement to escape danger, gather food and reproduce to name just a few things. According to Lee and Schmidt (2011), movement can be classified into 2 main classes. The first class describes movement that is genetically defined. Some examples of this class include the ability human beings have to control their limbs, or the blink reflex of the eye in response to an unexpected puff of air. The second class describes movement that is learned. These types of movements are also referred to as skills. Guthrie (1952), has the following definition for skill: “Skill consists in the ability to bring about some end result with maximum certainty and minimum outlay of energy, or time and energy.”

Movements of all types of magnitudes require complex processing by the central nervous system to produce a co-ordinated result, how this process occurs is known as motor control (Lee and Schmidt, 2011; Shea and Wright, 1997).

Movement time (MT) may be defined as the time take to complete a predefined motor task (Davis and Fang, 2010). Movement time measures the interval between the initiation of a movement and its termination (Lee and Schmidt, 2011). Movement time differs to that of reaction time as it starts at the initiation of movement up until the movement has been completed, rather than at the start of the prompt. MT can be just about any value, ranging from just a few milliseconds for a quick movement such as in a Fitts’ law task, to a slightly larger value in the case of a 100m sprint. MT can be used in skills research due to its overall external validity in practical settings (Lee and Schmidt, 2011). There was research conducted in 2010 showing that individuals with chronic neck pain have larger MT than individuals who don’t (Descarreaux, Passmore and Cantin, 2010).

According to research conduction by Haavik-Taylor and Murphy (2010c and 2007c) and Haavik-Taylor, Holt and Murphy (2010), areas of the spine known to have segmental spinal dysfunction have been shown to have an altered state of afferent input which in turn is responsible for the central plastic changes that occur within the central nervous system (CNS). The research then went on to say that if there is a change in the afferent input into
the CNS, this will in turn alter the sensorimotor integration (SMI). Haavik-Taylor and Murphy (2011, 2007a, b), conducted studies where they utilized transcranial magnetic stimulation (TMS) to measure the change in the sensorimotor integration following SMT to dysfunctional spinal segments. SMT delivered to dysfunctional segments alters the central processing as well as the sensorimotor integration process for at least 20-30 minutes post manipulation (Haavik and Murphy, 2012; Haavik-Taylor and Murphy, 2011).

1.2 Problem Statement

The literature has often reported that after receiving spinal manipulative therapy people seem to move better or move with more ease. A patient saying that they feel that they are moving better, in itself, is not sufficient to measure the effects that spinal manipulative therapy may have on a motor task. Spinal manipulation is a mechanical event and, in order to assess its impact on the human motor system, valid and reliable objective outcome measures need to be used in order to assess these changes.

Research has shown that spinal manipulative therapy has therapeutic benefits such as reducing pain and muscle spasms, but there is limited research showing if spinal manipulative therapy influences the motor system. A pilot study conducted in 2006 titled, “The Immediate Effect of Chiropractic Adjustments on Movement Time: A Pilot Study using Fitts Law”, explored the immediate effects of spinal manipulative therapy on movement time. The study showed that there was a decrease in movement time, or an improvement, following spinal manipulative therapy. Participants of this study received manipulations to multiple levels of the spine and as a result the study failed to isolate which region receiving a manipulation, if any, yielded the greatest result.

1.3 Aim of Study

This research was exploratory in nature. The primary aim of this study was to explore the immediate effect that SMT had on a predefined motor task by measuring the time it took to complete a motor task in asymptomatic individuals, or by assessing the movement time. This
study also focused on assessing if there was any specific region receiving SMT that yielded greater results.

1.4 Benefits of this Study

Possible outcomes of this study may provide the chiropractic profession with a more concise knowledge of exactly how SMT influences the neurophysiological mechanism of movement. This study may also confirm that spinal dysfunction may also alter perceptual and behavioural changes. This study may assist the chiropractic profession by providing a better understanding for the mechanisms that are responsible for the restoration of functional ability as well as the reduction of pain that has been documented following SMT.

A performance based outcome measure, such as MT, may yield measurable differences following treatment, whereas other functional tests such as range-of-motion may not always be adequate. This study may also indicate which area of SMT gives the maximum benefit specifically related to the task. This research may build the foundation for further research in determining whether or not SMT may help people with movement disorders as MT has been used as an objective measure of bradykinesia in people suffering with Parkinson’s disease and other movement disorders (Davis and Fang, 2010).
CHAPTER TWO:
LITERATURE REVIEW
2.1 Introduction

This chapter includes the relevant anatomy and reviews the neurophysiological principles that govern motor control. This chapter also discusses and links the relevance of spinal manipulative therapy (SMT) in relation to motor control.

2.2 Anatomy

2.2.1 The Vertebral Column

The vertebral column or more commonly known as the spine, is made up of the bony vertebrae, the intervertebral discs, the supporting ligaments and surrounding musculature. This aggregate structure not only houses the spinal cord but it also provides a column of support for the head, neck and trunk. It also provides a semi rigid axis about which movement may occur. An adult vertebral column is typically made up of 33 vertebrae arranged in 5 different regions and its length extends from the base of the cranium to the apex of the coccyx (Moore, Dalley and Agur, 2010). The regions, from superior to inferior are the cervical spine, the thoracic spine, the lumbar spine, the sacrum and finally the coccyx.

The vertebral column is not a straight structure, but instead exhibits 4 spinal curvatures which can be seen in Figure 2.1. The thoracic and sacral regions have a kyphotic curve associated with them, while the cervical and lumbar spine have a lordotic curve associated with them. Kyphotic curves are known as primary curves as they are visible in the late stages of foetal development, while the lordotic or secondary curves only appear several months after birth when a child begins crawling and extending their head (Martini and Nath 2009; Moore et al., 2010).

There are also a number of joints associated with the vertebral column which include the joints between the vertebral bodies, the joints between the vertebral arches, the craniovertebral joints, the costovertebral joints and finally the sacroiliac joints. For the purpose of this study, the joints between the vertebral bodies and vertebral arches will be
discussed in greater detail later on in this chapter. The vertebral column is innervated by the recurrent meningeal branches of the spinal nerves. These rare branches are the only branches to arise from a mixed spinal nerve (Moore, et al., 2010).

2.2.2 The Vertebra

A vertebra typically consists of a vertebral body, a vertebral arch as well as seven processes (Figure 2.2.). The size and shapes of the vertebrae differs slightly between the various regions due to the nature of their function as well as the load that they are expected to carry, for example, the vertebral bodies of the lumbar spine are much larger in comparison to the bodies found within the cervical spine and hence have larger vertebral bodies (Martini and Nath, 2009; Moore et al., 2010). Vertebrae which exhibit different characteristics such as C2 with the presence of the odontoid process are known as atypical vertebrae. For the purpose of this study only the basic structure of a typical vertebrae will be discussed.
The vertebral body is the largest anterior portion of the vertebrae and is responsible for transferring weight along the axis of the vertebral column. The size of the vertebral body increases as the column descends as it needs to accommodate for the increasing amount of body weight. The superior and inferior surfaces of the vertebral body are covered with a thin layer of hyaline cartilage and this is known as the vertebral end plates. The peripheral edges of the vertebral bodies exhibit a ring of smooth bone, known as the epiphysial ring which is fused to the body. These structures provide a degree of support and protection to the vertebral bodies as well as provide a surface for which the intervertebral discs articulate between adjacent vertebrae (Martini and Nath, 2009; Moore et al., 2010).

The vertebral arch which lies posterior to the vertebral body is formed by the two sets of pedicles and lamina. The pedicles arise from the posterior aspect of the vertebral bodies and project posteriorly until they meet the laminae as seen in Figure 2.3. The vertebral arch and the posterior surface of the vertebral body forms the wall of the vertebral foramen. Successive vertebral foramina form the vertebral canal which houses the spinal cord, the spinal nerves, the meninges, fat and the vessels that surround them (Martini and Nath, 2009; Moore et al., 2010).
The articular processes arise at the point where the lamina join the pedicles. There are four articular processes, two superior and two inferior and exhibit articular surfaces known as facets. The articular processes between adjacent vertebrae articulate with one another and these are known as zygapophyseal joints and will be discussed in greater detail later in this chapter. Each vertebra also has two transverse processes that projects posterolaterally from the junction between the pedicle and the laminae. Each vertebrae also has one spinous process that projects posteriorly from the posterior arch. Both the spinous and transverse processes serve as an important attachment site for the deep back muscles as well as serve as levers which are an important component in the movement of the vertebral column (Martini and Nath, 2009; Moore et al., 2010).

Adjacent vertebrae are separated from one another by means of intervertebral discs (IVD) and gaps known as intervertebral foramina separate adjacent pedicles from one another. Intervertebral foramina provide a passageway through which spinal nerves can travel once they have exited the spinal cord (Martini and Nath, 2009; Moore et al., 2010).

Figure 2.3: Posterior and sectional view of 3 articulated vertebrae (Martini and Nath, 2009).
2.2.3 The Zygapophyseal Joints

The zygapophyseal joints (Z-joints), also known as the facet joints, are plane synovial joints formed by the articulating surfaces of the inferior and superior articular processes of two adjacent vertebrae. There are left and right Z-joints between each vertebrae each of which is covered by a thin layer of articular cartilage. These small synovial joints allow for movement to occur within the vertebral column. The shape and size of the facet joints vary between the different regions and thus determines the direction of movement permitted between each joint (Gatterman, 2005; Moore et al., 2010), while the size of the IVD determines the range of movement (Moore et al., 2010).

Each Z-joint is enclosed posterolaterally by a thin joint capsule. The capsule which is somewhat loose, contains a large number of receptors (mechanoreceptors and nociceptors), which plays an important role in SMT. The inner layer of the capsule is made from synovial tissue and is responsible for supplying the joint with synovial fluid. Synovial fluid is believed to have an important role in reducing the amount of friction between the articulating surfaces by providing lubrication.

The synovial membrane and its associated synovial fluid is also believed to be a source of nutrition for the avascular cartilage that surrounds the articular surfaces of the joints. The synovial membrane has protrusions that extend into the joint cavity, these extensions are known as synovial folds and are believed to fill the joint space by increasing the congruency between the two joint surfaces. The facet joints are innervated by the articular branches that arise from the medial branch at the level it exits as well as by one level inferior to it of the posterior rami of spinal nerves (Moore et al., 2010).
2.2.4 The Intervertebral Discs

The intervertebral discs (IVD) are fibrocartilaginous structures that are located between two adjacent vertebral bodies. Besides the IVDs providing a strong attachment between the vertebral bodies, they are responsible for allowing movement to occur between the vertebral bodies. The IVD’s also have an important role in motion and acts as shock absorbers due to their unique and resilient structure (Bergmann and Peterson, 2011).

Each disc has three distinct regions (Figure 2.5): an outer layer known as the annulus fibrosis and an inner layer known as the nucleus pulposus and lastly the cartilaginous endplates. The annulus fibrosis is made up concentric rings of fibrocartilage that appear to cross one another obliquely and encloses the inner, nucleus pulposus. The annulus is responsible for protecting the nucleus pulposus and preventing it from bulging beyond the annulus into the spinal canal. The central nucleus pulposus, a remnant of the notochord, is a gelatinous mucopolysaccharide matrix that contains chondroitin sulphate, hyaluronic acid as well as keratin sulphate (Kapandji, 2008).

The nucleus pulposus is highly hydrophilic thus giving the disc a high water content. The main function of the nucleus pulposus is to provide an effective mechanism by which compressive forces may be distributed (Bergmann and Peterson, 2011). The cartilaginous
endplates are made up of hyaline cartilage and assist in attaching the IVDs to the vertebral end plates located on the superior and inferior aspects of the vertebral body. The vertebral endplates are also responsible for providing a permeable barrier between the disc and the vertebral bodies allowing for the exchange of nutrients in an otherwise avascular structure. The annulus fibrosis is innervated by branches that arise from the anterior ramus of spinal nerves. The annulus fibrosis is also rich in nociceptors and mechanoreceptors, which will be discussed later on in this chapter.

![Image](Image)

**Figure 2.5: Anterosuperior view of the vertebral column transversely sectioned through IVD (Moore et al., 2010).**

### 2.3 The Spinal Cord and Related Anatomy

The spinal cord, along with the cerebellum and cerebrum, forms the central nervous system (CNS), while the nerve roots that emerge from the spinal cord and extend to the periphery form the peripheral nervous system (PNS). The spinal cord is the major reflex centre between the body and the brain (Moore et al., 2010). The spinal cord is a continuation of the medulla oblongata as it exits the cranium via the foramen magnum and extends down though the spinal canal located within the vertebral column where it terminates around the L1/L2 vertebral level. The tapering end of the spinal cord is known as the conus medullaris. The conus medullaris is firmly anchored to the coccygeal ligament by a fibrous tissue known as the filum terminale (Martini and Nath, 2009).
The spinal cord has a posterior median sulcus located on the posterior surface and a deeper median fissure located anteriorly. The spinal cord gives off rootlets on both anterior and posterior surfaces which in turn give rise to spinal nerves. The spinal cord relays sensory information and motor commands between the periphery and the brain and vice versa (Moore, et al., 2010). The spinal cord is surrounded by a series of highly specialised tissue known as spinal meninges, which will be discussed in greater detail later on in this chapter, and is suspended comfortably within the vertebral canal in cerebrospinal fluid (CSF) (Martini and Nath, 2009; Moore et al., 2010).

2.3.1 Organisation of the Spinal Cord

The spinal cord is organised into two distinct regions based on the appearance of the colour, these regions are known as the gray and white matter:

1. Gray Matter
   The gray matter surrounds the central canal of the spinal cord and is predominantly made up of the cell bodies, neuroglia, of unmyelinated neurons. The cell bodies of the neurons are organised into functional groups known as nuclei. There are both sensory and motor nuclei. Figure 2.6 demonstrates the organisation of the nuclei as seen through a cross section of the spinal cord. The posterior gray horns contain both somatic and visceral sensory nuclei. The lateral gray horns contain the visceral motor nuclei, but is only found in the thoracic and lumbar regions (Martini and Nath, 2009; Moore et al., 2010). The anterior gray horns contain the somatic motor nuclei. At each level of the spine, the same areas can be identified. The lamina are numbered from I-X as seen in Figure 2.6 (Latash, 2008). The gray matter facilitates spinal cord reflex (Guyton and Hall, 2011).

2. White Matter
   The white matter is divided into regions known as columns or funiculi. The 3 columns that make up the white matter are the posterior white column, the
lateral white column and the anterior white column. The columns contain tracts which are made up of bundles of myelinated axons. The axons that run in the same tract will all convey similar information. Smaller or shorter tracts carry motor or sensory signals between various segments of the spinal cord, while the longer tracts carry information from the spinal cord to the brain. Sensory information is conveyed from the spinal cord to higher processing centres via ascending tracts while motor information travels from higher processing centres to the spinal cord via descending tracts. The white and gray matter of the spinal cord is so highly organised that it is quite simple to predict the result of an injury to a specific segment (Martini and Nath, 2009; Moore, et al., 2010).

Figure 2.6: Cross section of the spinal cord showing the gray and white matter as well as the rexed lamina (Accessed from: http://what-when-how.com/neuroscience/the-spinal-cord-organization-of-the-central-nervous-system-part-1/).

2.3.2 Spinal Nerves

A spinal cord segment, is the portion of the spinal cord that gives rise to a set of anterior and posterior rootlets that merge to form one bilateral pair of spinal nerves. They arise in bilateral pairs form specific spinal segments. There are 31 spinal cord segments and 31 pairs of spinal nerves. The spinal nerves, which are mixed nerves (carrying both motor and sensory
fibres), exits the vertebral column via the intervertebral foramina (Moore et al., 2010). The anterior or ventral nerve roots are made up of motor or efferent fibres that arise from anterior horn of gray matter and run to effector organs.

The posterior or dorsal roots are made up of sensory or afferent fibres from cell bodies in the dorsal root ganglion that extend peripherally to the sensory receptors and proximally to the posterior horn of gray matter. As spinal nerves exit the intervertebral foramen they divide into anterior and posterior branch. These branches are known as the anterior primary rami and the posterior primary rami. These spinal nerves extend into the periphery where they relay motor and sensory information between the peripheries to the spinal cord (Martini and Nath, 2009; Moore et al., 2010).

Figure 2.7: Diagram illustrating the formation of spinal nerves and the composition of the spinal meninges (Moore et al., 2010).
2.3.3 The Meninges

The meninges are a group of highly specialised membranous coverings that surround the brain and spinal cord as seen in Figure 2.7. Their main function is to protect the delicate nervous tissue but it also provides a supporting framework for arteries veins and venous sinuses. The meninges also forms a space known as the subarachnoid space which contains cerebral spinal fluid (CSF) which is vital for neural tissue survival.

There are 3 main layers that make up the meninges, these are, from outermost to innermost layer, the dura mater, the arachnoid mater and finally the pia mater. The outer layer, the dura mater, is a tough and fibrotic membrane. The dura mater is separated from the periosteal covered bone of the vertebral canal by what is known as the epidural space. This space contains the internal vertebral plexus as well as a large amount of fatty matrix tissue, providing extra support.

The second layer, the arachnoid mater, is a delicate and avascular layer. It is made up of primarily fibrotic and elastic tissue. It also lines the spinal dural sac as well as the dural root sheaths. It encloses the CSF filled subarachnoid space that contains the spinal cord, nerve roots as well as the spinal ganglia (Moore et al., 2010). The 3rd and final layer, the pia mater is the membrane covering the spinal cord. This layer is thin and transparent and can also been seen covering the rootlets that emerge from the various spinal segments.

2.3.4 The Dentate Ligament

The dentate ligaments are fibrotic extensions of the pia mater extending from either side of the spinal cord. The right and left dentate ligaments run longitudinally down the entire length of the spinal cord. There are 21 bilateral pairs that extend from C1 caudally down to L1. The ligaments, which are tooth-like in shape, firmly anchor and suspend the spinal cord within the vertebral column. According to Middleditch and Oliver (2005), the dentate ligaments play an important role in transmitting tension from the dura mater to the spinal cord especially during flexion where it prevents excessive elongation of the spinal cord.
2.3.5 Spinal Reflexes

Spinal reflexes range from a simple reflex that would involve a single segment of the spinal cord to a more complicated reflex that would involve multiple segments or levels of the spine. These more complicated reflexes are known as intersegmental reflex arcs. Intersegmental reflex arcs are responsible for producing coordinated and highly variable motor responses, such as kicking or catching a ball (Martini and Nath, 2009).

An example of a simple reflex is the stretch reflex. This type of reflex is also known as a monosynaptic reflex. This reflex provides automatic regulation of the length of skeletal muscle. This occurs when a stimulus activates a sensory neuron. The sensory or afferent fibres in turn, activates an immediate response that counteracts the stimulus (Martini and Nath, 2009). The receptors responsible for the stretch reflex are known as muscle spindles and will be discussed in detail later on in the chapter.

Polysynaptic reflexes on the other hand, are capable of producing more complex movements. This is due to the presence of interneurons which are able to control multiple muscle groups. The interneurons produce inhibitory or excitatory postsynaptic potentials at central nervous system motor nuclei which means that the response can involve the stimulation of some muscles and the inhibition of others (Martini and Nath, 2009). Higher processing centres can have an important effect on the final outcome of a reflex by either inhibiting or facilitating a motor reflex pattern. This is made possible due to the descending tracts that originate in the brain and then synapse on motor neurons and interneurons throughout the spinal cord (Martini and Nath, 2009).

2.4 The Sensory System

The sensory part of the nervous system is the part that detects changes of any type within the internal and external environment. It then relays the information accordingly, so that a change may be brought about via the motor system, ensuring homeostasis. The sensory system is often referred to as the afferent system. There are multiple components that make
up the sensory system, but only the components relative to this study will be discussed in detail.

### 2.4.1 Afferent Fibres

Afferent fibres, also known as sensory fibres, carry information away from sensory receptors toward the spinal cord. Afferent fibres enter the spinal cord via the dorsal roots to enter the spinal cord at dorsal horns. There are different classes of afferent fibres, classed according to their function and conduction speeds. Table 2.1 shows a detailed summary of the types of afferent fibres as well as the structures innervated. Afferent fibres are generally classed into A or C fibres. A fibres are further subdivided into α, β, γ or δ fibres. A fibres, which are myelinated, are the medium to larger size fibres that have higher conduction velocity speeds, while C fibres are the smaller unmyelinated fibres with a lower conduction velocity speed.

<table>
<thead>
<tr>
<th>Group</th>
<th>General Classification</th>
<th>Structure Innervated</th>
<th>Sensations Carried</th>
<th>Myelination</th>
<th>Fibre Diameter (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>(Aα)</td>
<td>Muscle spindles, primary endings</td>
<td>Proprioception</td>
<td>Myelinated</td>
<td>≈17</td>
</tr>
<tr>
<td>Ib</td>
<td>(Aα)</td>
<td>Golgi tendon organ</td>
<td>Proprioception</td>
<td>Myelinated</td>
<td>≈16</td>
</tr>
<tr>
<td>II</td>
<td>(Aβ &amp; γ)</td>
<td>Muscle spindles, secondary endings</td>
<td>Proprioception Deep pressure &amp; touch</td>
<td>Myelinated</td>
<td>≈8</td>
</tr>
<tr>
<td>III</td>
<td>(Aδ)</td>
<td>Muscle deep pressure endings</td>
<td>Deep pressure &amp; touch Pricking Pain</td>
<td>Myelinated</td>
<td>≈3</td>
</tr>
<tr>
<td>IV</td>
<td>(C)</td>
<td>Nociceptors</td>
<td>Crude touch &amp; Pressure Tickle Aching Pain Temperature</td>
<td>Unmyelinated</td>
<td>≈ 0.5-2</td>
</tr>
</tbody>
</table>

**Table 2.1: Summary of the afferent fibres (Guyton and Hall, 2011; Latash, 2008).**
Figure 2.8 shows where the various afferent fibres enter the spinal cord via the dorsal horns. The small group III and IV fibres terminate in rexed lamina I and II. A α fibres terminate in lamina III-IV, while the large group Ia and II afferent terminate anywhere from lamina V-IX.

Figure 2.8: Diagram illustrating where the afferent fibres enter the spinal cord through the dorsal horns (Latash, 2008).

2.4.2 Sensory Receptors

Sensory receptors are responsible for detecting various stimuli from the external environment and relaying the information to the central nervous system. Receptors are highly specialised in order to pick up the many different various types of stimuli.

Guyton and Hall (2011), have identified 5 basic types of sensory receptors:

1. Mechanoreceptors, which detect any type of mechanical compression, stretching or distortion that may occur within a tissue or surrounding tissue, they therefore have an important role in proprioception.
2. Thermoreceptors, which detects even the slightest change in temperature.
3. Nociceptors, also known as pain receptors, pick up any damage, whether mechanical or chemical, within the tissue and relay this information to higher processing centres in the form of pain signals.

4. Electromagnetic receptors, these are located within the eye and pick up changes with regards to the amount of light arriving at the retina.

5. Chemoreceptors pick up changes regarding the chemical composition within the body.

For the purpose of this research study, only mechanoreceptors and nociceptors will be discussed in greater detail as they are deemed relevant for the understanding of how afferent information reaches the spinal cord.

a) Articular Neuroreceptors

There are 4 types of neuroreceptors that have been identified in the viscoelastic structures of the vertebral column, all picking up different stimuli and therefore all serving unique purposes. The first 3 types are mechanoreceptors while type IV is a nociceptor.

1. Type I mechanoreceptors, also known as ruffini endings or Golgi tendon organs, are globular or oval in shape. They are located within the outer portion of joint capsules, skeletal periosteum as well as in tendons and ligaments. These mechanoreceptors have a low threshold, which means they are extremely sensitive and are therefore easily stimulated in response to any change in tension within the joint capsule. They are also classed as static and dynamic receptors as they are continually monitoring the position of the joint, even if there is little to no movement happening at the joint. They also monitor any type of intra-articular pressure changes. This gives type I receptors an important function in maintaining and regulating posture by having a tonic effect on the lower motor neuron pool. These receptors also assist with inhibiting pain signals from reaching higher processing centres via inhibiting interneurons at the spinal cord level. Type I receptors are innervated by group Ib afferent fibres. (Bergmann and Peterson, 2011; Gatterman, 2005).
2. Type II mechanoreceptors, also known as Pacinian and Krause corpuscles, are cylindrical in shape and located within the deeper, dense connective tissue layers of the joint capsules (Guyton and Hall, 2011). Like type I, type II mechanoreceptors have a low threshold but they do not fire continuously. That is, type II receptors are only stimulated by a moving joint and are therefore classed as dynamic receptors. These receptors are responsible for monitoring all movements as well as perceptual sensations, particularly with the Z-joints. These receptors also have a pain inhibiting function similar to that of type I receptors (Bergmann and Peterson, 2011). Depolarization of these receptors results in a transient alteration in muscle tone due to a reflex motor unit discharge arising from the movement within the joint capsule. Type II receptors are innervated by group II afferents.

3. Type III mechanoreceptors functions are poorly understood. These mechanoreceptors are predominantly located within the intrinsic and extrinsic ligaments of peripheral joints. A study conducted in 1994 found that there were, in fact, type III receptors located within the joint capsules of the cervical spine (McLain, 1994). These receptors are slow adapting and have a high threshold, which means they are not easily depolarised. Although not fully understood, their functions include monitoring the direction of movement as well as identifying potentially harmful movements by creating a reflex effect on segmental muscle tone by providing a braking mechanism (Bergmann and Peterson, 2011). These receptors are innervated by group Ia afferents.

4. Type IV receptors are nociceptors that are composed of a network of free nerve endings and unmyelinated fibres. They are responsible for monitoring any mechanical or chemical damage that may be present within a tissue. Nociceptors are located through the joint capsule, surrounding ligaments as well as synovial folds. There are, however, no nociceptors located within the articular cartilage or synovial lining of the Z-joints. These receptors have a high threshold and are therefore only activated in the presence of mechanical or chemical damage of surround tissues or structures (Bergmann and Peterson, 2011). Nociceptors are innervated by group IV afferent fibres (Gatterman, 2005).
b) Muscle Spindles

Muscle spindles are sophisticated structures located within muscle fibres that let other neurons with the CNS know the length and velocity of that corresponding muscle fibre. They are the main receptors involved in the stretch reflex (Martini and Nath, 2009). Muscle spindles have an elongated shape (Figure 2.9) with a thicker midsection, giving them the spindle looking shape. The spindles are vastly scattered amongst muscle fibres. Each muscle spindle has both intrafusal and extrafusal muscle fibres. Intrafusal muscle fibres are specialised fibres that are situated parallel to the power-producing extrafusal muscle fibres.

