THE INFLUENCE OF CERVICAL MANIPULATION ON SPINAL MOTION

A PILOT STUDY DETERMINING THE INFLUENCE OF CERVICAL MANIPULATION ON SPINAL MOTION DURING GAIT IN PREVIOUSLY CONCUSSED INDIVIDUALS

By

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Abstract

This pilot study was performed in order to examine the potential beneficial effects of cervical spinal manipulative therapy on volunteers suffering from post-concussive neck syndrome. The study of concussions and post-concussive neck syndrome is still a relatively new topic in the existing literature. Little research has been done in the area of spinal manipulation and the treatment of volunteers suffering from post-concussive neck syndrome, from a biomechanical standpoint.

Forty-one volunteers who were suffering from post-concussive neck syndrome were recruited from McMaster University in Hamilton, Ontario to participate in the study. In order to assess the severity of neck complaints, the severity of their post-concussive symptoms and overall general health, the volunteers completed the Neck Disability Index, the Visual Analog Scale, the Standardized Assessment of Concussion and the Short Form-36 Health Survey. During testing sessions, volunteers were fitted with several light emitting markers placed strategically on the head, mid-back, sacrum and heels of the volunteers' footwear. Each volunteer would then walk on a treadmill for four separate five minute trials, after an initial familiarization period. The 3D position of these markers during gait were recorded by a rear-mounted kinematic data acquisition system (Optotrak 3020). After the initial five minute walk (trial 1), the volunteer was

treated with a cervical spinal manipulation, and immediately resumed walking for the second trial on the treadmill. The volunteers performed four walking trials in total.

Both manual and automated procedures were used to identify the multiple right-heel treadmill surface contacts during each five minute walk. Objective biomechanical outcome measures used in the study included relative phase measurements between the head and thorax in the transverse plane, the Biomechanical Efficiency Quotient and the Neck-Walk Index.

Clinically significant results in relative measurements, post-intervention, were found when certain volunteers were removed (due to slow walking velocity). These differences can be attributed to the intervention of spinal manipulation which caused a significant increase in cervico-thoracic spinal motion, which appeared to decrease again at 35 minutes. This is clinically significant because it poses the theory that initial short-term biomechanical changes in the cervical spine are caused by SMT.

Clinically significant results in the Biomechanical Efficiency Quotient were found when specific volunteers were removed. The results however, were in the opposite direction than was previously hypothesized. The reason for the increase in BEQ post-manipulation compared to pre-manipulation could be a result of the familiarization walking period before the initial trial. By allowing volunteers several minutes to get accustomed to walking on the treadmill, a learning effect had taken place, decreasing the variability in their gait in the initial pre-intervention trial. Although BEQ increased in the second and third trials, it decreased again at 35 minutes post-intervention, meaning the walking economy had once again increased.

The specific intervention of cervical spinal manipulative therapy was hypothesized to change the variability of head movement disturbances during gait (Neck-Walk Index). No reference in the literature is made in relation to Neck-Walk Index and how it evaluates change in head carriage, post-intervention. This study suggests however, that although results approached significance, cervical manipulative therapy did not change biomechanical head carriage in this volunteer population.

With respect to future studies, several recommendations have been made in this thesis which are aimed at increasing the clinical significance of the results. This would be done through the incorporation of more affected volunteers (increase in functional disability due to post-concussive neck syndrome), the incorporation of a more lengthy and specific treatment protocol (to sustain biomechanical and physical changes), and an increased treadmill walking velocity (to assess antiphasic movements more easily).

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Chapter 1

Introduction

Concussion, or mild traumatic brain injury, is a major sports medicine issue in the current literature as well as in the popular media (Kelly & Rosenberg, 1998). The improvement of patients with concussion continues to be a challenging problem faced by medical personnel (Kelly & Rosenberg, 1998;McCrea, 2001a;Wojtys *et al.*, 1999).

Among the 300,000 new head injuries reported each year, concussions remain the most commonly reported (Cooper *et al.*, 2003). Post-concussive neck pain is a commonly reported symptom experienced by this population and has been referred to as post-concussive neck syndrome (PCNS) (De Kruijk *et al.*, 2002). This type of neck pain can be attributed to intervertebral disk, muscle and joint damage and can cause long-lasting, chronic symptoms (Cote *et al.*, 2001;Cote *et al.*, 2004;Hill *et al.*, 2004). In a Canadian sample, Cote *et al.* (2004) found that 14.6% of the population was suffering from neck pain and that 0.6% suffered from disabling pain. Hill *et al.* (2004) found that 48% of people who were suffering from neck pain continued having this pain one year later. With reference to sport, the chronicity of symptoms such as these may cause an athlete to diminish their performance as well as to miss games completely (Cooper *et al.*, 2003). For example, in contact sports such as football, concussions are extremely common (Viano & Pellman, 2005). It is believed that as many as 5.6% of high school players will suffer a concussion in a given season, and as many as 20% of players will suffer a concussion over the course of their careers (Guskiewicz *et al.*, 2000).

Therefore, due to the fact that concussions and post-concussive neck pain is increasing in the athletic environment, it is necessary to find methods of therapy or rehabilitation to restore the athlete to their pre-concussive status, allowing them to function optimally. Patients with chronic episodic neck pain (CENP) who have been diagnosed with a previous concussion are thought to exhibit abnormal spinal mechanics in the cervical and upper thoracic spine due to poor motor regulation and movement patterns sustained from the prior trauma (Triano, 2001). This may contribute to constant overloading of mechanical structures in the neck and upper back in an attempt to stabilize head motion during activities of normal daily living. Research has suggested that spinal manipulative therapy (SMT) may restore typical motor control and movement patterns thereby decreasing the impact of PCNS and CENP (Maigne & Vautravers, 2003;Triano, 2001).

The current study examined the effect of cervical spinal manipulation on spinal motion as measured during gait in patients suffering from PCNS. It was achieved using specific objective biomechanical outcome measures including transverse plane – relative phase measurements (RP), the Biomechanical Efficiency Quotient (BEQ) and the Neck-Walk Index (NWI).

Clinically, these outcome measures were important because they are measured an everyday activity performed by most people – walking. The ability to walk is extremely important in today's society. There can also be several functional limits to a person's gait pattern, including that of relative head and neck motion for general stability of gaze during gait. Using all three outcome measures not only allowed input into the relative movement of the head and thorax during gait, but it also allowed the clinician to understand head carriage during gait as well as overall walking economy.

Relative measurements during gait between the head and thorax in the transverse plane were taken to see whether there was a clinically meaningful increase in spinal motion post-cervical manipulation. Previous studies (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a;Lamoth *et al.*, 2005) have shown that, in patients with low back pain, pelvis-thorax synchronicity evolves towards an antiphasic counterrotation as gait velocity increases. This was a more rigid, less flexible thoraco-pelvic motion. The same research states that this coordination measure is more adequate in assessing quality of walking in patients with low back pain than are other kinematic measures aimed at individual segmental rotation. If this was shown in low back pain patients, would the same be seen in neck pain volunteers, and if so, would there be a difference in RP post-intervention?

The Biomechanical Efficiency Quotient is used to measure biomechanical walking economy, independent of cardiac, pulmonary, psychologic, or other nonbiomechanical factors (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996). It would be useful for both clinical and research purposes to have a tool that helps assess a treatment's specific effects on global walking economy. Most gait laboratory assessments demonstrate, for instance, that hip motion or torque about the hip during walking is improved with a particular treatment (Kerrigan *et al.*, 1996). It is important to also note that patients with neurologically based gait disabilities have lower extremity impairments and a decreased overall biomechanical walking efficiency. Recently concussed volunteers can be included in this group. In this study, the author proposed that a clinically meaningful difference would be seen in this PCNS volunteer group's gait, post cervical manipulation.

Detrended fluctuation analysis shows whether there is an intrinsic self-similarity embedded in what appears to be a seemingly non-stationary time series. For example, stride interval fluctuations during gait are not random rather, they exhibit long range power law correlations (α), such that a given stride interval is influenced by earlier variations in the stride intervals (Pierrynowski *et al.*, 2005). The Neck-Walk Index showed what the variability was with respect to head movement disturbances during gait, within this PCNS volunteer group, pre and post cervical manipulation.

1.1 Purpose

The purpose of this thesis was two-fold:

1. To determine if there was a measurable change in spinal motion (post minus pre) after cervical manipulation in a post-concussive neck pain volunteer group.
2. To determine, if a measurable change in spinal motion does in fact exist, what the half-life of this change actually is.

Spinal motion was measured using the following three outcome measures:

- relative phase (RP) as measured using transverse plane measurements of the head relative to the thorax
- walking economy as measured using the Biomechanical Efficiency Quotient (BEQ)
- long - range power law correlation as measured using the Neck-Walk Index (NWI)

1.2 Hypotheses

The primary purpose of this study examined the effect of cervical spinal manipulation on spinal motion as measured during gait in patients suffering from PCNS.

The hypotheses concerning the current study were as follows:

1. there will be a clinically meaningful increase of five percent in relative head-thorax spinal motion, post cervical manipulation, lasting greater than 35 minutes,

2. there will be a clinically meaningful increase of five percent in global walking economy, post cervical manipulation, lasting greater than 35 minutes and
3. there will be a clinically meaningful change of five percent in the variability of head movement disturbances during gait, post manipulation, lasting greater than 35 minutes.
4. All volunteers will respond similarly (i.e. in the same direction) to the spinal manipulative therapy.

1.3 Delimitations

1. Volunteer selection could have included those who had scored low (≤ 25) on the Standardized Assessment of Concussion however, this would not have been ethical. Spinal manipulation on a concussed individual is considered a contraindication (Spitzer *et al.*, 1995), therefore volunteers with a high Standardized Assessment of Concussion score were used.
2. This thesis was designed to look at the immediate response (i.e. ≤ 35 minutes) of spinal manipulative therapy in a post-concussive population. Ideally, an intervention/treatment program would have been prescribed and followed for approximately four to six weeks. This is the clinical standard of practice covered by third party payers.

1.4 Limitations

1. The inclusion of an affected control group would not have been ethical. The use of concussed volunteers with specific neurocognitive symptoms may increase the likelihood of an accident occurring on the treadmill.
2. The outliers in the study may have skewed the results. Although this may have been the case, it may be important to note that these "outliers" may be unique in that their results may be used to suggest investigation for future research.

Chapter 2

Literature Review

There has been limited research on the mechanisms of post-concussive neck syndrome from a biomechanical standpoint. However there is extensive literature focusing on cervical spine biomechanics as well as the biomechanics behind specific mechanisms of cervical spine injury that may be very similar to those causing PCNS. These topics will be examined in this Chapter, along with concussion assessment, the biomechanics of SMT, and how SMT may benefit abnormal spinal mechanics. The literature on subjective outcome measures, including the Standardized Assessment of Concussion, Neck Disability Index, SF-36 Health Survey, Visual Analog Scale, and objective outcome measures including transverse plane-relative phase measurements, the Biomechanical Efficiency Quotient and the Neck-Walk Index will also be discussed.

2.1 Epidemiology of Head and Neck Injuries in Sport

Prospective data collection continues to be used by coaches and sports medicine professionals alike to identify accident patterns and alter specific sporting practices (i.e. spearing in football) to lessen the risk of serious head and neck injury in sport. Of the approximately 300, 000 newly reported athletic head and neck injuries per year, concussions are the most common injury reported (Cooper *et al.*, 2003). It has also been estimated that five to ten percent of the cervical spine injuries occurring each year in the United States results from sport-related activity (Maroon & Bailes, 1996).

Axial loading to the cervical spine has been identified as the most important mechanism causing catastrophic athletic neck injuries, including fractures, dislocations and intraspinal hemorrhage (Torg *et al.*, 1990). Although catastrophic head injuries such as spinal fractures and hemorrhages often receive much more attention, less severe injuries such as ligament sprains and muscle strains are much more common and can result in significant sports-related disability (Cantu, 2000). In contact sports such as football, concussions are extremely common (Viano & Pellman, 2005). In the Unites States, it is believed that as many as 5.6% of high school players will suffer a concussion in a given season, and as many as 20% of players will suffer a concussion over the course of their careers (Guskiewicz *et al.*, 2000).

Although neck pain is a common source of disability, little is known about its incidence and course (Cote *et al.*, 2004). Cote *et al.* (2004) published a cohort study using 1,100 subjects and found that 14.6% of this population experienced neck pain, 0.6% of which was disabling. They found that the annual rate of resolution of neck pain was 36.6% while 32.7% reported improvement. He also stated that a neck injury sustained from a collision occurred most often (Cote *et al.*, 2000). Therefore, previously concussed athletes who intend to continue playing their respective sport with

CENP/PCNS, may make their actions in their sport that much more difficult to perform due to a possible biomechanical inefficiency in the cervical and thoracic spine.

Research has suggested that SMT may restore typical motor control and movement patterns thereby decreasing the impact of PCNS and CENP (Coulter & Shekelle, 2005;Maigne & Vautravers, 2003;Triano, 2001). This could assist in increasing an athlete's rate of recovery as well as decrease the total cost imposed on the health-care system by neck pain (Borghouts *et al.*, 1999).

Other treatment options for PCNS may include physiotherapy, massage, medical intervention and self-education. Evidence and comparison is however lacking in this area (Kirshner & Guyatt, 1985;Kjellman *et al.*, 1999).

2.2 Kinematics of Normal and Abnormal Spinal Motion

2.2.1 Kinematics of Normal Cervical Spinal Motion

The head houses our sensory apparatuses for hearing, vision as well as vestibular sensation. In order to function optimally, these sensory organs must be able to scan the environment towards objects of interest (Bogduk & Mercer, 2000). In a typical person, it is the cervical spine that allows this movement. Although initiated movements of the head are executed by muscles, these types of movements are made possible by the different shapes and structures of the different cervical vertebrae. Therefore, the anatomy of the bones that make up the neck as well as the joints that they form, establish a basis for the kinematics of the cervical spine (Bogduk & Mercer, 2000).

The seven vertebrae making up the cervical spine can be divided into three separate sections (due to their anatomical biomechanical differences): C0-C1, C1-2, and C3-7.

1. C0 (Occiput) - C1 (atlas):

The occipital condyles are cradled by the superior articular facets of the atlas. Compared with other regions of the spine, the upper cervical spine represents quite a unique anatomy and displays a complicated combination of motions, including flexion–extension, lateral bending, and axial rotation (Pang & Li, 2004). In head rotation, the upper cervical spine offers a large amount of axial rotation combined with lateral bending and flexion–extension - these are known as coupled motions (Pang & Li, 2004). In vitro studies have previously been the only method for obtaining quantitative data on three-dimensional intervertebral motions (Panjabi *et al.*, 2001), however, the lack of physiologic tonus within the musculature makes the results of in vitro study impractical. It has been previously thought that the movement at C0-C1 was only flexion-extension of the occipital condyles on the superior articular facets of the atlas (Bogduk & Mercer, 2000;Koebke & Brade, 1982;Van Mameren *et al.*, 1990). More recently however, Pang and Li (2004) and Ishii *et al.* (2004) observed that, at C0-C1, coupled lateral bending with axial rotation occurs in the opposite direction to that of the actual axial rotation.

They also found that coupled extension with axial rotation occurred at C0-C1, irrespective of the direction of head rotation.

2. C1 (atlas) - C2 (axis):

The atlas carries the head, and it also sits on the axis. The weight of the head is dispersed through the lateral atlanto-axial joints. After weight-bearing, the core function of the atlanto-axial junction is to permit a large range of axial rotation (36.3 – 41.5°) (Bogduk & Mercer, 2000;Dvorak *et al.*, 1987a;Dvorak *et al.*, 1987b;Pang & Li, 2004;Panjabi *et al.*, 2001). C1-C2 has also been found to play a major role in the initial phase of head rotation (Dvorak *et al.*, 1987a;Ishii *et al.*, 2004b;Pang & Li, 2004). Axial rotation at the atlanto-axial junction comprises approximately 60% of the entire cervical spine, (Ishii *et al.*, 2004b;Pang & Li, 2004). The rotatory movement requires the anterior arch of the atlas to pivot around the odontoid process of the axis. The ipsilateral lateral mass of the atlas must also slide posteriorly and medially, while the contralateral lateral mass must slide anteriorly and medially (Bogduk & Mercer, 2000).

