1-1-2011

Cervical flexion relaxation phenomenon during upright standing and the modulating effect of trunk flexion angle.

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by

Tara L. Diesbourg

A Thesis
Submitted to the Faculty of Graduate Studies
through the Faculty of Human Kinetics
in Partial Fulfillment of the Requirements for
the Degree of Master of Human Kinetics at the
University of Windsor

Windsor, Ontario, Canada

2011

Your file Votre référence
ISBN: 978-0-494-76286-8

Our file Notre référence
ISBN: 978-0-494-76286-8

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DECLARATION OF ORIGINALITY

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ABSTRACT

The purpose of this study was to assess the presence of the flexion relaxation phenomenon (FRP) in cervical paraspinal musculature in an upright standing posture, and to examine the modulating effect of non-neutral trunk postures on cervical FRP (cFRP). Cervical spinal angles and muscle activation patterns were monitored in 17 participants while performing a neck flexion task in six postures. EMG and angle traces from the flexion trials were used to determine the presence and magnitude of the cFRP (Extension Relaxation Ratio: ERR) and the cervical angles associated with cFRP (onset and cessation angles). The cFRP was observed in the cervical paraspinal muscles (CPS) muscles unilaterally in 11 participants (64.7 %), and bilaterally in 8 participants (47.1 %), across all postures and conditions. Onset angle was lower and ERR was higher in the 45° trunk inclination condition compared to the upright and slumped conditions. ERRs and onset angles were not significantly different in the slumped condition compared to the upright condition. The data from this study contributed to the knowledge base for the under-researched area of cFRP.

DEDICATION

This work is dedicated to my dad, Leo Diesbourg. It was his passion and enthusiasm for learning new things and figuring out how the world works that fuelled my interest in the same things. He always encouraged me to ask questions, and to never stop trying to learn new things. Without his support, I would not be the researcher I am now! It is also dedicated to my mom, Mary Anne Diesbourg, who taught me never to settle for what is easy. If you think something is worthwhile, then it is worth putting yourself out of your comfort zone, and working hard to achieve it. It is never too late to achieve your dreams!

ACKNOWLEDGEMENTS

I would first and foremost like to thank my family and friends. Your help and support over the last 6 years of University studies have been invaluable to me. Your ability to sit and listen to me ramble on and on about all of the new stuff I learned every day, and your helpful advice when I got frustrated at teachers, projects, or exams were what allowed me to survive and stay sane! Even though biomechanics doesn't really interest most of you, you feigned interest and pretended to listen to me talk about everything that I continually got excited or frustrated about. I will miss each and every one of you as I move on with my studies and my career. It will not be as fun or as easy to complete my next degree without your kind words and encouragement to push me through, but thanks to the phone, and a short 5 hour drive, I will still be able to benefit from your listening ear, your sarcasm, your advice, and your reassurance.

Tom, as a history major, I know you never expected to learn the meaning of the words flexion, and cervical spine. I appreciate every moment you spent with me in the lab on weekends, and the late nights I spent neglecting you in place of data processing. You have been my rock, and without you, I would have caved under the pressure! The next degree will be much worse, so I thank you in advance for your advice, support, and patience! The next 4 years will be interesting and fun to say the least. Here's to the next step!

A huge thanks also goes out to my advisor, Dr. Nadia Azar. I'm sure it can't be easy to be both a new mom and a Masters' advisor. Draft after draft would take her away from her kids, but she was always available for any extra advice I might have needed.

The ridiculous timelines that I tried to impose and enforce were stressful on both of us to say the least, but it paid off. Graduate school would have been a very long, arduous, and frustrating process if it weren't for her help, support and advice! The passion that she showed for teaching and for research is what drove me to pursue a PhD of my own. I hope that someday, I will be fortunate enough to work and collaborate with her again.

I would also like to thank my committee members for their input on this project. Their advice and input enhanced this project and made the data and information collected that much more valuable, and will increase the impact it has on scientific knowledge. I would especially like to thank my external committee member, Dr. Janessa Drake for all of her contributions to the design and implementation for this study. Her extensive knowledge of EMG and data collection protocols was an invaluable asset to me when I hit snags in collections.

To all of the faculty and staff in the Department of Kinesiology at the University of Windsor, thanks for always listening to my questions both in class and outside of it. Even though you were busy with your own students and your own work, you always made yourself available to me when I had questions about statistics, data collection methods, writing formats, and conference presentations. Your enthusiasm and the joy you show in the work that you do is what convinced me to pursue a Masters Degree and a PhD over all of the other career options I had in mind!

I would also like to thank my lab mates, especially Phill McKeen and Mike Angelidis for all of your help in the piloting, and MVC collection as well as your participation in the study!

Lastly, a big thank you goes out to the Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) for providing the funding necessary to carry out this research project. Their generosity did not go unnoticed.

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GLOSSARY

Term	**Definition**
Axial Rotation	Rotation about a long axis running through a body or a body segment (Hamill & Knutzen, 2005).
Cessation Angle	The trunk or neck angle at which the myo-electric silence of the FRP ceases; that is, the angle at which the extensor muscles are re-activated to initiate the extension phase.
Common Mode Rejection Ratio	Measure of the tendency of the differential amplifier to reject input signals common to both input leads in an EMG signal (e.g. ambient noise from power cords or fluorescent lighting; noise within amplifier components) (Winter, 2005).
Concentric Contraction	Muscle tension generated actively by the shortening of the muscle fibres (Hamill & Knutzen, 2005).
Critical Point	The cervical or lumbar angle at which the extensor muscles become silent in forward neck or trunk inclination. The value of this point varies between individuals (also referred to as the onset angle).
Eccentric Contraction	The muscle is subjected to an external force that is greater than the force produced by the muscle's contraction, causing the muscle to lengthen while contracting (Hamill & Knutzen, 2005).
Elastic Limit	The limit of a tissue to withstand deformation and still return to its original shape. Beyond this point of the deformation-time curve, the deformation is permanent (Hamill & Knutzen, 2005).
Electrogoniometer	A device that measures the changing angle of a joint using a reference of one endpoint to the other.
Extension	A straightening motion where the angle of a joint gradually increases until it has reached its neutral position (Hamill & Knutzen, 2005).
Extension Relaxation Ration (ERR)	The ratio of the muscle activity in the extension phase to the muscle activity in the fully flexed (held) phase. For the purpose of this study, the ERR was specifically defined as the ratio of

	the peak activity in the extension phase to the average activity in the fully flexed phase.
Flexion	A bending motion where the relative angle between two segments decreases gradually (Hamill & Knutzen, 2005).
Flexion Relaxation Phenomenon (FRP)	The myo-electric silencing of the erector spinae muscles in full forward trunk inclination (Floyd & Silver, 1955).
Flexion Relaxation Ratio (FRR)	The ratio of the muscle activity in the flexion phase and the muscle activity in the fully flexed (held) phase. For the purpose of this study, the FRR was specifically defined as the ratio of the peak activity in the flexion phase to the average activity in the fully flexed phase.
Isometric Contraction	The muscle is active and tension is developed however there is no visible or external change in joint position (Hamill & Knutzen, 2005).
Lateral Bend	The movement of the head or trunk in the frontal plane wherein the head or trunk tilts sideways (Hamill & Knutzen, 2005).
Moment Arm	The perpendicular distance from an applied force (line of action) to a pivot point (axis of rotation) in an angular motion system (Hamill & Knutzen, 2005).
Onset Angle	The trunk or neck angle at which the myo-electric silence of the FRP is initiated; also referred to as critical point.
Slumped Posture	A posture commonly assumed by the general population whereby the participants' shoulders are rounded forward, back is rounded, and neck is slightly extended.
Surface electromyography (EMG)	A process by which the electrical activity of a muscle is recorded using surface electrodes that detect the muscle activity through the skin.