The middle part of the muscle spindle is encapsulated with a thin layer of connective tissue (Latash, 2008). The intrafusal muscle fibres are connected at both ends to either extrafusal fibres. This therefore allows the intrafusal fibre to shorten or lengthen in response to what is occurring at the extrafusal fibres. Muscle spindles are innervated by both group Ia and II afferents (Martini and Nath, 2009).

![Image: Anatomy of a muscle spindle](https://example.com/image.png)

Figure 2.9: Anatomy of a muscle spindle (Martini and Nath, 2009).
2.4.3 The Sensory Pathways

Figure 2.10 is a cross section through the spinal cord showing the anatomy and distribution of the ascending sensory tracts. There are 3 main sensory pathways which will be discussed.

![Figure 2.10: Cross section of the spinal cord showing the ascending tracts (Guyton and Hall, 2011).](image)

a) Dorsal Column-Medial Lemniscal System

The Dorsal Column-Medial Lemniscal System is also commonly known as the posterior column pathway. This pathway, which is composed of large myelinated fibres, carries fine touch, pressure, vibration and proprioception. This pathway begins at a peripheral receptor and ends at the primary sensory cortex of the cerebral hemisphere. The fibres enter the spinal cord via the dorsal roots where they divide into a medial and a lateral branch. The medial branch proceeds almost immediately up the dorsal column up to the brain. The spinal tracts that make up the dorsal column are known as the fasciculus gracilis and the fasciculus cuneatus. These two tracts are located on either side of the median sulcus.

The fasciculus gracilis, which is located more medially to the posterior median sulcus, carries sensory information from spinal nerves below T6. The lateral fasciculus cuneatus, relays sensory information from spinal nerves above T6, as seen in figure 2.11 (Guyton and Hall, 2011; Martini and Nath, 2009). The lateral branches divide many times and give rise to terminal branches that synapse with local neurons in the middle and anterior portions of the
gray matter. Some of these fibres will travel up the dorsal column, while others terminate locally within the gray matter of the spinal cord to illicit local responses (Guyton and Hall, 2011).

The axons of the first order neurons carrying the sensations via the dorsal column, will synapse at the nucleus gracilis or nucleus cuneatus, depending from which part of the body the information is coming. Information from the bottom half of the body (below T6) will travel up the fasciculus gracilis and therefore synapse on the nucleus gracilis while sensory information arriving from the top half of the body will travel up via the fasciculus cuneatus and synapse on the nucleus cuneatus. Both nuclei are located within the medulla oblongata. This synapse gives rise to the second order neurons, which will then decussate, or crosses over to the opposite side of the spinal cord, where the axons enter into the medial lemniscus. The axons will then ascend from the medial lemniscus up into the thalamus where they will synapse at the ventrobasal complex. This gives rise to the 3rd order neurons, which then takes the information to the primary sensory cortex which will then process the information and issue an appropriate response (Guyton and Hall, 2011; Martini and Nath, 2009).
b) The Spinothalamic Pathway

The spinothalamic pathway (Figure 2.12) carries sensory information regarding crude touch, pressure, pain and temperature. This tract has two divisions, the anterior spinothalamic tract and the lateral spinothalamic tract. These tracts are named according to their location within the white matter of the spinal cord. The anterior spinothalamic tract carries crude touch and pressure whereas the lateral spinothalamic tract carries pain and temperature sensations.
The axons of first order synapse on the second order neurons as they enter the spinal cord. The second order neurons ascend up to the thalamus where the thalamus will sort and process the information and relay it to the sensory cortex accordingly via the 3rd order neurons (Martini and Nath, 2009). The second or third order neurons determine what type of sensation is felt, while the sensory cortex localises or isolates what region that stimulus was coming from.

Figure 2.12: The spinothalamic pathway (accessed from: http://classroom.sdmesa.edu/eschmid/Chapter10-Zoo145.htm).
c) The Spinocerebellar Pathway

The spinocerebellar pathway carries proprioceptive information from structures like, skeletal muscle, tendons and joints. This proprioceptive information never reaches our conscious awareness, that is, it is not processed by the primary motor cortex. The axons of the first order neurons synapse on the interneurons located in the dorsal horn of the gray matter before ascending up the pathway to the cerebellum. The spinocerebellar pathway has two distinct tracts: the anterior and the posterior spinocerebellar tracts. The anterior spinocerebellar tract is primarily made up of axons that have crossed over to the opposite side of the spinal cord, although it does contain axons from the same side of the spinal cord as well. The tract ascends to the cerebellar cortex via the superior cerebellar peduncle (Martini and Nath, 2009).

![Figure 2.13: The spinocerebellar pathway (Martini and Nath, 2009).]
2.5 The Motor System

The motor system or also known as the efferent system, is the part of the nervous system that brings about a change in response to the afferent information. The somatic motor system is responsible for controlling skeletal muscles to contract. The somatic motor pathway will always involve at least 2 motor neurons, an upper and lower motor neuron. The upper motor neuron is situated within the CNS and a lower motor neuron is situated within the nucleus of the brain or spinal cord. The upper motor neuron will synapse on the lower motor neuron and this will then innervate a motor unit within that specific muscle. The lower motor neuron may be inhibited or excited in response to the upper motor neuron (Martini and Nath, 2009).

2.5.1 Efferent Fibres

Efferent or motor fibres, are the fibres that make up the motor system. These fibres carry motor commands from the spinal cord to skeletal muscle. These neurons that originate in the anterior horns of the gray matter, give rise to nerve fibres that exits the spinal cord via the ventral rootlets known as anterior motor neurons. Figure 2.14 shows the connection between a motor tract, the interneurons and the anterior motor neurons.

![Diagram illustrating the connection between the peripheral sensory fibres, interneurons and anterior motor neurons](image)

*Figure 2.14: Diagram illustrating the connection between the peripheral sensory fibres, interneurons and anterior motor neurons (Guyton and Hall, 2011).*
According to Guyton and Hall (2011), there are two types of motor neurons: alpha motor neurons and gamma motor neurons. Type A alpha (A\(\alpha\)) motor neurons are relatively large motor neurons with an average diameter of 14 micrometres. These neurons innervate skeletal muscle by activating a motor unit. A motor unit is formed by hundreds of muscle fibres grouped together. The second type of efferent fibres, type A gamma motor neurons (A\(\gamma\)), are much smaller in diameter, with an average diameter of 5 micrometres, innervate the intrafusal muscle fibres found within the muscle spindle. These efferent fibres are responsible for controlling muscle tone (Guyton and Hall, 2011).

2.5.2 Motor Pathways

Skeletal muscles are controlled by conscious and subconscious commands that travel in one of three pathways: the corticospinal pathway, the medial pathway and finally the lateral pathway. Figure 2.15 is a cross section of the spinal cord showing the locations and distributions of the descending motor tracts. The main tracts will be discussed in detail below.

![Figure 2.15: Ascending and descending motor tracts in the spinal cord (Martini and Nath, 2009).](image)
a) The Corticospinal Pathway

The corticospinal pathway is also known as the pyramidal system because the pathway begins with neurons originating at the pyramidal cells located within the primary motor cortex, premotor and supplementary areas as well as from the somatosensory areas posterior to the central sulcus (Guyton and Hall, 2011). The axons will descend into the brain stem and spinal cord and go on to synapse on the lower motor neuron that will cause contraction of a specific skeletal muscle. The corticospinal pathway contains three pairs of descending tracts: the corticobulbar tracts, the lateral corticospinal tracts and lastly the anterior corticospinal tracts. All 3 of these tracts enter the white matter of the internal capsule where they descend into the brain stem and emerge in the mesencephalon as the cerebral peduncles.

1. The Corticobulbar Tract
The axons of the upper motor neurons of the corticobulbar tract synapse with lower motor neurons in the motor nuclei of cranial nerves III-VII, IX, and XI-XII. Most of the tract fibres cross over in the midbrain and terminate on the contralateral cranial motor nuclei. This tract provides conscious control over the muscles that move the eye, jaw, face and some muscles of the neck. This tract also innervates certain motor centres of the medial and lateral pathways.

2. Anterior and Lateral Corticospinal Tract
Axons in the anterior and lateral corticospinal tracts synapse on lower motor neurons located in the anterior horns of the gray matter of the spinal cord. As these two tracts descend down the medulla oblongata, they can be seen as pyramids on the ventral surface. At roughly the midline of the medulla oblongata, approximately 85% of the fibres will cross over to the other side, this is known as the decussation of the pyramids. It is after the decussation, where the lateral and anterior corticospinal tracts become apparent as seen in Figure 2.16. The anterior corticospinal tract is made up from the 15% of fibres that did not cross over while the lateral corticospinal tract is comprised mainly of the decussated fibres.
The axons in the anterior tract will cross over to the opposite side of the spinal cord in the anterior white commissure once the axons has reached its target segment.

Figure 2.16: The corticospinal pathway (accessed from: http://what-when-how.com/wp-content/uploads/2012/04/tmp14104_thumb2.jpg).
b) Medial Pathway

This pathway, which carries motor commands processed at a subconscious level, is mainly concerned with the control of muscle tone and gross movements of the muscles of the proximal limbs, neck and trunk. The upper motor neurons can be found within vestibular nuclei, the superior and inferior colliculi as well as the reticular formation. This gives rise to 3 smaller tracts named according to the location of their nucleus.

1. Vestibulospinal Tract
   The vestibular nuclei, located at the border of the pons and the medulla oblongata, give rise to axons that descend down the spinal cord and it is these fibres that constitutes the vestibulospinal tract. This tract is responsible for conveying motor commands that will change the position of the head, neck, arms and trunk as well as controlling the muscle tone related to these structures.

2. Tectospinal Tracts
   The tectospinal tracts originate at the tectum, or roof of the mesencephalon where the superior and inferior colliculi are located. The superior colliculi receives visual sensations and the inferior colliculi receives auditory sensations. The axons, formed by the upper motor neurons, descend in the tectospinal tract, and terminates on lower motor neurons located within the anterior horns of gray matter, but this is limited to the cervical spine region. The axons cross over nearly immediately before descending and direct reflexive changes in the position of the head, neck and limbs in response to sudden movements or loud noises (Martini and Nath, 2010).

3. Reticulospinal Tracts
   The reticulospinal tract originates within the reticular formation, which is a collection of loosely organised neurons that extends throughout the brainstem. The reticular formation receives input from most pathways, both ascending and descending. As a result, it has multiple connections with the nuclei of the cerebellum, cerebrum and
brainstem. The axons do not cross over as they descend down the spinal cord. The tract terminates with lower motor neurons located within the anterior horns of gray matter (Martini and Nath, 2010).

c) Lateral Pathway

This pathway also known as the rubrospinal tract, carries information processed at a subconscious level but it is more concerned with the control of muscle tone and precise movements of the distal parts of the limbs. The upper motor neurons originate at the red nuclei, located within the mesencephalon. The axons cross over to the opposite side of the spinal cord at the level of the brainstem where the axons then descend in the rubrospinal tract. This tract is relatively small and terminates at the cervical region of the spinal cord (Martini and Nath, 2009; Moore et al., 2010; Guyton and Hall, 2011).

2.6 Motor Control and Motor Behaviour

Motor control is the scientific field of study that deals with the understanding of the neural, physical and behavioural aspects of human movement (Lee and Schmidt, 2011). Motor control takes into account the sensory information that will need to be processed by the central nervous system in order to produce a co-ordinated movement (Lee and Schmidt, 2011; Shea and Wright, 1997). Motor behaviour, which is closely associated to motor control, is an area of study that mainly stresses the principles of human skilled movement generated at a behavioural level of analysis (Lee and Schmidt 2011). Understanding movement can be a complex topic as there are multiple factors that govern it.

According to Latash (2008), motor control is concerned with the study of action. The action, however, will be influenced by the external environment the individual finds oneself in. As a person performs an action, that person is continually gathering sensory information about the position of their body in relation to the external environment, so it would be safe to assume that motor control also includes the study of perception. Cognitive processing is also required in order to organise all the information in order to produce the action.
2.7 Neuroanatomy Involved in Motor Control

2.7.1 The Cerebrum

The cerebral cortex or the cerebrum, the largest part of the human brain is largely responsible initiating any type of voluntary movements (Guyton and Hall, 2011). The cerebral cortex is divided into right and left cerebral hemispheres. The cerebral hemispheres are covered by a layer of gray matter known as the neural cortex. The neural cortex is arranged in a series of elevated ridges that are known as gyri, thus giving the cerebral cortex a large surface area. The gyri are further separated by sulci which are large shallow depressions (Martini and Nath, 2009; Moore et al., 2010). The cerebrum is mainly responsible for processing somatic sensory and motor information (Martini and Nath, 2009).

The cerebral hemispheres are divided up into lobes or regions and are named according to the overlying bones of the skull. The lobes contain functional regions that are responsible for processing and coordinating a person’s intellectual thoughts and movements (Martini and Nath, 2009). It is also important to note that each cerebral hemisphere receives sensory information and issues motor commands. The right cerebral cortex will control movements on the left hand side of the body and vice versa, this cross over make up however has no known functional significance (Martini and Nath, 2009).

The two regions that is relevant to this research are the somatosensory cortex and the motor cortex. These two regions work in conjunction with one another as the somatosensory cortex provides the motor cortex with the information needed in order to initiate a motor activity (Guyton and Hall, 2011).

2.7.2 The Motor Cortex

The motor cortex is divided up into 3 district regions: the premotor area, the primary motor cortex and the supplementary motor area. The primary motor cortex is located within the frontal lobes anterior to the central sulcus. More than one half of the entire primary motor cortex is responsible for controlling the muscles of the upper limb, hands and the muscles
that control and regulate speech production (Guyton and Hall, 2011). The neurons located within the primary motor cortex are responsible for controlling voluntary movements by controlling somatic motor neurons located within the brainstem and spinal cord (Martini and Nath, 2009). The neurons of the motor cortex are specific, which means that a specific neuron will cause contraction of a specific muscle when stimulated (Martini and Nath, 2009).

The premotor area lies 1-3 cms anterior to the primary motor cortex. This area is responsible for producing and coordinating learned movements. The nerve signals that are generated within this area are therefore responsible for generating complex patterns of movements, as opposed to the simple or basic movements produced by the primary motor cortex (Guyton and Hall, 2011). The premotor area generates task specific movements, such as the movements required to complete the Fitts’ Law task.

The supplementary area lies mainly in the longitudinal fissure. This area mainly causes movements that involve contraction of both sides, like that of an action similar to climbing. This area works in close conjunction with that of the premotor area to provide body movements such as positional movements of the eyes and fixation movements of the various limbs, to name just a few (Guyton and Hall, 2011). This area along with the aforementioned areas, all work together in order to provide the precise and fine movements produced by the hand and fingers (Guyton and Hall, 2011).

The motor cortex also contains areas of highly specialized regions which control very specific motor functions. Researchers have identified these regions by means of electrical stimulation (Guyton and Hall, 2011). The specialised areas relevant to this study are the head rotation area as well as the area for hand skills. Dum & Strick (2005) have found evidence that suggests the primary motor cortex, the premotor area and the supplementary area form an interconnected network which allows specific and precise hand movements.
2.7.3 Association Areas

Association areas connect the motor and sensory areas with one another. These regions of the cortex interpret all incoming information or produce a motor response. This area is connected to the motor and sensory cortex by means of association fibres. There are a number of association areas which have specific functions. For example, the visual association area will monitor and interpret all activity related to vision (Martini and Nath, 2009).

2.7.4 The Cerebellum and Basal Ganglia

The cerebellum play a vital role in motor control. Although the cerebellum on its own cannot produce a movement it works in conjunction with other systems in order to produce accurately timed movements as well as assist in ensuring muscle movements are rapid and smooth while progressing through the movement. The cerebellum is most active during movements such as running, typing or even playing the piano. The cerebellum receives a constant influx of both motor and sensory information including updated proprioception. The cerebellum then compares the information to assess whether or not the two sets of information are compatible or not. If the information is found to be incompatible, subconscious corrective signals are transmitted back to the motor system to rectify the movement (Guyton and Hall, 2011).

The cerebellum also assists the cerebral cortex to produce a smooth and coordinated movement between the various muscles that have been activated. The cerebellum is also able to learn from its mistakes. When a mistake has been made, changes occur within the excitability of the cerebellar neurons that will bring about a change within the muscle to achieve a better movement (Guyton and Hall, 2011). The cerebellum is actively involved in the process of motor learning as well as in sensorimotor integration of afferent input from the Z-joints of the vertebral column (Daligadu, Haavik, Yilder, Baarbe and Murphy, 2013). It has been suggested that the cerebellum regulates activity and assists with motor learning through the formation of internal schema and network connections that ultimately decide what movements are required in order to execute a motor task (Daligadu et al., 2013).
The basal ganglia is another accessory motor system that cannot function independently. It works in conjunction with the cerebral cortex and the corticospinal tract. The basal ganglia receives most of its information from the cerebral cortex (Guyton and Hall, 2011).

2.8 Measuring Motor Skills

According to Lee and Schmidt (2011), measuring motor control and motor behaviour can be assessed in three different manners. The first level of analysis is one that involves describing how well a movement was performed, or the outcome of an intended movement. The second level of analysis assess how a movement was performed by evaluating the biomechanics involved in performing the movement. The 3rd and final level of analysis is concerned with the activity of the Central Nervous System (CNS) during the various stages of movement, including the time prior to the time the movement is executed.

When describing the outcome of a movement, one will usually assess how well the movement was executed. For example, if a task requires the performer to hit a target, as in the case of a Fitts’ law task, the evaluation of the movement will most certainly include whether or not the target was in fact hit. If the performer failed to hit the desired target it can be said that they completed the desired task inaccurately. The outcome will also assess the speed and accuracy at which the performer managed to complete the desired movement. Lee and Schmidt (2011), have stated that there are four fundamental ways in which these factors can be measured to assess the overall outcome of a movement. The first two factors will be discussed in this section.

The first factor that can be assessed is by measuring error. What this entails is assessing if the performer executed a movement with maximum accuracy. A measure of error is represented by the degree that the target was not achieved. The second class of possible factors used to determine the outcome of a movement is measuring the time and speed taken to execute a movement. Two valid and reliable methods of measuring time and speed is by testing for reaction time as well as movement time (Lee and Schmidt, 2011).
2.8.1 Movement Time

Movement time (MT) may be defined as the time taken to complete a predefined motor task (Davis and Fang, 2010). Movement time measures the interval between the initiation of a movement and its termination (Lee and Schmidt, 2011). Movement time differs to that of reaction time as it starts at the initiation of movement up until the movement has been completed, rather than at the start of the prompt. MT can be any value, ranging from just a few milliseconds for a quick movement such as in a Fitts’ law task, to a slightly larger value in a 100m sprint. MT can be used in skills research due to its overall external validity in practical settings (Lee and Schmidt, 2011).

There was research conducted in 2010 showing that individuals with chronic neck pain have larger MT than individuals who don’t (Descarreaux et al., 2010). In general, the smaller the movement time, the quicker the action or task was performed. However, when assessing the speed of a task, the accuracy at which the task is performed is often compromised. A well-known phenomenon in motor behaviour that describes this relationship is known as the speed-accuracy trade-off. This name implies that performers must trade off speed in order to increase accuracy or trade off accuracy to increase speed (Shea and Wright, 1997). MT can be predicted by Fitts’ Law, which is a mathematical relationship describing speed and accuracy of motor skill performance (Fitts, 1954; Lee and Schmidt, 2011).

2.8.2 Fitts’ Law

Fitts’ law has proven to be a successful model of human motor behaviour (Bi, Li and Zhai, 2013; Boyle and Shea, 2011). Fitts (1954) reported the results of three experiments on target acquisition performance showing that: the performance capacity of the human motor system plus its associated visual and proprioceptive feedback mechanisms, when measured in information units, is relatively constant over a considerable range of task conditions (Fitts, 1954). Fitts’ law models rapid, aimed, movements, where one appendage (like a hand) is used to complete a predefined motor task. The task needs to be completed by aiming at specific targets within a specific target area (Mackenzie and Soukreff, 2015). MT is mathematically described as:
**MT** = \( a + b \log_2 \left( \frac{2A}{W} \right) \)

**ID** = \( \log_2 \left( \frac{2A}{W} \right) \)

In Fitts’ law, \( a \) is the intercept and represents the movement time when the index of difficulty (ID) is equal to zero, constant \( b \) represents the change in movement time associated with 1 unit change in index of difficulty and thus is the slope. \( A \) is amplitude of the distance between targets and \( W \) is the width of the targets (Fitts, 1954; Descarreaux et al., 2010). The ID implies that, the higher the ID, the more difficult the task will be to complete as more time will be required in order to complete the task accurately. Figure 2.17 shows the linear relationship between the movement time and the ID.

![Figure 2.17: Average movement time (MT) as a function of the index of difficulty, (Schmidt and Lee, 2011).](image)
2.9 Motor Control Theories

To successfully perform any type of movement or motor skill, we need to coordinate multiple joints and muscles to function together (Astill and Utley, 2008; Magill, 2004). Any movement that a person makes has to be carefully planned, constructed and finally executed. Motor control theories attempt to describe and explain how the nervous system is able to produce these movements (Magill, 2004). Most theories relating to motor control incorporate 2 basic systems of control, the closed loop control system and the open loop control system. These systems attempt to describe the basic mechanism in which the CNS and PNS initiate, control and regulate movement (Magill, 2004).

2.9.1 Closed-Loop Control System

In order to understand motor control, it is imperative to take into account the sensory contributions that govern the outcome of the intended movement. Closed loop systems are of particular importance as they are able to control themselves by the continual feedback that is given from the environment. Figure 2.18 is a diagram illustrating how a basic closed system works.

The reference mechanism is fed information regarding the final goal via a stimulus. The reference mechanism will then sample the environment in which it is trying to control, and will obtain feedback. The reference mechanism then compares the value of the goal obtained from sampling the environment and computes a degree of error. This degree of error represents the difference between the actual and desired states. This information will be passed along to an executive level to a control centre, where a decision will be made in how to reduce the degree of error, if applicable. Instructions usually reach the effector level by means of muscles or the action the muscle performed. Proprioceptive input is then sent back to the reference mechanism and decisions about future actions can be made. This type of system is known as a closed loop system because the loop of control from the environment to decisions to actions and back to the environment is completed (Lee and Schmidt, 2011).
2.9.2 Open-Loop Control System

In an open loop control system, the behaviour is not sensitive to feedback which means that the instructions for a particular movement are structured in advance and is not dependant on the environment. Figure 2.18 is a diagram representing a basic open loop system. The input for a specific goal reaches the control centre. The information is processed and then the effector will carry out the desired goal. The feedback coming from the environment is not being used to change the action, so this means that the effector will carry out the same action, regardless what may have changed within the environment. It has been suggested that ballistic movements, or movements that are performed very quickly and as a result not allowing for correction during the movement, use the open loop control system as they are pre-programmed.

![Diagram illustrating open and closed loop systems (Lee & Schmidt, 2011).](image)

2.10 The Vertebral Subluxation Complex

The vertebral subluxation complex (VSC) is a theoretical model that describes the consequences of a dysfunctional motion segment. This model has various components, each describing the pathological changes that subluxation, or segmental dysfunction, has on the 3 joint complex. This model provides insight into the foundations and principles that govern the chiropractic theory. Figure 2.19 is a schematic drawing depicting how the various
components of the VSC interact with one another in the presence of subluxation or restriction.

![Figure 2.19: The vertebral subluxation complex](http://www.chiro-online.com/lc/principles/module3/module3_6.html)

2.10.1 The Kinesiological Component

Kinesiology is the field of study that addresses the physiological, mechanical and psychological mechanisms that govern movement. This component describes the consequences that occur due to abnormal movement between motion segments. A motion segment within the vertebral column is often referred to a 3 joint complex. A 3 joint complex is made up of the 2 articulating Z-joints, the articulation between the end plates and the intervertebral discs as well as all the surrounding tissues (Gatterman, 2005). This component also describes that a dysfunctional motion segment at one level, can lead to other levels, especially the one directly above and below, also becoming dysfunctional due to the fact they are a part of a kinematic chain (Levangie and Norkin, 2013).
Altered movement between motion segments alters the spinal mechanics of that motion segment due to a change in sensory input from surrounding paraspinal and spinal tissues (Bergman and Peterson, 2011). This mechanical component of joint dysfunction is considered as a major source of not only pain, but also a potential source to spinal degeneration (Bergmann and Peterson, 2011).

There are 2 models that attempt to explain the pathological and degenerative changes that occur in response to segmental dysfunction. The first model, known as the Gillet model, considers joint dysfunction to develop as a result of 3 various phases of joint fixation. The fixations include a muscular, ligamentous and articular component. Gillet hypothesised that the muscular fixation was due to segmental muscle hypertonicity and contraction. The ligamentous fixation was due to shortening and tightening of the joint capsule and surrounding ligaments and the articular fixation was due to the fibrotic adhesions located between the articular surfaces (Bergmann and Peterson, 2011).

The second model, known as the Kirkaldy-Willis of spinal degeneration focuses on the fact that spinal degeneration often begins with local mechanical derangement without structural alteration being present, in other words, joint hypomobility is thought to initiate the degenerative cycle by altering the segmental biomechanics of the joint (Bergmann and Peterson, 2011). If the hypomobile joint persists, it leads to abnormal repetitive loading, which in turns leads to fatigue and degenerative changes of the surrounding tissues. This causes the capsules to become lax and the IVD to become disrupted and eventually making the joint unstable. The joint will eventually stabilize itself through the deposition of fibrotic tissue and the formation of osteophytes (Bergmann and Peterson, 2011; Gatterman, 2005).

### 2.10.2 The Neurological Component

The neurological component discusses the theory of intervertebral encroachment and nerve root compression. It was first hypothesized that subluxations induced nerve root compression as a result of direct anatomic compression of the neurovascular bundle within the intervertebral foramen (IVF), and it is the compression of the nerve root that induced a
loss of function (Bergmann and Peterson, 2011). This theory has however, received a large amount of scepticism outside the chiropractic profession (Bergmann and Peterson, 2011).