More recent in vivo studies suggest that the motion in the C1-C2 junction is not simply rotation. Pang and Li (2004) and Ishii et al. (2004) suggest that coupled lateral bending in the opposite direction to axial rotation and coupled extension were demonstrated at C1-C2. This would mean that intervertebral movements at C1-C2 during i.e. left rotation, would include right lateral bending and coupled extension, while during right rotation, movements would include left lateral bending and coupled extension.

3. C3 – C7 (Typical cervical vertebrae):

The fundamental movements of the lower cervical spine is flexion and extension (Bogduk & Mercer, 2000;Dvorak *et al.*, 1993;Panjabi *et al.*, 2001). Although the study of axial rotation is definitely more demanding, the advent of magnetic resonance imaging (MRI) has allowed intervertebral axial rotation of the subaxial cervical spine to be investigated more in-depth.

Studies have indicated that the cervical intervertebral joints are saddle joints (Bogduk & Mercer, 2000;Penning & Wilmink, 1987). These segments consist of two concavities which are at right angles to each other. The inferior surface of the superior segment is concave inferiorly in the sagittal plane, while across the coronal plane, the superior surface of the inferior segment is concave superiorly (Bogduk & Mercer, 2000). This allows the vertebral motion segment to move around a transverse axis in flexion and extension. It can also allow for axial rotation in a modified axis which is perpendicular to the plane of the zygapophyseal joints (approximately 45° to the transverse plane, in the sagittal plane), and cradled by the uncinate processes.

The use of MRI has permitted researchers to study axial rotation in vivo (Ishii *et al.*, 2004a). Ishii *et al.* (2004) suggest that there is also coupled motion in these subaxial vertebrae. During maximal head rotation, C3-C4 showed the greatest amount of ipsilateral axial rotation while C7-T1 showed the least. Coupled lateral bending to the ipsilateral side of axial rotation was also shown to be greatest at C3-C4 while C7-T1 showed the least. Interesting to note, however, was that Ishii *et al.* (2004) found that coupled extension with axial rotation occurred in the middle cervical region (C2-C3-C4-C5, greatest at C3-C4) while in the lower cervical region, flexion was coupled with axial rotation (C5-C6-C7-T1, greatest at C7-T1). The reason for this difference may have to do with the lordotic curve in the cervical spine. The lower cervical segments are already in somewhat of a 'flexed' position (the lower the cervical segment, the more flexed – greatest at C7-T1), while the middle segments are in a greater 'extended' position within a lordotic posture compared to the lower segments.

2.2.2 Kinematics of Abnormal Cervical Spinal Motion – A Discussion on Post-Concussion Neck Syndrome

A single traumatic or cumulative event can cause a mechanical overload on a normally functioning spinal unit (Manchikanti *et al.*, 2004). This mechanical overload may induce a buckling or a collapse at a specific spinal level (Triano, 2001). Localized joint buckling in the spine is opposed only by adequate timing in the recruitment of specifically attached muscles appropriate to the action being performed. If the mechanical load on the muscle becomes unbearable, the muscle can strain or tear. Muscles can also become strained as a protective mechanism against joint sprain (Maigne & Vautravers, 2003;Manchikanti *et al.*, 2004;Triano, 2001).

When a critical buckling load is reached, the linear force displacement causes movement of the specific vertebra, which still remains within a normal segmental range. The affected segmental area therefore, reaches, and is operating at its maximum or extreme range, which is out of phase with other vertebral segments for the desired task. It can be assumed that such a difference in functional configuration may result in altered stress distribution within the spine, thereby causing segmental point sensitivity as well as pain with motion (Manchikanti *et al.*, 2004;Triano, 2001). Individual structural elements, such as the disc, facets, ligaments, nerves, and muscles, may experience the concentration of these local stresses thereby decreasing functional limits. This may also lead to local inflammatory changes and increasing pain symptoms through the release of vasoactive byproducts (histamine, bradykinin, prostaglandins) and neuroactive chemicals (substance P) (Brennan *et al.*, 1992).

A syndrome can be considered a collection of traits or health problems which an individual has, due to one underlying cause (Cusick *et al.*, 2001). Post-concussive neck syndrome is therefore a set of symptoms including but not limited to headache, dizziness, tinnitus, short-term memory impairment, poor concentration, fatigue, irritability, visual changes, as well as neck pain (LaBotz *et al.*, 2005). The neck pain itself can present in several different ways, including cervical muscle strains and cervical joint sprains. Bogduk and Yoganandan (2001) have found that in minor injuries of the cervical spine, cervical zygapophyseal joint pain is the single most common basis for *chronic* neck pain after injury, which may compromise a person's ability to function with everyday tasks.

Research has shown that the instantaneous axis of rotation displaces upwards during a whiplash type movement associated with that of a fall during head injury (Kaneoka *et al.*, 1999). Kaneoka *et al.* (1999) showed that the instantaneous axis of rotation (flexion/extension around a horizontal axis) during normal movements lies below the disc of the moving segment. This would mean that the inferior articular facet of the superior segment would glide smoothly posterior along the surface of the superior articular facet of the inferior segment. During a whiplash-type movement however, the instantaneous axis of rotation is displaced upwards into the moving vertebral body (Bogduk & Yoganandan, 2001;Kaneoka *et al.*, 1999). This means that the inferior articular facet of the superior segment (the moving segment), rotates backwards about this new superior axis of rotation, causing its tip to chisel into the surface of the superior articular facet of the inferior segment (refer to Figure 1).

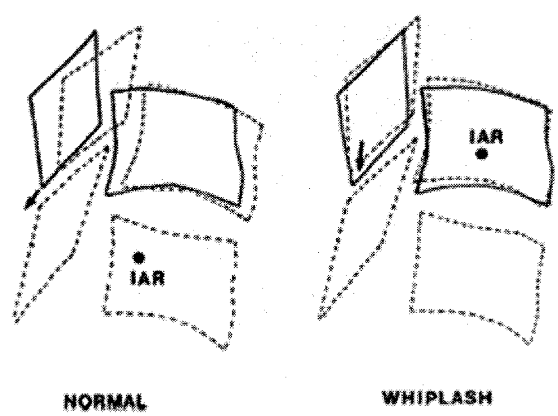

Figure 1 (Bogduk & Yoganandan, 2001)

Zygapophyseal capsular sprain, as well as cervical muscle strain, are very common injuries after this type of trauma, and is the basis for the pain felt in PCNS (Bogduk & Yoganandan, 2001).

2.3 Biomechanical Effects of Spinal Manipulative Therapy

Spinal manipulative therapy acts on specific components of the "three-joint complex" of the vertebral motion segment. These three joints consist of vertebral body (superior segment) to vertebral body (inferior segment), left inferior articular facet (superior segment) to left superior articular facet (inferior segment), and right inferior articular facet (superior segment) to right superior articular facet (inferior segment). Spinal manipulative therapy, in this case, was defined as a high velocity, low amplitude thrust to the cervical segments' transverse process, taking them beyond their physiological range of motion into a paraphysiological range (Maigne & Vautravers, 2003). Spinal manipulation uses controlled forces and moments applied to the spine along with inertial forces generated by acceleration of relevant body segment mass (Triano & Schultz, 1997;Triano, 2001). The sum of these forces are transmitted to the spine and are designed to reduce local mechanical stresses, as well as increase the general range of motion in a functional spinal unit (Triano & Schultz, 1997;Triano, 2001). The mechanism of action of SMT is only partly understood and is clearly more complex than a simple "readjustment" of vertebra, which is a common misconception of the general public (Maigne & Vautravers, 2003).

2.3.1 The Functional Spinal Unit or Vertebral Motion Segment

A manipulative thrust takes a segment passively to its end range of motion, i.e. a paraphysiological range. The high velocity, low amplitude thrust is done mostly in an anterior to posterior direction, with slight rotation and lateral bend to the ipsilateral side.

2.3.1.1 The Cavitation

Although manipulation has been previously described as targeting a single vertebral level, studies have shown that several levels are mobilized simultaneously, i.e. above or below the targeted segmental level (Ross *et al.*, 2004). The audible ‘crack" or "pop" heard during SMT is related to the cavitation of the cervical zygapohyseal joint. Cavitation does not have to occur for a manipulation to take place (Evans, 2002b). When a cavitation does not occur, the surfaces were usually separated gradually and at a constant speed which was not fast enough to cause a pressure release within the actual joint (Maigne & Vautravers, 2003). In the cavitating joint, cohesive forces prevent separation until the movement is sufficiently strong enough to create a pressure decrease within the joint. When the pressure difference deteriorates, gas and vapor bubbles accumulate within the joint. The sudden separation of the joint surfaces at a high velocity displaces the joint fluid from the high pressure area to the low pressure area resulting in a reduction of the gaseous phase in the joint cavity, culminating in an audible "cracking' or "popping" sound. This is the characteristic sound heard during SMT (Maigne & Vautravers, 2003;Evans, 2002c).

2.3.1.2 Muscular Effects

During SMT, the high velocity, low amplitude thrust is applied to the cervical zygapohyseal joints, passively taking them beyond their physiological range of motion. Superficially however, the thrust is applied over paraspinal and associated cervical musculature. These soft tissues absorb part of the thrust, however most of the thrust still continues through to the spine to allow for mobilization of the joint (Triano, 1992;Triano, 2001). When properly relaxed, the muscles do not seem to cause noticeable resistance, as the high velocity of the thrust does not allow enough time for a splinting action to develop (Triano & Schultz, 1997;Triano, 1992;Triano, 2001;Fryer *et al.*, 2004). However, if muscles are hypertonic (as a protective mechanism for decreased joint movement), SMT becomes nearly impossible because the splinting and resistance of the tissues does not allow any passive motion to occur (Fryer *et al.*, 2004). The protective role of the musculature against potentially harmful force to joints, by way of reflex arcs, creates synergism between the passive (capsuloligamentous) and active (muscular) joint restraints. These have been studied in various animal and human joints (Wyke, 1979). Experiments have indicated that an excitatory stimulus rather than an inhibitory (relaxing) stimulus was given to these muscles after stress was placed through their related joint capsules. Due to the fact that the human zygapophyseal joints are richly innervated, it would be reasonable to suggest that a similar synergistic relationship between the capsular and ligamentous structures and paraspinal muscles also occurs in humans (Evans, 2002b).

The manipulation itself though, has been suspected to cause a heightened stretch of the associated musculature inducing a reciprocal relaxation response (Adams *et al.*, 1996;Buchmann *et al.*, 2005). When the patient is brought to their passive end range of motion (loading), the musculature in that area is stretched to the passive end range as well. The high velocity low amplitude manipulative thrust is thought to separate the zygapophyseal joints, further increasing the stretch on the associated musculature, inducing a relaxation response via reciprocal 1a inhibition of the antagonistic muscles (Buchmann *et al.*, 2005;Dishman & Burke, 2003). The joint separation may also cause a stretching of the zygapophyseal capsule, causing a decrease in the alpha-motoneuron pool associated with hypertonic musculature. The stretching of the capsule is therefore thought to cause a reciprocal relaxation response in the associated muscles (Buchmann *et al.*, 2005;Dishman & Burke, 2003;Maigne & Vautravers, 2003).

2.3.1.3 Intradiscal Effects

In cadaveric studies, SMT has also shown to cause intradiscal pressure changes (Maigne & Guillon, 2000;Maigne & Vautravers, 2003). Pressure increases at the beginning of the thrust, as the vertebral bodies are brought closer together, and then as the vertebral endplates separate at the end of the thrust, the intervertebral pressure decreases below baseline. Maigne and Guillon (2000) found that the pressure returns to baseline approximately one minute post manipulation. Their data, obtained from cadavers, needs to be confirmed by studies *in vivo*. These findings may suggest that

SMT produces pain relief in some patients with disc-related pain (Maigne & Vautravers, 2003;Browder *et al.*, 2004;Lisi & Bhardwaj, 2004).

2.3.1.4 Effects on Pain

Descending pain inhibitory systems may be activated with SMT(Evans, 2002a;Maigne & Guillon, 2000;Maigne & Vautravers, 2003;Pang & Li, 2004;Vernon, 2000). There are few studies however directly investigating the effects of spinal manipulation on pain. Recent research has suggested that manipulation alone does not relieve pain in patients with persistent mechanical neck disorder, but rather that manipulation along with exercise was more beneficial (Gross *et al.*, 2004).

Fibro-adipose meniscoids have also been identified as structures capable of creating a painful situation (Bogduk & Jull, 2002). Bogduk and Jull (2002) proposed that on flexion of the lumbar spine, the inferior articular process of a zygapophyseal joint moves upward, taking a meniscoid with it. On attempted extension, the inferior articular process returns toward its neutral position, but instead of re-entering the joint cavity, the meniscoid impacts against the edge of the articular cartilage and buckles, forming a space-occupying "lesion" under the capsule - called a meniscoid entrapment. A large number of nociceptive nerve fibers have been observed within the capsules of zygapophyseal joints. Pain may occur with the distension of the joint capsule. Muscle spasm would then occur to prevent the impaction of the meniscoid within the joint. It may this reason that chronic neck pain patients find themselves with a decreased range of motion as well as fixed positions (i.e. slight flexion – so as to decrease overall pain) (Bogduk & Jull, 2002;Evans, 2002b). The release of this entrapped meniscoid through gapping of the zygapophyseal joint, relieves impact on the meniscoid, allowing it to return to its normal position in the joint cavity. This would cease the distension on the joint capsule, thereby reducing impact on nociceptive nerves, decreasing pain symptoms (Bogduk & Jull, 2002).

There have also been theories on increases in plasma beta-endorphin levels after cervical manipulation which may be associated with a decrease in pain sensation (Vernon, 2000). The actual mechanisms behind this effect are currently unknown (Vernon *et al.*, 1986;Vernon *et al.*, 1992;Vicenzino *et al.*, 2001).

There continue to be theories regarding whether or not the theorized pain inhibiting process is centrally generated, as in the brain stem, or more at the level of the spinal cord (Vernon, 2000). After receiving a manipulation, patients neither indicate that they feel no pain in their bodies, nor do they indicate that they feel mildly euphoric in a way that would signal that some central analgesic state had been induced. This may indicate that the effect of manipulation is probably not targeted to a center located too high in the nervous system, rather it is more likely that this effect is targeted segmentally (Vernon, 2000).

Vernon's theory (2000) that the pain effect is more segmental is rationalized by Pickar et al. (2002). They state that the spinal manipulation increases joint mobility and decreases pain by producing a barrage of impulses in muscle spindle afferents ultimately silencing gamma motoneurons. Gamma motoneurons are hypothesized to cause an increase in contractility in intrafusal muscle fibers (Pickar, 2002;Korr, 1975). Restricted segments, or those that respond to manipulation, are though to exhibit elevated gamma motoneuron discharge. This increase therefore impairs joint mobility by sensitizing the stretch reflex to very small changes in muscle length (Korr, 1975). Spinal manipulative therapy is therefore thought to decrease or inhibit this gamma input. It also allows for an increase in simultaneous proprioceptive afferent firing (i.e. muscle spindles, golgi tendon organs) which in turn causes a "corrective" action on involved musculature.

2.4 Concussions

2.4.1 Concussion Assessment

In 1975, Jennet and Bond proposed the Glasgow Coma Scale as a prospectively validated prognostic scale for the assessment of traumatic brain injury. This scale distinguishes mild, moderate and severe brain injury on the basis of a standardized score at six hours following injury. Due to the fact that the Glasgow Coma Scale was designed to be applied after brain injury, it does not define "minimal" injuries that fall below its "mild" threshold (Jennett & Bond, 1975). This "minimal" injury subset must also somehow be included in a validated scale so as to encompass the full spectrum of brain injury. In clinical practice, the majority of sporting concussions fall into this "minimal" group (Johnston *et al.*, 2001). It is for this reason that other subjective outcome measures were used, such as the Standardized Assessment of Concussion (McCrea *et al.*, 1997;McCrea *et al.*, 1998), to accommodate the Glasgow Coma Scale in categorizing this "minimal" subject group suffering from chronic neck pain. A Glasgow Coma Scale score of 13 or higher correlates with mild traumatic brain injury, 9-12 is moderate injury and 8 or less is considered severe injury (Jennett & Bond, 1975).