CHAPTER I

INTRODUCTION

Neck pain is a common health problem around the world. In Finland, more than half the adult population experienced neck pain at some point in their lives (Makela et al., 1991). In a British study, 33.7 % (*n* = 4,384) of the sample reported neck pain in the year preceding the study, and 19.6 % of the sample reported neck pain in the week preceding the study (Palmer et al., 2001). Of the individuals reporting neck pain, 11 % stated that their neck pain interfered with their normal activities (Palmer et al., 2001). At any point in time, 54 % of Canadian adults suffer from neck pain and a further 4.6 % of the population experience activity limitations due to their neck pain (Coté et al., 1998). By comparison, 84 % of Canadian adults suffer from low back pain (LBP) at any given time, and 49 % are limited in their activities due to LBP (Cassidy et al., 1998). Although neck pain is less prevalent than LBP; neck pain (like LBP) follows an episodic course, and a large majority of workers with neck pain report persistent or recurrent pain at a 1-year follow-up (up to 80 %: Carroll et al., 2009). In Saskatchewan, 37.3% of patients with neck pain reported persistent neck pain, and 10 % reported a worsening of their pain after one year (Coté et al., 2004). Twenty-three percent of the individuals with neck pain report a recurrent episode at follow-up (six months, and twelve months) (Coté et al., 2004). Neck pain may interfere with many aspects of the lives of those individuals experiencing it, including in the workplace. Thus, it is important to learn the mechanisms behind neck injuries so that precautions can be taken to prevent them from occurring or worsening.

Certain demographic factors have been associated with an increased risk of developing neck pain. For example, the incidence of neck pain has been shown to increase with increasing age; the strength of the association peaked in the fourth and fifth decades of life and levelled off after that (with 95 % of lost time claimants falling between the ages of 20 and 59 years) (Coté et al., 2009a, 2009b). Also, males have been shown to claim lost time due to neck pain twice as often as females (68 % of lost time claimants versus 32 % of lost time claimants) (Coté et al., 2009b). Whether other demographic factors such as education level, marital status, occupation, years of employment, and occupational class are positively correlated with increased neck pain is currently up for debate as the numerous studies examining these factors have varied widely in results (Coté et al., 2009a).

Occupational activities have been implicated as causes of neck disorders (Ariens et al., 2000; Palmer et al., 2001). Research has shown a positive relationship between neck pain and neck flexion, such that prolonged neck flexion may leave a worker more susceptible to neck pain, especially among workers who spend at least 70 % of their day with a neck flexion angle of 20° or more (Ariens et al., 2000, 2001). Working in construction and secretarial settings were associated with the highest occurrence of neck pain for men and women, respectively (Palmer et al., 2001), although the actual incidence values and percentages vary widely among the various studies and country of employment. It was also discovered that people who spend 95 % of their day sitting, are at an increased risk of developing neck pain (Ariens et al., 2001). Occupations such as dentistry, service industry, public sector, manufacturing and nursing were also highly correlated with an increased incidence of neck pain, often resulting in limitations to occupational tasks (Coté et al., 2009a, 2009b).

Carroll et al. (2009) reported that recovery from neck pain and injury was related to the amount of control that the worker has over their own work situation. White-collar workers (often, those with more flexible schedules) had a better prognosis for recovery than blue-collar workers (generally those with less control over their schedules, often shift-work). Also, individuals who reported participating in a regular, general exercise routine had a better prognosis for recovery; whereas previous neck pain and prior time off for sick leave were associated with poorer prognoses for recovery (Carroll et al., 2009).

The flexion relaxation phenomenon (FRP) is an occurrence in the lumbar spine characterized by the myo-electric silencing of the erector spinae muscles in forward trunk flexion (Floyd & Silver, 1955). The erector spinae muscles contract eccentrically during trunk flexion to control the speed of the movement, and once the critical point has been reached, the erector spinae muscles silence and no longer contract. The FRP onset angle is a term used to denote the trunk angle at which the critical point occurs; in other words, the point where the erector spinae muscles become silent during trunk flexion. This angle varies from person to person as well as from study to study and thus; there is no set value to represent the critical point for FRP (Descarreaux et al., 2008). This point is said to represent the transfer of the load-supporting role from the actively contracting muscles to the passive components of the spine (i.e. tendons, ligaments, vertebrae, and elastic components of muscle tissue) (McGill, 1991). Following the held flexion phase, the concentric contraction of the erector spinae muscles initiates trunk extension and causes the trunk to return to its full, upright posture. The cessation angle refers to the trunk angle at which muscle activity resumes, (i.e. the point where myo-electric silence ends).

Early studies determined the presence of FRP by visually examining EMG traces for evidence of myo-electric silencing. The flexion relaxation ratio (FRR: Watson et al., 1997) was developed to provide a reliable, repeatable, and more objective method to affirm whether FRP is actually occurring during trunk flexion trials. Trunk movement during these trials is broken down into four distinct phases (Figure 1). The first phase is upright, relaxed standing. This is the starting position for the flexion task. Phase 2 is the flexion phase. This is the period of time where the participant is moving from the upright posture to the position of full flexion. Phase 3 is the fully flexed phase. This fully flexed position is held for a pre-determined amount of time before returning to the upright