The intervertebral foramen, as discussed earlier on in this chapter, provides a passageway in which the spinal nerves may exit from the spinal cord. The IVF also have an important protective function; it protects the lateral aspect of the spinal cord, the dorsal root ganglia as well as other neurovascular structures passing through the IVF (Bergmann and Peterson, 2011; Gatterman, 2005).

The dorsal root ganglion (DRG) is a collection of the cell bodies of the sensory neurons and is located within the IVF in close proximity to the articular capsule. The DRG and associated spinal nerve rootlets lack the epineural covering that covers the peripheral nerves and thus makes these structures more susceptible to pressure, ischemia and inflammation. Prolonged misalignment or inflammation of a segment may alter the integrity of the structures within the IVF and thus alter the blood supply to these structures. Compression or inflammation will lead to a change within the blood supply and cause localised ischaemia (Bergmann and Peterson, 2011).

2.10.3 The Histological Component

Joint hypomobility or immobilization has been identified as being the primary contributor for inducing degeneration of the 3 joint complex. The degeneration that occurs also effects the integrity of the histological components around the spinal cord (Bergmann and Peterson, 2011).

Synovial fluid undergoes fibro-fatty consolidation, with progressive adherent fibrous tissue formation prone to calcium deposits, as seen in the final stages of joint ankylosis. Shrinking and softening of the articular cartilage occurs as a result of decreased proteoglycans. The lack of proteoglycans make the articular cartilage more vulnerable to damage. This leads to the articular surfaces becoming ulcerated which, in turn, leads to intra-articular joint
disruption and eventually the formation of subchondral bone cysts. Once the subchondral bone has been exposed to the fibro-fatty synovial fluid, this eventually results in intra-articular ossification (Bergmann and Peterson, 2011).

The ossifications that have formed between the intra-articular and juxta-articular structures become evident as a result of immobilization. Adhesions may form not only between the nerve root sleeve and the adjacent osseous and capsular structures in the intervertebral canal, but also between joint capsules and contiguous ligaments or tendons. With regards to bone, abnormal distribution of stress from hypomobility alters the mineral deposition. In areas of increased stress, the body responds by enhancing bone deposition in the form of osteophytes, whereas non-weight bearing segments squander the normal and necessary osseous sedimentation (Bergmann and Peterson, 2011; Gatterman, 2005).

2.10.4 The Myological Component

The musculoskeletal system clearly defines the interdependent relationship between the dynamic function muscles portray in relation their corresponding joints. In fact, the process of immobilization in joints as seen in the VSC, consequently results in disuse atrophy. Although these changes in muscle function are almost completely reversible, the time required to obtain complete resolution of muscle function is directly dependant on the duration of the immobilization period (Bergmann and Peterson, 2011; Gatterman, 2005).

The second phase of the Kirkaldy-Wills’ model stipulates that there is a period of joint hypermobility in response to the initial hypomobility. This hypermobile phase predisposes the joints to developing ligamentous and capsular laxity resulting in an increased translation between articulating surfaces and ultimately a loss in joint coherence and integrity (Gatterman, 2005).

The dynamic stabilisers which include the surrounding musculature attempts to counteract the extreme joint range of motion, but continuous stabilization is not the primary function of
skeletal muscles and causes muscle fatigue as their metabolism can’t sustain the increased demand. The muscular fatigue results in a tetanic or continuous contraction and evidently an abnormal metabolism will generate copious amounts of waste products, in turn stimulating chemoreceptors and nociceptors (Gatterman, 2005).

2.10.5 The Vascular Component

Each nerve root depends on a single radicular artery for nutritional purposes. These radicular arteries pass through the intervertebral foraminae, endangering and possibly compromising nerve root blood supply. The existence of collateral blood supply does offer some safety but the assurance for sufficient provision is considered remote. Venous congestion is also a contributing factor regarding elevation in intraforaminal pressure (Gatterman, 2005).

Anatomically, the radicular and intervertebral veins are positioned adjacent to the osseous border of the IVF. This signifies that any form of osteophytic alterations within the foramen would induce compression upon the venous structures. The elasticity of venous walls enables the veins to tolerate a minimal amount of pressure, but venous wall expansion will consequently apply pressure to spinal nerve roots and the dorsal root ganglia (Bergmann and Peterson, 2011; Esposito and Philipson, 2005; Gatterman, 2005).

2.10.6 The Inflammatory and Biochemical Component

The inflammatory response is a result of cellular and biomechanical processes that are mediated by the vascular system but initiated in response to a disruption in the histological tissues. One of the cardinal manifestations on inflammation is pain, which occurs in response to the activation of chemoreceptors and nociceptors, but also in response to the presence of bradykinin, an inflammatory mediator (Bergmann & Peterson, 2011; Gatterman, 2005).

The arthritic degeneration implicated with the VSC model produces a condition where an inflammatory response ensues as a result of structural deterioration within a joint known as
osteoaarthritis. The disruption within the intra-articular disruption stimulates an inflammatory influx, which attempts to remove debris and other toxic metabolites from the affected area and permits fibrotic tissue deposition to take place.

Considering a joint virtually becomes immobilized in the re-stabilisation phase of Kirkaldy-Willis model, chronic intra-articular deterioration becomes evident as well as the inflammation becomes chronic. Continuous fibrotic tissue infiltration from continual remodelling leads to synovial tissue hyperplasia, loss of articular space, subchondral erosion and cyst formation. The fibrous invasion eventually impeded synovial vascularity, further provoking the inflammatory cascade with eventual fibrotic ankylosis as the final outcome (Bergmann and Peterson, 2011; Gatterman, 2005).

2.11 Spinal Manipulative Therapy

Spinal manipulative therapy, a type of manual therapy often used by chiropractors, is a physical type of therapy designed to induce joint motion by applying a thrust to that joint. The thrust is typically a high velocity low amplitude thrust. Manipulation is used to treat disorders relating to the neuromusculoskeletal system, to reduce pain and also to restore range of motion in joints that are restricted (Bergmann and Peterson, 2011). Bergmann and Peterson (2011) have the following definition for manipulation, “A specific form of joint manipulation using either long-or short-leverage techniques with specific anatomic contacts.”

2.12 The Effects of Spinal Manipulative Therapy

2.12.1 Mechanical Effects of Spinal Manipulative Therapy

The spine is a malleable construct and manipulative therapy applied to the spine will facilitate physiological and mechanical deformation to improve function and flexibility. Several structures including muscles, tendons, ligaments, bones, discs, articular cartilage all form part of the internal structural design of the body and the spine and chiropractic manipulations mechanically affects all of these structures, either directly or indirectly (Herzog, 2000).
Soft tissue derangement is primarily responsible for mechanical dysfunction and common phenomena like trauma, repetitive motion injuries, postural decompensation, developmental anomalies, immobilization and degenerative conditions have all been identified as contributing factors. As previously discussed, peri-articular fibrosis and adhesions develop as a result of joint hypomobility, manipulative therapy applies distractive forces on the joint capsule and peri-articular soft tissue and breaks intra-articular capsular adhesions, ultimately restoring proper joint mobility and function (Bergmann and Peterson, 2011).

Spinal manipulation produces an audible sound known as a cavitation. This sound is produced when a facet joint surpasses the elastic barrier as well as overcoming the intra-articular synovial fluid tension when a quick and dynamic thrust has been applied to that joint. The cavitation is the result of carbon dioxide gas forming bubbles within the joints semi-viscous synovial fluid. A manipulation marginally separates the articular surfaces and stretches the joint capsule, therefore increasing the volume of the joint, creating a negative intra-articular pressure (Cramer, Ross, Pocius, Cantu, Laptook, Fergus, Gregerson, Selby and Raju, 2011; Bergmann and Peterson, 2011).

Segmental muscle spasms and joint dysfunction presents frequently as a collective unit. This pattern is consequently evident as muscles not only impart movement, but impede movement as well. Articular mobility depends on the synergistic equilibrium maintained between agonistic and antagonistic muscles. An impairment or alteration of any muscle creates compensatory changes within the kinematic chain which results in limited range of motion with associated joint restrictions. Spinal manipulation eliminates the physiological musculoskeletal constraints by restoring joint function and motion as well as re-establishing proper kinematic function (Bergmann and Peterson, 2011).

2.12.2 Neurophysiological Effects of Spinal Manipulative Therapy

If there is any abnormality in the anatomy, physiological or biomechanical dynamics of the vertebrae, these abnormalities may have an adverse effect on the nervous systems function (Pickar, 2002). SMT has the ability to correct any of those abnormalities. Chiropractors
mostly use the high velocity, low amplitude impulse thrust method of spinal manipulation to correct areas of spinal dysfunction. When SMT is delivered to a joint, it has a mechanical effect at that joint.

The mechanical force introduced into the vertebral column during a spinal manipulation may directly alter segmental biomechanics by releasing trapped meniscoids, releasing adhesions or by reducing the distortion of the annulus (Pickar, 2002). Biomechanical changes caused by the manipulation in turn have a physiological effect as it effects the inflow of sensory information to the central nervous system (Pickar, 2002).

The biomechanical changes that occurs to a vertebral segment due to spinal manipulation affects neural input which subsequently alters central processing and affects reflex somatomotor or somatovisceral output (Dishman, Ball and Burke, 2002; Pickar, 2002). This may explain the mechanisms responsible for the effective relief of pain and restoration of functional ability documented following spinal manipulation (Haavik-Taylor and Murphy, 2007a, b and c). Haavik-Taylor and Murphy (2007a, b, and c) have also conducted research that suggests SMT may cause changes with the processing of sensory information, motor excitability and reflex excitability.

2.12.3 The Effects of Spinal Manipulative Therapy on the Somatosensory System

The exact mechanism that is responsible for reducing pain and restoring functional abnormalities following SMT is poorly understood (Haavik Taylor and Murphy, 2008). According to Haavik-Taylor and Murphy (2008), there is a limited amount of research that accurately describes and explains the neurophysiological effects of SMT.

A dysfunctional spinal segment as in the case of a subluxation or vertebral restriction has a negative effect on the central neural processing by altering the afferent or sensory input into the central nervous system. Altered afferent input over time leads to plastic changes within the CNS (Haavik-Taylor and Murphy, 2008). The plastic changes could then result in an
abnormal response of the CNS in response to afferent input. There have been subsequent studies done that suggest SMT delivered to a dysfunctional joint has an impact by altering the central processing of afferent information and thus sensorimotor integration.

Haavik-Taylor & Murphy (2010a and b), have done extensive research on the effects that cervical SMT has on central integration of dual somatosensory input. They concluded that dysfunctional segments that received SMT showed a remarkable change in the cortical processing and sensorimotor integration as seen by amplitude changes measured by somatosensory evoked potentials (SEP). A SEP is an electrical potential elicited by stimulating the somatosensory receptors either by a physiological or electrical stimulation. This type of stimulation has been used in clinical trials to show how cortical processing is altered (Tinazzi et al., 2000).

Haavik-Taylor & Murphy (2010a and b) concluded that SMT delivered to dysfunctional segments within the cervical spine resulted in the CNS changing its response to a motor task. They were therefore able to conclude that SMT leads to an improved ability to integrate dual input from the upper limb. SMT amongst other neurophysiological responses, alters sensorimotor integration as well as changes the way in which the CNS responds to a motor training task (Haavik-Taylor, 2010a and b).

Somatosensory information is vital for motor control and can be integrated at multiple levels within the CNS ranging from a simple reflex loop to a more complex that involves the cortical and subcortical levels (Haavik-Taylor and Murphy, 2010a and b). Sensorimotor circuits form part of the sensorimotor integration system. The sensorimotor integration system is responsible for continuously monitoring and responding to all peripheral input. It responds to these changes by altering the connectivity and the strength of the synaptic connections within the axons of the neurons. These changes however can also be due to injury and therefore the changes can then be considered to be neural plastic changes (Haavik-Taylor and Murphy, 2010a and b).
Sensorimotor integration (SMI) is the process in which the CNS processes and coordinates all incoming sensory information from all aspects of the body and in turn integrates with the various components of the motor system to control and produce movements (Haavik-Taylor and Murphy, 2010a and b).

2.12.4 The Effects of Spinal Manipulative Therapy on Motor Control

Studies have shown that there are acute alterations in motor neuron pool activity following spinal manipulation in asymptomatic individuals (Cardinale, Boccia, Greenway, Evans and Rainoldi, 2014). SMT has been known to affect neural outputs to the manipulated section of the spine due to the alternation in the motor neuron pool activity (Christou et al., 2005). Neural input activity to the \( \alpha \) motor neuron pool in the spinal cord controls the motor unit activity of a muscle. Muscle spindle afferents and Golgi tendon organ afferents are also stimulated by spinal manipulation. Spinal manipulation also has the ability to alter how pain signals are processed by altering the central facilitated state of the spinal cord as well as it can affect the motor control system (Pickar, 2002).

Areas of spinal dysfunction, or joints that are restricted, contain altered afferent inputs which has been shown to be a cause of central plastic changes. Altered afferent feedback from an area of spinal dysfunction alters the afferent fibres environment into which subsequent afferent feedback from the spine and limbs is received and processed (Haavik and Murphy, 2012). There have been studies using transcranial magnetic stimulation that show manipulating dysfunctional segments in the cervical spine can alter sensorimotor integration of input from the upper limb (Haavik and Murphy, 2012).

SMT as well as spinal mobilization has been shown to induce a physiological change that affects the functioning of the central nervous system including the reflex excitability, cognitive processing, sensory processing as well as motor output (Daligadu et al., 2013).
2.12.5 The Effects of Spinal Manipulative Therapy on Movement Time

A pilot study conducted in 2006 by Smith et al., wanted to investigate the effect of chiropractic manipulations on movement time. The study was a randomised controlled trial that used 10 participants who were allocated to either the control group, or non-intervention group and an experiment group. The results of the study that all participants in the experiment group had significantly lower movement times following SMT in comparison to only 1 participant of the control group. The average improvement in MT for the experimental group was 183 ms or a total of 9.2% improvement. The control group only showed a 29 ms improvement or a 1.7% increase. Smith et al., (2006) concluded that spinal manipulative therapy may influence motor control. The study however failed to isolate which region, if any, receiving SMT yielded a better result.

2.13 Conclusion

This chapter discussed the growing body of evidence suggests that the presence of spinal dysfunction of various kinds has a negative effect on central neural processing. It also emphasized that in the presence of continued spinal dysfunction it is more likely to be the cause of changing the afferent input to the CNS. Any change to the afferent input to the CNS will then cause neural plastic changes. Altered afferent input from joints can lead to both inhibition and facilitation of neural input to related muscles. Spinal dysfunction alters the balance of afferent input to the CNS and over a period of time results in neural plastic changes.

Spinal manipulation of dysfunctional segments alters sensorimotor integration at the cortical level of the CNS. This concept help explains why SMT is able to relieve pain as well as improve range of motion.
CHAPTER THREE: METHODOLOGY
3.1 Introduction

This chapter discusses the process in which the participants were recruited, selected and placed within their respective groups. This chapter also discusses, in detail, how the participants were assessed, tested and treated.

3.2 Study Design and Selection Criteria

This was a controlled explorative clinical study using random group allocation.

3.2.1 Participant Recruitment

Participants for this research study were recruited by means of advertisements (Appendix A). These advertisements were distributed around the University of Johannesburg Doornfontein Campus as well as placed on notice boards at the day clinic located on campus. Participants were also recruited by word of mouth. All assessments and treatments pertaining to this study took place at the University of Johannesburg Chiropractic Day Clinic under the supervision of qualified Chiropractors.

3.2.2 Sample Selection and Size

One hundred willing participants between the ages of 18 and 45 were recruited for this study. Participants were either male or female. The willing participants, who met the inclusion criteria, were then invited to take part in the study. The researcher explained in detail what would be required from each participant. Before the researcher commenced with any assessment or treatment, the participants were required to read the information form (Appendix B) and sign the consent form (Appendix C).

There were 4 groups in this research study. Group 1 was the combination group and received SMT to vertebral restrictions located within the cervical, thoracic and lumbar spine regions. Group 2 received SMT to restrictions located within the cervical spine only. Group 3 received
SMT to restrictions located within the thoracic spine only while the 4th and final group received SMT to restrictions located within the lumbar spine.

3.2.3 Inclusion Criteria

In order for a potential participant to have been included in the research study, the participant needed to adhere to the following criteria:

- Be between the ages of 18 and 45.
- Be either male or female.
- Must be right handed as the input device was designed for right handed individuals.
- Have positive results for cervical, thoracic and lumbar spine restrictions as assessed by motion palpation which included (Docrat, Lakhani and Nook, 2009):
  - End-feel restriction within the joint.
  - Loss of springy joint play within the joint.
  - Decreased segmental range or motion.

3.2.4 Exclusion Criteria

Participants were excluded from the study if they presented with any of the following criteria:

- Participants who were not able to perform daily activities such as standing, sitting or walking.
- Any participant who was visually or audibly impaired as they needed to complete a computer related task that requires both senses.
- Any participant who showed any contra-indication to spinal manipulative therapy (Appendix D).
• Any participant who had received chiropractic treatment or any type of spinal manipulative therapy within the past 24 hours.

• Any individual who was participating in another research study as that may have compromised the results of this study.

3.2.5 Random Group Allocation

Participants who were eligible to take part in this study were randomly allocated into 1 of 4 groups. The researcher prepared a box that contained 100 folded up pieces of paper bearing the numbers 1, 2, 3 or 4. These numbers represented the previously described groups. The participant selected a piece of paper and was placed into a group accordingly.

3.3 Treatment Approach

3.3.1 Initial Consultation

This study required participants to undergo a single once off treatment. No follow up visits were required. The initial consultation (Figure 3.1) commenced once the participant had read the information form and signed the consent form. During the consultation the researcher performed the following:

• An explanation of how the research would be performed and what would be expected from each participant.

• A complete case history (Appendix E).

• A complete physical examination (Appendix F).

• A cervical spine regional (Appendix G).

• A lumbar spine regional (Appendix H).
• Assessed for vertebral restrictions in the cervical, thoracic and lumbar/sacroiliac regions as per motion palpation techniques.

By performing the above mentioned procedures the researcher was able to assess whether a participant may have exhibited any contra-indications to SMT. The researcher then recorded all findings in the S.O.A.P note (Appendix I).

The participants were then required to complete 2 tests before they received treatment, these tests, the Fitts’ Tapping Task (FTT) (Appendix J) and the computerised Fitts’ Law test, The Generalized Fitts’ Law Model Builder (GFLMB) (Appendix K- N), will be discussed later on in this chapter. Once they had completed the first set of tests, they were adjusted accordingly and then repeated the two tests again.
Figure 3.1: Summary of the treatment protocol.
3.3.2 Motion Palpation

Palpation is a skill that manual therapists learn that requires both extensive psychomotor training as well as a thorough understanding of the functional anatomy, biomechanics as well as the pathomechanics of the region being assessed (Bergman and Peterson, 2011). Motion palpation of the spine is a diagnostic procedure that chiropractors and other manual therapists use to determine tenderness, shape, size, consistency, position and the mobility of the tissues beneath the surface of the skin.

Motion palpation specifically assesses for intersegmental hyper/hypomobility by placing the joint into its maximal end range of motion and then assessing for the end feel (Hansen, Simonsen and Leboeuf-Yde, 2006). There are two main types of motion palpation, namely static and dynamic motion palpation. Static motion palpation, as its name suggests, is motion palpation that is performed while the participant’s joints are in a stationary position.

Dynamic motion palpation is when the participant is moving by either an active or a passive movement while the researcher is assessing for the movement of the joint as well as assessing for the end feel (Bergmann and Peterson, 2011). Motion palpation was used to assess for the presence or absence of restrictions. The researcher used motion palpation to assess the cervical, thoracic, lumbar spine and sacroiliac regions.

a) Motion Palpation of the Cervical Spine

Due to the anatomical make-up of the cervical spine, the researcher assessed the cervical spine for restrictions in the following manner according to Schafer and Faye (1989):

- C0/C1 for rotation.
- C0/C1 for flexion & extension.
- C0/C1 for lateral flexion.
b) Motion Palpation of the Thoracic Spine

The thoracic spine was assessed in the following manner:

- T1-T12 for rotation.
- T1-T12 for flexion & extension.
- T1-T12 for lateral flexion.

c) Motion Palpation of the Lumbar Spine

The Lumbar spine was assessed in the following manner:

- L1-L5 for rotation.
- L1-L5 for flexion/extension.
- L1-L5 for lateral flexion.

d) Motion Palpation of the Sacroiliac Joint

The sacroiliac joint was assessed in the following manner:

- Upper SIJ for flexion & extension.
- Middle SIJ for flexion & extension.
- Lower SIJ for flexion & extension.
3.3.3 Treatment

Following all the necessary diagnostic assessments and tests, the researcher adjusted the participants according to their specific groups. Group 1 which was the combination group, received spinal manipulative therapy to restrictions found within the cervical, thoracic and lumbar spine regions. Group 2 received spinal manipulative therapy to restrictions located within the cervical spine. Group 3 received spinal manipulative therapy to restrictions located within the thoracic spine and the 4th and final group received spinal manipulative therapy to restrictions located within the lumbar spine.

The researcher used the Diversified Chiropractic Technique, which uses high velocity low amplitude impulse thrusts delivered to restricted segments as assessed by motion palpation techniques described by Schafer and Faye (1989). Once the spinal manipulation had been performed, all participants were required to complete the 2 tests again. All assessments and manipulations took place at the Chiropractic day clinic under the supervision of qualified chiropractors.

3.4 Subjective Data

There was no subjective data collected in this research.

3.5 Objective Data

Fitts’ Law has been proven to be a valid and reliable tool in measuring movement time (Fitts’, 1954). Fitts’ Law is one of only two laws in the field of Human Motor Behaviour and can be used as an objective performance outcome measure for spinal manipulation (Passmore and Descarreaux, 2012). Fitts’ tasks are well suited to pre- and post-intervention studies, as performance on them is resistant to learning effects (Lee and Schmidt, 2011; Passmore and Descarreaux, 2012). MT is a quantifiable measure that may be used in a clinical or research setting (Davis and Fang, 2010).
Objective data was obtained using The Generalized Fitts’ Law Model Builder (GFLMB) and the Fitts’ Tapping Task. The GFLMB is a software tool which allows the experimenter to design experiments, capture data, and build models using Fitt’s law. The GFLMB measured MT in milliseconds and has been proven valid and reliable for research purposes (MacKenzie and Soukoreff, 2015). The GFLMB records all data, including error rates. The Tapping Task measured movement time in seconds. The data was collected and compiled into an EXCEL spreadsheet so that STATKON could analyse the data for statistical purposes.

3.5.1 Fitts’ Tapping Task

Participants were required to perform a Fitts’ Tapping Task (FTT). The participants were required to use a pen and tap from one box to another over a period of 10 seconds. A stop watch was used to time the participants for the 10 second period. Table 3.1 summarizes the 9 test conditions that are determined by the difference in size of the targets (W) as well as by the distances from one another (D). The participants were urged to move as quickly as possible between the targets but were also encouraged to remain as accurate as possible by not overshooting the targets.

The amounts of taps back and forth were counted as the total number of taps. Every tap that fell outside the target box was measured and calculated as a percentage error by taking the total number of errors divided by the total number of taps multiplied by 100. The final number of accurate taps was determined by subtracting the number of errors from the total number of taps. Information was collected and substituted into Fitts’ formula to calculate movement time. The total number of accurate taps was divided by 10 to get an average time in seconds between each tap. FTT has no angular targets. All participants were required to perform the tapping task before treatment was administered as well as immediately after receiving treatment.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Target Distance (D)</th>
<th>Target Width (W)</th>
<th>Ratio (D)/(W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>1</td>
<td>8</td>
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<tr>
<td>8</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

### 3.5.2 Generalized Fitts’ Law Model Builder

The generalised Fitts’ law model builder is a computerised Fitts’ Law task and is an alternative method to assess MT. Participants were seated behind a laptop where they sat arm’s length from the monitor. This task required the participant to use a mouse to move the cursor from one circular target to another (Figure 3.2). There was a total of 4 separate test conditions each containing 25 trials (Appendix K-N). A single trial consisted of moving the cursor from one circle to another circle.

The trial commenced at the start of the click on the first target and the click on the second target terminated the trial. The timing between the two clicks on the targets measured the movement time in milliseconds (ms). The participant needed to move between the two targets as quickly and as accurately as possible. If the participant missed the target, the participant heard an error beep, and that data was also recorded.
The target diameter and width between the two targets was also adjusted so that various indices of difficulty may be achieved. There were 25 trials per index of difficulty. Table 3.2 gives a summary of the experiment parameters. A total of 4 ID’s were tested as it has been shown that performance differs over various ID’s (Boyle and Shea, 2011).

![Figure 3.2: Example of a test condition for the GFLMB.](image)

Table 3.2: Summary of the test conditions for GFLMB.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Index of Difficulty</th>
<th>Amplitude</th>
<th>Width</th>
<th>Number of Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ID=4</td>
<td>300</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>ID=3</td>
<td>300</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>ID=5</td>
<td>500</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>ID=3.5</td>
<td>500</td>
<td>50</td>
<td>25</td>
</tr>
</tbody>
</table>

3.6 Data Analysis
The objective data was collected by the researcher during the study period. The data was analysed by a statistician at STATKON (located at the University of Johannesburg Kingsway Campus).

3.6.1 Tests for Normality

The Shapiro-Wilk Test was used to determine whether the data-set followed a normal distribution or not. This test was used due to the fact that the groups each contained less than 50 participants. A p-value greater or equal to 0.5 \((p>0.05)\) indicated a normal distribution of the data with the sample group while a p-value less than or equal to 0.5 \((p\leq0.05)\) showed an abnormal distribution of the data within the sample group. Assessing whether or not the data follows a normal distribution helps one into deciding whether parametric or non-parametric testing should be used, based on normality assumption.