2.4.2 Rehabilitation - Motor relearning and exercise

Activity-dependent increases in cellular and synaptic mechanisms may contribute to the beneficial effect of motor-relearning procedures that reduce degeneration and promote recovery of function in models of brain damage and neurodegeneration in closed head injuries (Cotman & Berchtold, 2002;Kleim *et al.*, 2003). Studies have demonstrated improvements in sensory-motor function after exercise, particularly in elderly subjects (Cotman & Berchtold, 2002). It remains unclear, however, which aspects of exercise contribute to neuroplasticity and to what extent motor learning is required for some of the brain changes (including the skills required to effectively negotiate voluntary movement on i.e. a treadmill or an activity wheel) to occur (Kleim *et al.*, 2003). Bachy-Rita (2000) had described promising developments in home-based training and testing however, improvements in behavioral interventions and assessment methods, as well as advances in understanding the mechanism of movement-dependent neurocellular events must be recognized first, before actual training methods can be employed. Regardless, the literature appears to navigate towards the fact that a regimen of exercise would reactivate mechanisms of brain plasticity and thus enhance rehabilitation targeting residual functional deficits, while discontinuation of exercise may leave the brain more vulnerable to degeneration (Bach-y-Rita, 2000;Cotman & Berchtold, 2002;Kleim *et al.*, 2003;Bach-y-Rita, 2000). This is important for post-concussed individuals who may currently be rehabilitating from their head injuries. Continuation of sport specific exercises will allow for an increase in brain plasticity and possibly a shorter time spent with cognitive dysfunction.

2.5 Outcome Measures and their Measurement Properties

The outcome measures used in this study include subjective as well as objective measures. The subjective outcomes include the Standardized Assessment of Concussion, the Neck Disability Index, the Short-Form 36 Health Survey and a Visual Analog Scale. These subjective outcome measures were used more as a screening procedure to distinguish between volunteers who would be included in the study and those who would not (those who met the inclusion criteria and those who did not).

The objective outcome measures included Transverse Plane – Relative Phase measurements, the Biomechanical Efficiency Quotient and the Neck-Walk Index. The relative phase measurements were done of the neck relative to the thorax in the transverse plane during gait. The BEQ measured global walking economy using average stride length, vertical displacement of the trunk during walking, and sacral height during standing. The Neck-Walk Index measured the variation in head carriage during gait, pre and post cervical manipulation. All three objective outcome measures were calculated pre and post intervention (cervical manipulation) to see whether a difference in them was evident.

The following section will outline information on the use of all of the outcome measures, but will focus primarily on measurement properties, reliability and validity, and methodological quality assessment of the objective outcomes.

2.5.1 Subjective Outcomes

1. Standardized Assessment of Concussion (SAC)

The SAC is a brief mental status and neurologic screening instrument originally developed to provide sports medicine clinicians with a standardized method of assessing athletes who have sustained a mild traumatic brain injury (McCrea *et al.*, 1998) and was designed according to the recommendations of the American Academy of Neurology Practice Parameter to assess four neurocognitive domains considered to be sensitive to change following a mild traumatic brain injury. These include: Orientation, Immediate Memory, Concentration and Delayed Recall (Barr & McCrea, 2001). The SAC requires approximately six minutes to administer and is designed to be used by a non-neuropsychologist with no prior expertise in psychometric testing (Barr & McCrea, 2001).

In their review, Johnston *et al.* (2001) state that although the SAC is a useful addition to the clinical armamentarium, it does not enable trainers to exclude a more significant cranial injury, which may masquerade as a concussion in the early stages. They also state that it is not validated as a return-to-play assessment tool. McCrea (2001), on the other hand states that the SAC was sensitive to subtle deficits in orientation, memory and concentration in injured subjects who were otherwise not displaying signs of disorientation, amnesia in the classic sense, or gross neurologic dysfunction. His findings may suggest that the decline in SAC score by injured subjects immediately after concussion represents the direct effect of injury on cognitive functioning and is not due to other extraneous factors such as fatigue, crowd noise and distractibility (McCrea, 2001b;McCrea, 2001a).

The ultimate goal of using standardized measures such as the SAC, is to provide the clinician with a more systematic framework for examining an injured athlete, to allow implementation of proper injury management strategies, and to permit more informed decisions on return to play. Early and accurate diagnosis of concussion is critical in reducing the potential risks of recurrent injury, neuropsychological impairment and the adverse effects associated with second-impact syndrome (Erlanger *et al.*, 2003). Although the SAC may not be validated as a return-to-play assessment tool (Johnston *et al.*, 2001), it was not to be intended as one. McCrea (2001) believes that the SAC is a useful *screening* tool which may be valuable in *assisting* the sports clinician in the assessment and management of concussion, but should not be used as a replacement for medical evaluation or as the sole determinant of an injured athlete's readiness to return to play after concussion. It may be useful to track the subject's recovery in order to determine whether they are fit to return to their previous activity.

In two cohort studies written by Barr and McCrea (2001) and McCrea et al. (1998), both demonstrated that the SAC is a reliable and valid measure for evaluating the neurocognitive deficits of sports-related head injury. Barr and McCrea (2001) found that high school and college athletes tested exhibited an average decrease of four points on a 30-point scale, while controls showed an average increase of less than one point when retested with the SAC. Their results indicated that a decline of 1 point on the SAC at retesting classified injured and non-injured participants with a level of 94% sensitivity and 76% specificity. Having as low a specificity of 76% however, means that the SAC does not appear to be that reliable in correctly detecting individuals who have *not* been concussed. McCrea does not examine this any more than stating it, possibly adding to a confirmation bias towards the high sensitivity measure. It must also be understood that the 95% sensitivity was calculated from a drop of 1 point or more from baseline scores. This may not be a large enough drop to consider the subject as potentially being concussed.

McCrea's study (1998) also showed the clinical validity of the SAC when the concussed players scored significantly lower than nonconcussed controls in terms of SAC total score as well as on the independent Orientation, Immediate Memory, Concentration and Delayed Memory sections of the SAC. The concussed players' performance immediately after injury was also compared to their own pre-injury baseline and revealed that their mean total score was significantly lower post-concussion. McCrea (1998) shows the SAC's sensitivity in detecting mental status abnormalities and differentiating injured from non-injured players, despite all of these injuries being independently classified by athletic trainers as grade 1 concussions without observable evidence of significant neurologic dysfunction. The SAC can therefore be considered beneficial in the assessment of concussions, which is currently a vague field of research without many valid and reliable tests. This can be considered the beginning of a process which needs more research to validate standardized methods of assessment.

It is important to note however, that due to a lack of studies presented in the area, it remains unclear whether the SAC is a clinically reliable and valid tool in recognizing whether a person has been concussed. Although more studies are beginning to look at the validity and reliability of specific measures used in concussion testing, we have only begun to scratch the surface on their consistency and strength. Larger randomized control trials must be done to conclude the SAC's reliability and validity.

2. Neck Disability Index (NDI)

The NDI consists of five items derived from the Oswestry Low Back Pain Disability Index (Fairbank *et al.*, 1980) and five items identified from feedback from practitioners, patients, and a review of the literature (Vernon & Mior, 1991). Vernon and Mior (1991) thought that the NDI could be used to measure treatment effectiveness and for medicolegal purposes. The items explore pain intensity, personal care, lifting, reading, headaches, concentration, work, driving, sleeping, and recreation. In ten 6-part questions, the NDI is scored from zero (no disability) to five (total disability), and the total score varies from 0 to 50 (total disability). Hains *et al* (1998) have shown, through factor analysis, that the NDI is a one dimensional scale.

The NDI has been tested for face validity, test-retest reliability, internal consistency, construct validity and concurrent validity, but the authors suggested that larger group studies should be conducted to strengthen the overall relevance of the NDI (Vernon & Mior, 1991). The Quebec Task Force also later suggested such studies must be conducted (Spitzer *et al.*, 1995).

In contrast to scales measuring overall health issues, region-specific functional scales such as the NDI, can concentrate on a more restricted body function, such as neck movement or pain. Region-specific scales might therefore be expected to have greater responsiveness and better content validity than more general or global scales (Hains *et al.*, 1998).

Psychometric properties of the NDI have been validated among several different populations, showing that it can remain stable in different settings (Pietrobon *et al.*, 2002). Pietrobon *et al.* (2002) concluded that the NDI is the best measure for evaluating groups of patients with neck pain.

3. Short-Form 36 Health Survey

The SF-36 is a general health status tool, developed with careful attention to the principles of test construction and evaluation (Bech, 1999;Menefee *et al.*, 2000). The SF-36 is a patient-based, generic health status survey that assesses patients' perceptions of their physical functioning, subjective well-being, and general health. The SF-36 assesses 8 different health domains including Physical (PF) and Social functioning (SF), Role limitations to physical (RP) and emotional problems (RE), Bodily Pain (BP), Vitality (VT), General Health perception (GH), and Mental Health (MH). The items are scored from 0-100, with the higher numbers indicating better health, and the entire survey takes approximately five to ten minutes to answer.

With more than 2000 publications worldwide, the SF-36 is one of the most widely used health status instruments and is increasingly being used for measuring outcomes in patients with pain (Bech, 1999;Menefee *et al.*, 2000). The SF-36 has been shown to be sensitive to change and able to differentiate between treatment responders and nonresponders (Bronfort & Bouter, 1999). The SF-36 has also been found to be a reliable and valid measure for use with subjects who have had a traumatic brain injury (Findler *et al.*, 2001). The current study used volunteers who had a mild traumatic brain injury, which has not been cited in the literature. Furthermore, the SF-36 has been used as a validation tool in the development of new disease-specific instruments including a pain specific tool (Ware, Jr., 2000).

The SF-36 has been found to have good psychometric properties which assess unique features of chronic pain (Flor *et al.*, 1992;Wittink *et al.*, 2004).

4. Visual Analog Scale

The visual analog scale (VAS) consists of a 100 mm line with two anchors, one at each end. The two anchors represent the extremes at which the pain sensation is being measured, with the left side representing 'no pain' and the right side representing 'unbearable pain' (Coll *et al.*, 2004). The patient is asked to mark a point on the line that indicates their *current* degree of pain. Intensity of pain is scored by measuring the millimeters from the left side of the scale to the mark made by the patient, thereby obtaining a number between 0 and 100 that represents the severity of pain (Briggs & Dean, 1998;Coll *et al.*, 2004).

Although many different population have been tested with this outcome measure, it has been shown to have moderate to high test-retest reliability (Ferraz *et al.*, 1990;Huskisson *et al.*, 1976) and cross-sectional validity (Ferraz *et al.*, 1990).

2.5.2 Objective Outcome Measures

The objective outcome measures used in this study are relatively new. A series of electronic database searches were conducted for information and usage of the three outcome measures used.

To assess the systematic reviews of the outcome measures, MEDLINE, EMBASE, and the Cumulative Index of Nursing and Allied Health Literature (CINAHL) were all searched from database root (from 1966 or earliest year, depending on the database) up to June 2004. To find randomized control trials, cohort, case control and expert opinion based studies involving the outcome measures used, a search without language restrictions was conducted in MEDLINE, EMBASE and CINAHL (November 2004 – May 2005).

In lieu of a lack of studies, a qualitative analysis was created in point format to present information on the measurement properties of each included study, using Finch *et al.*'s Measure Review Template (Finch *et al.*, 2002). This will include typical reliability and validity estimates as well as interpretability. The methodological quality of the included studies regarding the outcome measures used will be assessed using a criteria list similar to that used by Carswell *et al.* in 2004 and Law *et al.* in 2003 (Carswell *et al.*, 2004;Law, 2003;Law *et al.*, 2003) (refer to Table 1).

1. Transverse Plane-Relative Phase

Measurements were taken to determine the head-thorax coordination during gait in this volunteer population who has been previously concussed and experiencing chronic episodic neck pain. One cervical adjustment was the intervention used to gain insight as to whether there was an increase in relative phase measurements (phase difference between neck and thorax) pre and post manipulation.

Five articles were found regarding the transverse plane-relative phase. Of the five articles found, three relevant cohort studies were used (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a;van Emmerik & Wagenaar, 1996). The three studies are presented in point form to show the measurement properties and critique the reliability and validity. The methodological quality of the outcome has also been assessed using an 11-point criteria list (Carswell *et al.*, 2004;Law, 2003;Law *et al.*, 2003).

Measurement Properties

The measurement properties referred to in this section are presented in point format using Finch et al.'s template (Finch *et al.*, 2002). The data was compiled from three relevant cohort studies (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a;van Emmerik & Wagenaar, 1996).

TRANSVERSE PLANE RELATIVE PHASE

Developers:

R. van Emmerik and R. Wagenaar (van Emmerik & Wagenaar, 1996)

Purpose: To assess the nature of coordination changes and stability features in the relative phase dynamics of the trunk and pelvis in the transverse plane.

Description:

van Emmerik and Wagenaar (1996) studied the coordination in terms of the phase difference between pelvic and thoracic rotation at each moment of the stride cycle as well as at certain discrete moments in the stride cycle. In healthy subjects, there is a gradual change in thorax-pelvis coordination as a function of walking velocity. The mean values of these measurements are regarded as indices of coordination mode, and their standard deviation as indices of coordinative stability. As walking velocity increases, pelvis-thorax coordination shifts from more or less in-phase to more or less anti-phase.

Groups Tested with This Measure:

Healthy individuals, pregnant women and persons with nonspecific low back pain.

Language:

English

Application/Administration:

This measure is not completed by the subject. A camera system (in this case the Optotrak 3020) which can compile data and convert it into a 3D format must be used. The subject walks comfortably on a treadmill while the camera, which is located behind the subject, collects data obtained from markers on the subject. With the use of computational aids, relative neck-thorax-pelvis motions in the transverse plane can be measured.

Typical Reliability Estimates:

Internal Consistency

Not applicable

Interrater

No reference to interrater reliability in literature.

Test-retest

No reference to test-retest reliability in literature

Typical Validity Estimates:

Content
Researchers suggest that this coordination measure is adequate in assessing quality of walking in patients with low back pain (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a). Lamoth et al. (2002a, 2002b) also suggest that conservative therapy should use methods aimed at intersegmental coordination.

Criterion
No gold standard exists for the construct being measured

Construct-Cross Sectional

Convergent – Not available.

Known Groups – Not available.

Discriminant – Not available.

Construct – Longitudinal/Sensitivity to Change

Convergent – Not available.

Known Group

- Discriminates between range of motion values of pelvis, thorax and trunk in low back pain patients and controls: F [1, 318] = 0.48, 0.53, and 0.48; $P>0.05$ (not significant) (Lamoth *et al.*, 2002b).
- Discriminates between range of motion of pelvis, thorax and trunk with increasing walking velocity in low back pain patients and controls – thorax ROM decreased significantly in low back patients, with increased velocity (F [5, 200] = 10.08; $P<0.001$); low back pain patient pelvis ROM was significantly affected by velocity (F [5, 200] = 21.28; $P<0.001$) and there was significant group by velocity interaction for pelvis ROM (F [1,45] = 5.9; P = 0.01); low back pain patient trunk ROM increased significantly with increased velocity (F [5, 200] = 190.61; $P<0.001$).
- Discriminates between index of harmonicity (effect of walking velocity) of the pelvis and thorax in low back pain patients and controls - index of harmonicity in the pelvis decreased significantly in low back patients, with increased velocity (F [5, 200] = 57.41; $P<0.001$).