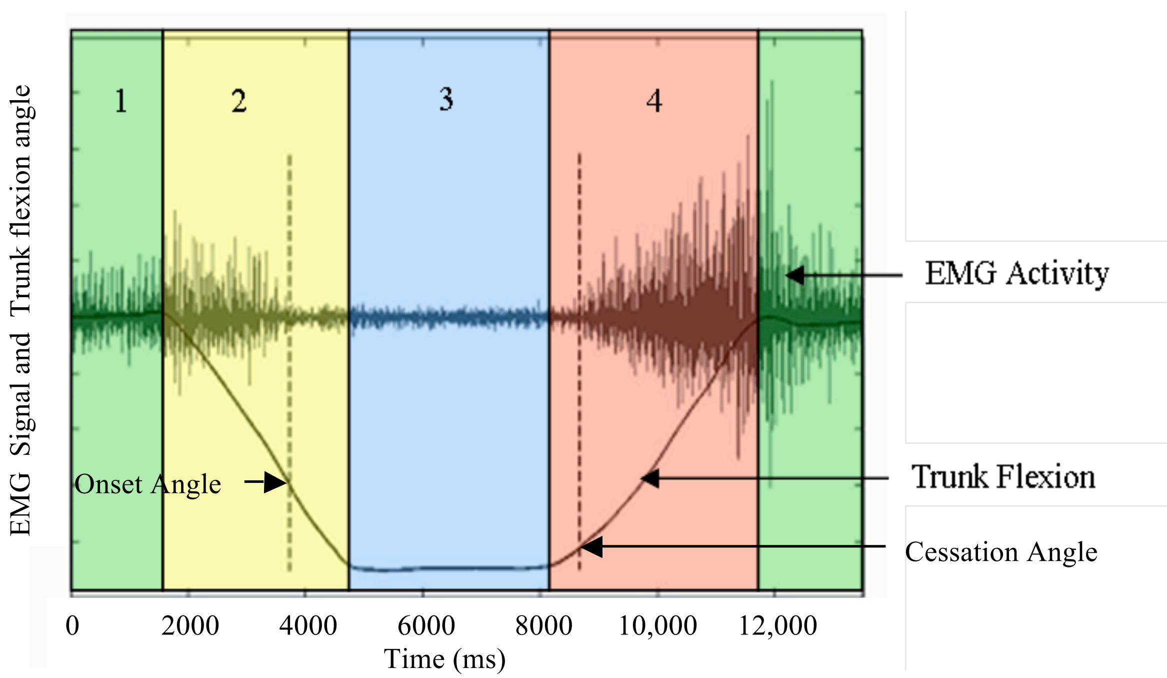

Figure 1: Phases of trunk inclination during a trunk flexion task with accompanying lumbar EMG trace. Phase 1: Upright standing (starting position), Phase 2: Forward flexion phase, Phase 3: Fully flexed position held, Phase 4: Extension to starting position. Adapted from Descarreaux et al., 2008, p. 10. (Biomed Central, London, UK.)

position. The onset angle may occur in Phase 2 or at the very beginning of Phase 3; likewise, the cessation angle may occur in Phase 4, or at the very end of Phase 3. Phase 4 is the period of extension, where the participant is returning to the starting, upright position. To calculate the FRR, muscle activation levels during one phase of the movement are compared to those in another phase. Which phases to use to calculate the FRR, and whether to use mean or peak activity during these phases, vary between studies. The most commonly used methods take the ratio of Phase 2 to Phase 3 (FRR: Watson et al., 1997), or the ratio of Phase 4 to Phase 3, also referred to as the extension relaxation ratio (ERR: Alschuler et al., 2009). In both cases, a ratio with a value greater than one indicates less muscle activity during full trunk flexion (Phase 3) than in the reference phase (i.e. Phase 2 or Phase 4).

The clinical significance of the lumbar FRP is well established. This mechanism is absent among individuals suffering from low back pain, and the increased muscle activity is believed to represent an attempt to protect injured or diseased spinal structures and to minimize pain (Colloca & Hinrichs, 2005). Furthermore, the extent to which FRP is lacking may vary between acute and chronic low back pain conditions, such that sufferers of acute low back pain may exhibit less lumbar FRP (i.e., less myo-electric silencing at full trunk flexion) than chronic low back pain (Leinonen et al., 2000). Marshall & Murphy (2006, 2008) recently demonstrated that lumbar FRP could be restored through rehabilitation. In these studies, patients showed increased myo-electric silencing during full trunk flexion after a four-week treatment (with manipulation/massage and adjustment) followed by twelve subsequent weeks of exercise. This suggests that while the presence (or absence) of FRP can be used to distinguish healthy individuals from those suffering from low back pain, it could also be used to indicate a patient's progress in their rehabilitation program.

While extensive research has been conducted on the lumbar FRP, the presence of the FRP in the cervical musculature and its clinical significance are less well established. To date, only a few studies have examined the presence of the cervical FRP (cFRP) (Meyer et al., 1993; Airaksinen et al., 2005; Burnett et al., 2009; Pialasse et al., 2009, 2010; Murphy et al., 2010), and while all of them show evidence for the existence of a cFRP, many of the modulating factors of the cFRP have yet to be investigated. For example, all of the previously mentioned studies have examined the cFRP with participants seated in a chair. Since many occupational tasks take place in a standing posture (e.g. where the work takes place on a waist-height conveyor or table top), the modulating effect of standing postures on the cFRP should be examined to help further the understanding of this response. Furthermore, due to workstation layouts and variability in worker anthropometrics, workers are likely to adopt non-neutral lumbar and/or cervical postures, whether seated or standing. Past research has examined the relationship between cFRP and trunk flexion angle; however this examination only took into account a seated posture and did not look at the participants while in standing (Pialasse et al., 2009). A slumped, seated posture results in constant muscle activation in the lumbar erector spinae, and myo-electric silencing of the thoracic erector spinae muscles during forward trunk flexion (Callaghan & Dunk, 2002). Although Caneiro et al. (2010) found constant activation in the cervical paraspinal muscles during slumped seated postures, studies have yet to be conducted to examine the effects of slumped postures on the cFRP.

Therefore, the purpose of this study was to assess the presence of the FRP in the cervical paraspinal musculature in an upright standing posture, and to examine the potential modulating effect of non-neutral trunk postures (flexed and slumped) on kinematic and EMG parameters of the cFRP. The specific aims of this study were:

I) To determine whether the cFRP is present in an upright standing posture.

II) To identify the potentially modulating effect of trunk inclination angle on the EMG (i.e. ERRs) and kinematic (i.e. onset and cessation angles) parameters of cFRP in seated and standing postures.

III) To compare the EMG and kinematic parameters of cFRP between standing and seated postures.

IV) To identify the potentially modulating effect of a slumped posture on the EMG and kinematic parameters of cFRP in both seated and standing postures.

To achieve these specific aims, two hypotheses and two research questions were formulated:

Hypothesis I: Based on previous cFRP research, the majority of the study participants would exhibit the flexion relaxation phenomenon in the dorsal cervical paraspinal musculature, in both upright seated and upright standing postures.

Hypothesis II: Based on previous cFRP research,

a) the muscle activity in Phase 4 would increase relative to Phase 3 with increases in trunk inclination angle, in both the seated and standing postures; and

b) there would be no effect of trunk inclination angle on onset and cessation angles for cFRP in the seated and standing trials.

Research Question #1: What effect, if any, does body posture (seated or standing) have on the kinematic and EMG parameters of the cFRP?