3.6.2 Data Distribution within the Fitts’ Tapping Task

The Fitts’ tapping task test had 9 separate conditions, as described in chapter 3. For each condition, the participant was required to tap in between a set of boxes while being timed for a period of 10 seconds. The number of taps was recorded. If the participant overshot one of the targets, the missed tap/s was subtracted from the original number to give a final accurate number of taps. The accurate number of taps was then divided by 10 to give a final result of accurate number of taps per second (taps/s). Movement time was thus analysed using the accurate number of taps per second. The number of missed taps was calculated into an error percentage and also considered within the dataset. For the Fitts’ Tapping Task, two variables were analysed, as discussed below:

1) Accurate taps per second: The Shapiro-Wilk test showed an inconsistent distribution of the data amongst the 4 groups over the 9 conditions pre and post SMT as both \(p>0.05\) and \(p\leq0.05\) values can be seen.
2) Error percent: The Shapiro-Wilk test showed that there was an abnormal distribution of the data amongst the 4 groups over the 9 conditions as most values were $p \leq 0.05$, indicating the data was not normally distributed.

3.6.3 Data Distribution within the Generalized Fitts’ Law Model Builder

The generalized Fitts’ law model builder (GFLMB) had 4 separate test conditions, as previously discussed. For each test condition, the participants were required to move between 25 targets while being timed. The GLFMB calculated the average time, in milliseconds; it took the participant to complete the motor task, or to move between 2 targets. MT was thus analysed using the average time in milliseconds. Any missed targets was also recorded by the program and calculated into an error percentage, which was also included into the data set. For the GFLMB, two variables were analysed, as discussed below:

1) MT in milliseconds: The Shapiro-Wilk test showed an inconsistent distribution of the data amongst the groups over the 4 test conditions as there were both $p > 0.05$ and $p \leq 0.05$ values.

2) Error percent: The Shapiro-Wilk test showed an inconsistent distribution of the data amongst the groups over the 4 test conditions as there were both $p > 0.05$ and $p \leq 0.05$ values.

3.6.4 Non-Parametric Tests

Non-parametric test do not make assumptions about the populations from which they have been drawn. These types of tests are the preferred test when samples, such as the samples sizes related to this study, are being tested. These tests are also used when the tests for normality do not show a normal distribution. Non-parametric testing will be used to analyse the results of this study for the following reasons:

1) Shapiro-Wilk Test for all 4 parameters showed an abnormal distribution.
2) The group samples are small, all containing 25 participants

3) There are multiple outlying data points within the dataset which need to be considered in the evaluation.

a) Wilcoxon Signed Rank Test

This is non-parametric test that is generally used when subjects are measured on different occasions, in this case, before receiving treatment and again after receiving treatment. The test converts the data into ranks and compares these ranks at 2 intervals, namely time 1 and time 2, to assess for a change. The Wilcoxon Signed Rank Test will be used for intragroup analysis, or to assess whether a change within a group has taken place. The 2 values that are important to consider when reporting the outcome of this test are the Z values and the associated significance values. These 2 values are useful when reporting on the effect size, which will be discussed later.

b) Kruskal-Wallis Test

This non-parametric test is also referred to as the one-way ANOVA on ranks. It is used to determine if there are statistically significant differences between 2 or more groups of an independent variable on a continuous or dependent variable. If the results of this test show a statistically significant result, post hoc testing would be warranted as this test is not able to tell you which specific groups of the independent variable are statistically significant from one another (Pallant, 2007). This test will therefore be used for intergroup analysis of the 2 tests.

3.7 Ethical Considerations

All participants that took part in this particular study was requested to read the information form and sign the consent form specific to this study. The information and consent forms outlined the names of the researcher, the purpose of the study and the benefits of taking part in the study, the participant assessment and the treatment procedure. Any risks, benefits
and discomforts pertaining to the treatments involved was clearly explained to the participants. The researcher took all the necessary precautions to ensure that the participant’s safety was ensured (prevention of harm). The safety of the participants was considered a primary concern and preservation of its value was kept in a high regard.

The participant’s privacy was protected as only the researcher and patient was present in the treatment room. The anonymity was ensured as the patient information was converted into data and therefore cannot be traced back to the individual. No personal information about the participants was revealed in any document relating to the final dissertation thus ensuring no traceability or identification of anyone involved. The participants were informed that their participation was on a voluntary basis and that they were free to withdraw from the study at any stage. If the participant had any further questions, those questions were explained thoroughly by the researcher, whose contact details were made available to all the participants. The participants were then required to read the information and sign the consent form, signifying that they understand all that was required of them for this particular study. Results of this study were made available to the particular individual if they so requested.

With regards to this particular study, the risks and discomforts included post adjustment tenderness and soreness. The participants were also warned that they may experience some discomfort during motion palpation especially if the researcher has located any tender areas. The most common risk that is associated with SMT, especially SMT of the cervical spine, is the potential injury to the vertebral artery and its subsequent effects on vertebrobasilar blood supply. However SMT is considered to be a safe and effective treatment protocol for dysfunctional spinal segments. The benefits of this study may reveal that SMT may have a beneficial effect on motor control by decreasing the MT.

Participants would have been referred for further assessment had the researcher picked up anything of concern while assessing the participants through the case history, physical exam or spinal regional exams. The researcher also emphasized to the participants that they
should inform the researcher if they had experienced any discomfort at all, even the days following treatment, so that the researcher could take the appropriate and necessary steps to ensure to refer the participant where necessary.

This research study was approved by the Faculty of Health Sciences Higher Degrees Committee (Appendix O) and the Academic Ethics Committee (Appendix P).

This dissertation has also been submitted to an anti-plagiarism software, Turnitin, with a value of 12% (Appendix Q).
CHAPTER FOUR:

RESULTS
4.1 Introduction

This chapter provides a detailed description of the statistical data recorded throughout the duration of the research study.

The objective data was collected and analysed by STATKON for the following purposes:

- Demographics: Was used to analyse the age and gender distribution amongst the sample as well as for the individual groups.
- Tests for normality: The Shapiro-Wilk test was used to test the groups for normality as each group contained less than 50 participants. This test is used to assess whether the group’s data followed a normal distribution.
- Paired –samples or repeated measures techniques: Non-parametric testing was used to compare the results pre and post treatment as the tests for normality showed an inconsistent distribution. This type of testing was also considered due to the small sample sizes within each group (N=25). There were also multiple outliers within the dataset, which the non-parametric tests take into account by using the median instead of the mode to compare and determine results. The Wilcoxon Signed Rank Test was used for intragroup analysis, while the Kruskal-Wallis Test was used for intergroup analysis.
- Effect size: The effect size was used to determine which group yielded greater results following SMT.

The p-value or sig. is a measure of the strength of the evidence against the null hypothesis, or the probability of getting the observed value of the test statistic. The p-value tells us how likely it is to get a result if the null hypothesis were true. A p-value of $p \leq 0.05$ is considered to be a statistically significant value as it provides evidence against the null hypothesis, or that the observed results are not due to chance. If the p-value was $p > 0.05$, it would suggest evidence for the null hypothesis and therefore is considered to be statistically insignificant.
4.2 Demographics

The sample group consisted of 100 participants (N=100), who were randomly allocated into 1 of 4 groups, giving each group a total of 25 participants. All four groups received treatment, but the treatment was directed to various regions, as discussed in chapter 3. All participants performed the two objective tests, the Fitts’ Tapping Task (FTT) and the computerized Fitts’ law test, the GFLMB before receiving treatment and repeated the two tests again after treatment.

4.2.1 Gender Analysis

Table 4.1: Summary of the demographic data showing the age and gender distribution amongst the 4 groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>N= No of participants</th>
<th>Mean age (years)</th>
<th>Standard deviation</th>
<th>Minimum age</th>
<th>Maximum age</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>24,44</td>
<td>3,83</td>
<td>18</td>
<td>40</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>27,32</td>
<td>2,70</td>
<td>23</td>
<td>32</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>23,16</td>
<td>2,75</td>
<td>18</td>
<td>31</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>24,28</td>
<td>2,69</td>
<td>20</td>
<td>31</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Entire sample</td>
<td>100</td>
<td>24,80</td>
<td>3,36</td>
<td>18</td>
<td>40</td>
<td>48</td>
<td>52</td>
</tr>
</tbody>
</table>

Group 1, the combination group, had a male to female distribution of 44% to 56%, Group 2, the cervical spine group, had a male to female distribution of 52% to 48%. Group 3, the thoracic group, had a male to female distribution of 56% to 44% while the last group, the lumbar spine group, had a male to female distribution of 40% to 60%. The overall male to female distribution for the entire sample was 48% to 52%. The Pearson Chi-Square Test was used to evaluate whether or not the gender distribution amongst the groups was evenly distributed and showed that it was as $p=0.66$, or statistically insignificant ($p>0.05$).
4.2.2 Age Analysis

Group 1, the combination group had an average age of **24.44 years**. The range of the group was between 18 and 40 years of age. Group 2, the cervical spine group had an average age of **27.32 years**. The range of the group was between 23 and 32 years of age. Group 3, the thoracic spine group had an average age of **23.16 years** of age. The range for group 3 was between 18 and 31 years of age. The fourth and final group had an average age of **24.28 years**. The range for group 4 was between 20 and 31 years of age.

The mean age for the entire sample (N=100) was **24.80 years**. The minimum age was 18 and the maximum age was 40. Group 2 had a slightly larger mean age in comparison than the other 3 groups, as seen in Figure 4.1. The One Way ANOVA Test was used to assess whether there was a statistical significance in the mean age between the groups. The test gave a statistically significant result of **p=0.00**. This implied that there was an alteration in the normal distribution of the ages between the groups.

![Figure 4.1: The mean age value amongst the 4 groups.](image-url)

Figure 4.1: The mean age value amongst the 4 groups.
4.3 Intragroup Analysis for Fitts’ Tapping Task

The Wilcoxon Signed Ranks test was used to for all four groups, to assess whether a change had taken place between time 1 (T1) and time 2 (T2) following spinal manipulative therapy. T1 was the median score obtained before any intervention, or SMT, had been administered, while T2 was the median score obtained following SMT. The Wilcoxon Signed rank test was used to test the two independent variables, the accurate taps per second and the error rate. The results for each group over the 9 conditions is discussed below.
4.3.1 Intragroup Analysis for the Fitts’ Tapping Task for Group 1

a) Accurate number of taps per second (taps/s)

Table 4.2: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the accurate number of taps per second over the 9 conditions pre and post manipulation for group 1.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median (Taps per second)</th>
<th>Z-Value</th>
<th>p-value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SMT (T1)</td>
<td>Post SMT (T2)</td>
<td>Difference (T2-T1)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.30</td>
<td>2.70</td>
<td>0.4</td>
<td>-3.94</td>
</tr>
<tr>
<td>2</td>
<td>2.80</td>
<td>3.50</td>
<td>0.7</td>
<td>-3.25</td>
</tr>
<tr>
<td>3</td>
<td>4.10</td>
<td>4.40</td>
<td>0.3</td>
<td>-3.71</td>
</tr>
<tr>
<td>4</td>
<td>2.40</td>
<td>2.50</td>
<td>0.1</td>
<td>-1.69</td>
</tr>
<tr>
<td>5</td>
<td>3.00</td>
<td>3.50</td>
<td>0.5</td>
<td>-3.23</td>
</tr>
<tr>
<td>6</td>
<td>3.90</td>
<td>4.60</td>
<td>0.7</td>
<td>-3.91</td>
</tr>
<tr>
<td>7</td>
<td>2.10</td>
<td>2.50</td>
<td>0.4</td>
<td>-3.71</td>
</tr>
<tr>
<td>8</td>
<td>2.60</td>
<td>3.40</td>
<td>0.8</td>
<td>-4.19</td>
</tr>
<tr>
<td>9</td>
<td>3.80</td>
<td>4.40</td>
<td>0.6</td>
<td>-3.32</td>
</tr>
</tbody>
</table>

The Wilcoxon Signed rank test revealed a statistically significant increase in the accurate number of taps per second following SMT for condition 1. The median score was 2.30 taps/s pre intervention and increased by 0.40 to 2.70 taps/s following SMT with a p-value of p=0.00. Condition 2 had a median score of 2.80 taps/s at time 1 (T1), with an increase of 0.70 taps/s to give a median score of 3.50 taps/s at time 2 (T2), following SMT, thus giving a statistically significant result of p=0.00.

Condition 3 had a median score of 4.10 taps/s at T1 and increased by 0.3 taps/s to 4.4 taps/s at T2 following SMT with p=0.00, thus giving a statistically significant result. Condition 4 had a median score of 2.40 taps/s at T1 and saw a small increase of 0.1 taps/s following SMT to give a median score of 2.50 taps/s at T2. This change was, however, not sufficient
to give a statistically significant result as the p-value was \( p=0.09 \). Condition 5 had a median score of 3.00 taps/s at T1. Following SMT, the median score increased by 0.5 taps/s to give a median score of 3.50 taps/s at T2, thus giving a statistically significant result, \( p=0.00 \).

Condition 6 had a median score of 3.90 taps/s at T1 and saw an increase of 0.70 taps/s to give a median score of 4.60 taps/s at T2 with a p-value of \( p=0.00 \), thus giving a statistically significant change. Condition 7 had a median score of 2.10 taps/s at T1 and increased to 2.50 taps/s, following SMT thus yielding a statistically significant result of \( p=0.00 \).

Condition 8 had the largest median score increase of 0.80 taps/s between T1 and T2 for the 9 conditions. Condition 8 had a median score of 2.60 taps/s at T2 and a median score of 3.40 taps/s at T2 with a p-value, \( p=0.00 \), thus giving a statistically significant change following SMT. The final condition, condition 9, saw a 0.60 taps/s increase from 3.80 taps/s at T1 to 4.40 taps/s at T2 yielding a statistically significant result of \( p=0.00 \).
b) Error rate (%)

Table 4.3: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the error rate measured as a percentage over the 9 conditions pre and post manipulation for group 1.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median (Error %)</th>
<th>Z-Value</th>
<th>p -value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SMT (T1)</td>
<td>Post SMT (T2)</td>
<td>Difference (T2-T1)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0,00</td>
<td>3,33</td>
<td>-1.02</td>
<td>0,31</td>
</tr>
<tr>
<td>2</td>
<td>3,85</td>
<td>4,76</td>
<td>-1.29</td>
<td>0,19</td>
</tr>
<tr>
<td>3</td>
<td>0,00</td>
<td>0,00</td>
<td>-0.70</td>
<td>0,48</td>
</tr>
<tr>
<td>4</td>
<td>5,00</td>
<td>10,00</td>
<td>-1.09</td>
<td>0,28</td>
</tr>
<tr>
<td>5</td>
<td>4,76</td>
<td>4,76</td>
<td>-0.23</td>
<td>0,82</td>
</tr>
<tr>
<td>6</td>
<td>0,00</td>
<td>0,00</td>
<td>-0.80</td>
<td>0,42</td>
</tr>
<tr>
<td>7</td>
<td>12,50</td>
<td>10,00</td>
<td>-2,50</td>
<td>-1.00</td>
</tr>
<tr>
<td>8</td>
<td>7,14</td>
<td>6,82</td>
<td>-0,32</td>
<td>-0,44</td>
</tr>
<tr>
<td>9</td>
<td>2,38</td>
<td>3,57</td>
<td>1,19</td>
<td>-0,34</td>
</tr>
</tbody>
</table>

Condition 1 had a median score of 0% error rate at T1 before receiving treatment and saw a 3.33% increase in error rate at T2 following SMT. This means that the participants of group 1 made 3.33% more errors in condition 1 following SMT that what they did before intervention. This median increase in error rates was, however, insufficient to provide a statistically significant result as the p-value was \( p=0.31 \).

Condition 2 had a median score of 3.85% error rate at T1 and saw an increase of 0.92% following SMT to give a median score of 4.76% at T2. This change was statistically insignificant suggesting the null hypothesis to be true as the p-value was \( p=0.19 \). Condition 3 had a median error rate of 0% at T1 with a 0% change at T2, thus indicating there was no change in the number of errors made following SMT. This gave a statistically insignificant result for condition 3 as the p-value was \( p=0.48 \).
Condition 4 had a median error rate of 5% before SMT was administered. Condition 4 saw a 5% increase in the amount of errors made following SMT to give a median score of 10% at T2 this value was however not sufficient enough to yield a statistically significant result to indicate that the error rate would change following SMT as p=0.28. Condition 4 also showed the biggest median difference between T1 and T2, indicating more errors were made at T2 than what were made at T1, for all 9 conditions.

Condition 5 had a median score of 4.76% error rate at T1 and T2 indicating no change in the number of errors made following intervention, therefore giving supporting the null hypothesis as p=0.82. Condition 6 had a similar outcome to that of condition 3 and saw a median score of 0% error rate at T1 as well as at T2, indicating that there was no change in the amount of errors made following SMT, this gave a result that supports the null hypothesis as p=0.42.

Condition 7 had a median score of 12.50% at T1, before receiving treatment. The median decreased by 2.50% to give a median score of 10% following SMT at T2, indicating that the participants of group 1 on average, made 2.50% fewer errors for condition 7, following SMT. This change, was however, not sufficient enough to produce a statistically significant result as p=0.32.

Condition 8 had a median score of 7.14% errors made before intervention. The median score decreased by 0.32% to a score of 6.82% following SMT, indicating that the participants, on average, made 0.32% fewer errors following SMT for condition 8. This change was however not statistically significant as the p-value was p=0.66. The 9th and final condition, saw an error rate of 2.38% at T1 before receiving treatment, change to give a final error rate of 3.57% following treatment, which means that participants on average, made 1.19% more errors following SMT. Although a change occurred, this change was not sufficient enough to yield a statistically significant result as p=0.73.
4.3.2 Intragroup Analysis for the Fitts’ Tapping Task for Group 2

a) Accurate number of taps (taps/s)

Table 4.4: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the accurate number of taps per second over the 9 conditions pre and post manipulation for group 2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median (taps per second)</th>
<th>Z-Value</th>
<th>p-value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SMT (T1)</td>
<td>Post SMT (T2)</td>
<td>Difference (T2-T1)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.10</td>
<td>2.40</td>
<td>0.3</td>
<td>-3.44</td>
</tr>
<tr>
<td>2</td>
<td>3.00</td>
<td>3.30</td>
<td>0.3</td>
<td>-3.06</td>
</tr>
<tr>
<td>3</td>
<td>3.60</td>
<td>4.00</td>
<td>0.4</td>
<td>-3.57</td>
</tr>
<tr>
<td>4</td>
<td>2.20</td>
<td>2.40</td>
<td>0.2</td>
<td>-2.54</td>
</tr>
<tr>
<td>5</td>
<td>2.90</td>
<td>3.20</td>
<td>0.3</td>
<td>-3.71</td>
</tr>
<tr>
<td>6</td>
<td>3.40</td>
<td>4.30</td>
<td>0.9</td>
<td>-4.07</td>
</tr>
<tr>
<td>7</td>
<td>2.00</td>
<td>2.30</td>
<td>0.3</td>
<td>-3.01</td>
</tr>
<tr>
<td>8</td>
<td>2.90</td>
<td>3.50</td>
<td>0.6</td>
<td>-3.66</td>
</tr>
<tr>
<td>9</td>
<td>3.60</td>
<td>4.70</td>
<td>1.1</td>
<td>-4.21</td>
</tr>
</tbody>
</table>

The Wilcoxon Signed rank test revealed a statistically significant increase in the accurate number of taps per second (taps/s) following SMT for condition 1. The median score was 2.10 taps/s pre intervention and increased by 0.30 to 2.40 taps/s following SMT with a p-value of p=0.00. Condition 2 had a median score of 3.00 taps/s at time 1 (T1), with an increase of 0.30 taps/s to give a median score of 3.30 taps/s at time 2 (T2), following SMT, suggesting the change does not support the null hypothesis but instead gives a statistically significant result of p=0.00.

Condition 3 had a median score of 3.60 taps/s at T1 and increased by 0.40 taps/s to 4.40 taps/s at T2 following SMT with p=0.00, thus giving a statistically significant result. Condition 4 had a median score of 2.20 taps/s at T1 and saw a small increase of 0.20 taps/s following
SMT to give a median score of 2.40 taps/s at T2. Although this change was small, it was sufficient to give a statistically significant result as the p-value was p=0.01, supporting evidence against the null hypothesis. Condition 5 had a median score of 2.90 taps/s at T1. Following SMT, the median score increased by 0.30 taps/s to give a median score of 3.20 taps/s thus giving a statistically significant result, p=0.00.

Condition 6 had a median score of 3.40 taps/s at T1 and saw an increase of 0.90 taps/s to give a median score of 4.30 taps/s at T2 with a p-value of p=0.00, thus giving a statistically significant change. Condition 7 had a median score of 2.00 taps/s at T1 and increased to 2.30 taps/s at T2 by 0.30 taps/s, following SMT thus yielding a statistically significant result of p=0.00. Condition 8, saw a 0.60 taps/s increase from 2.90 taps/s at T1 to 3.50 taps/s at T2 yielding a statistically significant result of p=0.00.

The 9th and final condition, had the largest median score increase of 1.10 taps/s between T1 and T2 for the 9 conditions. Condition 9 had a median score of 3.60 taps/s at T1 and a median score of 4.70 taps/s at T2 with a p-value, p=0.00, thus giving a statistically significant change following SMT.
b) Error rate (%)

Table 4.5: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the error rate measured as a percentage over the 9 conditions pre and post manipulation for group 2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median (Error %)</th>
<th>Z-Value</th>
<th>p-value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SMT (T1)</td>
<td>Post SMT (T2)</td>
<td>Difference (T2-T1)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8,33</td>
<td>0,00</td>
<td>-8,33</td>
<td>-2.33</td>
</tr>
<tr>
<td>2</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>-0.45</td>
</tr>
<tr>
<td>3</td>
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<td>0,00</td>
<td>0,00</td>
<td>-2.31</td>
</tr>
<tr>
<td>4</td>
<td>7,69</td>
<td>6,25</td>
<td>-1,44</td>
<td>-0.56</td>
</tr>
<tr>
<td>5</td>
<td>5,00</td>
<td>4,00</td>
<td>-1,00</td>
<td>-1.20</td>
</tr>
<tr>
<td>6</td>
<td>0,00</td>
<td>10,00</td>
<td>10,00</td>
<td>-1.54</td>
</tr>
<tr>
<td>7</td>
<td>10,00</td>
<td>10,00</td>
<td>0,00</td>
<td>-0.37</td>
</tr>
<tr>
<td>8</td>
<td>6,25</td>
<td>7,14</td>
<td>0,89</td>
<td>-1.32</td>
</tr>
<tr>
<td>9</td>
<td>2,08</td>
<td>1,85</td>
<td>-0,23</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Condition 1 had a median score of 8.33% error rate at T1 before receiving treatment and saw a 8.33% decrease in error rate at T2, following SMT. This means that the participants of group 1 made 8.33% less errors in condition 1 following SMT than what they did before intervention. This median decrease in error rates was, however, sufficient to provide a statistically significant result as the p-value was \[ p=0.02 \], supporting evidence against the null hypothesis.

Condition 2 had a median score of 0% error rate at T1 and saw no change in median score following SMT to give a median score of 0% at T2. This change was statistically insignificant suggesting the null hypothesis to be true as the p-value was \[ p=0.65 \]. Condition 3 had a median error rate of 0% at T1 with a 0% change at T2, thus indicating there was no change in the number of errors made following SMT. This gave a statistically significant result for condition 3 as the p-value was \[ p=0.02 \].
Condition 4 had a median error rate of 7.69% before SMT was administered. Condition 4 saw a 1.44% decrease in the amount of errors made following SMT to give a median score of 6.25% at T2. This value was however, not sufficient enough to yield a statistically significant result to indicate that the error rate would change following SMT as $p=0.58$.

Condition 5 had a median score of 5% at T1 and a median score of 4% at T2 indicating a decrease in the number of errors made following intervention, therefore giving a result of $p=0.82$. Condition 6 saw a median score of 0% error rate at T1 and a 10% median at T2, indicating that there was a 10% increase in the amount of errors made following SMT, although there was a rather large increase in the median scores between T1 and T2, it was still not significant enough to reject the null hypothesis as $p=0.12$.

Condition 6 also showed the biggest median difference between T1 and T2, indicating more errors were made at T2 than what were made at T1, for all 9 conditions. Condition 7 had a median score of 10% at T1 before receiving treatment and remained unchanged to give a median score of 10% following SMT at T2, indicating no change and that the participants made the same number of errors before intervention as what they did post intervention. This was not sufficient enough to produce a statistically significant result as $p=0.72$.

Condition 8 had a median score of 6.25% before intervention. The median score increased by 0.89% to a score of 7.14% following SMT, indicating that the participants, on average, made 0.89% more errors following SMT for condition 8. This change was however not statistically significant as the p-value was $p=0.19$.

The 9th and final condition saw an error rate of 2.08% at T1 before receiving treatment, change to give a final error rate of 1.85% following treatment, which means that participants on average, made 0.23% less errors following SMT. Although there was a decrease in the error rate following SMT, this change was not sufficient enough to yield a statistically significant result as $p=0.98$. 
4.3.3 Intragroup Analysis for the Fitts’ Tapping Task for Group 3

a) Accurate number of taps per second (taps/s)

Table 4.6: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the accurate number of taps per second over the 9 conditions pre and post manipulation for group 3.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median (taps per second)</th>
<th>Post SMT (T2)</th>
<th>Difference (T2-T1)</th>
<th>Z-Value</th>
<th>p -value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre SMT (T1)</td>
<td>Post SMT (T2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.50</td>
<td>2.80</td>
<td>0.3</td>
<td>-3.54</td>
<td>0.00</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>3.30</td>
<td>3.60</td>
<td>0.3</td>
<td>-2.66</td>
<td>0.01</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>4.20</td>
<td>4.80</td>
<td>0.6</td>
<td>-3.62</td>
<td>0.00</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>2.40</td>
<td>2.40</td>
<td>0</td>
<td>-1.21</td>
<td>0.23</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>3.30</td>
<td>3.80</td>
<td>0.5</td>
<td>-2.94</td>
<td>0.00</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>4.30</td>
<td>4.80</td>
<td>0.5</td>
<td>-3.32</td>
<td>0.00</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>2.10</td>
<td>2.30</td>
<td>0.2</td>
<td>-1.40</td>
<td>0.16</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>2.80</td>
<td>4.00</td>
<td>1.2</td>
<td>-4.25</td>
<td>0.00</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>4.30</td>
<td>5.00</td>
<td>0.7</td>
<td>-3.44</td>
<td>0.00</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The Wilcoxon Signed rank test revealed a statistically significant increase in the accurate number of taps per second (taps/s) following SMT for condition 1. The median score was 2.50 taps/s pre intervention and increased by 0.30 to 2.80 taps/s following SMT with a p-value of p=0.00. Condition 2 had a median score of 3.30 taps/s at time 1 (T1), with an increase of 0.30 taps/s to give a median score of 3.60 taps/s at time 2 (T2), following SMT, suggesting the change does not support the null hypothesis but instead gives a statistically significant result of p=0.00. Condition 3 had a median score of 4.20 taps/s at T1 and increased by 0.60 taps/s to 4.80 taps/s at T2 following SMT with p=0.00, thus giving a statistically significant result.
Condition 4 had a median score of 2.40 taps/s at T1 and saw no increase following SMT as the median score remained 2.40 taps/s at T2. This produced a statistically insignificant result as p=0.23. Condition 5 had a median score of 3.30 taps/s at T1. Following SMT, the median score increased by 0.50 taps/s to give a median score of 3.80 taps/s thus giving a statistically significant result, p=0.00.