- Discriminates between coordination in terms of phase difference between pelvis and thoracic motions in low back patients and controls – mean RFP was affected significantly by both walking velocity ($F [5, 200] = 135.79$, $P<0.001$) and group ($F [1, 44] = 7.18$, $P = 0.001$); mean RFP increased with increasing walking velocity and was higher in control than low back pain group.
- Discriminates between coupling patterns of pelvis and thorax in low back pain patients and controls – Cw decreased significantly with increasing walking velocity ($F [5, 200] = 31.86$; $P<0.001$) meaning that the pelvis and thorax rotations were more strongly coupled at lower than at higher walking velocities; at low velocities a group main effect was found ($F [1, 54] = 4.42$, $P<0.05$) implying that coupling between pelvis and thorax was stronger in the low back pain group than in the control group.

Discriminant – Not available.

Interpretability

General Population Values (Customary or Normative Values)
Not available.

Typical Responsiveness Estimates
Not available.

Methodological Review

The reliability of the transverse plane - relative phase measurements as an outcome measure has not been confirmed in the literature. This outcome measure was not shown to be reproducible in a consistent format. Although it was shown to discriminate between the range of motion of the pelvis, thorax and trunk in low back pain patients, no internal consistency coefficient was measured (Lamoth *et al.*, 2002b). Neither study made conclusions regarding intra-observer, inter-observer or test-retest reliability either (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a).

Due to the fact that this outcome measure is not in a written questionnaire format, it is more difficult to assess the content validity. The literature (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a) shows however, that this item does assess the domain of interest, which is that of pelvis-thoracic coordination in the transverse plane, yet it does this without comparison to another measure.

This outcome measure does not have a gold standard to be measured against to judge its criterion validity. The construct validity however, is adequate. The transverse plane – relative phase measurements were able to discriminate between the range of motion in the pelvis, thorax and trunk in low back pain patients compared to those of controls during comfortable gait (Lamoth *et al.*, 2002b). The same findings were seen when there was an increase in velocity during gait. The phase measurements were still able to discriminate between the range of motion in the pelvis, thorax and trunk in low back pain patients compared to those of controls.

With respect to responsiveness estimates, the phase measurements were not used to measure a meaningful or clinically important change in the patient rather, it was used to see whether there was a within and between group difference in specific populations during comfortable gait and gait with an increase in velocity (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a;Lamoth *et al.*, 2005). In the existing literature, the transverse plane – relative phase measurements measured range of motion differences in pelvis, thorax and trunk relative to one another and not after any type of intervention.

Since this measure is being used to quantify whether there is a treatment benefit in this study, the purpose of this instrument was an evaluative one. An evaluative index is used to measure the magnitude of longitudinal change in an individual or group on the dimension of interest (Kirshner & Guyatt, 1985) - in this case the relative movements between the neck and thorax in the transverse plane.

2. Biomechanical Efficiency Quotient (BEQ)

The BEQ is an outcome measure that uses three variables – average stride length, vertical displacement of the trunk during walking, and sacral height during standing – to assess biomechanical walking efficiency, independent of cardiac, pulmonary, psychologic, or other non-biomechanical factors (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996). The BEQ was used to assess the effect that one cervical manipulation had on the overall biomechanical walking economy of volunteers who have been previously concussed and have been experiencing chronic episodic neck pain.

Two relevant articles were found involving the BEQ (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996). Both were cohort studies aimed at testing the measure in question. The two studies are presented in point form to show the measure's measurement properties as well as to critique its reliability and validity. The methodological quality of the outcome has also been assessed using an 11-point criteria list (Carswell *et al.*, 2004;Law, 2003;Law *et al.*, 2003).

Measurement Properties

The measurement properties referred to in this section are presented in point format using Finch *et al.*'s template (Finch *et al.*, 2002). The data was compiled from two relevant cohort studies (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996).

BIOMECHANICAL EFFICIENCY QUOTIENT (BEQ)

Developers:

Kerrigan, DC., Division of Physical Medicine and Rehabilitation, Harvard Medical School, Boson, Massachusetts.

Purpose:

To evaluate and assess the efficiency of the overall biomechanical performance of walking, independent of cardiac, pulmonary, psychologic or other nonbiomechanical factors.

Description:

The BEQ uses three variables – average stride length, vertical displacement of the trunk during walking, and sacral height during standing. The equation is as follows: BEQ = m / p (m = measured vertical sacral displacement; $p = \frac{1}{2} (h - \sqrt{} (h^2 - (\frac{1}{4}l)^2)$, p = predicted vertical sacral displacement, h = standing sacral height, l = stride length). BEQ scores vary however, the closer a score is to one (as score approaches one), the more efficient the gait.

Groups Tested with This Measure:

Healthy individuals with and without ankle-foot orthoses, healthy individuals with and without a knee immobilizer, and patients who had a neurological diagnosis, lower extremity paretic impairment, and gait disability for which they had been referred to a gait laboratory (included in this group were stroke patients, spinal cord injuries, traumatic brain injuries, cerebral palsy, radiculopathy, familial spastic paraparesis, spinal stenosis, poliomyelitis, Guillain-Barre syndrome, and multiple sclerosis patients).

Language:

English

Application/Administration:

This measure is not completed by the subject. A camera system (in this case the Optotrak 3020) which can compile data and convert it into a 3D format was used. The subject walks comfortably on a treadmill while the camera, which is located behind the subject, collects data obtained from markers on the subject. Measurements of stride length, vertical displacement of the trunk during walking and sacral height during standing were taken by the Optotrak. With the use of computational aids, BEQ was calculated.

Typical Reliability Estimates:

Internal Consistency

Not available.

Interrater

No reference to interrater reliability in literature.

Test-retest

No reference to test-retest reliability in literature.

Typical Validity Estimates:

Content

Researchers suggest that this measure may be useful in assessing biomechanical walking efficiency in patients with neurologically-based gait disability, independent of cardiac, pulmonary, psychologic or other non-biomechanical factors (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996). Moreover, the change in BEQ may be useful to evaluate the effect on biomechanical efficiency of a particular physiatric treatment (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996).

Criterion

No gold standard exists for the construct being measured.

Construct-Cross Sectional

Convergent

Correlation with oxygen consumption: 0.90 (Kerrigan *et al.*, 1995).

Known Groups
Not available.

Discriminant
Not available

Construct – Longitudinal/Sensitivity to Change

Convergent
Not available.

Known Group

- Capable of discriminating between people with and without ankle-foot orthoses (P = 0.005) (Kerrigan *et al.*, 1996). Capable of discriminating between people with neurologically based gait impairments (P = 0.005) (Kerrigan *et al.*, 1996).
- Capable of discriminating between people with and without knee immobilizing brace (P<0.0001) (Kerrigan *et al.*, 1995).

Discriminant
Not available.

Interpretability

General Population Values (Customary or Normative Values)
Increased efficiency occurs when BEQ values approach one. "Normals" will have scores closer to one than subjects with neurologically based gait impairments or immobilized lower limbs.

Typical Responsiveness Estimates
Not available.

Methodological Review

The reliability of the BEQ as an outcome measure has not been confirmed in the literature. Like the phase measurements, this outcome measure was not shown to be reproducible in a consistent format. Although it was shown to discriminate between people wearing ankle-foot orthoses, people with neurologically-based gait impairments and subjects wearing knee immobilizers, no internal consistency coefficient was measured (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996). Neither study made conclusions regarding intra-observer, inter-observer or test-retest reliability either (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996).

Although no gold standard exists to compare the BEQ with, it is more difficult to assess its content validity. The literature (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996) shows, however, that the BEQ does assess the domain of interest, which is walking economy. It does this without comparison to another measure.

The construct validity however, is adequate. The BEQ was able to discriminate between people wearing ankle-foot orthoses, people with neurologically based gait impairments and subjects wearing knee immobilizers (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996). The vertical displacement of the sacrum was also found to reliably predict oxygen consumption ($r = 0.9$) indicating that potential energy is a reliable predictor of total biomechanical energy at slow and normal walking velocities in normal subjects as well as those with various walking disabilities (Kerrigan *et al.*, 1995).

With respect to responsiveness estimates, the BEQ was not used to measure a meaningful or clinically important change in the patient rather, it was used to see whether there was a within and between group difference in specific populations during comfortable gait and gait with an increase in velocity (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996). In the existing literature, the BEQ measured biomechanical walking efficiency, independent of cardiac, pulmonary, psychologic, or other nonbiomechanical factors, without any type of intervention.

Since the BEQ is being used to quantify whether there is a treatment benefit in this study, the purpose of its use was an evaluative one - in this case global biomechanical walking economy.

3. Neck-Walk Index

The Neck-Walk Index is a relatively new outcome measure which does not currently have any referenced literature within peer-reviewed journals. There have been however, several unpublished pilot studies done (Chunara *et al.*, 2004;Dosen & Rajah, 2002;Guy *et al.*, 2003) on the NWI to determine its reliability and validity. Also, due to the fact that the NWI is based on detrended fluctuation analysis, this analysis will be discussed as well.

Detrended fluctuation analysis is a method used to accurately quantify long-range power law correlations embedded in a non-stationary time series (Hausdorff *et al.*, 1996;Hausdorff *et al.*, 1997;Hausdorff *et al.*, 2001;Pierrynowski *et al.*, 2005). Alpha (α) is determined from detrended fluctuation analysis, and it quantifies the correlation properties of a signal (in this case, gait pattern) (Hausdorff *et al.*, 1996;Hausdorff *et al.*, 1997;Hausdorff *et al.*, 2001;Pierrynowski *et al.*, 2005). The NWI represents the variability of head movement disturbances during gait. This will provide information about the status of head/neck motion pre and post cervical manipulation/intervention.

Three relevant articles were found (Chunara *et al.*, 2004;Dosen & Rajah, 2002;Guy *et al.*, 2003;Pierrynowski *et al.*, 2005) involving the NWI. All three studies were cohort studies aimed at testing the measure in question. The studies are presented in point form (Finch *et al.*, 2002) to show the measure's measurement properties as well as to critique its reliability and validity. The methodological quality of the outcome has also been assessed using an 11-point criteria list (Carswell *et al.*, 2004;Law, 2003;Law *et al.*, 2003).

Measurement Properties

The measurement properties referred to in this section are presented in point form using Finch *et al.*'s template (Finch *et al.*, 2002). The data was compiled from three relevant cohort studies (Chunara *et al.*, 2004;Dosen & Rajah, 2002;Guy *et al.*, 2003).

NECK-WALK INDEX (NWI)

Developers:

Pierrynowski, M.R., PhD.; Human Movement Laboratory, School of Rehabilitation Science, McMaster University, Hamilton, Ontario, Canada.

Purpose:

To assess and evaluate the variability of head movement disturbances during individual gait patterns.

Description:

The NWI is a performance-based biomechanical outcome measure designed to evaluate change in mechanical neck disorders (Chunara *et al.*, 2004;Pierrynowski *et al.*, 2005). The NWI captures the position of the head and body in space in relation to stride patterns during gait (Chunara *et al.*, 2004). The rhythmical movement of the head and body have been shown to be associated with gait patterns (Hirasaki *et al.*, 1999). Humans with neck disorders, including those who are experiencing mechanical neck pain from a previous concussion, have these rhythms disrupted which then affects later rhythms in time.

Groups Tested with This Measure:

Healthy individuals as well as individuals with mechanical neck disorders.

Language:

English

Application/Administration:

This measure is not completed by the subject. A camera system (in this case the Optotrak 3020) which can compile data and convert it into a 3D format was used. The subject walks comfortably on a treadmill while the camera, which is located behind the subject, collects data obtained from markers on the subject. With the use of computational aids, NWI was calculated.

Typical Reliability Estimates:

Internal Consistency

Not available.

Interrater

Controls (high and moderate correlation): ICC within-day = 0.372, ICC between-day = 0.055; Mechanical Neck Pain group (little or no correlation – head bobbing becomes more random for people with mechanical neck pain) - ICC within-day = 0.890, ICC between-day = 0.549 (Dosen & Rajah, 2002;Hirasaki *et al.*, 1999).

Test-retest
No reference to test-retest reliability in literature.

Typical Validity Estimates:

Content
Researchers suggest that this measure may be useful in assessing the variability of head movement disturbances during gait, which may provide greater information about the changes in status of individuals with mechanical neck disorders (Chunara *et al.*, 2004;Dosen & Rajah, 2002;Guy *et al.*, 2003). Moreover, the NWI may be useful to evaluate the effect on biomechanical efficiency of a particular physiatric treatment (Chunara *et al.*, 2004;Dosen & Rajah, 2002;Guy *et al.*, 2003;Hausdorff *et al.*, 1997).

Criterion
No gold standard exists for the construct being measured.

Construct-Cross Sectional

Convergent
- Poor correlation with NDI, DASH (Disabilities of the Arm, Shoulder and Hand), and HDI (Headache Disability Index) (Guy *et al.*, 2003).
- Moderate to good association with NDI – $r = 0.659$, $P<0.002$ (Chunara *et al.*, 2004).

Known Groups
Not available.

Discriminant
Not available

Construct – Longitudinal/Sensitivity to Change

Convergent
Not available.

Known Group

- Capable of discriminating between people with simple mechanical neck pain and healthy controls (sensitivity 89.5; specificity 87) (Guy *et al.*, 2003).

Discriminant
Not available.

Interpretability

General Population Values (Customary or Normative Values)
The NWI is the Standard Error of Measurement of α, the coefficient derived from detrended fluctuation analysis. The greater the variability of α, the more likely the patient is suffering from a mechanical neck disorder. Having the ability to distinguish between healthy controls and those suffering from mechanical neck pain makes the NWI important in being able to quantify patients' neck disorders.

Typical Responsiveness Estimates
Not available.

Methodological Review

Important to note is that the studies used to critique the NWI have not been published. The NWI is a relatively new outcome measure and research on it is just now being published.

The overall methodological quality of the NWI is adequate. The reliability of the NWI has been shown to be poor to adequate. No internal consistency coefficient has been measured however, interrater reliability was shown to be quite high (Chunara *et al.*, 2004;Dosen & Rajah, 2002;Guy *et al.*, 2003). None of the studies made reference to test-retest reliability.

Although no gold standard exists to compare the NWI with, it is more difficult to assess its content validity. The literature (Chunara *et al.*, 2004;Dosen & Rajah, 2002;Guy *et al.*, 2003) shows however, that the NWI does assess the domain of interest, which is the variability of head movement during gait. It does this without comparison to another measure.

The construct validity however, was shown to be adequate. The NWI was shown to have a poor correlation with the NDI and DASH in one study (Guy *et al.*, 2003) however, another study showed a good association with the NDI (Chunara *et al.*, 2004).

With respect to responsiveness, the NWI was not used to assess a minimal clinically important difference in time, rather, it was used to discriminate between a population with mechanical neck disorders and healthy controls (Guy *et al.*, 2003).

The purpose of the NWI in the recent, unpublished literature has been discriminative in nature. In the current study however, due to the fact that there is an intervention (pre-post cervical manipulation), the outcome measure is being used with an evaluative purpose. Its use will be to see whether there was a clinically meaningful change of greater than five percent in head carriage pre and post cervical manipulation.

Table 1: Methodological review of objective outcome measures used

TEST	OVERALL METHOD. QUALITY	RELIABILITY				VALIDITY					INSTRUMENT PURPOSE
		RIGOUR	INTERNAL CONSISTENCY	INTER-RATER	TEST-RETEST	RIGOUR	CONTENT	CONSTRUCT	CRITERION	RESPONSIVE.	
Biomechanical Efficiency Quotient	POOR	C	C	C	C	B	B	B	N/A	C	E
Transverse Plane Relative Phase	POOR	C	C	C	C	B	B	B	N/A	C	E
*Neck Walk Index**	POOR	B	C	B	C	B	A	B	N/A	N/A	D

Scoring System: A. Excellent = more than 2 well designed studies; B. Adequate = 1-2 studies; C. Poor = no studies
Tool Purpose: D = Discriminative; P = Predictive; E = Evaluative
*Pilot studies used, which have not been published

Chapter 3

Methodology

This chapter will address the manner in which the volunteers were recruited and assessed, as well as explain how the intervention of cervical spinal manipulative therapy was performed. The statistical analysis of the data will also be explained.