Research Question #2: What effect, if any, does a slumped posture have on the kinematic and EMG parameters of the cFRP?

Currently, there is minimal literature on the existence of the cFRP itself, and even less on the modulating effects of standing and trunk postures. Since the mechanisms behind occupational neck injury and the associated pain remain poorly understood to this date, this work is expected to increase knowledge of the presence and modulating factors of the cFRP, which will further our understanding in an under-researched area. It is hoped that this work will lay the foundation for further research towards the development of the clinical relevance of the cFRP (similar to the work that has already been done for the lumbar FRP). With further research, the cFRP could eventually be used as a clinical aid to guide and monitor the rehabilitation of neck injuries.

CHAPTER II

REVIEW OF LITERATURE

2.1 Cervical Spinal Anatomy

Movement of the human body is a complex process involving the co-operation of numerous muscles and structures. There are many bones that make up the spine and axial skeleton, each of which plays an intricate part in the functioning of the human body. In general, the bones provide structure to the system and supply attachment sites for the muscles and ligaments. Several muscles surround the joints of the neck and back, which enable movement of the system as well as provide stability to the spine. Since the muscles are attached to the bones on either side of a joint, muscle contraction causes the bones to move either toward or away from each other. The ligaments are also attached to the bones surrounding a joint, however, rather than provide movement to the joint, ligaments provide passive stability and increase the structural integrity of the joint, and help to protect the joint against perturbations that might cause injury and damage.

2.1.1 Cervical Vertebrae

The cervical spine is made up of seven bones (C1-C7: Figure 2). Each of these bones is comprised of a vertebral body, a vertebral arch, foramina and seven processes; with the exception of C1, which has neither a vertebral body nor a spinous process (Tortora, 2005). The bodies of the cervical vertebra are smaller, and the arches are larger, than those seen in other vertebrae. There are also three foramina found in each cervical vertebra. These are the vertebral foramen and two transverse foramina (Tortora, 2005). The vertebral foramen is the hole through which the spinal cord passes. Each of the

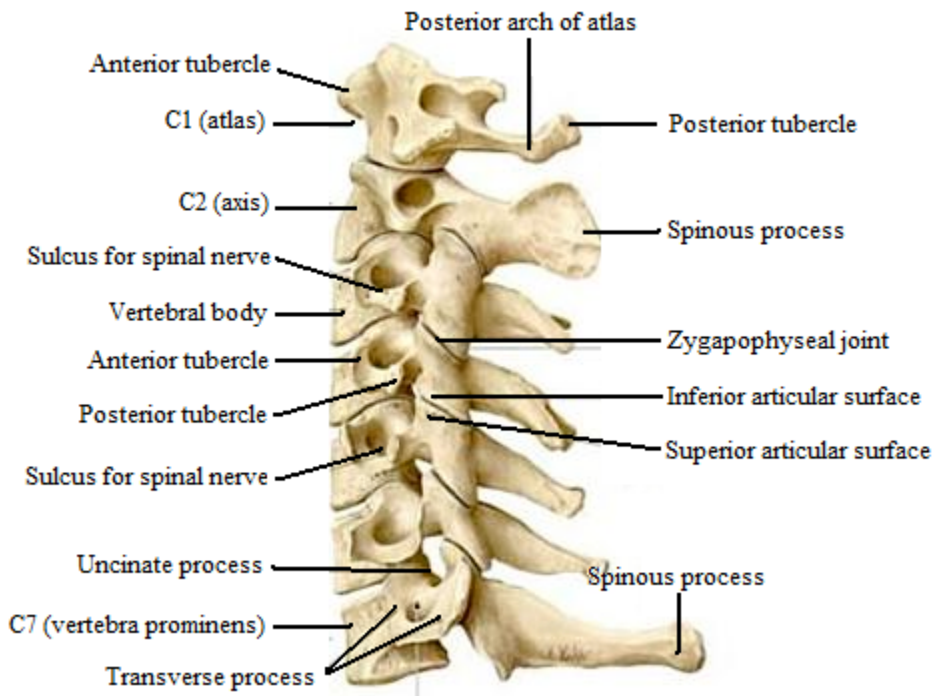

Figure 2: Lateral view of human cervical vertebrae. Adapted from Gilroy et al., 2008, pp. 18-19. Thième Medical Publishers, Inc. (New York, NY).

transverse processes of the cervical vertebrae contains a transverse foramen. These are the holes through which the vertebral artery, vein, and nerve fibres pass. The spinous processes of the C2-C6 vertebrae are bifid (meaning, split similar to the tongue of a snake) (Tortora, 2005).

2.1.2 Cervical Joints

Each of the cervical vertebral bones articulates with the bone above and below it at the superior and inferior articular facets, respectively. The first cervical vertebra (atlas) lacks a vertebral body; however, it has two additional articular surfaces on the superior aspect of the bone. These are the surfaces that will articulate with the base of the skull (specifically, the occipital bone) and will allow for the motion in the sagittal plane, such as nodding (Tortora, 2005). The inferior articular facets articulate with the second cervical vertebra, known as the axis. It is called this because of a peg-like protrusion known as the dens, jutting superiorly from the body of the vertebra on which atlas is able to turn. This allows for the motion in the transverse plane such as shaking one's head "No".

From C2 through C7, the inferior articular facets of the more superficial vertebra form intervertebral joints with the superior articular facets of the vertebra directly beneath it. These are referred to as zygapophyseal or facet joints. Unlike the articular surfaces, the bodies of the vertebrae never come into direct contact with each other as an intervertebral disc separates them. These discs are found between all vertebral bodies from C2 to the sacrum and consist of an outer fibrous ring (annulus fibrosus) and an inner soft centre (nucleus pulposus). These discs are attached tightly to the vertebral endplates and permit various movements of the vertebral column as well as absorb vertical shock applied to the spine (Tortora, 2005).

2.1.3 Cervical Soft Tissues

A complex network of bones such as the spine requires a large number of ligaments to stabilize it (see Figures 3 and 4). The anterior longitudinal ligament extends from the axis (C1) to the sacrum (S1) along the anterior portion of the vertebral bodies (Figure 3A). In flexion, this ligament is relaxed, and in extension it is stretched. The posterior longitudinal ligament is found inside the spinal canal and extends along the posterior surface of the vertebral bodies from the axis (C1) to the sacrum (S1) (Figure 3B). In flexion, this ligament is stretched while in extension it is relaxed. Capsular ligaments surround the joined articular surfaces, creating a fluid-filled sac around each joint. The nuchal ligament (or ligamentum nuchae) extends from the external occipital protuberance and the median nuchal line of the occipital bone of the cranium to the spinous process of the seventh cervical vertebra (Gray & Carter, 2008) (Figure 3C). The supraspinal ligament joins all of the apices of the spinous processes from every vertebra from C7 to the sacrum (Figure 3). The interspinous ligaments (Figure 4) connect the adjacent spinous processes and extend the entire length of each spinous process. They originate on the ligamenta flava anteriorly and meet the supraspinal ligament posteriorly (Figures 3 and 4).