Condition 6 had a median score of 4.30 taps/s at T1 and saw an increase of 0.50 taps/s to give a median score of 4.80 taps/s at T2 with a p-value of p=0.00, thus giving a statistically significant change. Condition 7 had a median score of 2.10 taps/s at T1 and increased to 2.30 taps/s at T2 by 0.20 taps/s, following SMT. This small change was however not sufficient to produce a statistically significant result as p=0.16.

Condition 8, saw a 1.20 taps/s increase from 2.80 taps/s at T1 to 4.00 taps/s at T2 yielding a statistically significant result of p=0.00. Condition 8 also had the largest median increase between T1 and T2 for the 9 conditions. The 9th and final condition had a median score of 4.30 taps/s at T1 and a median score of 5.00 taps/s at T2 therefore increasing by 0.70 taps/s with a p-value, p=0.00, thus giving a statistically significant change following SMT.
b) Error Rate (%)

Table 4.7: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the error rate measured as a percentage over the 9 conditions pre and post manipulation for group 3.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median (Error %)</th>
<th>Z-Value</th>
<th>p-value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SMT</td>
<td>Post SMT</td>
<td>Difference</td>
<td>(T2-T1)</td>
</tr>
<tr>
<td>1</td>
<td>8.82</td>
<td>3.57</td>
<td>-5.25</td>
<td>-2.59</td>
</tr>
<tr>
<td>2</td>
<td>2.38</td>
<td>3.23</td>
<td>0.84</td>
<td>-0.40</td>
</tr>
<tr>
<td>3</td>
<td>2.17</td>
<td>0.00</td>
<td>-2.17</td>
<td>-2.54</td>
</tr>
<tr>
<td>4</td>
<td>13.33</td>
<td>12.50</td>
<td>-0.83</td>
<td>-0.47</td>
</tr>
<tr>
<td>5</td>
<td>6.25</td>
<td>5.88</td>
<td>-0.37</td>
<td>-0.31</td>
</tr>
<tr>
<td>6</td>
<td>2.08</td>
<td>2.08</td>
<td>0.00</td>
<td>-0.08</td>
</tr>
<tr>
<td>7</td>
<td>15.38</td>
<td>16.67</td>
<td>1.28</td>
<td>-2.42</td>
</tr>
<tr>
<td>8</td>
<td>11.11</td>
<td>6.52</td>
<td>-4.59</td>
<td>-1.63</td>
</tr>
<tr>
<td>9</td>
<td>2.56</td>
<td>2.38</td>
<td>-0.18</td>
<td>-0.41</td>
</tr>
</tbody>
</table>

Condition 1 had a median score of 8.82% error rate at T1 before receiving treatment and saw a 5.25% decrease in error rate to give a median score T2, following SMT. This means that the participants of group 3 made 5.25% less errors in condition 1 following SMT than what they did before intervention. This median decrease in error rates was, however, sufficient to provide a statistically significant result as the p-value was $p=0.01$, supporting evidence against the null hypothesis.

Condition 2 had a median score of 2.38% error rate at T1 and saw a small change in median of 0.84% score following SMT to give a median score of 3.23% at T2. This change was statistically insignificant suggesting the null hypothesis to be true as the p-value was $p=0.69$. Condition 3 had a median error rate of 2.17% at T1 with a median score of 0% at T2, thus indicating there was a decrease in the number of errors made following SMT. This gave a statistically significant result for condition 3 as the p-value was $p=0.01$. 
Condition 4 had a median error rate of 13.33% before SMT was administered and saw a 0.83% decrease in the amount of errors being made following SMT to give a median score of 12.50% at T2. This value was however, not sufficient enough to yield a statistically significant result to indicate that the error rate would change following SMT as p=0.64.

Condition 5 had a median score of 6.25% at T1 and a median score of 5.88% at T2 indicating a decrease of 0.37% in the number of errors made following intervention, therefore giving a statistically insignificant result of p=0.76. Condition 6 saw a median score of 2.08% error rate at T1 and T2, indicating that there was no change in the amount of errors made following SMT, this was not significant to reject the null hypothesis as p=0.94.

Condition 7 had a median score of 15.38% at T1 before receiving treatment and increased to give a median score of 16.67% following SMT at T2, indicating that the participants, on average made 1.28% more errors following SMT. This was sufficient enough to produce a statistically significant result as p=0.02.

Condition 8 had a median score of 11.11% before intervention. The median score decreased by 4.59% to a score of 6.52% following SMT, indicating that the participants, on average, made 4.59% fewer errors following SMT for condition 8. This change was however not statistically significant as the p-value was p=0.10. The 9th and final condition saw an error rate of 2.56% at T1 before receiving treatment, change to give a final error rate of 2.38% following treatment, which means that participants on average, made 0.18% less errors following SMT. Although there was a decrease in the error rate following SMT, this change was not sufficient enough to yield a statistically significant result as p=0.69.
4.3.4 Intragroup Analysis for the Fitts’ Tapping Test for Group 4

a) Accurate number of taps per second (taps/s)

Table 4.8: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the accurate number of taps per second over the 9 conditions pre and post manipulation for group 4.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median (taps per second)</th>
<th>Z-Value</th>
<th>p-value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SMT (T1)</td>
<td>Post SMT (T2)</td>
<td>Difference (T2-T1)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.10</td>
<td>2.40</td>
<td>0.3</td>
<td>-3.60</td>
</tr>
<tr>
<td>2</td>
<td>3.00</td>
<td>3.40</td>
<td>0.4</td>
<td>-2.54</td>
</tr>
<tr>
<td>3</td>
<td>4.30</td>
<td>4.20</td>
<td>-0.1</td>
<td>-2.99</td>
</tr>
<tr>
<td>4</td>
<td>2.40</td>
<td>2.40</td>
<td>0</td>
<td>-1.87</td>
</tr>
<tr>
<td>5</td>
<td>3.00</td>
<td>3.40</td>
<td>0.4</td>
<td>-3.15</td>
</tr>
<tr>
<td>6</td>
<td>4.00</td>
<td>4.60</td>
<td>0.6</td>
<td>-3.24</td>
</tr>
<tr>
<td>7</td>
<td>2.20</td>
<td>2.40</td>
<td>0.2</td>
<td>-2.03</td>
</tr>
<tr>
<td>8</td>
<td>2.80</td>
<td>3.40</td>
<td>0.6</td>
<td>-2.98</td>
</tr>
<tr>
<td>9</td>
<td>3.70</td>
<td>4.40</td>
<td>0.7</td>
<td>-4.21</td>
</tr>
</tbody>
</table>

The Wilcoxon Signed rank test revealed a statistically significant increase in the accurate number of taps per second (taps/s) following SMT for condition 1. The median score was 2.10 taps/s pre intervention and increased by 0.30 to 2.40 taps/s following SMT with a p-value of p=0.00. Condition 2 had a median score of 3.00 taps/s at time 1 (T1), with an increase of 0.40 taps/s to give a median score of 3.40 taps/s at time 2 (T2), following SMT, suggesting the change does not support the null hypothesis but instead gives a statistically significant result of p=0.01.

Condition 3 had a median score of 4.30 taps/s at T1 and decreased by 0.10 taps/s to 4.20 taps/s at T2 following SMT with p=0.00, thus giving a statistically significant result but for a decrease in the accurate number of taps per second following SMT.
Condition 4 had a median score of **2.40 taps/s** at T1 and saw no increase following SMT as the median score remained **2.40 taps/s** at T2. This produced a statistically insignificant result as \( p=0.06 \). Condition 5 had a median score of **3.00 taps/s** at T1. Following SMT, the median score increased by **0.40 taps/s** to give a median score of **3.40 taps/s** thus giving a statistically significant result, \( p=0.00 \). Condition 6 had a median score of **4.00 taps/s** at T1 and saw an increase of **0.60 taps/s** to give a median score of **4.60 taps/s** at T2 with a p-value of \( p=0.00 \), thus giving a statistically significant change.

Condition 7 had a median score of **2.20 taps/s** at T1 and increased to **2.40 taps/s** at T2 by **0.20 taps/s**, following SMT. This small change was sufficient to produce a statistically significant result as \( p=0.04 \). Condition 8, saw a **0.60 taps/s** increase from **2.80 taps/s** at T1 to **3.40 taps/s** at T2 yielding a statistically significant result of \( p=0.00 \). The 9th and final condition had a median score of **3.70 taps/s** at T1 and a median score of **4.40 taps/s** at T2 therefore increasing by **0.70 taps/s** with a p-value, \( p=0.00 \), thus giving a statistically significant change following SMT.
b) Error rate (%)

**Table 4.9: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the accurate number of taps per second over the 9 conditions pre and post manipulation for group 4.**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median (Error %)</th>
<th>Z-Value</th>
<th>p -value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SMT (T1)</td>
<td>Post SMT (T2)</td>
<td>Difference (T2-T1)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8.33</td>
<td>3.57</td>
<td>-4.76</td>
<td>-1.02</td>
</tr>
<tr>
<td>2</td>
<td>2.78</td>
<td>0.00</td>
<td>-2.78</td>
<td>-1.29</td>
</tr>
<tr>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.70</td>
</tr>
<tr>
<td>4</td>
<td>7.69</td>
<td>10.71</td>
<td>3.02</td>
<td>-1.09</td>
</tr>
<tr>
<td>5</td>
<td>5.26</td>
<td>4.35</td>
<td>-0.92</td>
<td>-0.23</td>
</tr>
<tr>
<td>6</td>
<td>2.00</td>
<td>0.00</td>
<td>-2.00</td>
<td>-0.80</td>
</tr>
<tr>
<td>7</td>
<td>11.54</td>
<td>11.76</td>
<td>0.23</td>
<td>-1.00</td>
</tr>
<tr>
<td>8</td>
<td>10.00</td>
<td>8.82</td>
<td>-1.18</td>
<td>-0.44</td>
</tr>
<tr>
<td>9</td>
<td>2.50</td>
<td>3.33</td>
<td>0.83</td>
<td>-0.34</td>
</tr>
</tbody>
</table>

Condition 1 had a median score of **8.33%** error rate at T1 before receiving treatment and saw a **4.76%** decrease in error rate to give a median score of **3.57%** at T2, following SMT. This means that the participants of group 4 made **4.76%** less errors in condition 1 following SMT than what they did before intervention. This median decrease in error rate was, however, not sufficient to provide a statistically significant result as the p-value was **p=0.31**, supporting evidence for the null hypothesis.

Condition 2 had a median score of **2.78%** error rate at T1 and saw a decrease in median scores of **2.78%** following SMT to give a median score of **0%** at T2. This change was statistically insignificant suggesting the null hypothesis to be true as the p-value was **p=0.20**.

Condition 3 had a median error rate of **0%** at T1 with a median score of **0%** at T2, thus
indicating there was no change in the number of errors made following SMT. This gave a statistically insignificant result for condition 3 as the p-value was $p=0.48$.

Condition 4 had a median error rate of 7.69% before SMT was administered and saw a 3.02% increase in the amount of errors being made following SMT to give a median score of 10.71% at T2. This value was however, not sufficient enough to yield a statistically significant result to indicate that the error rate would change following SMT as $p=0.28$.

Condition 5 had a median score of 5.26% at T1 and a median score of 4.35% at T2 indicating a decrease of 0.92% in the number of errors made following intervention, therefore giving a statistically insignificant result of $p=0.82$. Condition 6 saw a median score of 2.00% error rate at T1 and a 0% score at T2, indicating that there was a 2% decrease in the amount of errors made following SMT, this was however, not significant to reject the null hypothesis as $p=0.42$.

Condition 7 had a median score of 11.54% at T1 before receiving treatment and increased to give a median score of 11.76% following SMT at T2, indicating that the participants, on average made 0.23% more errors following SMT. This was not sufficient enough to produce a statistically significant result as $p=0.32$. Condition 8 had a median score of 10.00% before intervention. The median score decreased by 1.18% to a score of 8.82% following SMT, indicating that the participants, on average, made 1.18% fewer errors following SMT for condition 8. This change was however not statistically significant as the p-value was $p=0.66$.

The 9th and final condition saw an error rate of 2.50% at T1 before receiving treatment, change to give a final error rate of 3.33% following treatment, which means that participants on average, made 0.83% more errors following SMT. Although there was a decrease in the error rate following SMT, this change was not sufficient enough to yield a statistically significant result as $p=0.74$. 
4.4 Intergroup Analysis for Fitts’ Tapping Test

Intergroup analysis was performed to assess whether there was a difference in results between the four groups, or to assess whether a particular group scored better results in comparison to the other groups. Intergroup analysis was assessed by using the Kruskall-Wallis Test. If the Kruskall-Wallis test showed any significant results, further testing would have be required to ascertain which group had the greatest improvement.

4.4.1 Intergroup Analysis for the Accurate Number of Taps (taps/s) for the Fitts’ Tapping Task

Table 4.10: Summary of the data analysis using the Kruskall-Wallis Test describing the accurate number of taps per second over the 9 conditions pre and post manipulation for all 4 groups.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median (taps per second)</th>
<th>p-value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SMT (T1)</td>
<td>Post SMT (T2)</td>
<td>Difference (T2-T1)</td>
</tr>
<tr>
<td>1</td>
<td>2.23</td>
<td>2.62</td>
<td>0.39</td>
</tr>
<tr>
<td>2</td>
<td>3.08</td>
<td>3.47</td>
<td>0.39</td>
</tr>
<tr>
<td>3</td>
<td>3.88</td>
<td>4.42</td>
<td>0.54</td>
</tr>
<tr>
<td>4</td>
<td>2.30</td>
<td>2.50</td>
<td>0.20</td>
</tr>
<tr>
<td>5</td>
<td>3.07</td>
<td>3.54</td>
<td>0.48</td>
</tr>
<tr>
<td>6</td>
<td>3.84</td>
<td>4.49</td>
<td>0.66</td>
</tr>
<tr>
<td>7</td>
<td>2.09</td>
<td>2.41</td>
<td>0.32</td>
</tr>
<tr>
<td>8</td>
<td>2.87</td>
<td>3.52</td>
<td>0.65</td>
</tr>
<tr>
<td>9</td>
<td>3.86</td>
<td>4.51</td>
<td>0.65</td>
</tr>
</tbody>
</table>

The Kruskall-Wallis Test was used to analyse the intergroup analysis. Table 4.10 provides a detailed summary of the mean values for the 9 conditions pre and post manipulation. Condition 1 had a mean score of **2.23 taps/s** before intervention at T1 and a mean score of
2.62 taps/s at T2 following SMT with an increase of 0.39 taps/s. This gave a statistically insignificant result as $p=0.53$, therefore indicating that there was no group who performed statistically better when compared to one another, for condition 1. Condition 2 had a mean score of 3.08 taps/s at T1 with an increase of 0.39 to give a mean score of 3.47 taps/s following SMT with a p-value of $p=0.29$, thus giving a statistically insignificant result between the 4 groups.

Condition 3 had a mean score of 3.88 taps/s at T1 and a mean score of 4.42 post manipulation, showing an average of 0.54 taps/s increase following SMT but giving a statistically insignificant result $p=0.44$. Condition 4 had a mean score of 2.30 taps/s at T1 and increased by 0.20 taps/s to give a mean score of 2.50 taps/s at T2 with $p=0.83$, thus indicating there is no difference between the groups for this condition.

Condition 5 had a mean score of 3.07 taps/s pre intervention with a change of 0.48 taps/s to give a mean of 3.54 taps/s post intervention with $p=0.59$. Condition 6 had a mean score of 3.84 taps/s at T1 and saw an increase of an average of 0.66 taps/s to give a mean of 4.49 taps/s at T2 following SMT. This change was not sufficient to give a statistically significant result between the 4 groups as $p=0.60$.

Condition 7 had a mean of 2.09 taps/s before manipulation with a 0.32 taps/s increase to give a mean score of 2.41 taps/s following manipulation, with $p=0.60$. Condition 8 had a mean score of 2.87 taps/s at T1 and increased by 0.65 taps/s to an average of 4.51 taps/s at T2 with $p=0.13$, thus indicating no statistical difference between the 4 groups. Condition 9 had a mean score of 3.86 taps/s before intervention, change by an average of 0.65 taps/s to give an average of 4.51 taps/s following SMT. The p-value was $p=0.27$ indicating the averages amongst the 4 groups were not statistically significant.
4.4.2 Intergroup Analysis for the Error Rate for the Fitts’ Tapping Task

Table 4.11: Summary of the data analysis using the Kruskall-Wallis Test describing the error rate measured as a percentage over the 9 conditions pre and post manipulation for all 4 groups.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Error Rate (%)</th>
<th>p-value</th>
<th>Statistically Significant (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SMT (T1)</td>
<td>Post SMT (T2)</td>
<td>Difference (T2-T1)</td>
</tr>
<tr>
<td>1</td>
<td>9.47</td>
<td>3.90</td>
<td>-5.57</td>
</tr>
<tr>
<td>2</td>
<td>3.98</td>
<td>3.98</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>1.83</td>
<td>0.91</td>
<td>-0.93</td>
</tr>
<tr>
<td>4</td>
<td>10.38</td>
<td>10.85</td>
<td>0.48</td>
</tr>
<tr>
<td>5</td>
<td>7.17</td>
<td>6.46</td>
<td>-0.70</td>
</tr>
<tr>
<td>6</td>
<td>3.70</td>
<td>2.24</td>
<td>-1.46</td>
</tr>
<tr>
<td>7</td>
<td>14.36</td>
<td>15.61</td>
<td>1.25</td>
</tr>
<tr>
<td>8</td>
<td>10.85</td>
<td>9.70</td>
<td>-1.15</td>
</tr>
<tr>
<td>9</td>
<td>5.27</td>
<td>4.68</td>
<td>-0.59</td>
</tr>
</tbody>
</table>

Condition 1 had a mean error rate of 9.47% before intervention, at T1 as seen in table 4.11. The mean error rate decreased, on average, by 5.57% at T2 following SMT to a mean score of 3.90%, with a p-value, p=0.52, which indicates that there were no statistically significant changes amongst the groups for condition 1 for the amount of errors made.

Condition 2 had a mean error rate of 3.98% before treatment that remained unchanged following SMT, this yielded a statistically insignificant result of p=0.53 indicating that there was not a statistically significant result amongst the 4 groups for the amount of errors made in condition 2 following SMT.

Condition 3 had a mean error rate of 1.83% at T1 and decreased by 0.93% to 0.91% following SMT at T2 with p=0.35. Condition 4 had an average error rate of 10.38% at T1
which increased to 10.85% following SMT at T2 with \( p=0.14 \) indicating that there was no statistically significant difference between the groups.

Condition 5 had an average error rate of 7.17% before receiving any treatment and decreased by 0.70% to 6.46% following SMT with \( p=0.50 \), indicating no significance between the groups as \( p>0.05 \). Condition 6 had an average error rate of 3.70% before any intervention at T1 and decreased by 1.46% to an average of 2.24% following SMT at T2 with \( p=0.26 \), thus indicating this condition had no statistically significant differences between the 4 groups.

Condition 7 had a mean score of 14.36% errors made at T1 with an average increase of 1.25% to give a final average error rate of 15.61% post SMT with \( p=0.24 \). The \( p \)-value for this condition was \( p>0.05 \) and therefore indicates no statistically significant differences between the 4 groups in terms of error rate.

Condition 8 had a mean score of 10.85% before intervention and saw on average, 1.15% fewer errors being made following SMT with \( p=0.43 \). Condition 9 had a mean value of 5.27% pre SMT that decreased by 0.59% to 4.68% post SMT with a \( p \)-value of \( p=0.72 \) indicating no differences between the 4 groups.

4.5 Effect Size for the Intergroup Analysis for the Fitts’ Tapping Task Test for Accurate Number of Taps

The intergroup analysis for the accurate number of taps/s revealed that for all 9 conditions, there was no statistically significant differences between the 4 groups as \( p>0.05 \). In other words, no specific group performed better when compared to the other groups following SMT. However, the differences between the groups can still be measured using a statistic known as the effect size. The effect size is the magnitude of the difference between groups whereas the statistical significance investigates whether the findings are due to chance. The
effect size \( (r) \) essentially describes how strong the relationship is between two variables, namely which region was adjusted and the accurate number of taps.

Cohen (1988) has the following guidelines to measure effect sizes:

- \( r \geq 0.1 \) represents a small effect size
- \( r \geq 0.3 \) represents a medium effect size
- \( r \geq 0.5 \) represents a large effect size

The effect size was calculated using the following formula:

\[
r = \frac{z}{\sqrt{N}}
\]

Where \( z \) is the z value obtained from the output values of the Wilcoxon Signed ranked tests and \( N \) is the total number of observations at time 1 and time 2, \( (25 \times 2 = 50) \).

4.5.1 The Effect Size of Condition 1 for Fitts' Tapping Task

<table>
<thead>
<tr>
<th>Group</th>
<th>( r = \frac{Z}{\sqrt{N}} )</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.56</td>
<td>Large</td>
</tr>
<tr>
<td>2</td>
<td>0.49</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>0.50</td>
<td>Large</td>
</tr>
<tr>
<td>4</td>
<td>0.51</td>
<td>Large</td>
</tr>
</tbody>
</table>

Condition 1 had an Index of Difficulty of 4.8. Group 1, the control group, showed an effect size of \( r = 0.56 \) and according to Cohen (1988) this is considered to be a large effect size. Therefore for condition 1, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a large effect on improving the accurate number of taps/s second when retested.
Group 2 had a medium effect size of $r=0.49$ which means that SMT delivered to the cervical spine region only has a medium effect on improving the amount of taps/s following SMT. Group 3 had an effect size of $r=0.50$ and group 4 had an effect size of $r=0.51$ respectively, both indicating a large effect size. Therefore this indicates that for both group 3 and 4, SMT had a large effect on increasing the number of taps/s at test 2.

### 4.5.2 The Effect Size of Condition 2 for Fitts' Tapping Task

Table 4.13: Summary of the effect size for the 4 groups for the accurate number of taps per second for condition 2.

<table>
<thead>
<tr>
<th>Group</th>
<th>$r=Z/\sqrt{N}$</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.46</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>0.43</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>0.38</td>
<td>Small</td>
</tr>
<tr>
<td>4</td>
<td>0.36</td>
<td>Small</td>
</tr>
</tbody>
</table>

Condition 2 had an Index of Difficulty of 2.4. Group 1, the control group, showed an effect size of $r=0.46$ and according to Cohen (1988), this is considered to be a medium effect size. Therefore for condition 2, SMT delivered to the cervical, thoracic and lumbar spine regions appeared to have a medium effect on improving the accurate number of taps/s second when re-tested.

Group 2 also had a medium effect size of $r=0.43$ which means that SMT delivered to the cervical spine region, only had a medium effect on improving the amount of taps/s following SMT. Group 3 had an effect size of $r=0.38$ and group 4 had an effect size of $r=0.36$ respectively, both indicating small effect sizes. Therefore this indicates that for both group 3 and 4, SMT had a small effect on increasing the number of taps/s at test 2.
4.5.3 The Effect Size of Condition 3 for Fitts’ Tapping Test

Table 4.14: Summary of the effect size for the 4 groups for the accurate number of taps per second for condition 3.

<table>
<thead>
<tr>
<th>Group</th>
<th>$r = Z / \sqrt{N}$</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.52</td>
<td>Large</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>Large</td>
</tr>
<tr>
<td>3</td>
<td>0.51</td>
<td>Large</td>
</tr>
<tr>
<td>4</td>
<td>0.42</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Condition 3 had an Index of Difficulty of 1.2. Group 1, the control group, showed an effect size of $r = 0.52$ and according to Cohen (1988) this is considered to be a large effect size. Therefore for condition 3, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a large effect on improving the accurate number of taps/s second when re-tested.

Group 2 and group 3 also had large effect sizes of $r = 0.50$ and $r = 0.51$ respectively, which means that SMT delivered to the cervical spine region and the thoracic region also had a large effect on improving the amount of taps/s following SMT. Group 4 had an effect size of $r = 0.42$ which means SMT delivered to the lumbar spine only yielded a medium effect on increasing the number of taps/s.
4.5.4 The Effect Size of Condition 4 for Fitts’ Tapping Test

Table 4.15: Summary of the effect size for the 4 groups for the accurate number of taps per second for condition 4.

<table>
<thead>
<tr>
<th>Group</th>
<th>( r = Z / \sqrt{N} )</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.24</td>
<td>Small</td>
</tr>
<tr>
<td>2</td>
<td>0.36</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>0.17</td>
<td>Small</td>
</tr>
<tr>
<td>4</td>
<td>0.26</td>
<td>Small</td>
</tr>
</tbody>
</table>

Condition 4 had an Index of Difficulty of 4.8. Group 1, the control group, showed an effect size of \( r = 0.24 \) and according to Cohen (1988) this is considered to be a small effect size. Therefore for condition 4, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a small effect on improving the accurate number of taps/s second when re-tested.

Group 2 had a medium effect size of \( r = 0.36 \) which means that SMT delivered to the cervical spine region only has a medium effect on improving the amount of taps/s following SMT. Group 3 had an effect size of \( r = 0.17 \) and group 4 had an effect size of \( r = 0.26 \) respectively, both indicating small effect sizes. Therefore this indicates that for both group 3 and 4, SMT had a small effect on increasing the number of taps/s at test 2.
4.5.5 The Effect Size of Condition 5 for Fitts’ Tapping Task

Table 4.16: Summary of the effect size for the 4 groups for the accurate number of taps per second for condition 5.