3.1 Recruitment (Inclusion/Exclusion Criteria)

Flyers were posted throughout McMaster University campus advertising information about the study and calling for volunteers. Several chiropractors in the Hamilton area were informed about the study as well and asked if they could refer volunteers who fulfill the set inclusion criteria.

Study participants who approached the research team consisted of both male (n = 20) and female (n = 21) athletes, aged 18 or older (range=18-32y). The individuals had played their particular sport at a competitive level for a minimum of two years, had suffered a concussion anywhere from six months to two years prior to testing, and had been experiencing episodic neck pain of a mechanical nature for over three months since their last concussion. The athletes recruited had no neurological deficits, bone or joint disorders, circulatory problems, metabolic disorders or arthritic conditions that would have made them unsuitable to participate in the study. Athletes were excluded if they had any contraindications to cervical spinal manipulative therapy or had a Glasgow Coma

Scale reading of 12 or less at the time of injury (indicating moderate or severe head injury).

3.2 Experimental Protocol

Each volunteer was informed of the type of intervention being employed in the study (cervical SMT) and had therefore signed an informed consent form agreeing to continue with the experiment. They were also informed that they would be walking for four separate five minute trials at a comfortable pace, and that their gait would be recorded by a kinematic data acquisition system (Optotrak 3020, Northern Digital, Inc., Waterloo, Canada).

Prior to the initial walking trial, each volunteer was required to complete condition-specific disability and self-reported pain assessments including the Neck Disability Index (NDI), Short-From 36 Health Survey Questionnaire (SF-36), Standardized Assessment of Concussion and the Visual Analog Scale (VAS). These questionnaires were designed to rate the volunteer's level of neck pain, general health status, current level of cognition and current level of pain, respectively. This was aimed at providing baseline information regarding the current health status of the participants. After measuring the volunteer's height and weight, they were prepped for treadmill walking. Each volunteer was wearing comfortable running shoes, shorts and a loose-fitting top. Each volunteer wore a water-polo cap on their head and a 'lumbar support belt' around their waist. The lumbar support belt was used to attach two strobers and a controller so as to minimize encumberance to facilitate easier walking.

Infra-red light-emitting diodes (IREDs) were placed on the head (water-polo cap), thoracic spine (shirt or sport-top), pelvis (lumbar support belt) and heels (running shoes), to gather information for the specific outcome measures being used. The Optotrak kinematic data acquisition system can record the location of each marker with a positional accuracy of less than 0.1 mm. Four IREDs were separately placed on the head – one on the posterior side of each ear piece on the water polo cap, and one on each superior nuchal line, next to the external occipital protuberance. A set of three IREDs were placed each on the thoracic spine and pelvis. The IREDs on the thoracic spine were placed on a rigid body (9 cm square) in an inverted isosceles triangle position (Figure 2) and then placed on the mid-back at a position where the base IRED was approximately at the level of the T7 spinous process.

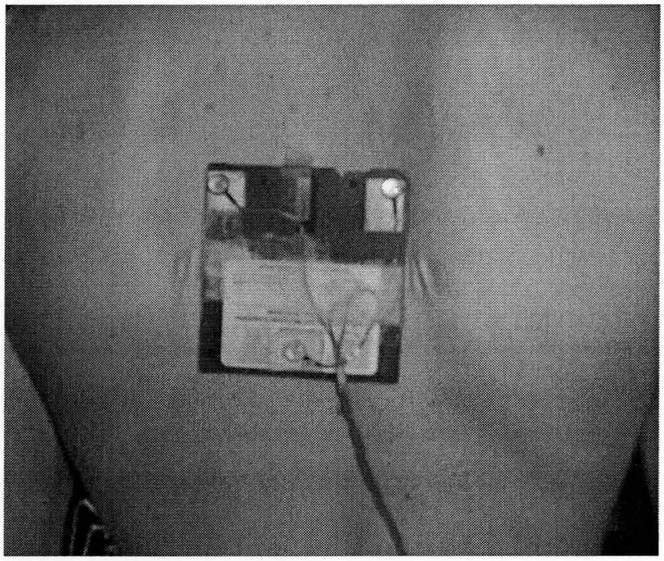

Figure 2: Lower IRED placed at approximate level of T7 spinous process

A triangular rigid body (11.5 cm x 9.5 cm x 7.5 cm) (Figure 3) was placed on the sacrum. The base IRED (of an inverted isosceles triangle) was placed at the approximate level of the sacral apex, mimicking the motion of the sacrum during gait. One IRED was also placed on the posterior aspect of each heel to gather information about time of heel contact during gait. All wires from IREDs were taped down so that none obscured the view to the camera.

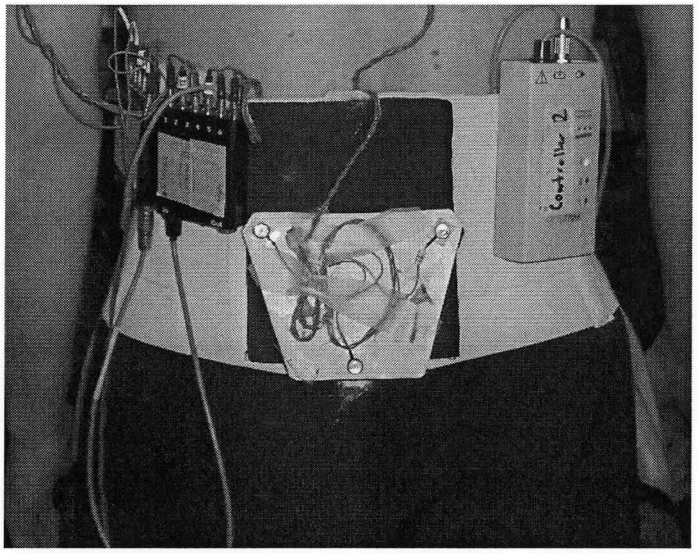

Figure 3: Lower IRED placed at approximate level of sacral apex

When the volunteers were equipped with the IREDs, they were asked to walk on a motorized treadmill (True S.O.F.T. System 500, True Fitness Technology, Inc., O'Fallon, MO). Before data recording, the volunteers walked on the treadmill for several minutes to get accustomed to the experimental setup and treadmill walking. All volunteers were asked to walk as naturally as possible in the middle of the treadmill belt without using the handrails. Each volunteer was also asked to self-select a "comfortable" walking speed.

The motion of each volunteer's pelvis, upper thoracic spine and head was monitored for five minutes. Multiple strides were recorded by the Optotrak 3020 System. This system recorded the three-dimensional displacements and three dimensional rotations of the instrumented body segments.

The motion data from each stride, within each trial, provided approximately 160 estimates each of the three objective outcome measures being used. Due to the great number of gait cycles, analyses would incur more power than if there were fewer cycles. The objective outcomes measure body and head-neck coordination (transverse plane – relative phase measurements), relative walking economy (Biomechanical Efficiency Quotient) and the variation in self-similarity of long-term gait patterns (Neck-Walk Index) in the volunteer group.

After selecting a "comfortable" walking speed, volunteers were instructed to maintain that speed for all four walking trials. Each trial was five minutes in duration. The timeline between trials and intervention occurred as follows:

Trial A – 5 min. walk prior to intervention

Intervention – cervical spinal manipulative therapy

Trial B – 5 min. walk *immediately* post intervention

Trial C – 5 min. walk *+15 min.* post intervention

Trial D – 5 min. walk *+35 min.* post-intervention

This timeline was chosen to determine the effect that could be attributed to the SMT.

3.3 Intervention

The intervention used in this experimental protocol was cervical spinal manipulative therapy (SMT). Prior to being accepted as a volunteer, each person was screened to make sure there were no neurological deficits, bone or joint disorders, circulatory problems, metabolic disorders or arthritic conditions that would not have made them candidates to receive SMT. A history, physical and neurological exam was done to verify this.

The SMT used in this experimental protocol consisted of a prone, diversified approach. Prior to the actual manipulation however, restricted and painful segments were palpated for to judge where on the cervical spine the intervention would take place. Humphreys *et al.* (2004) suggested that clinicians can correctly identify inter-segmental fixations using commonly used cervical motion palpation techniques. The motion palpation technique used in this experiment had the patient sitting, facing forward, with the chiropractor standing posterior to the patient facing in the same direction (Humphreys *et al.*, 2004). When palpating the right side of the cervical spine, the practitioner placed his left hand on the patient's forehead and rotated the patient's head to the left. Simultaneously, the practitioner's right hand palpated each segmental level on the patient's right side, for restrictions in segmental motion. The same motion palpation procedure was performed on the patient's the left side.

The cervical spinal manipulative procedure consisted of a high-velocity, low-amplitude thrust, as commonly preformed by practitioners of chiropractic. This procedure entailed having the patient lying in a prone position on a chiropractic table, with the cervical spine resting in a slightly flexed position (approximately 20°) on the flexed head-rest. The force was applied to the spine in approximately 100 ms with a linear vertebral displacement of less than five millimeters (Triano, 1992;Triano, 2001). The manual force applied to the zygapophyseal joint was done so at the end of the physiologic range of motion and extended into the "paraphysiological range" of joint motion. This "paraphysiologic range" is defined as the endpoint range of motion at which a joint can be passively forced without any deleterious effects (Duenas *et al.*, 2003). During the spinal manipulative therapy, the chiropractor stood at the head of the table and provided a manual contact on the tissues overlying the specific, restricted cervical zygapophyseal joints to be manipulated. The neck was slightly contralaterally rotated, as well as laterally flexed to the ipsilateral side of manipulation, thereby increasing the mechanical load on the soft tissues. Once the tissue tension was preset, a high-velocity, low-amplitude impulsive force was applied to the specific area of contact on the cervical spine. The primary force vector applied to the zygapophyseal joint was directed in a posterior-anterior direction with little to no rotation. The manipulative procedure was performed bilaterally at different restricted segments in order to promote the greatest amount of spinal motion.

Ross et al. (2004) have shown that specificity in manipulation cannot be obtained. What they have intended to show is that if the practitioner planned on manipulating the C5-C6 segment, although they may succeed in their attempt, chances are likely that motion may have been initiated in the segment above and/or below as well (Ross *et al.*, 2004).

3.4 Data Processing

3.4.1 Cycling

Both manual and automated procedures were used to identify the multiple right-heel treadmill surface contacts during each five minute walk. First, the author manually identified and marked this gait event, during the first 15 seconds of each walk, by observing the vertical displacement-time curve of the right heel marker (IRED). This data was then used to automatically identify all of the gait events within each trial.

3.4.2 Transverse Plane Relative Phase

The Optotrak 3020 System provided the 3D motion of the multiple markers on both the head and thorax, as a function of time. The data was analyzed at right heel contact. The orientation and position of the head and thorax were calculated as a function of time. The transverse plane rotation of each segment, as a function of time, was then extracted (θ). This data was smoothed and differentiated to calculate transverse plane angular velocity (ω). The relative phase measurements (RP) between the neck and thorax were then measured using the following equation:

$$RP = \arctan2 (\omega / \theta)$$

where, ω = relative angular velocity of the head in the transverse plane relative to the thorax in the transverse plane at right heel contact
θ = relative angular position of the head in the transverse plane relative to the thorax in the transverse plane at right heel contact

3.4.3 Biomechanical Efficiency Quotient

The Optotrak 3020 System provided the 3D motion of the multiple markers on the sacrum and right heel, as a function of time. The 3D motion of the marker on the right heel, from right heel contact to right heel contact, was used to measure stride length. The orientation and position of the sacrum and right heel were used to calculate the BEQ using the following equation:

$$BEQ = m / p$$

$$p = \tfrac{1}{2} (h - \sqrt{(h^2 - (\tfrac{1}{4} l)^2)})$$

where, m = measured vertical sacral displacement during each stride
p = predicted vertical sacral displacement during each stride
h = standing sacral height
l = stride length, measured by right heel contact to right heel contact

3.4.4 Neck-Walk Index

The Optotrak 3020 System provided the 3D motion of the multiple markers on the head. The rhythmical pattern of each marker was continuously captured while volunteers walked on the treadmill. The effect of rhythm disturbances on subsequent rhythms was quantified using detrended fluctuation analysis to calculate α, the long-range power law correlation scaling coefficient. The Standard Error of Measurement of alpha between the pre-intervention variables and the post-intervention variables was equated as the NWI (Pierrynowski *et al.*, 2005).

3.4.5 Statistical Limitations

All of the quantitative measures (RP, BEQ, NWI) were statistically analyzed using a two-way, between-within mixed factorial analysis of variance (ANOVA) to assess statistically significant differences of the effects of cervical SMT (factor A – between groups) on relative transverse motion between the head and thorax (RP), walking economy (BEQ) and head carriage (NWI) over time (factor B – within trials). These will be measured by RP measurements, BEQ and NWI (dependent variables). The p value was set at $P \leq 0.05$.

Chapter 4

Results

The primary purpose of this investigation was to determine if a biomechanical change occurred post-manipulation and was sustained for greater than 35 minutes. This chapter will examine the volunteer population characteristics, as well as present results of the data obtained from the specific subjective and objective outcome measures.

4.1 Volunteer Population

Forty-one volunteers were recruited in Hamilton, Ontario. The majority were student-athletes from McMaster University. Table 2 presents the volunteer characteristics.

Table 2: Volunteer characteristics

# of volunteers		Avg age (yrs.)	Avg mass (kg)	Avg height (cm)	Avg walking velocity (m/s)	Avg time to manipulation after initial walk (sec)
Male	Female					
20	21	22	77.7	169	0.95	72
Range		19-25	53.5-114	93-193	0.4-1.5	53-113

4.2 Subjective Outcome Measures

Table 3 presents the average results of the subjective outcome measures, including the Neck Disability Index, the Visual Analog Scale, the Standardized

Assessment of Concussion and the Short Form – 36. The average Glasgow Coma Scale (GCS) score is presented as well. It must be noted that although minimal NDI and VAS scores were zero for very few volunteers, these volunteers were still included because their scores were only indicative of their "current" physical status that day. They made a point however to tell the researcher that although they were feeling good that day, they still suffered chronically before the experiment. The chiropractor also manually palpated for restrictions in this minimal group and several restrictions were found, indicating they remained candidates for manipulative therapy.

Table 3: Average results of subjective outcome measures

NDI	VAS	SAC	SF-36	GCS
mild disability (6)	Mild pain (2)	normal (29.5)	very good overall health (4.6)	13 (mild injury)
Range 0-23	Range 0-8	Range 28-30	Range 3.4-5	

Note that in the Glasgow Coma Scale score, the volunteer either gave their own recollection of their injury, or what other witnesses have told them had occurred. The average score of 13 indicates a mild head injury group. The GCS can also be broken down to eye, verbal and motor response components (Jennett & Bond, 1975).

Although the GCS is a relatively old outcome to measure head injury at the time of injury, it remains one of the most widely used by on-field trainers today (Hsiang, 2005). The GCS indicates the general severity of the head injury at that exact time using eye, verbal and motor response components. Clinically, it is a worthwhile tool to use because it gives on-site practitioners a general understanding of the ramifications of the head injury as well as what the next clinically viable option for treatment is.

4.3 Objective Outcome Measures

The primary purpose of this investigation was to determine if there is a measurable change in spinal motion (post minus pre) after cervical manipulation in a post-concussive neck pain volunteer group. A secondary purpose was to determine, if there was a measureable change in spinal motion post manipulation, how long would this change persist (what is the half-life of this change).

4.3.1 Transverse Plane - Relative Phase Measurements

This measurement assessed the nature of coordination changes and stability features in the relative phase dynamics between the head and thorax in the transverse plane. All trials included all 41 subjects. No statistical significance was found (sig = 0.266) (refer to Table 4).