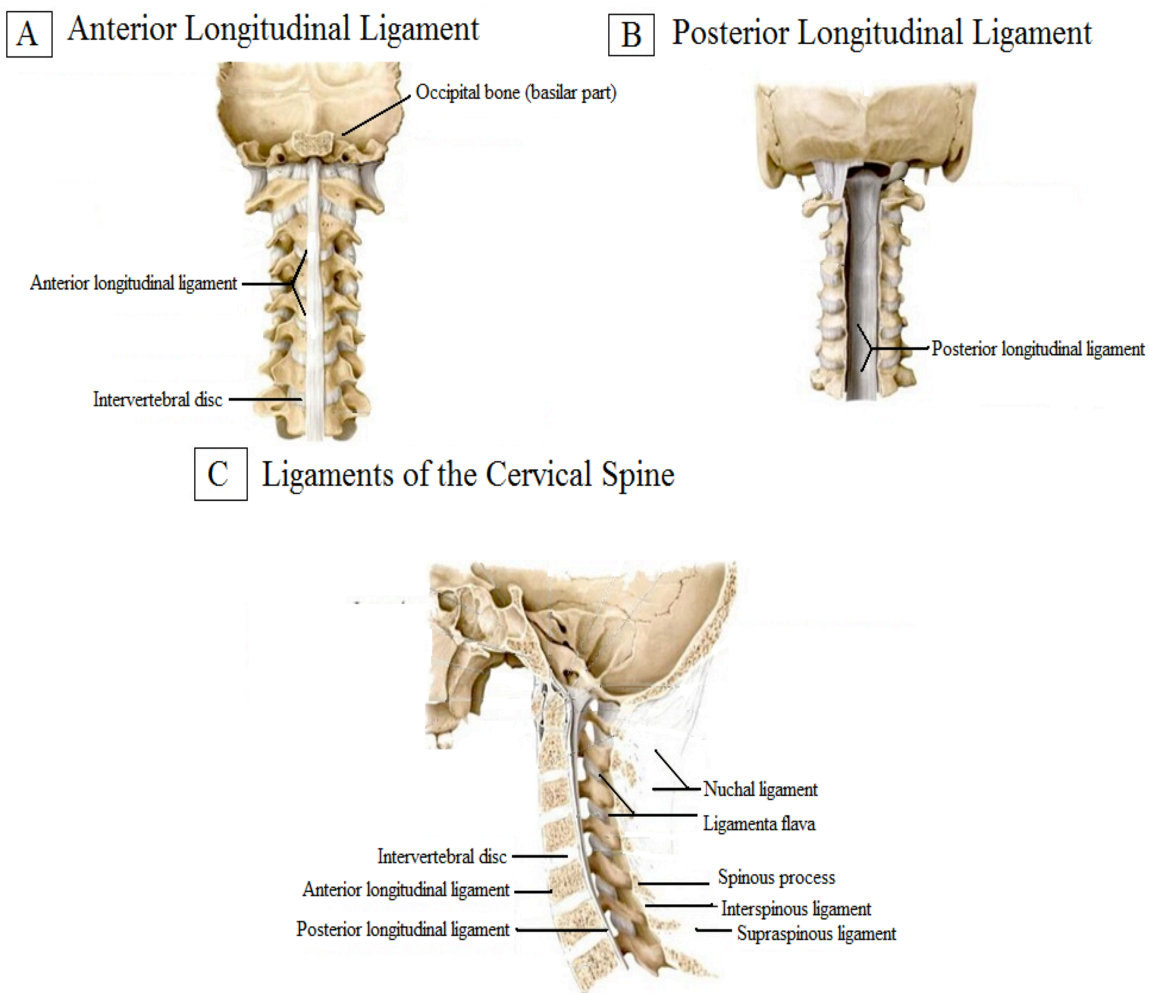

Figure 3: Illustration of cervical spinal ligaments and structures. Adapted from Gilroy et al., 2008, pp. 18-19. Thième Medical Publishers, Inc. (New York, NY).

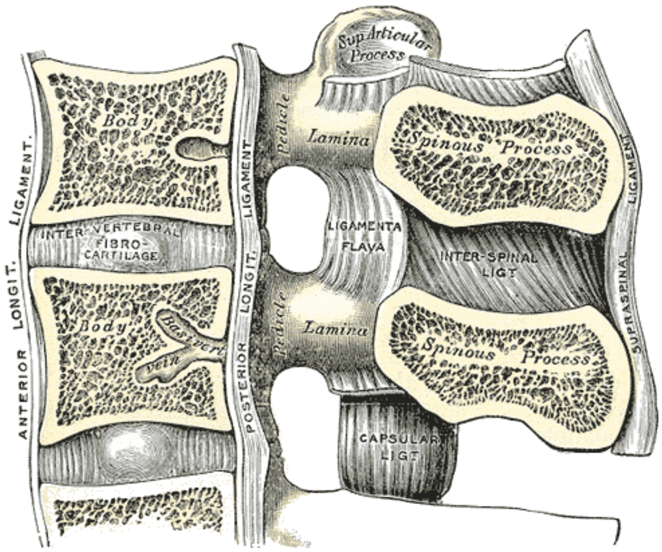

Figure 4: Cross-section of lumbar spinal ligaments and vertebrae. Many of these ligaments extend the length of the cervical spine as well. Gray & Carter, 2008, p. 225 (Arcturus Publishing, London, UK.)

The need for stability about the atlantoaxial joint requires the presence of a great deal more ligaments in this region. There are two anterior atlanto-axoid ligaments, the most superficial of which is a rounded cord that extends from the tubercle on the anterior arch of the atlas, to the base of the dens on the body of the axis (Gray & Carter, 2008). The deeper of these two ligaments is more of a membrane, which extends from the lower border of the anterior arch of the atlas to the base of the dens on the body of the axis. The posterior atlanto-axoid ligament is another thin membranous layer, which extends from the lower border of the posterior arch of the atlas to the upper edge of the lamina of the axis (Gray & Carter, 2008). The transverse ligament extends across the ring of the atlas and acts to ensure a strong contact between the dens and its articular surface. There are two capsular ligaments in this articulation, which surround the facet joints of these bones. These capsular ligaments are lined with synovial membranes, as are the joints between the dens and the atlas and the joints between the dens and the transverse ligament (Gray & Carter, 2008).

There are also a large number of ligaments connecting the cervical spine to the base of the skull. These ligaments extend from the atlas to the occipital bone as well as from the axis to the occipital bone. These ligaments will not be discussed further.