<table>
<thead>
<tr>
<th>Group</th>
<th>$r=Z/\sqrt{N}$</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.46</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>0.52</td>
<td>Large</td>
</tr>
<tr>
<td>3</td>
<td>0.42</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>0.45</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Condition 5 had an Index of Difficulty of 2.4. Group 1, the control group, showed an effect size of $r=0.46$ and according to Cohen (1988) this is considered to be a medium effect size. Therefore for condition 5, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a medium effect on improving the accurate number of taps/s second when re-tested.

Group 2 had a large effect size of $r=0.52$ which means that SMT delivered to the cervical spine region, had a large effect on improving the amount of taps/s following SMT. Group 3 had an effect size of $r=0.42$ and group 4 had an effect size of $r=0.45$ respectively, both indicating a medium effect size. Therefore this indicates that for both group 3 and 4, SMT had a medium effect on increasing the number of taps/s at test 2.
4.5.6 The Effect Size of Condition 6 for Fitts’ Tapping Task

Table 4.17: Summary of the effect size for the 4 groups for the accurate number of taps per second for condition 6.

<table>
<thead>
<tr>
<th>Group</th>
<th>$r=Z/\sqrt{N}$</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.55</td>
<td>Large</td>
</tr>
<tr>
<td>2</td>
<td>0.57</td>
<td>Large</td>
</tr>
<tr>
<td>3</td>
<td>0.47</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>0.46</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Condition 6 had an Index of Difficulty of 1.2. Group 1, the control group, showed an effect size of $r=0.55$ and according to Cohen (1988) this is considered to be a large effect size. Therefore for condition 6, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a large effect on improving the accurate number of taps/s second when re-tested.

Group 2 had a large effect size of $r=0.57$ which means that SMT delivered to the cervical spine region, had a large effect on improving the amount of taps/s following SMT. Group 3 had an effect size of $r=0.47$ and group 4 had an effect size of $r=0.46$ respectively, both indicating a medium effect size. Therefore this indicates that for both group 3 and 4, SMT had a medium effect on increasing the number of taps/s at test 2.
4.5.7 The Effect Size of Condition 7 for Fitts’ Tapping Task

Table 4.18: Summary of the effect size for the 4 groups for the accurate number of taps per second for condition 7.

<table>
<thead>
<tr>
<th>Group</th>
<th>r=Z/√N</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.52</td>
<td>Large</td>
</tr>
<tr>
<td>2</td>
<td>0.42</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>0.20</td>
<td>Small</td>
</tr>
<tr>
<td>4</td>
<td>0.29</td>
<td>Small</td>
</tr>
</tbody>
</table>

Condition 7 had an Index of Difficulty of 4.8. Group 1, the control group, showed an effect size of \( r=0.52 \) and according to Cohen (1988) this is considered to be a large effect size. Therefore for condition 1, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a large effect on improving the accurate number of taps/s second when re-tested.

Group 2 had a medium effect size of \( r=0.42 \) which means that SMT delivered to the cervical spine region only has a medium effect on improving the amount of taps/s following SMT. Group 3 had an effect size of \( r=0.20 \) and group 4 had an effect size of \( r=0.29 \) respectively, both indicating small effect sizes. Therefore this indicates that for both group 3 and 4, SMT had a small effect on increasing the number of taps/s at test 2.
4.5.8 The Effect Size of Condition 8 for Fitts’ Tapping Task

Table 4.19: Summary of the effect size for the 4 groups for the accurate number of taps per second for condition 8.

<table>
<thead>
<tr>
<th>Group</th>
<th>( r = Z / \sqrt{N} )</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.59</td>
<td>Large</td>
</tr>
<tr>
<td>2</td>
<td>0.52</td>
<td>Large</td>
</tr>
<tr>
<td>3</td>
<td>0.60</td>
<td>Large</td>
</tr>
<tr>
<td>4</td>
<td>0.42</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Condition 8 had an Index of Difficulty of 2.4. Group 1, the control group, showed an effect size of \( r = 0.59 \) and according to Cohen (1988) this is considered to be a large effect size. Therefore for condition 1, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a large effect on improving the accurate number of taps/s second when re-tested.

Group 2 had a large effect size of \( r = 0.52 \) which means that SMT delivered to the cervical spine region also had a large effect on improving the amount of taps/s following SMT. Group 3 had an effect size of \( r = 0.60 \), indicating a large effect size. Group 4 had an effect size of \( r = 0.42 \) indicating a medium effect size.
4.5.9 The Effect Size of Condition 9 for Fitts’ Tapping Task

Table 4.20: Summary of the effect size for the 4 groups for the accurate number of taps per second for condition 9.

<table>
<thead>
<tr>
<th>Group</th>
<th>$r = \sqrt{Z/N}$</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.47</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>0.59</td>
<td>Large</td>
</tr>
<tr>
<td>3</td>
<td>0.49</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>0.60</td>
<td>Large</td>
</tr>
</tbody>
</table>

Condition 9 had an Index of Difficulty of 1.2. Group 1, the control group, showed an effect size of $r=0.47$ and according to Cohen (1988) this is considered to be a medium effect size. Therefore for condition 9, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a medium effect on improving the accurate number of taps/s second when re-tested.

Group 2 had a large effect size of $r=0.59$ which means that SMT delivered to the cervical spine region had a large effect on improving the amount of taps/s following SMT. Group 3 had an effect size of $r=0.49$, indicating SMT had a medium effect on increasing the taps/s when tested again. Group 4 had an effect size of $r=0.60$ indicating a large effect size.
4.6 Intragroup Analysis for the GFLMB Test

The Wilcoxon Signed Ranks test was used to analyse the data collected by the GLFLMB for all four groups. It was used to assess whether or not a change had taken place between time 1 and time 2, following spinal manipulative therapy. T1 was the median score obtained before any intervention, or SMT, had been administered, while T2 was the median score obtained following SMT.

The test was used to test the two independent variables, the movement time, in milliseconds, as well as the errors made, measured as a percentage. The control group had 24 valid cases as the data from one participant was excluded due to a corrupt file within the dataset. The remainder 3 groups all had 25 valid datasets. The results for each group over the 4 conditions are discussed below.

4.6.1 Intragroup Analysis of the GFLMB Test for Group 1

a) Movement Time (milliseconds)

Table 4.21: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the movement time in milliseconds for the 4 conditions pre and post manipulation for group 1.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median MT (ms) T1</th>
<th>MT (ms) T2</th>
<th>T2-T1</th>
<th>Z- Value</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1052.06</td>
<td>1030.62</td>
<td>-21.44</td>
<td>-2.37</td>
<td>0.02</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>872.14</td>
<td>788.44</td>
<td>-83.70</td>
<td>-3.31</td>
<td>0.00</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>1216.26</td>
<td>1200.22</td>
<td>-16.04</td>
<td>-2.40</td>
<td>0.02</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>956.3</td>
<td>910.78</td>
<td>-45.52</td>
<td>-2.17</td>
<td>0.03</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The Wilcoxon Signed rank test revealed a statistically significant decrease in the MT following SMT for condition 1. The median score was 1052.06 ms pre intervention and
decreased by 21.44 ms to 1030.62 ms following SMT with a p-value of \( p=0.02 \). Condition 2 had a median score of 872.14 ms at time 1 (T1), with a decrease of 83.70 ms to give a median score of 788.44 ms at time 2 (T2), following SMT, suggesting the change does not support the null hypothesis but instead gives a statistically significant result of \( p=0.00 \).

Condition 3 had a median score of 1216.26 ms at T1 and decreased by an average of 16.04 ms to 1200.22 ms at T2 following SMT with \( p=0.02 \), thus giving a statistically significant result. The 4\(^{th} \) and final condition had a median score of 956.3 ms at T1 and saw a 45.52 ms decrease in MT following SMT as the median score at T2 was 910.78 ms. This produced a statistically insignificant result as \( p=0.03 \).

b) Error Rate (%)

Table 4.22: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the error rate measured as a percentage over the 4 conditions pre and post manipulation for group 1.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median Error Rate</th>
<th>T2-T1</th>
<th>Z-Value</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Error (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8,00</td>
<td>8,00</td>
<td>0,00</td>
<td>-1,53</td>
<td>0,13</td>
</tr>
<tr>
<td>2</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>-0,88</td>
<td>0,38</td>
</tr>
<tr>
<td>3</td>
<td>12,00</td>
<td>8,00</td>
<td>-4,00</td>
<td>-1,53</td>
<td>0,01</td>
</tr>
<tr>
<td>4</td>
<td>4,00</td>
<td>2,00</td>
<td>-2,00</td>
<td>-1,53</td>
<td>0,06</td>
</tr>
</tbody>
</table>

Condition 1 had a mean error rate of 8.00% before intervention, at T1 as seen in table 4.14. The median error rate remained unchanged following SMT to give a median rate of 8.00% at T2 with a p-value, \( p=0.12 \), which indicated that there was no statistically significant change amongst group 1, condition 1 for the amount of errors made.
4.6.2 Intragroup Analysis of the GFLMB Test for Group 2

a) Movement Time (milliseconds)

Table 4.23: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the movement time in milliseconds for the 4 conditions pre and post manipulation for group 2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median MT T1 (ms)</th>
<th>Median MT T2 (ms)</th>
<th>T2-T1</th>
<th>Z-Value</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1052.40</td>
<td>1022.68</td>
<td>-29.72</td>
<td>-2.70</td>
<td>0.01</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>824.20</td>
<td>780.80</td>
<td>-43.40</td>
<td>-2.92</td>
<td>0.00</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>1192.48</td>
<td>1149.12</td>
<td>-43.36</td>
<td>-1.90</td>
<td>0.06</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>931.32</td>
<td>899.40</td>
<td>-31.92</td>
<td>-2.26</td>
<td>0.02</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The Wilcoxon Signed rank test revealed a statistically significant decrease in the MT following SMT for condition 1. The median score was 1052.40 ms pre intervention and decreased by 29.72 ms to 1022.68 ms following SMT with a p-value of p=0.01. Condition 2 had a median score of 824.20 ms at time 1 (T1), with a decrease of 43.40 ms to give a median score of 780.80 ms at time 2 (T2), following SMT, suggesting the change does not support the null hypothesis but instead gives a statistically significant result of p=0.00.

Condition 3 had a median score of 1192.48 ms at T1 and decreased by an average of 43.36 ms to 1149.12 ms at T2 following SMT with p=0.06, thus giving a statistically insignificant result. The 4th and final condition had a median score of 931.32 ms at T1 and saw a 31.92
ms decrease in MT following SMT as the median score at T2 was 899.40 ms. This produced a statistically significant change as $p=0.02$.

b) Error Rate

Table 4.24: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the error rate measured as a percentage over the 4 conditions pre and post manipulation for group 2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median Error Rate</th>
<th>T2-T1</th>
<th>Z-Value</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error (%)</td>
<td>Error (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>T2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.00</td>
<td>8.00</td>
<td>-0.80</td>
<td>0.43</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>-1.75</td>
<td>0.10</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>8.00</td>
<td>8.00</td>
<td>-0.21</td>
<td>0.83</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>4.00</td>
<td>4.00</td>
<td>-0.75</td>
<td>0.45</td>
<td>No</td>
</tr>
</tbody>
</table>

Condition 1 had a median error rate of 4.00% before intervention, at T1 as seen in table 4.16. The median error rate increased following SMT to give a median rate of 8.00% at T2 with a p-value, $p=0.43$, which indicated that there was no statistically significant change amongst group 1, condition 1 for the amount of errors made. Condition 2 had a median error rate of 0.00% before treatment and remained unchanged following SMT, this yielded a statistically insignificant result of $p=0.10$.

Condition 3 had a median error rate of 8.00% at T1 and remained unchanged following SMT at T2 with $p=0.83$. Condition 4 had a median error rate of 4.00% at T1 which also remained unchanged following SMT at T2 with $p=0.45$ indicating a statistically insignificant result.
4.6.3 Intragroup Analysis of the GFLMB Test for Group 3

a) Movement Time (milliseconds)

**Table 4.25:** Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the movement time in milliseconds for the 4 conditions pre and post manipulation for group 3.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median MT MT (ms) T1</th>
<th>MT (ms) T2</th>
<th>T2-T1</th>
<th>Z- Value</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 081,36</td>
<td>1 025,88</td>
<td>-55,48</td>
<td>-2,41</td>
<td>0,02</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>815,28</td>
<td>765,40</td>
<td>-49,88</td>
<td>-2,92</td>
<td>0,00</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>1 249,56</td>
<td>1 107,36</td>
<td>-142,20</td>
<td>-3,40</td>
<td>0,00</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>932,88</td>
<td>916,92</td>
<td>-15,96</td>
<td>-2,54</td>
<td>0,01</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The Wilcoxon Signed rank test revealed a statistically significant decrease in the MT following SMT for condition 1. The median score was **1081.36 ms** pre intervention and decreased by **55.48 ms** to **1025.88 ms** following SMT with a p-value of **p=0.02**. Condition 2 had a median score of **815.28 ms** at time 1 (T1), with a decrease of **49.88 ms** to give a median score of **765.40 ms** at time 2 (T2), following SMT, suggesting the change does not support the null hypothesis but instead gives a statistically significant result of **p=0.00**.

Condition 3 had a median score of **1249.56 ms** at T1 and decreased by an average of **142.20 ms** to **1107.36 ms** at T2 following SMT with **p=0.00**, thus giving a statistically significant result. The 4th and final condition had a median score of **932.88 ms** at T1 and saw a **15.96 ms** decrease in MT following SMT as the median score at T2 was **916.92 ms**. This produced a statistically significant result as **p=0.01**.
b) Error Rate

Table 4.26: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the error rate measured as a percentage over the 4 conditions pre and post manipulation for group 3.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median Error Rate</th>
<th>T2-T1</th>
<th>Z-Value</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Error (%) T1</td>
<td>Error (%) T2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4,00</td>
<td>8,00</td>
<td>4,00</td>
<td>-2,51</td>
<td>0,01</td>
</tr>
<tr>
<td>2</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>-1,09</td>
<td>0,28</td>
</tr>
<tr>
<td>3</td>
<td>8,00</td>
<td>8,00</td>
<td>0,00</td>
<td>-0,61</td>
<td>0,54</td>
</tr>
<tr>
<td>4</td>
<td>0,00</td>
<td>4,00</td>
<td>4,00</td>
<td>-0,61</td>
<td>0,54</td>
</tr>
</tbody>
</table>

Condition 1 had a mean error rate of 4.00% before intervention, at T1 as seen in table 4.18. The median error rate increased by 4.00% following SMT to give a median rate of 8.00% at T2 with a p-value, p=0.01, which indicated that there was a statistically significant change amongst group 3, condition 1 for the amount of errors made. Condition 2 had a median error rate of 0.00% before treatment and remained unchanged following SMT, this yielded a statistically insignificant result of p=0.28.

Condition 3 had a median error rate of 8.00% at T1 and remained unchanged following SMT at T2 with p=0.54. Condition 4 had a median error rate of 0.00% at T1 and increased to 4.00% following SMT at T2 with p=0.54 indicating a statistically insignificant result.
4.6.4 Intragroup Analysis of the GFLMB Test for Group 4

a) Movement Time (milliseconds)

Table 4.27: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the movement time in milliseconds for the 4 conditions pre and post manipulation.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median MT T1 (ms)</th>
<th>MT (ms) T2</th>
<th>T2-T1</th>
<th>Z- Value</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 059.68</td>
<td>986.00</td>
<td>-73.68</td>
<td>-0.85</td>
<td>0.40</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>850.12</td>
<td>764.24</td>
<td>-85.88</td>
<td>-3.51</td>
<td>0.00</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>1 154.84</td>
<td>1 062.12</td>
<td>-92.72</td>
<td>-2.65</td>
<td>0.01</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>900.00</td>
<td>869.56</td>
<td>-30.44</td>
<td>-1.39</td>
<td>0.17</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The Wilcoxon Signed rank test revealed a statistically insignificant decrease in the MT following SMT for condition 1. The median score was 1059.68 ms pre intervention and decreased by 73.68 ms to 986.00 ms following SMT with a p-value of p=0.40. Condition 2 had a median score of 850.12 ms at time 1 (T1), with a decrease of 85.88 ms to give a median score of 764.24 ms at time 2 (T2), following SMT, suggesting the change does not support the null hypothesis but instead gives a statistically significant result of p=0.00.

Condition 3 had a median score of 1154.84 ms at T1 and decreased by an average of 92.72 ms to 1062.12 ms at T2 following SMT with p=0.01, thus giving a statistically significant result. The 4th and final condition had a median score of 900.00 ms at T1 and saw a 30.44 ms decrease in MT following SMT as the median score at T2 was 869.56 ms. This produced a statistically insignificant result as p=0.17.
b) Error Rate

Table 4.28: Summary of the data analysis using the Wilcoxon Signed Rank Test to describe the error rate measured as a percentage over the 4 conditions pre and post manipulation.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median Error Rate</th>
<th>T2-T1</th>
<th>Z-Value</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Error (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8,00</td>
<td>8,00</td>
<td>0,00</td>
<td>-1,50</td>
<td>0,14</td>
</tr>
<tr>
<td>2</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>-1,02</td>
<td>0,31</td>
</tr>
<tr>
<td>3</td>
<td>12,00</td>
<td>8,00</td>
<td>4,00</td>
<td>-0,92</td>
<td>0,36</td>
</tr>
<tr>
<td>4</td>
<td>4,00</td>
<td>4,00</td>
<td>0,00</td>
<td>-1,19</td>
<td>0,23</td>
</tr>
</tbody>
</table>

Condition 1 had a mean error rate of 8.00% before intervention, at T1 as seen in table 4.14. The median error rate remained unchanged following SMT to give a median rate of 8.00% at T2 with a p-value, \( p=0.14 \), which indicated that there was no statistically significant change amongst group 4, condition 1 for the amount of errors made. Condition 2 had a median error rate of 0.00% before treatment and remained unchanged following SMT, this yielded a statistically insignificant result of \( p=0.31 \).

Condition 3 had a median error rate of 12.00% at T1 and decreased by 4.00% to 8.00% following SMT at T2 with \( p=0.36 \). Condition 4 had a median error rate of 4.00% at T1 and remained unchanged following SMT at T2 with \( p=0.23 \) indicating a statistically insignificant result.
4.7 Intergroup Analysis for the GFLMB Test

Intergroup analysis was performed to assess whether there was a difference in results between the four groups, or to assess whether a particular group scored better results in comparison to the other groups. Intergroup analysis was assessed by using the Kruskall-Wallis Test. If the Kruskall-Wallis test showed any significant results, further testing would have been required to ascertain which group had the greatest improvement.

4.7.1 Intergroup Analysis for Movement Time (milliseconds) for the GFLMB Test

Table 4.29: Summary of the data analysis using the Kruskall-Wallis Test describing the movement time in milliseconds over the 4 conditions pre and post manipulation for all 4 groups.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean MT (ms) T1</th>
<th>Mean MT (ms) T2</th>
<th>T2-T1</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1093,42</td>
<td>1037,25</td>
<td>-56,17</td>
<td>0,94</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>869,26</td>
<td>796,20</td>
<td>-73,06</td>
<td>0,70</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>1239,49</td>
<td>1116,32</td>
<td>-123,17</td>
<td>0,23</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>981,97</td>
<td>923,95</td>
<td>-58,02</td>
<td>0,63</td>
<td>No</td>
</tr>
</tbody>
</table>

The Kruskall-Wallis Test was used to analyse the intergroup analysis. Table 4.21 provides a detailed summary of the mean values for the 4 conditions pre and post manipulation. Condition 1 had a mean score of **1093.42 ms** before intervention at T1 and a mean score of **1037.25 ms** at T2 following SMT, with **p=0.94**. Condition 2 had a mean score of **869.26 ms** at T1 with a decrease of **73.06** to give a mean score of **796.20 ms** following SMT with a **p-value of p=0.70**, thus giving a statistically insignificant result between the 4 groups.

Condition 3 had a mean score of **1239.49 ms** at T1 and a mean score of **1116.32 ms** post manipulation, showing an average of **123.17 ms** decrease following SMT but giving a statistically insignificant result **p=0.23**. Condition 4 had a mean score of **981.97 ms** at T1 and decreased by **58.02 ms** to give a mean score of **923.95 ms** at T2 with **p=0.63**, thus indicating there is no difference between the groups for this condition.
4.7.2 Intergroup Analysis for the Error Rate for the GFLMB Test

Table 4.30: Summary of the data analysis using the Kruskall-Wallis Test describing the error rate as a percentage over the 4 conditions pre and post manipulation for all 4 groups.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean Error (%) T1</th>
<th>Mean Error (%) T2</th>
<th>P-Value</th>
<th>Statistically Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8,00</td>
<td>9,33</td>
<td>0,25</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>2,55</td>
<td>3,23</td>
<td>0,52</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>10,91</td>
<td>9,90</td>
<td>0,52</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>4,93</td>
<td>4,28</td>
<td>0,67</td>
<td>No</td>
</tr>
</tbody>
</table>

Condition 1 had a mean error rate of 8.00% before intervention, at T1 as seen in table 4.22. The mean error rate increased, on average, by 1.33% at T2 following SMT to a mean score of 9.33%, with a p-value, $p=0.25$, which indicates that there were no statistically significant changes amongst the groups for condition 1 for the amount of errors made.

Condition 2 had a mean error rate of 2.55% before treatment that increased by 0.69% to 3.23 % following SMT, this yielded a statistically insignificant result of $p=0.52$ indicating that there was a statistically insignificant result amongst the 4 groups for the amount of errors made in condition 2 following SMT. Condition 3 had a mean error rate of 10.91% at T1 and decreased by 1.01% to 9.90% following SMT at T2 with $p=0.52$. Condition 4 had an average error rate of 4.93% at T1 which decreased to 4.28% following SMT at T2 with $p=0.67$ indicating that there was no statistically significant difference between the groups.
4.8 Effect Size for the Intergroup Analysis for the GFLMB Test

4.8.1 The Effect Size of Condition 1 for the GFLMB Test

Table 4.31: Summary of the effect size for the 4 groups for the MT for condition 1.

<table>
<thead>
<tr>
<th>Group</th>
<th>r=Z/√N</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.34</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>0.38</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>0.34</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>0.12</td>
<td>Small</td>
</tr>
</tbody>
</table>

Condition 1 had an Index of Difficulty of 4. Group 1, the control group, showed an effect size of \( r=0.34 \) and according to Cohen (1988) this is considered to be a medium effect size. Therefore for condition 1, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a medium effect on improving the MT when re-tested. Group 2 had a medium effect size of \( r=0.38 \) which means that SMT delivered to the cervical spine region only has a medium effect on improving the MT following SMT. Group 3 had an effect size of \( r=0.34 \), indicating that SMT only had a medium effect on improving the MT. Group 4 had an effect size of \( r=0.12 \) indicating a small effect size.

4.8.2 The Effect Size of Condition 2 for the GFLMB Test

Table 4.32: Summary of the effect size for the 4 groups for the MT for condition 2.

<table>
<thead>
<tr>
<th>Group</th>
<th>r=Z/√N</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.48</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>0.41</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>0.41</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>0.50</td>
<td>Large</td>
</tr>
</tbody>
</table>
Condition 1 had an Index of Difficulty of 3. Group 1, the control group, showed an effect size of \( r=0.48 \) and according to Cohen (1988) this is considered to be a medium effect size. Therefore for condition 2, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a medium effect on improving the MT when re-tested.

Group 2 had a medium effect size of \( r=0.41 \) which means that SMT delivered to the cervical spine region only has a medium effect on improving the MT following SMT. Group 3 had an effect size of \( r=0.41 \), indicating that SMT only had a medium effect on improving the MT. Group 4 had an effect size of \( r=0.50 \) indicating a large effect size.

### 4.8.3 The Effect Size of Condition 3 for the GFLMB Test

<table>
<thead>
<tr>
<th>Group</th>
<th>( r=Z/\sqrt{N} )</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.35</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>0.27</td>
<td>Small</td>
</tr>
<tr>
<td>3</td>
<td>0.48</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>0.37</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Condition 1 had an Index of Difficulty of 5. Group 1, the control group, showed an effect size of \( r=0.35 \) and according to Cohen (1988) this is considered to be a medium effect size. Therefore for condition 3, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a medium effect on improving the MT when re-tested.

Group 2 had a small effect size of \( r=0.27 \) which means that SMT delivered to the cervical spine region only has a small effect on improving the MT following SMT. Group 3 had an effect size of \( r=0.48 \), indicating that SMT only had a medium effect on improving the MT. Group 4 had an effect size of \( r=0.37 \) indicating a medium effect size.
4.8.4 The Effect Size of Condition 4 for the GFLMB Test

Table 4.34: Summary of the effect size for the 4 groups for the MT for condition 4.

<table>
<thead>
<tr>
<th>Group</th>
<th>r = Z/√N</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.31</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>0.32</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>0.36</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>0.20</td>
<td>Small</td>
</tr>
</tbody>
</table>

Condition 4 had an Index of Difficulty of 3.5. Group 1, the control group, showed an effect size of $r=0.31$ and according to Cohen (1988) this is considered to be a medium effect size. Therefore for condition 4, SMT delivered to the cervical, thoracic and lumbar spine regions appears to have a medium effect on improving the MT when re-tested.

Group 2 had a medium effect size of $r=0.32$ which means that SMT delivered to the cervical spine region only has a medium effect on improving the MT following SMT. Group 3 had an effect size of $r=0.36$, indicating that SMT only had a medium effect on improving the MT. Group 4 had an effect size of $r=0.20$ indicating a small effect size.
CHAPTER FIVE:

DISCUSSION
5.1 Introduction

This chapter will discuss, in detail, the results obtained in chapter 4 and make reference to the primary and secondary aims described in chapter 1. This chapter will also make reference to the literature that was reviewed in chapter 2 and correlate the findings with previous research that has been conducted. It will also highlight and discuss all the statistically significant results and explain these results so that this information may be used in future studies and as well as being applied to various clinical settings.