Table 4: Statistical values for Relative Phase scores

Trial	Mean (degrees)	Standard Error of Mean	Standard Deviation	Overall F-value
RP 1	-0.88	6.08	38.93	1.34
RP 2	-6.23	6.28	40.23	
RP 3	11.07	6.29	40.26	
RP 4	5.34	7.53	48.19	

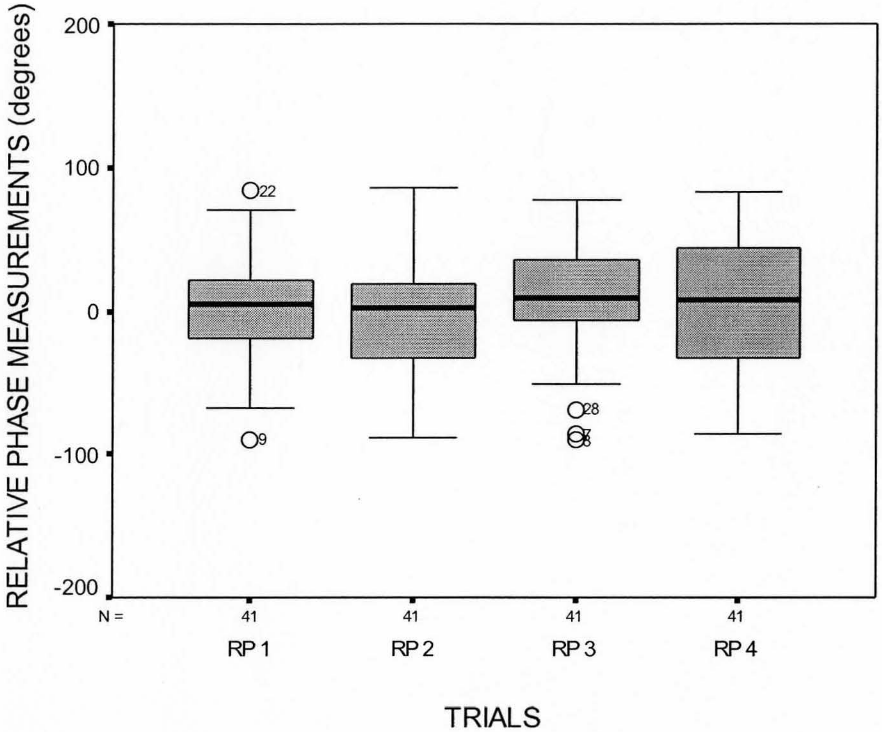

Figure 4: Relative Phase box and whiskers plot

In Figure 4, one notes the presence of several outliers. Therefore, an analysis was done without volunteers 7, 8, 9, 22 and 28. All trials thus included 36 volunteers. Statistical within-group differences were found at $P \leq 0.05$ (sig = 0.04) (refer to Table 5 and Figure 5).

Table 5: Statistical values for Relative Phase without specific volunteers

Trial	Mean (degrees)	Standard Error of Mean	Standard Deviation	Overall F-value
RP 1	-1.73	5.25	33.61	2.81
RP 2	-5.36	6.13	39.21	
RP 3	17.77	4.75	30.39	
RP 4	2.22	7.17	45.90	

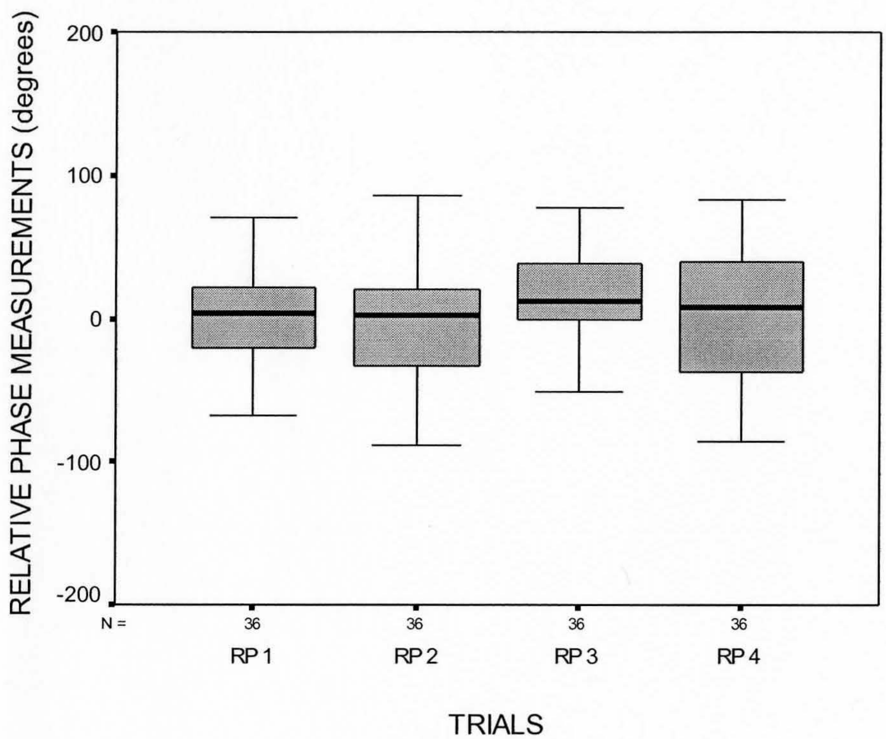

Figure 5: Relative Phase measurements without volunteers 7, 8, 9, 22 and 28

Post-hoc analysis (Tukey HSD – critical value = 19.12) revealed that there were clinically significant differences between RP 1 and RP 3, as well as RP 2 and RP 3.

4.3.2 Biomechanical Efficiency Quotient

The BEQ allows the researcher to evaluate and assess the efficiency of the overall biomechanical performance of walking, independent of cardiac, pulmonary, psychologic or other nonbiomechanical factors. It incorporates three major variables: measured vertical sacral displacement, predicted vertical sacral displacement and standing sacral height.

All trials included all 41 subjects. Although results approached significance, no statistical significance was found (sig = 0.164) (refer to Table 6).

Table 6: Statistical values for Biomechanical Efficiency Quotient scores

Trial	Mean	Standard Error of Mean	Standard Deviation	Overall F-value
BEQ 1	1.47	0.08	0.53	1.73
BEQ 2	1.59	0.11	0.73	
BEQ 3	1.59	0.10	0.66	
BEQ 4	1.47	0.05	0.34	

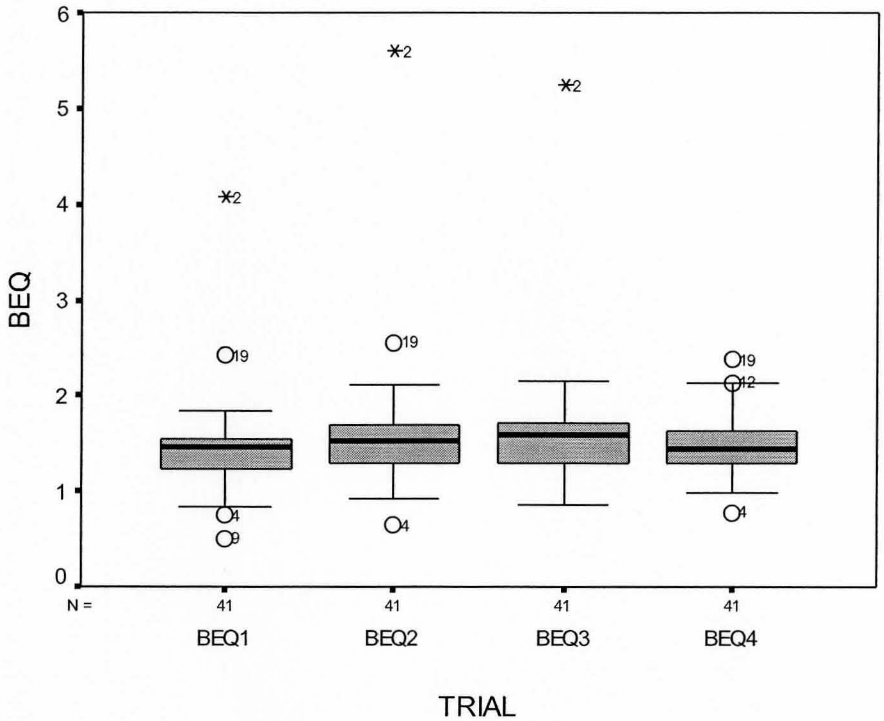

Figure 6: Biomechanical Efficiency Quotient box and whiskers plot

Descriptive statistics revealed the presence of several BEQ outliers. Therefore, an analysis was done without volunteers 2, 4 and 19. All trials thus included 38 volunteers. Statistical within-group differences were found at $P \leq 0.05$ (sig = 0.04) (refer to Table 7 and Figure 7).

Table 7: Statistical values for Biomechanical Efficiency Quotient without specific volunteers

Trial	Mean	Standard Error of Mean	Standard Deviation	Overall F-value
BEQ 1	1.39	0.04	0.27	3.24
BEQ 2	1.48	0.04	0.29	
BEQ 3	1.49	0.04	0.28	
BEQ 4	1.46	0.05	0.29	

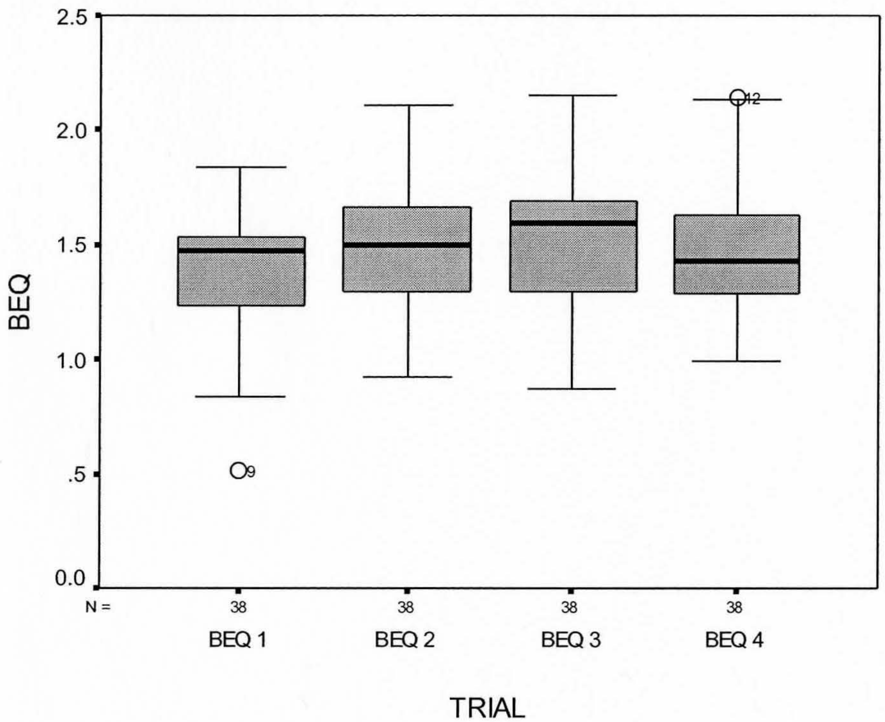

Figure 7: Biomechanical Efficiency Quotient values without volunteers 2, 4 and 19

Post-hoc analysis (Tukey HSD – critical value = 0.0883) revealed that the intervention of cervical SMT allowed for clinically significant differences between BEQ 1 and BEQ 2, as well as BEQ 1 and BEQ 3.

4.3.3 Neck-Walk Index

The NWI is a performance-based biomechanical outcome measure designed to evaluate change in mechanical neck disorders (Chunara *et al.*, 2004;Pierrynowski *et al.*, 2005). Due to the fact that the rhythmical movement of the head and body is associated with gait patterns (Hirasaki *et al.*, 1999), a person with a neck disorder (i.e. mechanical in nature) may have these rhythms disrupted. The NWI evaluates the variability of head movement disturbances during individual gait patterns.

All trials included all 41 subjects. No statistical significance was found (sig = 0.89).

Table 8: Statistical values for Neck-Walk Index

Trial	Mean	Standard Error of Mean	Standard Deviation	Overall F-value
NWI 1	0.02	0.001	0.008	0.20
NWI 2	0.03	0.002	0.014	
NWI 3	0.03	0.001	0.009	
NWI 4	0.03	0.002	0.014	

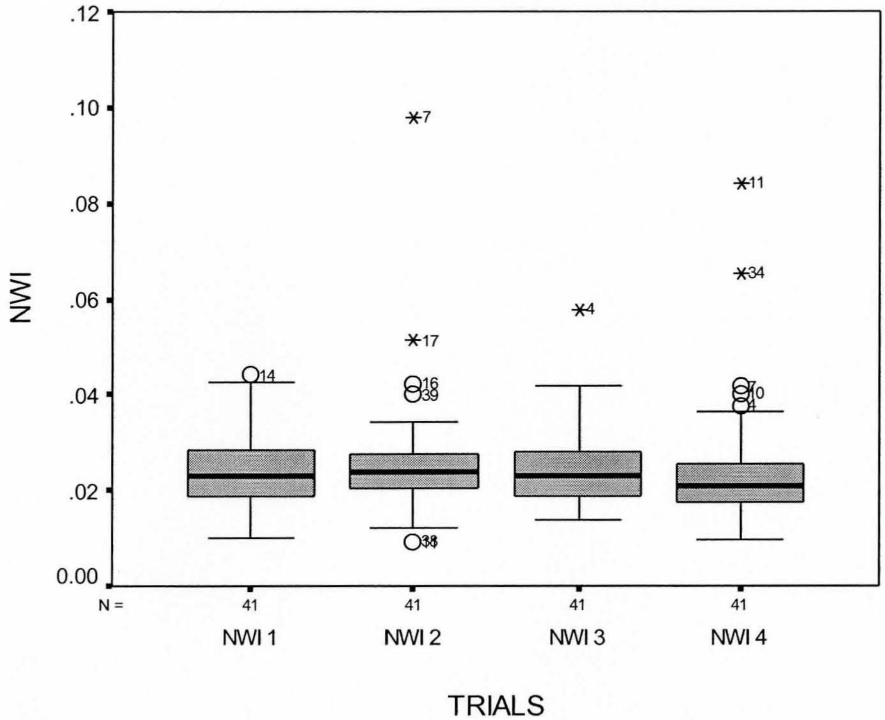

Figure 8: Neck-Walk Index box and whiskers plot

Descriptive statistics revealed the presence of several NWI outliers. Therefore, an analysis was done without volunteers 4, 7, 11, 17 and 34. All trials thus included 36 volunteers. Although results approached significance, no statistical significance was found (sig = 0.20).

Table 9: Statistical values for NWI scores without specific volunteers

Trial	Mean	Standard Error of Mean	Standard Deviation	Overall F-value
NWI 1	0.02	0.001	0.01	1.57
NWI 2	0.02	0.001	0.01	
NWI 3	0.03	0.001	0.01	
NWI 4	0.02	0.001	0.01	

Chapter 5

Discussion

In the literature, no studies have yet looked at biomechanical properties of the cervical spine post-manipulation, during gait, in a post-concussion group of volunteers. Several outcome measures have been used in this study, to screen individuals for the necessary inclusion/exclusion criteria (subjective outcome measures), and to assess the biomechanical properties/changes in the cervical spine during gait of the post-concussive volunteer group (objective outcome measures). This Chapter will discuss the results of this study and relate analysis to the current literature on the topic.

5.1 Volunteer Population, Subjective Outcome Measures and Self-Selected Speed

The volunteer population who participated in this study were all between the ages of 19 to 25, with an average age of 22, half of the subjects being female and half male. This volunteer group contributes to the generalizability of the research in a university-based athletic population, because all volunteers competed in a particular sport for two years or longer (or were still competing) at the time they participated in the study. Due to the fact that all data from each of the volunteers was analyzed, this constituted a representative sample of a university-based athletic population.