2.1.4 Cervical Muscles

The two primary actions of interest to this study are flexion and extension. Cervical flexion is accomplished primarily by the bilateral contraction of the sternocleidomastoid (Tillmann, 2007). The sternocleidomastoid extends from the sternum and the clavicle to the mastoid process of the temporal bone and lies beneath the platysma muscle (Figure 5). When the sternocleidomastoid muscles contract bilaterally, they act to flex the cervical spine, extend the head (posterior fibres), and elevate the sternum upon inhalation. Unilateral contraction of the sternocleidomastoid muscles causes ipsilateral flexion and contralateral rotation of the head (Tortora, 2005).

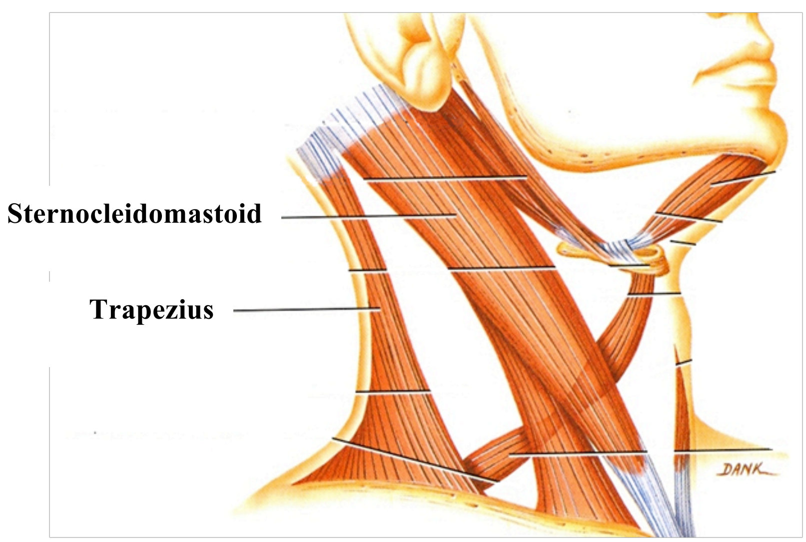

Figure 5: Illustration of the sternocleidomastoid, and a portion of the trapezius. Lateral view. Adapted from Tortora, 2005, p. 312. John Wiley and Sons (Hoboken, NJ).

Neck extension is accomplished by the bilateral contraction of many muscles, including the cervical paraspinal muscles and upper trapezius (Tortora, 2005; Tillmann, 2007). The cervical paraspinal (CPS) muscles consist of the erector spinae muscles (splenius capitis, splenius cervicis, semispinalis capitis, longissimus capitis, and ilicostalis cervicis: Figure 6) as well as the levator scapulae, the rectus capitis major and minor, and the obliquus capitis muscles. The CPS muscles extend from various locations throughout the spine to the external occipital protuberance on the base of the cranium (Tortora, 2005). Unilateral contraction of the CPS muscles causes ipsilateral flexion and rotation of the head. The trapezius muscle (Figure 7) acts primarily on the scapulae, as well as on

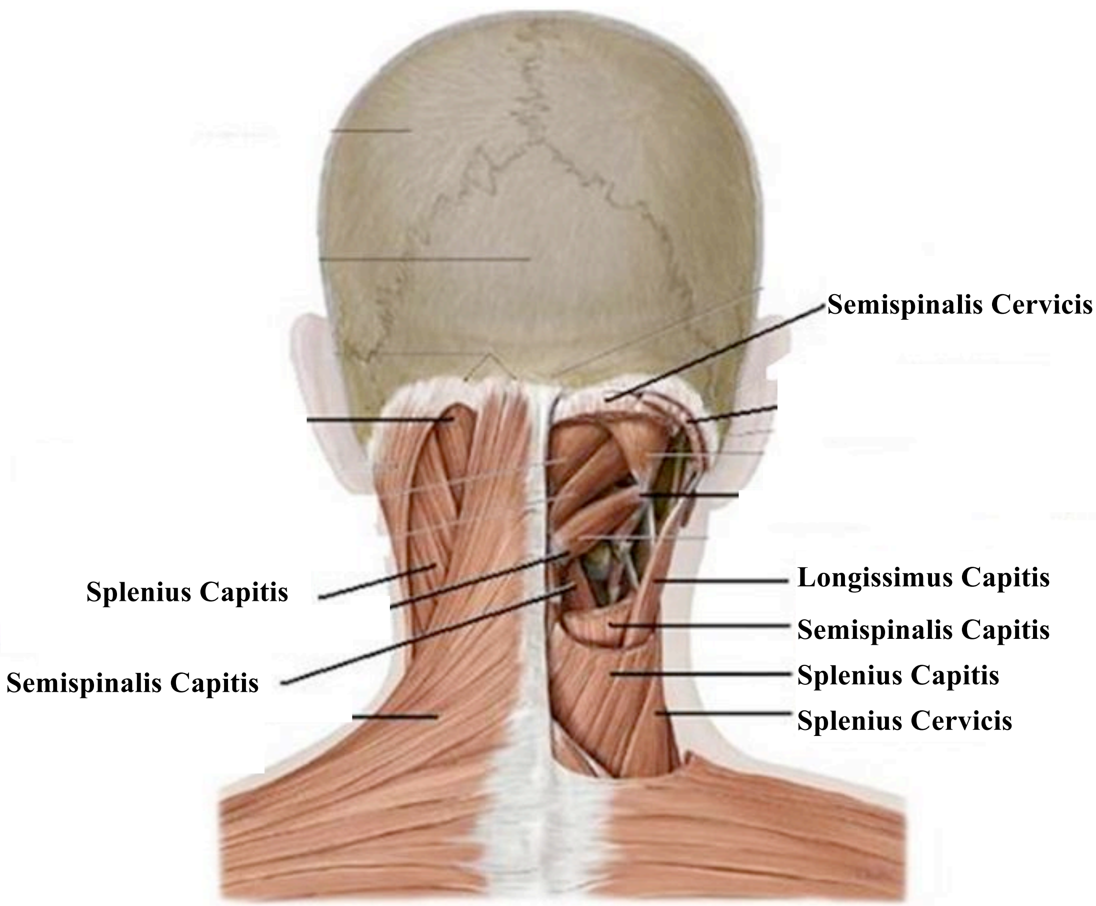

Figure 6: Illustration of the cervical muscles (underlying the trapezius muscle) that make up the CPS muscle group. Adapted from Gilroy et al. 2008, p. 27. Thième Medical Publishers, Inc. (New York, NY).