5.2 Demographics

5.2.1 Gender Analysis

The sample for this study included both males and female participants as it has been shown that there are no significant differences in movement time when comparing males and females during a Fitts’ Law task (Davis and Fang, 2010). The sample size consisted of 100 participants that were randomly allocated into 1 of the 4 groups, as described in chapter 3. The male to female ratio for the sample was 48 to 52. Group 1 had a male to female ratio of 11 to 14. Group 2 had a male to female ratio of 13 to 12. Group 3 had a male to female ratio of 14 to 11 and the 4th and final group had a male to female ratio of 10 to 15. The Pearson Chi-Square test revealed a statistically insignificant result indicating that the male to female ratio distribution was equally distributed.

5.2.2 Age Analysis

The inclusion criteria stipulated that the participants were to be between the ages of 18 and 40 in order to take part in the research study. It has been shown that movement time decreases with age (Davis and Fang, 2010). The age parameters was also based on the fact that the degeneration commences at the age of 40 (Division of Adult and Community Health, National Centre for Chronic Disease Prevention and Health Promotion, 2014). It has also been shown that Fitts’ head movement tasks decrease with aging (Descarreaux et al., 2010).
The minimum age was 18 while the maximum age was 40 with a mean age of 24.80 years for the entire sample. Group 1 had a mean age of 24.44 years, group 2 had a slightly higher average age with a mean of 27.32 years. Group 3 had a mean age of 23.16 years and group 4 had a mean age of 24.28 years. The intragroup analysis revealed that there was normal distribution within each group. The intergroup analysis revealed that there was not a normal distribution of ages between the 4 groups. This finding may be attributable to the outliers that were within the sample size.

5.3 General Discussion of Results

Each group was analysed individually to see whether or not a change in movement time had taken place following SMT. This was done by testing the participants before SMT was administered as well as retesting the participants post SMT. As previously discussed in chapter 3, the participants were tested using the two objective tests, the Fitts Tapping Task and the computerised test, the GFLMB test.

For the Fitts Tapping Task, two variables were taken into consideration, namely the accurate taps per second as well as the number of errors that were made that was expressed in terms of a percentage. The Fitts Tapping Task had 9 separate test conditions. Conditions 1, 4 and 7 had the highest index of difficulty, ID=4.8. Conditions 2, 5 and 8 had an index of difficulty of ID=2.4, implying that these conditions should theoretically be scored with a larger increase in accurate number of taps and fewer errors as stated by Fitts’ Law (Fitts’, 1954). The final three conditions, 3, 6 and 9 had an index of difficulty of ID=1.2 thus making them the easiest set of test parameters.

The accurate number of taps per second was used namely to assess whether or not the participant increased or decreased their movement time following SMT. The movement time was also measured over 9 conditions that had different indices of difficulty as summarised in Table 3.1.
The GFLMB measured the movement time in milliseconds as well as the error rate, also expressed in terms of a percentage. The GFLMB had 4 separate test conditions as summarised in Table 3.2 with 4 different indices of difficulty. Condition 3 had the highest Index of difficulty, $\text{ID}=5$ while condition 2 had the smallest index of difficulty, $\text{ID}=3$.

Chapter 2 discussed the basic principles of Fitts' Law which stated that movement will increase if the width of the targets are further apart or if the diameter of the targets are smaller. In other words, the further away the targets are from one another or the smaller the size of the targets, the longer it will take the participant to move between the two targets (Descarreaux et al., 2010; Smith et al., 2006; Fitts 1954). The index of difficulty is the logarithmic relationship between the amplitude or target distance and the width between the targets (Descarreaux et al., 2010; Smith et al., 2006; Fitts 1954). The results obtained from this study indicated that there was in fact a linear relationship between the ID and the MT, as predicted by Fitts' Law and this was observed through all conditions (Descarreaux et al., 2010; Smith et al., 2006; Fitts 1954).

The error rate for both tests was taken into consideration to measure whether or not the participants where adhering to the speed accuracy trade off phenomenon. This phenomenon states that participants will trade off accuracy in order to increase speed (Shea and Wright, 1997). An example that attempts to describe this principal is when a person increases the speed at which they complete the task but as a result increases the number of errors made. With regards to the Fitts' Tapping Task, if a participant increased the number of accurate number of taps per second or decreased their movement time following SMT while making fewer errors it provides evidence that the improvement in results are not likely due to the speed accuracy trade off phenomenon.

Research conducted by Haavik-Taylor and Murphy (2008) suggest that spinal dysfunction influences central neural processing, this means that in the presence of spinal dysfunction, sensorimotor integration and cortical somatosensory processing are negatively influenced which then eventually lead to plastic changes within the CNS.
There is conclusive evidence indicating that SMT is able to alter the excitability of the motor neuron pools (Dishman et al., 2008) as well as alter the processing of sensory information (Zhu et al., 2000). Research conducted by Haavik-Taylor and Murphy (2006) aimed at studying the immediate effects that SMT, specifically to dysfunctional joints of the cervical spine, had on sensorimotor integration by using somatosensory evoked potentials.

The participants in combination group received SMT to restricted segments located within the cervical, thoracic, lumbar and sacroiliac regions. Table 4.2 provides a summary of the median values for the accurate number of taps pre and post SMT for the results of the participants who received SMT to all 3 regions of the spine for the 9 conditions for the FTT. Conditions 1-3 and 5-9 all showed a statistically significant increase \( p<0.00 \) in the number of accurate taps per second following SMT. In other words, the participants who were manipulated in all regions, all improved their overall movement time for the above mentioned conditions, or performed the action quicker, once they had received SMT to the cervical, thoracic and lumbar spine regions. Condition 4 was the only condition for these participants which did not result in a statistically significant change or improvement in the accurate number of taps following SMT. With regards to the GFLMB, manipulating the cervical, thoracic and lumbar spine regions showed statistically significant improvements for all 4 conditions following SMT as described in Table 4.13.

The participants of the second group received SMT to restricted segments within the cervical spine. Table 4.4 provides a summary of the results obtained for these participants over the 9 conditions. Across all 9 conditions measured and compared for the FTT, statistical significances were noted. This finding supports the concept that the mechanism for SMT produces a neurological response in addition to the known biomechanical response. The participants who were manipulated in the cervical spine were the only participants to show statistically significant improvements for all 9 conditions. With regards to the GFLMB, group 2 also showed statistically significant results for all 4 conditions following SMT. SMT appears to have a brief physiological response that causes sensory information to be relayed into the CNS that in turn causes a change within the motoneuron excitability levels (Dishman et al., 2008).
The movement time decreased following SMT. Kelly, Murphy & Backhouse, (2000), have done studies that suggest SMT has an overall effect on cognition. They used a mental rotation reaction time task to demonstrate improvement in a complex reaction time task following SMT to upper cervical segments. They went on to describe that SMT may also have an overall effect on cognition. They were able to arrive at this conclusion due to the fact that simple reaction time tasks required little cognitive processing and as a result little to no changes were seen when tested.

According to a research conducted by Haavik and Murphy (2012), and Haavik-Taylor and Murphy (2010a and b; 2008), the authors concluded that SMT delivered to dysfunctional segments within the cervical spine may influence cortical integration of dual somatosensory input. The large increase in accurate number of taps/s for this condition may also be attributed to the fact that the ID for this condition was $\text{ID}=2.4$, which meant that it was not the most difficult condition and therefore correlates with the linear relationship of movement time and the index of difficulty, as predicted by Fitts’ law.

Smith et al., (2006) proposed that future research should be conducted to investigate which ID are improved following SMT as this will provide better insight to what degree chiropractors are able effect the complexity of a movement. The authors did not compare the effects of SMT at the various IDs and as a result were not able to conclude to what degree SMT had on the overall complexity of the movement. Based on the findings presented in chapter 4, this research provides evidence that SMT delivered to restrictions located within the cervical influences the movement time for all the ID. Manipulating participants who exhibited areas of spinal dysfunction were the only participants to show statistically significant results for all test parameters. This could be due to the fact that research has shown that SMT delivered to the cervical spine improves movement and accuracy (Enebo, 2003; Smith et al., 2006).

The 3rd group was the thoracic spine group and therefore received SMT to dysfunctional vertebral segments located within the thoracic spine. With regards to the FTT, the participants who received intervention at the thoracic spine did not show statistically
significant improvements in the accurate number of taps per second following SMT for conditions 4 and 7 as summarised in table 4.1. Both 4 and 7 had an index of difficulty \textbf{ID=4}. With regards to the GFLMB, manipulating the thoracic spine produced statistically significant improvements for all 4 conditions as summarised in Table 4.2. Further investigation is therefore required to ascertain whether or not these inconsistent results was due to the nature of the makeup of the two tests. The FTT required the user to use a pencil while the GFLMB required the participant to use a computer mouse.

Group 4, the lumbar spine group saw a similar pattern to that of those participants who were manipulated in all regions as it revealed that all conditions except condition 4 showed statistically significant changes following SMT for the FTT. A summary of the results obtained pre and post SMT can be seen in Table 4.8. With regards to the GFLMB, the results indicated that manipulating the lumbar spine does not appear to have a beneficial effect, as the results did not produce statistically significant results for condition 1. The clinical significance and possible findings of this will be discussed in detail later on in this chapter.

Movement time, as stated by Fitts' (1954) is a linear function of the amplitude in relation to the ID, therefore the more difficult the parameters, the larger the movement time is expected to be (Danion, Duarte and Grosjean, 1999). This can be seen in the results as condition 1 and 7 saw the smallest improvement following SMT. The improvements for these conditions, were however sufficient to produce a statistically significant results, indicating that SMT may have a beneficial effect on improving movement time in conditions that have a higher ID and thus having an effect on motor control. A slight improvement in movement time can be expected but research has shown that Fitts' tasks are resistant to learning (Lee and Schmidt, 2011; Passmore and Descarreaux, 2012). The results indicated that there was a linear relationship between the ID and the MT, as predicted by Fitts' Law and this was observed through all conditions (Descarreaux et al., 2010; Smith et al., 2006; Fitts 1954).

Haavik-Taylor and Murphy (2011, 2010a and b) have concluded that SMT delivered to dysfunctional joints within the cervical spine improve suppression of SEPs evoked by dual
upper limb nerve stimulation at the level of the motor cortex, premotor areas and/or subcortical areas like the basal ganglia. The study also suggests that the changes that occurred post SMT were at the cortical level. The reduction in the SEP thus indicates an improvement of neural plastic changes that was caused due to spinal dysfunction. The authors have thus concluded that SMT therefore improves both somatosensory processing as well as functional ability.

It has also been shown that there is an impairment in motor function in chronic neck pain sufferers. Impairment of deep cervical neck flexors and postural disturbances has also been noted. This then leads to an altered state of sensory input and ultimately to dysfunctional motor output (Haavik and Murphy, 2012; Haavik-Taylor and Murphy, 2011, 2010a and b). Proprioception and motor control has also been shown to be affected in the presence of spinal dysfunction (Haavik-Taylor and Murphy, 2010a; Smith et al., 2006). It has been shown that spinal dysfunction can cause either inhibition or facilitation of neural input to surrounding musculature. The central plastic changes that occur in the presence of spinal dysfunction not only affect proprioceptive input, but it also affects the way in which pain signals are processed (Haavik-Taylor and Murphy 2010c, 2008, 2007a, b and c).

There have also been multiple studies done (Haavik-Taylor and Murphy, 2010c, 2007c; Holt et al., 2010) where the authors used somatosensory evoked potentials to demonstrate that manipulation delivered to the cervical spine altered somatosensory processing and early sensorimotor integration from the upper limb. These studies went on to show that there was in fact a change in the amplitude of the SEP indicating that SMT has a direct effect on the afferent information arriving at the spinal cord. The authors therefore concluded based on their findings that spinal manipulation delivered to dysfunctional segments within the cervical spine can lead to a change in the early stages of sensory information as well as sensorimotor integration of the upper limb. This may explain why manipulating the cervical spine was able to improve their overall movement time as the task was performed using the upper limb.
Research has shown that spinal manipulation causes changes within the cortical level and thus influences central changes. The SEP peaks that was noted confirms that there is a loop that links the cortical and subcortical levels by means of the basal ganglia, thalamus, premotor areas and primary motor cortex (Haavik and Murphy, 2012; Haavik-Taylor and Murphy, 2010a, b).

Studies have also shown that SMT can assist with improving spinal proprioception when they tested participants with subclinical neck pain.

5.3.1 Discussion of the Fitts’ Tapping Task

As previously discussed, the participants who received manipulation within the cervical spine were the only participants to have statistically significant changes for all 9 conditions following SMT for this particular test. Referring back to the aim as stated in chapter 1, the purpose of this study was also to assess whether or not manipulating a certain region would produce better results. The statistical analysis revealed no statistically significant differences amongst the groups over the 9 conditions. The differences were still measured using a type of analysis known as effect size. The effect size measures the relationship between two variables, in this case the relationship between adjusting a particular region and its overall effect on movement time.

Table 4.12 provides a summary of the effect sizes for condition 1. The effect size for all four groups was $r > 0.50$ indicating that there is a large effect size. This indicates that there exists a strong relationship between manipulating any region and improving MT. This may be attributed to the fact that SMT has numerous benefits including altering SMI, altering cortical processing as well as other neurophysiological benefits as previously discussed.

With regards to the error rate made for condition 1, those who were manipulated within the cervical spine had a statistically significant changes in the number of errors that was made following SMT. The participants who were manipulated in the cervical spine region made...
8.33% fewer errors following SMT. This therefore implies that the improvement in MT following SMT is not likely due to speed accuracy trade off phenomenon but rather due to the neurophysiological effects SMT seems to have on motor control. In order to produce movement, a number of factors need to be taken into consideration. A person needs to interact with the external environment and thus perception, cognition and action all need to work together to produce the final result. Given this information, it is plausible to deduce that SMT must have an influence on at least one of these factors, but further research is needed to determine which of the components SMT effects.

Condition 2 had an index of difficulty ID=2.4. The effect size as summarised in table 4.13 shows that for participants who received either a combination of manipulations or those who received cervical spine manipulations, the relationship between SMT and the overall MT had a medium effect size, while those participants who received manipulations to the thoracic or lumbar spine regions had a small effect spine. Group 1 and 2 both had cervical spine manipulation included in their treatment protocol. As previously discussed, there is a growing body of evidence that indicates that SMT delivered to the cervical spine has a beneficial effect on altering SMI as well as motor control and overall movement time for an upper limb task. With regards to the error rate for condition 2, there were no statistically significant changes for the 4 groups. This then confirms that the increase in the accurate number of taps following SMT was not due to the speed accuracy phenomenon.

Condition 3 had an index of difficulty of 1.2 and by definition was the easiest set of test parameters to complete. The results showed that for all four groups statistically significant improvements following SMT was noted. According to Table 4.12, groups 1-3 all had a large effect size. Although group 4, the lumbar spine group had statistically significant improvements in the accurate number of taps per second following SMT, the effect size revealed that there was only a medium effect size. This indicates that manipulating the lumbar spine only has a medium effect on improving MT following SMT. Further research should be conducted to observe why this relationship exists.
With regards to the error rate, participants who received cervical or thoracic spine adjustment showed statistically significant changes in the amount of errors made pre and post SMT. Table 4.5 and Table 4.7 show a summary of the error rates pre and post SMT. The tables reveal that for both conditions an improvement, or fewer errors were made following SMT. This finding is important because it eliminates the possibility of the results having improved due to the speed accuracy trade off phenomenon, as accuracy was as well as speed was improved.

Condition 4 had an index of difficulty $ID=4.8$. For groups 1, 3 and 4 this condition did not see a statistically significant result as $p>0.05$. Although there was a slight increase in the median values following SMT the increase was not sufficient enough to produce statistically significant results. This finding may be attributed to the smaller diameter of the targets and therefore in order to remain accurate the participants were forced to slow down their movements as per the speed accuracy trade off phenomenon.

The participants who received cervical spine adjustments, on the other hand produced statistically significant results for this condition following SMT. Table 4.12 gives a summary of the effect size for the 4 groups for condition 4. Group 2 was the only group to have produce a medium effect size. The remaining three groups had a small effect size. This means that for condition 4 receiving SMT to restricted segments within the cervical spine had a medium effect on the final time it took to complete the condition. This result suggests that the improvement is due to SMT having an effect on the way sensorimotor information is processed and ultimately having an effect on motor control. With regards to the error rates made for condition 4, none of the groups revealed any statistically significant changes in the error rate following SMT.

Condition 5 yielded statistically significant results for all four groups following SMT. This means that all participants improved their movement time or increased the accurate number of taps/s for this condition. With regards to the error rates made for condition 5, none of the participants revealed any statistically significant changes in the error rate following SMT.
Table 4.12 is a summary of the effect size for condition 5. Groups 1, 3 and 4 exhibited a medium effect size while participants who received SMT aimed at dysfunctional segments within the cervical spine showed a large effect size. This indicates that delivering SMT to the cervical spine has a better relationship on the movement time for a task that requires the use of an upper limb. This finding then implies that the increase in the speed at which the task was performed may be attributed to the fact that SMT has been shown to influence the excitability of the motor system and thus having an influence on motor control (Colloca & Keller, 2000).

Condition 6 yielded statistically significant results for all four groups following SMT. This means that all 4 groups showed a marked improvement in the accurate number of taps/s following SMT. With regards to the error rates made for condition 6, none of the groups revealed any statistically significant changes in the error rate following SMT. Table 4.13 is a summary of the effect size for condition 6. Groups 1 and 2 exhibited a large effect size while groups 3 and 4 produced a medium effect size. This indicates that delivering SMT to the cervical spine has a better relationship on the movement time for a task that requires the use of an upper limb. This finding then implies that the increase in the speed at which the task was performed may be attributed to the fact that SMT has been shown to influence the excitability of the motor system and thus having an influence on motor control (Colloca & Keller, 2000). There seems to be a stronger relationship between manipulating the cervical spine and improving a Fitts' law task using the upper limb.

Condition 7 yielded statistically significant results for all groups 1, 2 and 4 following SMT. This means that 3 of the 4 groups showed a marked improvement in the accurate number of taps/s following SMT. Group 3, the thoracic spine group did see a small improvement in the number of accurate number of taps following SMT but this change was not sufficient to produce statistically significant results. This may be due to the fact that condition 7 had an index of difficulty ID=4.8, which meant that it was one of the more difficult test parameters. Further research is required to determine to what level of ID SMT is able to effect when manipulating the thoracic spine.
With regards to the error rates made for condition 7, none of the groups revealed any statistically significant changes in the error rate following SMT. Table 4.13 is a summary of the effect size for condition 6. Groups 1 and 2 exhibited a large effect size while groups 3 and 4 produced a medium effect size. This indicates that delivering SMT to the cervical spine has a better relationship on the movement time for a task that requires the use of an upper limb. This finding then implies that the increase in the speed at which the task was performed may be attributed to the fact that SMT has been shown to influence the excitability of the motor system and thus having an influence on motor control (Colloca & Keller, 2000). There seems to be a stronger relationship between manipulating the cervical spine and improving movement time a Fitts' law task of the upper limb.

Condition 8 yielded statistically significant results for all four groups following SMT. This means that all 4 groups showed a marked improvement in the accurate number of taps/s following SMT. With regards to the error rates made for condition 6, none of the groups revealed any statistically significant changes in the error rate following SMT.

Table 4.13 is a summary of the effect size for condition 8. Groups 1, 2 and 3 exhibited a large effect size while group 4 produced a medium effect size. This indicates that delivering SMT to the cervical spine has a better relationship on the movement time for a task that requires the use of an upper limb. This finding then implies that the increase in the speed at which the task was performed may be attributed to the fact that SMT has been shown to influence the excitability of the motor system and thus having an influence on motor control (Colloca & Keller, 2000). There seems to be a stronger relationship between manipulating the cervical spine and improving a Fitts' law task of the upper limb.

Condition 9 yielded statistically significant results for all four groups following SMT. This means that all 4 groups showed a marked improvement in the accurate number of taps/s following SMT. With regards to the error rates made for condition 9, none of the groups revealed any statistically significant changes in the error rate following SMT. Table 4.15 is a summary of the effect size for condition 9. Groups 2 and 4 exhibited a large effect size while
groups 1 and 3 produced a medium effect size. This indicates that delivering SMT to the cervical spine has a better relationship on the movement time for a task that requires the use of an upper limb. This finding then implies that the increase in the speed at which the task was performed may be attributed to the fact that SMT has been shown to influence the excitability of the motor system and thus having an influence on motor control (Colloca & Keller, 2000). There seems to be a stronger relationship between manipulating the cervical spine and improving a Fitts' law task of the upper limb.

5.3.2 Discussion of the GFLMB

Condition 1 of the GFLMB had an index of difficulty ID=4. Groups 1-3 all produced statistically significant results following intervention. Group 1 on average improved the movement time 21.44 ms quicker after receiving SMT. Group 2 performed the test on average 29.72 ms quicker following SMT. Group 3 improved their movement time on average 55.48 ms quicker following SMT. Group 4 was the only group for condition 1 to not obtain a statistically significant change in movement time following SMT. With regards to the error rate for the 4 groups for condition 1, group 3 revealed a statistically significant result in the number of errors made following SMT. Group 3 had an error rate of an average of 4% before receiving any type of intervention. The error rate increased to a total of 8% following SMT. This means that the participants made 4% more errors following SMT. The decrease in movement time can therefore be attributed to the speed accuracy trade-off phenomenon.

Table 4.23 provides a summary of the effect sizes for condition 1. The relationship between SMT and the improvement of MT reveals that groups 1-3 all have a medium effect size. Group 4 only revealed small effect size, which means that delivering SMT to the lumbar spine has a small effect on improving movement time.

Condition 2 of the GFLMB had an index of difficulty of ID=3, making condition 2 the easiest set of test parameters. All 4 groups produced statistically significant results following SMT. Group 1 improved their overall movement time by an average of 83.70 ms following SMT. Group 2 improved their overall movement time by an average of 49.88 ms following SMT.
Group 3 improved their overall movement time by an average 49.88 ms. Group 4 improved the movement time by an average of 85.88 ms.

The effect size interestingly enough reveals that delivering SMT to the lumbar spine has a large effect size in comparison to the other groups which all only revealed that SMT delivered to the other regions only had a medium effect size for condition 2. The error rates for all 4 groups revealed statistically insignificant results following SMT. This then indicates that the improvements seen for condition 2 are most likely due to the neurophysiological effects SMT seems to have on SMI and not due to the speed accuracy trade off phenomenon.

Condition 3 had an index of difficulty of ID=5, thus making it the most difficult set of test parameters for the GFLMB. Groups 1, 3 and 4 all produced statistically significant changes in movement time following SMT. Group 2 did not produce statistically significant results following SMT for condition 3. Table 4.25 provides a summary of the effect sizes for condition 3. Group 2 has a small effect size while the other remaining groups all had a medium effect size, in other words SMT has a medium effect on improving movement time. Group 2 indicated that SMT has a small effect on increasing the movement time for a set of test parameters of ID=5.

With regards to the amount of errors that was made for this condition, group 1 was the only group that revealed statistically significant changes. Group 1 had an average error rate of 12% before SMT. Following SMT the participants of group 1 made 4% less errors. Group 1 also showed a statistically significant improvement in movement time following SMT, it can be concluded that the improvement in MT was due to the neurophysiological effects of SMT and not due to the speed accuracy trade off phenomenon.

The 4th and final condition, had an index of difficulty ID=3.5. All 4 groups revealed statistically significant improvements of MT following SMT. Table 4.34 provides a summary of the effect sizes for condition 4. Groups 1-3 all had a medium effect size while group 4 had a small
effect size. This indicates that manipulating the lumbar spine has the smallest influence on improving the MT of a motor task.

Group 1 had a statistically significant change in the amount of errors made. Before any SMT was administered to the participant, they scored an average error rate of 4%. Following SMT, the participants made 2% less errors while improving their overall movement time. This indicates that the improvement in MT is not due to the speed accuracy trade off but rather due to the neurophysiological effects that SMT has on central motor neuron excitability.

5.4 Conclusion

Based on previous discussions it can be concluded that areas of spinal dysfunction represents a state of altered afferent input. The altered afferent input is responsible for the ongoing central plastic changes associated with dysfunctional segments. The dysfunctional segment causes the afferent information that enters into the spinal cord to be altered, in other words, spinal dysfunction causes a change in sensorimotor integration which is normalised following SMT. The manipulation not only changes the way these messages are received but also affects the way the afferent information is processed. Figure 5.1(a) is a diagrammatic illustration explaining how spinal dysfunction alters sensorimotor integration. In Figure 5.1 (b) the diagram illustrates how SMT influences the CNS by normalising the afferent input and restores the appropriate sensorimotor function and integration.

![Figure 5.1: Diagram illustrating how spinal dysfunction alters sensorimotor integration](Haavik and Murphy, 2013).

A complex cortical and subcortical loop exists that links the basal ganglia, thalamus, pre-motor areas and primary motor cortex. SMI as previously mentioned, is the process whereby
the nervous system coordinates afferent information from various parts of the body and integrates with the motor system to produce movement. SMT has been shown to significantly influence corticospinal and spinal reflex excitability (Daligadu et al., 2013) by increasing the excitability of the alpha motor neuron pool (Keller and Colloca, 2000). There is evidence that suggests that chiropractic manipulation can affect the CNS by having an influence on the reflex excitability, cognitive processing, sensory processing as well as motor output (Daligadeu et al., 2013).

Motor learning, as discussed in chapter 2, refers to the acquisition of a motor skill by means of practicing that skill. During the process of motor learning changes are occurring at the primary motor cortex. The cerebellum is a structure that is involved in both motor learning as well as it is a major structure that is involved in sensorimotor integration. Research has shown that the cerebellum is a plastic structure that is directly involved in the process of motor learning. The cerebellum has an internal schema that represents the body and network connections that dictate the movements needed for a specific task. The authors go on to describe that in the presence of dysfunctional spinal segments an altered state of sensorimotor integration is occurring within the cerebellum. The altered state within in the cerebellum ultimately leads a derangement in the production of motor commands within the upper limb (Daligadu et al., 2013). The cerebellum plays a vital role in picking up the afferent signals and relay the messages to the motor cortex. Now when the information that is being relayed is altered, as in the case of when SMT is delivered, the cerebellum must adjust to the new signals and thus a better motor task is performed (Baarbe et al., 2016).