The subjective outcome measures used in this study were done so as a screen for inclusion/exclusion within the study. The Standardized Assessment of Concussion is a brief mental status and neurologic screening instrument originally developed to provide sports medicine clinicians with a standardized method of assessing athletes who have sustained a mild traumatic brain injury (McCrea *et al.*, 1998). The use of this outcome measure in this study allowed the author to classify volunteers, from a neurocognitive perspective, as being able to take part in the study. The average SAC score of 29.5 out of 30 showed that post-concussive neurocognitive symptoms were not a factor in this volunteer group.

The Neck Disability Index, Visual Analog Scale and Short Form-36 Health Survey results showed that, although some volunteers were experiencing neck pain, all were healthy enough to participate in the study. More importantly, volunteer histories, physical exams, and neurological exams confirmed that they were all candidates for cervical SMT.

According to the literature, this is currently the most effective way to screen for possibilities of vertebrobasilar injury or other possible contraindications of cervical SMT. The literature, to this date, does not assist in identifying offending mechanical trauma, specific neck movements, or type of manipulations which precipitate vertebrobasilar artery dissection or the identification of the patient at risk. Therefore, given the current status of the literature, it is impossible to advise patients or physicians about how to avoid vertebrobasilar artery dissection when considering cervical manipulation or about specific sports or exercises that result in neck movement or trauma (Haldeman *et al.*, 1999;Haldeman *et al.*, 2001).

The use of self-selected speeds in this study can viewed as a limitation due to the fact that several volunteers may have been uncomfortable walking on the treadmill. This caused them to decrease the velocity they walked at, in turn skewing the results of the data. The goal of allowing the subject to self-select a comfortable walking speed was just that – to allow them to walk at their own, comfortable pace throughout the four trials of the experiment. Some volunteers however, walked at an extremely slow pace, which cannot be considered "normal" or average walking velocity. Future research should include a set walking velocity to normalize this variable.

5.2 Objective Outcome Measures

The RP, BEQ and NWI measures are all novel outcome measures used to asses biomechanical changes post-manipulation, during gait, in a post-concussed group of volunteers. The threshold difference of 5% was selected due to the fact that this was thought to be the most minimal difference that volunteers would appreciate a biomechanical and clinically significant change. The minimal clinically important difference for a group of volunteers is substantially less than it is for an individual volunteer (Finch *et al.*, 2002). The minimal clinically important difference may also vary depending on a volunteer's level of disability or the risk associated with a proposed intervention (Finch *et al.*, 2002). In this case, the intervention was SMT. As a clinician, it was the author's expert proposal that the threshold difference of 5% would show the necessary physical changes that were expected to be seen in the PCNS volunteer group.

This section will address the objective outcome measures used and the results found in this study, and relate it to the current literature and use of the same outcome measures.

5.2.1 Transverse Plane – Relative Phase Measurements

Previous studies incorporating the use of RP were done only on pelvis-thorax coordination – and this was done without any type of treatment intervention (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a;Lamoth *et al.*, 2005). These studies found that pelvis-thorax coordination evolved from in-phase coordination to antiphase coordination as walking velocity increased, and that the gait of patient's with low back pain was characterized by more of a rigid and less flexible pelvis-thorax coordination in comparison with healthy participants.

When incorporating this type of outcome measure to the cervical spine, we are looking at different relative measurements (specifically cervico-thoracic coordination) in comparison to relative pelvic-thorax measurements during gait. According to Lamoth *et al.* (2002 a, b, 2005), at lower and intermediate walking velocities, little or no counter rotation between the pelvis and thorax is present. With increasing walking velocity, there is a gradual shift to counter rotation at the pelvis and thorax, thus moving more in antiphase. They concluded that simultaneous coordination between thorax and pelvis is required as walking velocity increases.

The current study incorporated one treadmill speed, which was self-selected by the volunteer as a "comfortable" walking pace. This may have decreased the significance of the results simply because the volunteer may have been walking at a very slow speed (i.e. 0.4 m/s), not allowing any possibility of antiphasic coordination in the upper spine as well as the lower spine. Future studies must incorporate increased walking velocities to allow for antiphasic movement (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a).

Although Lamoth *et al.* used volunteers with non-specific low back pain, they did not incorporate a clinical intervention to see if there is any type of relative difference in pelvis-thorax coordination pre and post intervention. In this study, clinically significant results in RP measurements, post-intervention, were found when certain volunteers were removed. The choice of slower walking velocity may have caused the low values of volunteers 7, 8, 9, 22 and 28 to be outliers in trials 1 and 3 (average velocity = 0.7 m/s) (Figure 4).

These differences can be attributed to the intervention of spinal manipulation. The intervention caused a clinically significant increase in cervico-thoracic spinal motion which appeared to decrease at 35 minutes (RP 4). This increase in spinal motion can be seen in head rotation during gait in order to stabilize and maintain posture and gaze (Haas *et al.*, 2004b;Hirasaki *et al.*, 1999). Hirasaki *et al.* (1999) characterized the head movements during gait over a range of velocities to clarify the role of the vestibular system during locomotion, and found that the relative contribution of each mechanism to head orientation depends on the frequency of head movement and consequently on walking velocity. The average walking velocity in this study was 0.95 m/s, which is not considered a fast pace for a normal, healthy population, yet clinically significant results were achieved approximately 15 minutes post intervention. This means that the cervical SMT caused very short-term changes in RP which did not last greater than 35 minutes as hypothesized.

The very short-term change can be attributed to the fact that the SMT had presented certain paraspinal tissues with a mechanical stimulus evoking high-frequency discharge in both muscle spindles and golgi tendon organs (Sung *et al.*, 2005). The high-velocity thrust may have temporarily altered primary afferents innervating paraspinal tissues, causing "corrective" actions on central neural mechanisms regulating paraspinal muscles and spinal mechanics (Pickar, 2002;Sung *et al.*, 2005). The proposed theory is that SMT decreased or inhibited gamma motoneuron discharge, causing a decrease in contractility of intrafusal muscle fibers (Korr, 1975). Simultaneously there was also thought to be an increase in proprioceptive afferent firing which allowed for a "corrective" change to occur.

The importance of proprioceptive input into the function of the vertebral column has been demonstrated recently in humans (Brumagne *et al.*, 2000). Healthy individuals have been shown to accurately reposition their lumbosacral spine, but their repositioning ability is impaired when the multifidus muscle is vibrated. Vibration stimulates muscle spindles and creates a sensory illusion that the multifidus is stretched and therefore that the spine is flexed more than it actually is (Pickar, 2002). The repositioning error occurs because of the misperception of vertebral position. This finding was associated with the altered proprioceptive input from muscle spindles (Borghouts *et al.*, 1999).

This is clinically significant because it poses the theory that initial short-term biomechanical changes in the cervical spine are caused by SMT. If this is the case, further research must be done with a specific treatment protocol (i.e. approximately 2-3 treatments per week for 4 weeks) (Descarreaux *et al.*, 2004;Haas *et al.*, 2004b) to examine whether greater biomechanical changes are produced and whether these changes are sustained for a prolonged period of time (i.e. weeks to months).

The increase in relative cervico-thoracic motion at 15 minutes and not immediately after the intervention may also be attributed to the fact that full end range of motion was not measured. The use of a goniometer or a cervical-range-of-motion instrument may have been more beneficial in measuring the effect of the cervical SMT immediately after the intervention (Youdas *et al.*, 1991).

5.2.2 Biomechanical Efficiency Quotient

The BEQ allows the researcher to evaluate and assess overall biomechanical walking economy independent of other nonbiomechanical measures (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996). Kerrigan *et al.* (1996) used the intervention of ankle-foot orthoses to determine whether walking economy changes with an intervention. The volunteer population included those with neurologically based gait deficiencies (i.e. Huntington's disease). These volunteers subjectively reported that one or two ankle-foot orthoses reduced the effort necessary to walk. The quotient was calculated and found that the BEQ was less with the orthoses than without (i.e. better walking efficiency), and that percent change in comfortable walking velocity correlated with percent change in BEQ with orthoses.

Previous studies used "external" methods of intervention (i.e. ankle-foot orthoses) to see if there was a change in global walking economy (Kerrigan *et al.*, 1995;Kerrigan *et al.*, 1996). The current study however, not only used an "internal" intervention (i.e. cervical SMT), but it also targeted this intervention on an area not often associated with gait economy (i.e. cervical spine).

Clinically significant results were found when specific volunteers were removed. Although significant results were found between BEQ 1 and BEQ 2, as well BEQ 1 and BEQ 3, the results were in the opposite direction than was previously hypothesized.

Biomechanical walking economy therefore appeared to decrease for a very short time after the cervical manipulation.

This would lead the reader to assume that cervical manipulation therefore decreases walking economy. There may however, be other reasons for the increase in BEQ post-manipulation compared to pre-manipulation. The fact that the person had become accustomed to walking on the treadmill for several minutes prior to the initial pre-intervention trial may also be a predisposing factor for the increase. By allowing volunteers several minutes to get accustomed to walking on the treadmill, a learning effect had taken place, decreasing the variability in their gait in the initial pre-intervention trial. Although BEQ increased in the second and third trials, it decreased by 35 minutes post-intervention. It appears that the total of ten minutes walked in the second and third trials allowed the subject to become reacclimated to walking comfortably and efficiently on the treadmill. This is evident in the final trial where the BEQ score is the same as in the initial pre-intervention trial.

Another reason for the increase in BEQ post-intervention may be attributed to the fact that the walking velocity on the treadmill was set. Volunteers walk most efficiently at their comfortable walking speeds. By having an intervention, the volunteer's comfortable walking velocity may have increased or decreased, meaning there would be a "new" comfortable walking velocity. Due to the fact that the velocity was set, the volunteer was now walking at a velocity which was not their most "comfortable", causing a decrease in their overall walking economy and an increase in their BEQ. This was evident in the second and third trials where the BEQ increased and once again decreased in the final trial.

A final reason for the increase in BEQ post-intervention may be attributed to the fact that the volunteer was going from receiving SMT, in a prone position, to immediately walking on the treadmill again. The volunteer's vestibulo-ocular system may not have had time to adjust accordingly, therefore causing a slight decrease in walking efficiency (Brandt & Strupp, 2005). When the volunteer had sufficient time to adjust, BEQ decreased once again as was evident in the final trial.

5.2.3 Neck-Walk Index

The NWI was used as a performance-based biomechanical outcome measure designed to evaluate change in mechanical neck disorders (Chunara *et al.*, 2004;Pierrynowski *et al.*, 2005) – in this case, chronic episodic neck pain caused by a previous concussion. Due to the fact that the rhythmical movement of the head and body is associated with gait patterns (Hirasaki *et al.*, 1999), a person experiencing chronic episodic neck pain from a previous concussion (i.e. mechanical in nature) may have these rhythms disrupted. The NWI was thought to evaluate the variability of head movement disturbances during individual gait patterns in this post-concussive neck syndrome volunteer group.

In this study, the specific intervention of cervical SMT was hypothesized to change the variability of head movement disturbances during gait. After the removal of specific outliers the results remained insignificant, indicating that cervical SMT did not change in the variability of head movement disturbances during gait. No reference in the literature is made in relation to NWI and how it evaluates change in head carriage, post-intervention. This study suggests however, that although results approached significance, cervical SMT did not change biomechanical head carriage in this volunteer population.

5.3 Global Implications

It must be noted that clinically meaningful significance may have not been reached due to the fact that only one cervical manipulation was used as an intervention. A treatment protocol of several manipulations over a period of three to four weeks, designed to initiate a definitive biomechanical change that would persist over several weeks to months (i.e. long-term change) was necessary. Physical change takes time (Kjellman *et al.*, 1999). When an athlete trains for a specific event, their physical gains from training (i.e. increased strength, increased speed, increased agility, etc.) are not seen or felt after one training session. Athletes practice and prepare their bodies for their specific events through many training sessions. This is the same approach that must be taken when making a "biomechanical change" in the cervical spine through SMT. Although one manipulation may have different short-term effects on different people (i.e. muscular, intradiscal, pain effects, etc.), a definitive biomechanical change would take place only after a longer, more specific treatment protocol (Haas *et al.*, 2004b;Harrison *et* *al.*, 2002). Hass *et al.* (2004) suggest that there was a positive and clinically important effect of the number of chiropractic treatments for low back pain on disability at four weeks. Harrison *et al.* (2002) attempted to physically restore lordosis in alordotic cervical spines using cervical SMT over four weeks as well, incorporating a traction method in therapy. They found statistically significant improvements in anterior head weight bearing and in the Cobb angle (cervical lordotic angle), meaning biomechanically significant changes were made. Both studies involved a treatment protocol of four weeks, consisting of two to three treatments per week, to allow for mechanical changes to take place.

Chapter 6

Conclusion

This pilot study was designed to examine the impact that cervical SMT had on specific biomechanical outcome measures on a PCNS volunteer group during gait. This impact was measured through transverse plane – relative phase measurements between the cervical and thoracic spine, through measures of global biomechanical walking economy and through evaluating the variability of head movement disturbances during individual gait patterns.

Statistical significance was found in relative phase measurements, which suggests that cervical SMT increases relative cervico-thoracic motion during gait in the short-term. The introduction of a goniometric measurement of cervical range of motion pre and post manipulation may show more significant results when assessing end range of motion in the cervical spine in rotation, lateral bend, flexion and extension (Youdas *et al.*, 1991).

The results of the BEQ measure suggest that global walking economy decreased in the short-term, post-manipulation. This could be attributed to the fact that when the initial BEQ score was taken, the volunteer had become accustomed to the speed and motion of the treadmill, allowing gait to become efficient. After the SMT, as well as lying down prone for approximately one to two minutes, the volunteer's vestibular system may not have become reacclimated as quickly as previously hypothesized (Brandt & Strupp, 2005). This can be seen in the decrease in BEQ by 35 minutes, meaning the walking economy had again increased.

Changes in the NWI were not statistically significant, however they did approach significance. Due to the fact that NWI was changing over time, it may be true that if tested for a longer duration, significance would have been noted. More importantly however, future studies should implement a longer treatment protocol (i.e. approximately four weeks, consisting of two to three treatments per week) to test for biomechanical changes in the cervical spine (Descarreaux *et al.*, 2004;Haas *et al.*, 2004b).

Chapter 7

Future Recommendations

This pilot study examined the biomechanical effects of cervical SMT on post-concussive neck syndrome volunteers. This study was done with the intention of carrying out a larger and more intensive research study. Several improvements could be made to a follow-up study. This Chapter will address those possible improvements.

7.1 Volunteer Profile

Greater significance may have been noted in the objective outcome measures if the volunteers were more affected – i.e. they had greater and more chronic neck pain. If function had been more of an issue for this population, a greater treatment effect could have been noted.

In future studies, it is recommended that the post-concussive volunteer population used remains in the mild category of head injury. It is more important however, that their NDI and VAS scores are higher, showing greater disability and lack of function. By incorporating a population whose neck disability is increased, there is a greater and more realistic possibility that clinical significance will be noted post-manipulation during a functional task such as gait.

7.2 Clinical Treatment Protocol

During this study, the treatment intervention consisted of one cervical spinal manipulation, as opposed to a treatment plan over approximately three to four weeks consisting of approximately nine to twelve manipulations. Recent research shows that after 12 treatments over a one-month period, chronic low back pain improvements (decreased pain, increased global motion) were seen in a group receiving SMT whereas another group receiving sham treatments remained at a high disability level (Descarreaux *et al.*, 2004). Another study showed a positive, clinically important effect in the number of chiropractic treatments on pain intensity and disability at three weeks (Haas *et al.*, 2004b). Biomechanically, ankle-foot orthoses are hypothesized to make a similar change (Johnson *et al.*, 2005). Foot orthoses have been shown to be effective in preserving soft-tissue integrity of the heel pad after bony or soft-tissue injury (Johnson *et al.*, 2005). The orthotic used in the Johnson *et al.* study (2005) had to be "worked in" (i.e. worn limitedly over the first few days, increasing wear within several weeks) over a specific period of time to allow a progressive biomechanical change in the foot to occur in order to "accept" the orthotic.