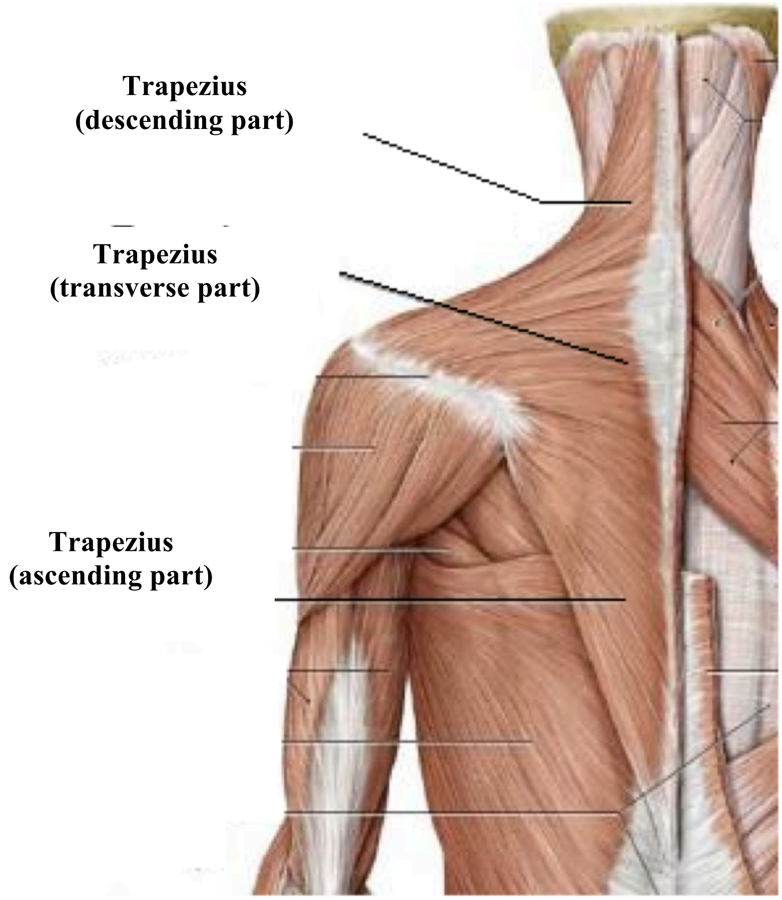

Figure 7: Illustration of the trapezius muscle. This muscle is made up of three portions, named for the direction in which the muscle fibres are oriented. Adapted from Gilroy et al., 2008, p. 23. Thième Medical Publishers, Inc. (New York, NY).

the thoracic spine; though it does play a role in extension of the cervical spine and the head (Tortora, 2005). The trapezius muscle extends from the occipital bone of the head as well as the ligamentum nuchae and the spines of the 7th cervical and all thoracic vertebrae to the clavicle, acromion process, and spine of the scapula (Tortora, 2005).

Similar paraspinal musculature exists in both the lumbar and thoracic spines, and is made up of the erector spinae muscles at these levels (longissimus, iliocostalis, and spinalis thoracis and lumborum muscle groups) as well as the deeper spinal muscles (multifidi, rotators brevi and longi, intertransversarii lateralis and medialis, and interspinales at the thoracic and lumbar spinal levels) (Tortora, 2005). All of these muscles, when contracting bilaterally will cause extension of the spine, and when contracting unilaterally, will cause various combinations of lateral bend and axial twist (Tortora, 2005). These muscles are very difficult to isolate individually using surface EMG, and are therefore often combined to form the paraspinal muscle groups.

2.2 Lumbar Flexion Relaxation Phenomenon (FRP)

Floyd & Silver (1955) were the first to observe the flexion relaxation phenomenon (FRP: Figure 8) in the musculature of the lumbar spine. At approximately 46°-50° of trunk flexion (from upright standing), the erector spinae muscles silence and no longer contract (Solomonow et al., 2003). The FRP is believed to represent the transfer of the load-supporting role from muscles to the passive-elastic components of the spine (e.g. posterior spinal ligaments, intervertebral discs, passive elasticity of muscle tissue: Schultz et al., 1985; McGill & Kippers, 1994). Although the neurophysiological mechanisms

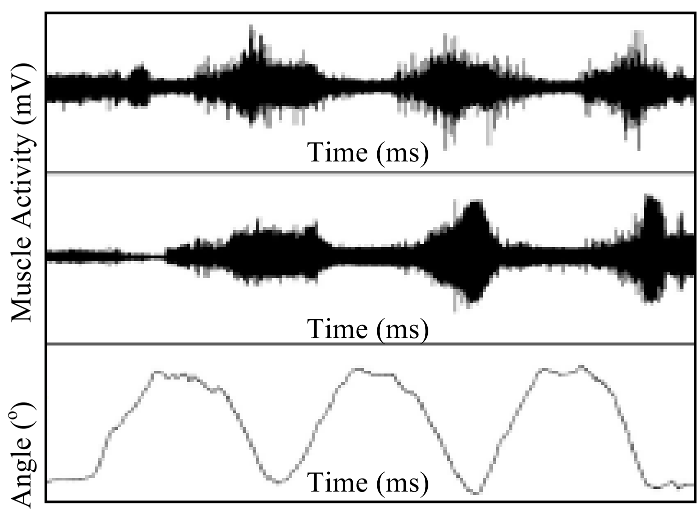

Figure 8: EMG profile of the lumbar FRP. Muscle activity is dramatically reduced during periods when the spine is maximally flexed. Top Trace: EMG activity in the left erector spinae. Middle Trace: EMG activity in the right erector spinae. Bottom Trace: Trunk inclination angle. Adapted from Colloca & Hinrichs, 2005, p. 624. Elsevier Inc. (Toronto, ON).

involved in producing the FRP have not been studied explicitly, a mechanism of reflex inhibition from stimulation of stretch receptors in the posterior spinal ligaments and intervertebral disc has been proposed (Colloca & Hinrichs, 2005). Stretch receptors in the ligaments are mechanoreceptors that are sensitive to joint angles (particularly at the end-range of a joint's motion) and tension in the joint capsules (Latash, 2008). Ligamento-muscular reflexes have been found between the spinal ligaments and discs as well as the paraspinal musculature, all of which act together to modify the load transferred through spinal ligaments by muscles (Solomonow et al., 2003). These reflexes can be either inhibitory or excitatory, depending on the need of the system in order to maximize joint stability (Solomonow et al., 2000; Solomonow, 2004). In the case of FRP, it is possible that tension in the joint capsules and spinal ligaments elicits an inhibitory reflex causing the muscles to relax.