The exact contribution of both the motor cortex and cerebellum need to be investigated so that we may better understand the effects of SMT and its impact on the internal schema (Baarbe et al, 2016).
CHAPTER SIX:
CONCLUSIONS AND RECOMMENDATIONS
6.1 Conclusion

The primary aim of this study was to determine the immediate effects that SMT had on a predefined motor task by assessing for a change in movement time using Fitts’ Law in asymptomatic individuals. The secondary aim was to assess if there was a specific region receiving SMT that yielded better results.

Based on the results and discussion there is evidence that suggests that SMT does in fact have a significant effect in reducing the movement time of a Fitts’ Law task involving the upper limb. The immediate effects of SMT on movement time may be due to the alteration of mechanoreceptive afferent input and thus sensorimotor integration. Crowe and Kleinman (1991) have suggested that manipulating the cervical spine effects structures within the CNS specifically at the level of the brainstem, basal ganglia, cerebellum and motor cortex. These centres are all responsible for motor output as well as postural control (Bergmann & Peterson, 2011).

SMT delivered to the cervical spine produced statistically significant results for both tests for all the test parameters. When looking at the effect size it can also be concluded that SMT delivered to the cervical spine has the largest effect size, in other words manipulating the cervical spine appears to have the biggest influence on the outcome of the movement, for all the levels of difficulty. Smith et al., (2006) makes reference to research that shows that SMT influences cognitive processing.

All four groups produced statistically significant results following SMT. However these results were present for the lower ID. Further research is needed to ascertain to what level of ID SMT is still able to affect. Assessing which levels of indices are affected by SMT, it will provide better insight into the mechanisms of action of MT. The intergroup analysis revealed that no group produced statistically significant results when compared with one another. We can therefore concluded that SMT delivered to any dysfunctional segment is likely to improve that participants MT. The improvement in the movement time was likely due to the neurophysiological effects of SMT and not due to the speed accuracy trade off phenomenon.
6.2 Recommendations

The following recommendations are provided for authors who wish to further investigate the effects of SMT on motor control:

- Use a sample size that is gender specific to include only male or female participants. This will improve statistical significance by eliminating the number of demographic variables.
- Use a sample size where the age demographics was all the same as it has been shown that movement time increases with age (Davis and Fang, 2010).
- Include a larger sample size. Have a minimum of 40 participants per group will give better statistical results and may also eliminate the outliers that were seen in this sample size.
- Perform the research using symptomatic patients, or patients who are experiencing pain as the final outcome may be attributed to the presence of pain. It has also been shown that people who are suffering from Subclinical neck pain have slower reaction times and have more difficulty performing a head rotation task (Baabe et al., 2016).
- Include a group that receives no intervention so that a baseline may be obtained.
- Conduct a trial whereby a Fitts' Law task for the lower limb is performed and assess if there are any changes that occur in the task following SMT. There is no research to date that involves SMT and testing Fitts' Law task for the lower limb.
- Investigate what length of time the effects of SMT may be seen by testing the participants prior to SMT, immediately after intervention, followed by a period of 5 minutes, followed by another test after 15 minutes and lastly 30 minutes after intervention.
- Use participants who have never previously been adjusted. This will provide concise information regarding the immediate effect of SMT on sensorimotor integration and may answer the question if one adjustment alone is able to influence the sensorimotor integration process that multiple researches have already proposed.
- Conduct a study on occupation specific individuals such as those who work daily on computers or computer gamers. Due to the fact the GFLMB was done on a computer, those participants who frequently use a computer or those who regularly
play computer games may have a better movement time as they have adequately acquired the skill of using a mouse.

- Determine the long term effects that SMT may have on MT. A study can be done to determine the long term effects that SMT has on movement time by including regular follow up visits for the participants.

- Use participants who suffer from movement disorders such as Parkinson's disease. MT has been shown to be a measure of bradykinesia and can therefore provide an objective based outcome to assess whether or not SMT has an effect on participants who suffer from any movement disorder.

- Include higher indices of difficulty that are larger than ID=4.8 and assess whether or not a change still occurs following SMT.
REFERENCES


APPENDIX A

ADVERTISMENT

CHIROPRACTIC RESEARCH

- Are you right handed?
- Are you able to use a computer?
- Are you between the ages 18-45?

IF YOU ANSWERED YES TO THESE 3 QUESTIONS, YOU ARE INVITED TO COME AND TAKE PART IN AN INTERESTING RESEARCH STUDY.

WHERE: The University of Johannesburg Chiropractic Day Clinic

WHEN: JUNE 2015- JULY 2015, under the supervision of a qualified chiropractor.
Good day, my name is Hannah Berry, and I am doing my Master’s Degree at the University of Johannesburg. I would like to invite you to consider participating in my research study. The purpose of this study is to determine whether chiropractic spinal manipulative therapy will have an effect on movement time.

Before agreeing to participate, there are a few points that I would like to bring to your attention:

- This study is entirely voluntary and you are free to withdraw at any point without reason and without any consequences.
- Your information will be kept confidential at all times and no data will be able to be traced back to you as your name will be converted to a file number on all documentation. The data from this study may however be used for publication purposes.
Some important details directly related to this study that I would like you to be aware of should you decide to participate:

- You need to be between the ages of 18-45, have a motion restriction of at least one joint in the neck, one in the mid-back and one at the lower back. You should not have any contraindications to chiropractic treatment or take any medications that may influence the results of this study, specifically any performance enhancing drugs. These criteria will be determined by the researcher and discussed in more detail with you at your consultation.

- You will have the motion restriction(s) manipulated by the researcher. Spinal manipulation is a standard procedure performed by Chiropractors on a regular basis. There are limited side effects, with a small chance of feeling some stiffness and mild discomfort after the treatment. You will need to notify me of any side effects that you do notice. Be aware that you may hear an audible clicking sound during treatment, this is completely normal.

- You will need to complete a Fitts’ Law Tapping Task as well as a computerised Fitts’ Law Task pre and post manipulation. The researcher will explain to you exactly how to perform these tasks.

- The duration of the study will be a once off visit only. All treatment will take place at the University of Johannesburg’s Chiropractic Day Clinic under the supervision of a qualified chiropractor.

If you have any questions at any time please contact me on 071 893 0770, or alternatively contact my supervisor, Dr C. Yelverton on 011 559 6218.

Thank you for taking the time to read this form and consider participation in this study. Results will be available on request.

This study protocol has been approved by the University of Johannesburg’s Academic Ethics Committee and written approval has been granted by that committee. The study has been structured in accordance with the Declaration of Helsinki of 2013, which deals with the recommendations guiding doctors in biomedical research involving human participants.
If you want any information regarding your rights as a research participant you may contact the Chairperson of the University of Johannesburg’s Academic Committee.
Prof Poggenpoel: Tel (011) 559 6686

UJ Ethics Clearance number: REC-01-266-2015

APPENDIX C

CONSENT FORM

DEPARTMENT OF CHIROPRACTIC

Date: _______________

CONSENT FORM

Dear participant

Before signing this consent form please take your time and read the information form.

Personal doctor/specialist notification option:
Please indicate below, whether you want me to notify your personal doctor or your specialist of your participation in this study:

- YES, I want you to inform my personal doctor/specialist of my participation in this study
- NO, I do not want you to inform my personal doctor/specialist of my participation in this study
- I do not have a personal doctor/specialist

Do you have any questions related to this study?

INFORMED CONSENT

- I hereby confirm that I have been informed by the researcher Hannah Berry about the nature, conduct, benefits and risks of this study with the title “The Immediate Effect of Spinal Manipulation on Movement Time.”
- I have also received, read and understood the above written information (participant information leaflet) regarding this study
- I am aware that the results of this study, including personal details regarding my sex, age, date of birth, and diagnosis will be anonymously processed into a study report
- In view of the requirements of research, I agree that the data collected during this study can be processed
- I may, at any stage, without prejudice, withdraw my consent and participation in this study
- I have had sufficient opportunity to ask questions and (of my own free will) I declare myself prepared to participate in this study.

Signed Participant

Printed name          Signature          Date and time
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<th>Date and time</th>
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Signed Researcher
APPENDIX D
CONTRA INDICATIONS TO SPINAL MANIPULATIVE THERAPY (Gatterman, 1990)

Vascular complications
- Vertebral artery syndrome
- Aneurysms

Tumours
- Primary to the bone
- Secondary (metastasis to the bone)

Bone infections
- Tuberculosis of the spine
- Osteomyelitis of the spine

Traumatic injuries
- Fractures
- Instabilities
- Dislocation
- Unstable spondylolisthesis

Arthritis
- Ankylosing spondylitis
- Rheumatoid arthritis
- Psoriatic arthritis
- Reiter’s syndrome
- Osteoarthritis

Psychological considerations
- Malingering
- Hysteria
- Hypochondriasis
- Pain intolerance
- Dependent personality
- Disability Syndromes

Neurological complications
• Cervical disc lesions and myelopathy
• Nerve root damage
APPENDIX E

CASE HISTORY

UNIVERSITY OF JOHANNESBURG
CHIROPRACTIC DAY CLINIC

CASE HISTORY

Date: _______________

Patient: __________________________ File No: _________

Age: _______ Sex: _______ Occupation: _______________

Student: __________________________ Signature: _____________

Complies with Inclusion criteria of the research:

Clinician: __________________________
Signature: __________________________

Examination:

Previous: UJ Current: UJ
Other Other

X-ray Studies:

Previous: UJ Current: UJ
Other Other

Clinical Path. Lab:

Previous: UJ Current: UJ
Case status:
PTT: Conditional: Signed off: Final sign out:

Recommendations:

Students case history

1. Source of history:

2. Chief complaint: (patient’s own words)

3. Present illness:
   Location
   Onset
   Duration
   Frequency
   Pain (character)
Progression

Aggravating factors

Relieving factors

Associated Sx’s and Sg’s

Previous occurrences

Past treatment and outcome

4. Other complaints:

5. Past history

General health status

Childhood illnesses

Adult illnesses

Psychiatric illnesses

Accidents/injuries

Surgery

Hospitalisation

6. Current health status and lifestyle
Allergies
Immunizations
Screening tests
Environmental hazards
Safety measures
Exercise and leisure
Sleep patterns
Diet
Current medication
Tobacco
Alcohol
Social drugs

7. Family history:
   Immediate family:

   Cause of death
   DM
   Heart disease
   TB
   HBP
   Stroke
   Kidney disease
   CA
   Arthritis
Anaemia
Headaches
Thyroid disease
Epilepsy
Mental illness
Alcoholism
Drug addiction
Other

8. Psychosocial history:

Home situation
Daily life
Important experiences
Religious beliefs

9. Review of systems:

General
Skin
Head
Eyes
Ears
Nose/sinuses
Mouth/throat
Neck
Breasts
Respiratory
Cardiac
Gastro-intestinal
Urinary
Genital
Vascular
Musculoskeletal
Neurologic
Haernatologic
Endocrine
Psychiatric
Underline abnormal findings in **RED.**

Date: __________________

Patient: __________________ File No: ________________

Clinician: __________________ Signature: ________________

Student: __________________ Signature: ________________

Height: ________ Weight: ________ Temp: ________

Rates: Heart: ________ Pulse: ________ Respiration: ________

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General Appearance:

_______________________________________________________________________________

_______________________________________________________________________________

_______________________________________________________________________________
STANDING EXAMINATION

1. Minor’s sign
2. Skin changes
3. Posture: Erect
   Adam’s
4. Ranges of motion (Thoracolumbar Spine)
   T/L spine: Flexion: 90º (fingers to floor)
   Extension: 50º
   R. lat. flex: 30º (fingers
down leg) L. lat. flex: 30º
   (fingers down leg)
   Rot. to R: 35º
   Rot. to L: 35º

L. Rot  R. Rot

L. Lat Flex  R. Lat Flex

Ext.
/ = pain-free limitation  // = painful limitation

5. Romberg’s sign
6. Pronator drift
7. Trendelenburg’s sign
8. Gait: - rhythm
   - balance
   - pendulousness
   - on toes
   - on heels
   - tandem
9. Half squat
10. Scapular winging
11. Muscle tone
12. Spasticity/Rigidity
13. Shoulder: skin
   - symmetry
   - ROM
   - glenohumeral
   - scapulo-thoracic
   - acromioclavicular
   - elbow
   - wrist
14. Chest measurement:
   - inspiration
   - expiration
15. Visual acuity
16. Breast examination:
   Inspection: - skin
   - size
   - contour
   - nipples
   - arms overhead
   - hands against hips - leaning forward
   - breast incl. tail
   Palpation - axillary lymph nodes

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**SEATED EXAMINATION**

1. Spinal posture
2. Head - hair
   - scalp
   - skull - face
- skin

3. Eyes:
   Observation - conjunctiva
   - sclera
   - eyebrows
   - eyelids
   - lacrimal glands
   - nasolacrimal duct
   - position and alignment
   - corneas and lenses

   • corneal reflex

   • ocular movement
     L
     R     III  IV  VI
     VI    III  IV  VI

   • visual fields
   • accommodation
   • Ophthalmoscopic Examination - iris
   - pupils
   - red reflex
   - optic disc
   - vessels
   - general background
   - macula
   - vitreous
   - lens

4. Ears: - auricle
   • Inspection - ear canal
     - drum

   • auditory acuity
   • Weber test
   • Rinne test

5. Nose:

   • External
   • Internal - septum
   - turbinates
   - olfaction
6. Sinuses  
   (frontal &  
   maxillary)  
   :  
   - tenderness  
   - transillumination

7. Mouth  
   and  
   pharynx:  
   • lips  
   • buccal mucosa  
   • gums and teeth  
   • roof  
   • tongue - inspection  
   - movement  
   - taste  
   - palpation

9. Neck  
   • posture  
   • size  
   • swelling  
   • scars  
   • discolouration  
   • hair line

**Ranges of motion (cervical spine)**

The following are normal ranges of motion

Forward flexion = 45° chin to larynx or sternum  
Extension = 55° forehead parallel to ground  
L/R Rotation = 70°
9. NEUROLOGICAL EXAMINATION (CERVICAL SPINE)

- L/R Lat Flexion = 40°

- L. Rot
- R. Rot

- Flex.

- L. Lat Flex
- R. Lat Flex

- Ext.

- lymph nodes
- trachea
- thyroid
- carotid arteries (thrills, bruit)
- Cranial Nerves
  - CN V
  - CN VII
  - CN VIII (nystagmus)
  - CN IX
  - CN XI
  - CN X11
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<td>Biceps C5</td>
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9. Peripheral vasculature:

- **Inspection**
  - skin
  - nail beds
  - pigmentation
  - hair loss

- **Palpation**
  - pulses: femoral - dorsalis pedis
  - popliteal - radial
  - post. Tibial - brachial
- lymph nodes - epitrochlear
- femoral (horizontal & vertical)
- temperature (feet and legs)

- Manual compression test
- Retrograde filling (Tredelenburg) test
- Arterial insufficiency test

10. Musculoskeletal:
(i) ROM

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- knee
- ankle

(ii) leg length

- Co-ordination - point to point
- dysdiachokinesia
10. TMJ
- Inspection - ROM
  - deviation
- Palpation - crepitus
  - tenderness

11. Thorax
- Inspection - skin - shape
  - respiratory distress
  - rhythm (respiratory)
  - depth (respiratory)
  - effort (respiratory)
  - intercostals supraclavicular retraction
- Palpation - tenderness
  - masses
  - respiratory expansion
  - tactile fremitus

- Percussion - lungs (posterior)
  - diaphragmatic excursion
  - kidney punch

- Auscultation (i) breath sounds
  - vesicular
  - bronchial
  (ii) adventitious sounds
  - crackles (rales)
  - wheezes (rhonchi)
  - rubs
  (iii) voice sounds
  - broncophony
  - whispered pectoriloquy
  - egophony

- Cardiovascular - auscultation (aortic murmurs)
  - Allen’s test

**SUPINE EXAMINATION**

1. JVP
2. PMI
3. Auscultation heart
   (L. lat. Recumbent)
4. respiratory excursion
5. percussion chest
   (anterior)
6. breast palpation
7. Abdominal Examination
   • Inspection - skin
   - umbilicus
   - contour
   - peristalsis
   - pulsations
   - hernias (umbilical/incisional)

   • Auscultation - bowel sound
   - bruit

   • Percussion - general
   - liver
   - spleen

   • Palpation - superficial reflexes
   - cough
   - light
   - rebound tenderness
   - deep
   - liver
   - spleen
   - kidneys
   - aorta
   - intra-/retro-abdominal wall mass
   - shifting dullness
   - fluid wave
   - where pain began and now
   - cough
   - tenderness
   - guarding/rigidity
   - rebound tenderness
   - rovsing’s sign
   - psoas sign
   - obturator sign
   - cutaneous hyperaesthesia
   - rectal exam
   - Murphy’s sign

MENTAL STATUS
(i) Appearance and behaviour
- level of consciousness
- posture and motor behaviour
- dress, grooming, personal hygiene
- facial expression
- affect

(ii) Speed and language
- quantity
- rate
- volume
- fluency
- aphasia (pm)

(ii) Mood

(v) Memory and attention
- orientation (time, place, person)
- remote memory
- recent memory
- new learning ability

(vi) Higher cognitive functions
- information and vocabulary
- (general and specialised knowledge)
- abstract thinking

NEUROLOGICAL EXAMINATION (LUMBAR SPINE)

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APPENDIX G

CERVICAL SPINE REGIONAL

UNIVERSITY OF JOHANNESBURG
CHIROPRACTIC DAY CLINIC

REGIONAL EXAMINATION
CERVICAL SPINE

Date: _______________________
Patient: ___________________________ File No: ______________________
Clinician: ___________________________ Signature: __________________

Student: ___________________________ Signature: __________________

OBSERVATION

• Posture
• Size
• Swellings
• Scars
• Discolouration
• Hairline
• Bony and soft tissue contours
• Shoulder level
• Muscle spasm
• Facial expression

5. RANGE OF MOTION
Flexion = 45º - 90º
Extension = 55º - 70º
L/R Rotation = 70º - 90º
L/R Lat Flexion = 20º - 45º

/ = Pain free limitation  // = Painful limitation

PALPATION

- Lymph nodes
- Trachea
- Thyroid gland
- Pulses/thrills
- Tenderness
- Muscle Tone
- Active MF Trigger Points
  - SCM
  - Trapezius
  - Scaleni
  - Levator Scapulae
  - Posterior Cervical musculature
ORTHOEPEDIC EXAMINATION

1. Doorbell Sign
2. Max. Cervical Compression
3. Spurling’s manoeuvre
4. Lateral Compression (Jackson’s test)
5. Kemp’s Test
6. Cervical Distraction
7. Shoulder abduction Test
8. Shoulder depression Test
9. Dizziness rotation Test
10. Lhermitte's Sign
11. O’ Donoghue Manoeuvre
12. Brachial Plexus Tension
13. Carpal tunnel syndrome: • Tinel’s sign
   ▪ Phalen’s Test
14. TOS: • Halstead’s test
   ▪ Adson’s test
   ▪ Eden’s (traction) test
   ▪ Hyperabduction (Wright’s) test – Pec minor
   ▪ Costoclavicular test

Remarks:
### Vascular

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APPENDIX H
LUMBAR SPINE REGIONAL

UNIVERSITY OF JOHANNESBURG
CHIROPRACTIC DAY CLINIC

REGIONAL EXAMINATION
LUMBAR SPINE AND PELVIS

Date: ____________________

Patient: ___________________________ File No: ________________

Clinician: ___________________________ Signature: ______________

Student: ___________________________ Signature: ______________

A. STANDING

1. BODY TYPE
2. POSTURE
3. OBSERVATION: -

• Muscle Tone
• Bony + Soft Tissue Contours
• Skin
• Scars
• Discolouration
• Step deformity

4. SPECIAL TESTS

• Schober’s Test
• Spinous Percussion • Treadmill • Minor’s Sign
• Quick Test
• Trendelenburg Test

5. RANGE OF MOTION

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/ = Pain free limitation
// = Painful limitation

6. GAIT

• Rhythm, pendulousness
• On Toes (S1)
• On Heels (L4, 5)
• Halt Squat on one leg (L2, 3, 4)
• Tandem Walking

7. MOTION PALPATION – sacroiliac joints

B. SITTING

01. SPECIAL TESTS

• Tripod Test
• Kem
p’s Test
• Valsa
  Iva
Mano
euvre

2. MOTION PALPATION

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C. SUPINE

01. OBSERVATION

• Hair, Skin, Nails
• Fasciculations

2. PULSES

• Femoral
• Popliteal
• Dorsalis Pedis
• Posterior Tibial

3. MUSCLE CIRCUMFERENCE

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4. LEG LENGTH
5. **ABDOMINAL EXAMINATION**

- Observation
- Abdominal Reflexes
- Auscultation Abdomen and Groin
- Palpation Abdomen and Groin

Comments: _____________________________________________________

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7. **SPECIAL TESTS**

- SLR
- WLR
- Braggard's
- Bowstring
- Sciatic Notch Pressure
- Sign of the Buttock
- Bilateral SLR
- Patrick Faber
- Gaenslen’s Test
- Gapping Test
- “Squish” Test
- Gluteus Maximus Stretch
- Thomas’ Test
- Rectus Femoris Contracture Test
- Hip Medial Rotation
- Psoas Test

**LATERAL RECUMBENT**

- Sacroiliac Compression
- Ober’s Test
- Femoral Nerve Stretch Test
• Myotomes:  - Quadratus Lumborum Strength
- Gluteus Medius Strength

PRONE

• Facet joint challenge

• Myofascial Trigger points:
  - Quadratus Lumborum
  - Gluteus Medius
  - Gluteus Maximus
  - Piriformis
  - Tensor Fascia Lata
  - Hamstrings

• Skin Rolling

• Erichsen’s Test

• Sacroiliac Tenderness

• Pheasant’s Test

• Gluteal Skyline

• Myotomes:
  - Gluteus Maximus strength

NON-ORGANIC SIGNS

• Pin-point pain

• Axial Compression

• Trunk Rotation
• Burn’s Bench Test
• Flip Test
• Hoover’s Test
• Ankle Dorsiflexion Test
• Pin-point pain
## APPENDIX I

### SOAP NOTE

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<td>Student:</td>
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<td>Date:</td>
<td>Clinician:</td>
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</tr>
</tbody>
</table>
APPENDIX J

FITTS’ TAPPING TASK

Instructions:

- Using a pencil, tap back and forth between each pair of targets. Have someone time you for 10 seconds as you tap.

- Speed up if all your taps are in the middle of the boxes, or slow down if they fall outside of the boxes. Be careful not to slow down for the small-distance targets.

- As you tap, count the number of taps you are making (count every other tap, and multiply later by 2). Then, record your results in the table on the left.

Does the number of taps (N) depend on the distance between targets (D) or the width of the target (W) or the ratio (D/W)?
APPENDIX K

GENERALIZED FITTS LAW MODEL BUILDER

CONDITION 1
APPENDIX L

GENERALIZED FITTS LAW MODEL BUILDER

CONDITION 2
APPENDIX M

GENERALIZED FITTS LAW MODEL BUILDER

CONDITION 3
APPENDIX N
GENERALIZED FITTS LAW MODEL BUILDER
CONDITION 4
APPENDIX O

HIGHER DEGREE COMMITTEE CLEARANCE LETTER

FACULTY OF HEALTH SCIENCES
HIGHER DEGREES COMMITTEE

TO WHOM IT MAY CONCERN:

Student: BERRY, HM
Student Number: 200911347

TITLE OF RESEARCH PROPOSAL: The Immediate Effect of Spinal Manipulative Therapy on Movement Time

DEPARTMENT OR PROGRAMME: CHIROPRACTIC

SUPERVISOR: Dr CJ Yelverton
CO-SUPERVISOR: 

The Faculty Higher Degrees Committee has scrutinised your research proposal and confirms that it complies with the approved research standards of the Faculty of Health Sciences, University of Johannesburg.

The proposal has been awarded a Code 02 – Approved with suggestions without re-submission. Attached recommendations were made by the Committee which will add value to your proposal.

Please make these amendments to the satisfaction of your supervisor/s and submit a corrected copy of the proposal to the Faculty Research Administrator after which your clearance number will be issued.

The HDC would like to extend their best wishes to you with your postgraduate studies.

Yours sincerely,

[Signature]

Prof Y Coopoo
Chair: Faculty of Health Sciences HDC
Tel: 011 559 6944
Email: yogac@uj.ac.za

UNIVERSITY OF JOHANNESBURG
APPENDIX P

ACADEMIC ETHICS COMMITTEE LETTER

FACULTY OF HEALTH SCIENCES
RESEARCH ETHICS COMMITTEE
NHREC Registration no: REC-241112-035

03 JUNE 2015

TO WHOM IT MAY CONCERN:

Student: BERRY, H
Student Number: 200911347

TITLE OF RESEARCH PROPOSAL: The Immediate Effect of Spinal Manipulative Therapy on Movement Time

DEPARTMENT OR PROGRAMME: CHIROPRACTIC

SUPERVISOR: Dr CJ Yelverton
CO-SUPERVISOR:

The Faculty Research Ethics Committee has scrutinised your research proposal and confirm that it complies with the approved ethical standards of the Faculty of Health Sciences, University of Johannesburg.

The proposal has been awarded a Code 02 – Approved with suggestions without re-submission. The attached recommendations were made by the Committee which will add value to your proposal.

Please make these amendments to the satisfaction of your supervisor/s and submit a corrected copy of the proposal to the Faculty Research Administrator after which your clearance number will be issued. The REC would like to extend their best wishes to you with your postgraduate studies.

Yours sincerely,

[Signature]

Prof M Poggenpoel
Chair: Faculty of Health Sciences REC
APPENDIX Q

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1.1 General Introduction

Movement is a fundamental aspect of life. Without it, humans and animals alike would not be able to survive. Humans require movement to escape danger, gather food and reproduce to name just a few things. According to Lee & Schmidt (2011), movement can be classified into 2 main classes. The first class describes movement that is genetically defined. Some examples of this class include the ability human beings have to control their limbs, or the blink reflex of the eyes in response to an unexpected puff of air. The second class describes movement that is learned. These types of movements are also referred to as skills. Gunnie (1992), has the following definition for skill: "Skill consists in the ability to bring about some result with minimum error and maximum outlay of energy, or time and energy." Movements of all types of magnitudes require complex processing by the central nervous system to produce a co-ordinated result, how this process occurs is known as motor control (Lee & Schmidt, 2011; Shea & Wright, 1997).