The thought process behind an increased amount of treatments being able to cause a biomechanical and physical change is similar to that of an athlete training for a sporting event. An athlete will not reach their physical peak after one training session. It is for this reason that they train their bodies – to accept a physical change from a specific load being placed on their body (Loveless *et al.*, 2005;Munn *et al.*, 2005;Symons *et al.*, 2005).

During future research studies in this field, the author recommends a treatment protocol of cervical SMT three to four times per week over a three to four week time span. This intensive treatment has been shown to give substantial relief in a low back population and it is assumed the same would be seen in this type of PCNS volunteer group (Descarreaux *et al.*, 2004;Haas *et al.*, 2004b). This does not undermine the fact that volunteers would find relief from pain earlier than several weeks. Several studies incorporating treatment protocols of three to four weeks have found that patients received relief from their pain only three to four treatments into their protocol (Haas *et al.*, 2004b;Haas *et al.*, 2004a). Although previous studies were based on patients suffering from chronic low back pain, the assumption could be made that a clinically important effect (pain, disability decrease over larger amount of time) was not seen after one treatment. The purpose of the extended protocol therefore, would be to induce a significant biomechanical and clinically important change/effect, which will be sustained for an extended period of time.

7.3 Walking Speed and Range of Motion Measurement

The walking speed in this study was different for each volunteer. Each volunteer was told to select a "comfortable" walking speed and that that was the speed at which they were to walk for each separate trial. In future studies examining similar biomechanical outcome measures, researchers should increase the walking speed to approximately three miles per hour and have this as a set speed for every volunteer (Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a).

Lamoth *et al.* (2001, 2002) showed that the relative pelvis-thorax coordination evolves from in-phase coordination to antiphase coordination as walking velocity increased. During this study, many volunteers were walking at a very slow set speed (i.e. 0.9 mph – 1.5 mph). This may have been to slow to detect any sort of antiphasic shift in cervico-thoracic coordination. An increase in speed would cause a greater increase in antiphase coordination at the pelvis-thorax (Haas *et al.*, 2004b;Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a), and if this was the case at a lower segment in the spine, the same could be expected at higher segments in the spine (i.e. cervico-thoracic motions).

If there was a greater shift towards antiphasic movements, there would be greater segmental motion within that spinal area (Haas *et al.*, 2004b;Lamoth *et al.*, 2002b;Lamoth *et al.*, 2002a). A change in range of motion would therefore have a greater chance of being noticed. Hence, the intervention of cervical SMT would also be more significant in a scenario such as this (i.e. attempting to increase the range of motion in a PCNS volunteer group in a situation (higher speed = increase in antiphase coordination) where segmental mobility should be increased).

The range of motion pre and post-intervention should also be measured prior to each walking trial. The use of a goniometer to measure whether there was an increase/decrease in range of motion post-manipulation would allow for more information to be analyzed in the study than to just have range of motion evaluated during locomotion when end range is not reached.

Chapter 8

Summary

The pilot nature of this study allowed us to work with a select population to see whether cervical spinal manipulation induced different biomechanical changes. The results of this study showed:

1. there was a short-term, clinically significant increase in cervicothoracic motion (< 35 minutes) as measured by transverse plane – relative phase data
2. there was a short term decrease in biomechanical walking economy (< 35 minutes) as measured by the Biomechanical Efficiency Quotient, which may have been attributed to a "warm-up" or learning effect on the treadmill prior to the initial trial
3. there was no change in head carriage, post-manipulation, as measured by the Neck-Walk Index.

As expected therefore, short-term changes were seen in relative motion in the cervical spine, post-manipulation. There are however, several important factors that must be considered when designing a new study to add to the current literature presented. Future research should incorporate the following factors in a new design:

1. the subject profile must consist of volunteers that are more affected than those in the current study (i.e. NDI > 6, VAS > 2). The increase in disability and, most likely function, would increase the possibility that clinically significant results would be seen in functional outcomes such as the BEQ (and NWI).
2. there should be an increase in walking velocity to increase the shift towards antiphasic movements in the spine. This would increase the possibility of seeing clinically significant results from the cervical SMT.
3. there should be a clinical treatment protocol implemented. This treatment protocol should consist of two to three treatments per week for approximately four to six weeks. By treating this volunteer population as one would in a clinical environment, it increases the possibility of making significant biomechanical changes that are sustained for a more lengthy period of time (i.e. several weeks to months). These biomechanical changes should increase the patient's overall functional and disability levels.

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Appendices

1. Informed Consent to Chiropractic Treatment
2. Standardized Assessment of Concussion
3. Neck Disability Index
4. Short Form – 36 Health Survey
5. Visual Analog Scale

INFORMED CONSENT TO CHIROPRACTIC TREATMENT

Doctors of chiropractic, medical doctors and physiotherapists who use manual therapy techniques such as spinal adjustments are required to advise patients that there are or may be some risks associated with such treatment. In particular you should note:

a) While rare, some patients have experienced rib fractures or muscle and ligament sprains or strains following lumbar spinal adjustments;

b) There have been reported cases of injury to a vertebral artery following cervical spine adjustments. Vertebral injuries have been known to cause stroke, sometimes with serious neurological impairment, and may on rare occasion result in serious injury. The possibilities of such injuries resulting from cervical spinal adjustment is extremely remote;

b) There have been rare reported cases of disc injuries following lumbar spinal adjustment although no scientific study has ever demonstrated such injuries are caused or may be caused, by spinal adjustments or chiropractic treatment.

Chiropractic treatment, including spinal adjustment, has been the subject of government and multi-disciplinary study conducted over many years. It has been demonstrated that lumbar spine manipulative therapy is an effective treatment for lumbar spine pain. The risk of injuries or complications from chiropractic treatment is lower than that associated with many medical or other treatments, medications, and procedures given for the same symptoms.

I acknowledge I have discussed, or have had the opportunity to discuss, with my chiropractor the nature and purpose of chiropractic treatment in general and my treatment in particular (including spinal adjustment) as well as the contents of the Consent.

I consent to the chiropractic treatments offered or recommended to me by my chiropractor, including spinal adjustment. I intend this consent to apply to all my present and future chiropractic care.

Date: D_______ M_____ Y_______

______________________________	______________________________
Patient Signature	Witness to Signature
______________________________	______________________________
Print Name:	Print Name

STANDARDIZED ASSESSMENT OF CONCUSSION

1) ORIENTATION:

Month: ____________________ 0 1
Date: ____________________ 0 1
Day of week: ____________________ 0 1
Year: ____________________ 0 1
Time (within 1 hr.):___________ 0 1

Orientation Total Score _______ / 5

2) IMMEDIATE MEMORY: (all 3 trials are completed regardless of score on trial 1 & 2; total score equals sum across all 3 trials)

List	Trial 1	Trial 2	Trial 3
Word 1	0 1	0 1	0 1
Word 2	0 1	0 1	0 1
Word 3	0 1	0 1	0 1
Word 4	0 1	0 1	0 1
Word 5	0 1	0 1	0 1
Total			

Immediate Memory Total Score ____ / 15

(Note: Subject is not informed of Delayed Recall testing of memory)

NEUROLOGICAL SCREENING:

Recollection of injury (pre- or post-traumatic amnesia)

Strength:

Sensation:

Coordination:

3) CONCENTRATION:

Digits Backward (If correct, go to next string length. If incorrect, read trial 2. Stop after incorrect on both trials)

4-9-3 6-2-9 _______ 0 1
3-8-1-4 3-2-7-9 _______ 0 1
6-2-9-7-1 1-5-2-8-6 _______ 0 1
7-1-8-4-6-2 5-3-9-1-4-8 _______ 0 1

Months in reverse order: (entire sequence correct for 1 point)
Dec-Nov-Oct-Sep-Aug-Jul
Jun-May-Apr-Mar-Feb-Jan _____ 0 1

Concentration Total Score _____ / 5

EXERTIONAL MANEUVERS
(when appropriate) :
5 jumping jacks **5 push-ups**
5 sit-ups **5 knee-bends**

4) DELAYED RECALL

Word 1 0 1
Word 2 0 1
Word 3 0 1
Word 4 0 1
Word 5 0 1

Delayed Recall Total Score _____ / 5

SUMMARY OF TOTAL SCORES:
Orientation ____/ 5
Immediate Memory ____/ 15
Concentration ____/ 5
Delayed Recall ____/ 5
Overall Total Score __________/ 30

NECK DISABILITY INDEX

Please Read: This questionnaire is designed to enable us to understand how much your neck pain has affected your ability to manage everyday activities. Please answer each Section by circling the **ONE CHOICE** that most applies to you. We realize that you may feel that more than one statement may relate to you, but Please **just circle the one choice which closely describes your problem *right now*.**

SECTION 1--Pain Intensity

A. I have no pain at the moment
B. The pain is mild at the moment.
C. The pain comes and goes and is moderate.
D. The pain is moderate and does not vary much.
E. The pain is severe but comes and goes.
F. The pain is severe and does not vary much.

SECTION 2--Personal Care (Washing, Dressing etc.)

A. I can look after myself without causing extra pain.
B. I can look after myself normally but it causes extra pain.
C. It is painful to look after myself and I am slow and careful.
D. I need some help, but manage most of my personal care.
E. I need help every day in most aspects of self-care.
F. I do not get dressed, I wash with difficulty and stay in bed.

SECTION 3--Lifting

A. I can lift heavy weights without extra pain.
B. I can lift heavy weights, but it causes extra pain.
C. Pain prevents me from lifting heavy weights off the floor but I can if they are conveniently positioned, for example on a table.
D. Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned.
E. I can lift very light weights.
F. I cannot lift or carry anything at all.

SECTION 4 --Reading

A. I can read as much as I want to with no pain in my neck.
B. I can read as much as I want with slight pain in my neck.
C. I can read as much as I want with moderate pain in my neck.
D. I cannot read as much as I want because of moderate pain in my neck.
E. I cannot read as much as I want because of severe pain in my neck.
F. I cannot read at all.

SECTION 5--Headache

A. I have no headaches at all.
B. I have slight headaches which come infrequently.
C. I have moderate headaches which come in-frequently.
D. I have moderate headaches which come frequently.
E. I have severe headaches which come frequently.
F. I have headaches almost all the time.

SECTION 6 -- Concentration

A. I can concentrate fully when I want to with no difficulty.
B. I can concentrate fully when I want to with slight difficulty.
C. I have a fair degree of difficulty in concentrating when I want to.
D. I have a lot of difficulty in concentrating when I want to.
E. I have a great deal of difficulty in concentrating when I want to.
F. I cannot concentrate at all.

SECTION 7--Work
A. I can do as much work as I want to.
B. I can only do my usual work, but no more.
C. I can do most of my usual work, but no more.
D. I cannot do my usual work.
E. I can hardly do any work at all.
F. I cannot do any work at all.

SECTION 8--Driving
A. I can drive my car without neck pain.
B. I can drive my car as long as I want with slight pain in my neck.
C. I can drive my car as long as I want with moderate pain in my neck.
D. I cannot drive my car as long as I want because of moderate pain in my neck.
E. I can hardly drive my car at all because of severe pain in my neck.
F. I cannot drive my car at all.

SECTION 9--Sleeping
A. I have no trouble sleeping
B. My sleep is slightly disturbed (less than 1 hour sleepless).
C. My sleep is mildly disturbed (1-2 hours sleepless).
D. My sleep is moderately disturbed (2-3 hours sleepless).
E. My sleep is greatly disturbed (3-5 hours sleepless).
F. My sleep is completely disturbed (5-7 hours sleepless).

SECTION 10--Recreation
A. I am able engage in all recreational activities with no pain in my neck at all.
B. I am able engage in all recreational activities with some pain in my neck.
C. I am able engage in most, but not all recreational activities because of pain in my neck.
D. I am able engage in a few of my usual recreational activities because of pain in my neck.
E. I can hardly do any recreational activities because of pain in my neck.
F. I cannot do any recreational activities all all.

SIGNATURE:____________________DATE:________

DISABILITY INDEX SCORE: %_____

SHORT FORM – 36 HEALTH SURVEY

SF36 Health Survey. INSTRUCTIONS: This set of questions asks for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities. Answer every question by marking the answer as indicated. If you are unsure about to answer a question please give the best answer you can.

1.	In general, would you say your health is: (Please tick **one** box.) Excellent ☐ Very Good ☐ Good ☐ Fair ☐ Poor ☐			
2.	Compared to one year ago, how would you rate your health in general now? (Please tick **one** box.) Much better than one year ago ☐ Somewhat better now than one year ago ☐ About the same as one year ago ☐ Somewhat worse now than one year ago ☐ Much worse now than one year ago ☐			
3.	The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much? **(Please circle one number on each line.)**			
	Activities	**Yes, Limited A Lot**	**Yes, Limited A Little**	**Not Limited At All**
3(i)	**Vigorous activities**, such as running, lifting heavy objects, participating in strenuous sports	1	2	3
3(ii)	**Moderate activities**, such as moving a table, pushing a vacuum cleaner, bowling, or	1	2	3

	playing golf			
3(iii)	Lifting or carrying groceries	1	2	3
3(iv)	Climbing **several** flights of stairs	1	2	3
3(v)	Climbing **one** flight of stairs	1	2	3
3(vi)	Bending, kneeling, or stooping	1	2	3
3(vii)	Waling **more than a mile**	1	2	3
3(viii)	Walking **several blocks**	1	2	3
3(ix)	Walking **one block**	1	2	3
3(x)	Bathing or dressing yourself	1	2	3

4.	During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health? **(Please circle one number on each line.)**		
		YES	**NO**
4(i)	Cut down on the **amount of time** you spent on work or other activities	1	2
4(ii)	Accomplished less than you would like	1	2
4(iii)	Were **limited** in the **kind** of work or other activities	1	2
4(iv)	Had **difficulty** performing the work or other activities (for example, it took extra effort)	1	2
5.	During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?		
	(Please circle one number on each line.)	**Yes**	**No**
5(i)	Cut down on the **amount of time** you spent on work or other activities	1	2
5(ii)	Accomplished less than you would like	1	2
5(iii)	Didn't do work or other activities as **carefully** as usual	1	2

6.	During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbours, or groups? (Please tick **one** box.) Not at all □ Slightly □ Moderately □ Quite a bit □ Extremely □
7.	How much physical pain have you had during the past 4 weeks? (Please tick **one** box.) None □ Very mild □ Mild □ Moderate □ Severe □ Very Severe □
8.	During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)? (Please tick **one** box.) Not at all □ A little bit □ Moderately □ Quite a bit □ Extremely □
9.	These questions are about how you feel and how things have been with you during the past 4 weeks. Please give the one answer that is closest to the way you have been feeling for each item.

	(Please circle one number on each line.)	All of the Time	Most of the Time	A Good Bit of the Time	Some of the Time	A Little of the Time	None of the Time
9(i)	Did you feel full of life?	1	2	3	4	5	6
9(ii)	Have you been a very nervous person?	1	2	3	4	5	6
9(iii)	Have you felt so down in the dumps that nothing could cheer you up?	1	2	3	4	5	6
9(iv)	Have you felt calm and peaceful?	1	2	3	4	5	6
9(v)	Did you have a lot of energy?	1	2	3	4	5	6
9(vi)	Have you felt downhearted and blue?	1	2	3	4	5	6
9(vii)	Did you feel worn out?	1	2	3	4	5	6
9(viii)	Have you been a happy person?	1	2	3	4	5	6
9(ix)	Did you feel tired?	1	2	3	4	5	6

10.	During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives etc.) (Please tick **one** box.) All of the time ☐ Most of the time ☐ Some of the time ☐ A little of the time ☐ None of the time ☐
11.	How TRUE or FALSE is each of the following statements for you?

	(Please circle one number on each line.)	Definitely True	Mostly True	Don't Know	Mostly False	Definitely False
11(i)	I seem to get sick a little easier than other people	1	2	3	4	5

11(ii)	I am as healthy as anybody I know	1	2	3	4	5
11(iii)	I expect my health to get worse	1	2	3	4	5
11(iv)	My health is excellent	1	2	3	4	5

VISUAL ANALOG SCALE

Place a mark along the line to indicate your current level of pain

No pain Worst pain ever