Research has yet to be conducted on the neurophysiology involved in FRP, thus explanations for the neurophysiological basis of the FRP are strictly hypotheses. The FRP may be partially mediated by a reflexive mechanism involving Golgi tendon organs (GTOs) found in the myo-tendinous junction (i.e. the junction of the muscle fibres and the muscle tendon) (Pearson & Gordon, 2000). GTOs are encapsulated mechanoreceptors that monitor even the minutest changes in tension in the myo-tendinous junction. As the muscle/tendon is stretched during flexion, the GTOs send afferent impulses to the spinal cord via the Ib afferent nerves to the Ib inhibitory interneurons in the dorsal horn of the spinal cord (Floyd & Silver, 1955; Pearson & Gordon, 2000). The inhibitory interneurons synapse on the Ib afferent motor neurons, which inhibits communication of the alpha motor neuron to the homonymous muscle, thereby ceasing contraction and causing muscle relaxation. In the case of the FRP, these impulses would trigger an inhibitory reflex arc with the inhibitory interneurons preventing the firing of the muscle fibres in the erector spinae muscles, thereby inhibiting their contraction (Pearson & Gordon, 2000). This inhibitory action would serve to reduce the tension in these muscles (Floyd & Silver, 1995; Kippers & Parker, 1984; Schultz et al., 1985), and allow the transfer of the load of the upper body from muscles to the passive-elastic components of the spine. That is, the back extensor muscles are relieved of their load-bearing role in supporting the trunk and it is transferred to the ligaments, tendons, and fascia that are attached to these muscles. Although it has not been investigated directly, it is likely descending input from higher brain centres could modulate the FRP to some extent. It has also been suggested that FRP is a result of the equilibrium between the moment caused by gravity and the moment caused by the stretched vertebral ligaments (Gupta, 2001). This is thought to occur because muscle contraction would no longer be needed in order to maintain this equilibrium, as the stretched ligaments would provide adequate resistance to the moment cause by gravity (Gupta, 2001).

2.2.1 The Flexion Relaxation Ratio

Previous FRP studies employing the FRR method vary in their choices of which phases to use, and whether to use mean or peak EMG in each phase, in calculating the ratio. For example, Ambroz et al. (2000) calculated lumbar FRRs by comparing the mean maximum EMG recording during Phase 2 to the mean maximum EMG recording during Phase 4. Sihvonen et al. (1991) compared the mean EMG activity during Phase 2 and Phase 4. Watson et al. (1997) compared maximum EMG during Phase 2 to mean EMG during Phase 3. In an effort to standardize the calculation of the FRR, Alschuler et al.

(2009) examined which of these ratios were more highly correlated with measures of musculoskeletal and clinical status (Alschuler et al., 2009). They assessed lumbar EMG in 75 participants in standing, flexion, maximum voluntary flexion and extension, as well as clinical status (pain level, perceived disability, and pain-related fear and musculoskeletal abnormalities) (Alschuler et al., 2009). The calculated relaxation ratios were correlated with the self-report questionnaires used to assess participants' pain level, perceived disability, pain-related fear, and musculoskeletal abnormalities. After correlations were conducted, they visually inspected the data and pinpointed the methods that were the most correlated with the greatest number of factors and how significant the associations were. The ratios comparing maximum EMG in Phase 2 to mean EMG in Phase 3 (flexion relaxation ratio: FRR), and maximum EMG in Phase 4 to mean EMG in Phase 3 (extension relaxation ratio: ERR), resulted in the highest associations with clinical and musculoskeletal status (Alschuler et al., 2009). Both ratios were significantly correlated with many factors, including range of motion during flexion, two measures of perceived disability, pain level during straight leg raise, and pain-related fear. However, the ERR showed higher correlations (increased *r* value) with all of these comparisons as well as with clinical status (Alschuler et al, 2009). Based on this study, they concluded that the best ratios to use to determine the presence of FRP were the ratio of peak muscle activation in Phase 4 to the mean muscle activation during Phase 3 (ERR), and the ratio of the peak muscle activation in Phase 2 to the mean muscle activation in Phase 3 (FRR). In the present study, the magnitude of both ratios (FRR and ERR) will be used in the determination of the presence of FRP. However, since the ERR showed the highest correlations with all factors as well as clinical status (Alschuler et al., 2009), this is the value which will be used in subsequent statistical comparisons between postures and conditions.

2.2.2 Clinical Relevance of the Lumbar FRP

Interestingly, the lumbar FRP is often absent in low back pain patients. Ahern et al. (1988) compared lumbar EMG activity during static and dynamic postures between 40 chronic low back pain patients and 40 matched healthy controls. Most of the patients (23 of the 40) did not show flexion relaxation (compared to 3 of 40 controls), which was thought to be due to restricted range of motion and compensatory posturing (Ahern et al., 1988). Watson et al. (1997) examined 20 healthy controls and 70 chronic low back pain patients with the purpose of assessing the test-retest reliability of a measure of FRP in back pain patients, as well as to identify the differences between the two groups. They noted significantly greater muscle activation in full flexion among the patient population than among the healthy controls. Kaigle et al. (1998) monitored intervertebral motion, trunk flexion, and EMG activity in lumber erector spinae among 7 patients with chronic low back pain and 6 healthy controls. They found a 78 % decrease in the EMG activity of the control group in full flexion, whereas the clinical population showed an average decrease of only a 13 % (some patients showed no decrease at all). The lack of FRP in the patient population is thought to be due to the initiation of intrinsic protective measures in which the body tries to guard injured or diseased spinal structures from further damage, and to avoid experiencing pain (Colloca & Hinrichs, 2005). Some believe the difference in the EMG recorded among clinical populations and control groups is likely the result of the clinical population's inability to reach maximum flexion (Kaigle et al., 1998; Ahern et al., 1988). However, since both the clinical population and the control group were able to reach the point of onset for FRP as set out by Kippers & Parker (1984), decreased range of motion is not likely the sole cause of the absence of FRP in the clinical population (Colloca & Hinrichs, 1995).

Conversely, some studies have not seen a difference in muscle activation patterns when comparing chronic back pain patients to healthy controls. Leinonen et al. (2000) noted that the muscle activation patterns in the lumbar paraspinal muscles as well as the biceps femoris were similar when comparing the two populations; however, it was the gluteus maximus muscle that showed the difference in activation. While all three muscle groups exhibited FRP, and FRP was observed in both populations, the chronic pain patients demonstrated shorter periods of silence in flexion for the gluteus maximus muscle. These authors suggested that the inconsistency in the presence or absence of FRP in clinical populations among the various studies might be due to the type (ie. sharp, stabbing, ache), severity (i.e. pain intensity), and duration of pain (ie. acute vs. chronic) experienced by the participants. In chronic back pain patients experiencing acute bouts of pain, lumbar muscle activation was thought to be increased or decreased depending on the patients' current pain and how it affected their motion and use of the lumbar muscles (Leinonen et al., 2000)

Recently, Marshall & Murphy (2006; 2008) demonstrated that FRP could be restored in clinical populations through exercise interventions. These authors reported an improvement in the disability and pain scores reported by the participants following a training intervention (Marshall & Murphy, 2008). Furthermore, although muscle activity at full trunk flexion decreased by 67 % following intervention, the trunk flexion angle and muscle recruitment pattern did not change (Marshall & Murphy, 2006). Exercise interventions involving either a stability/exercise ball (Swiss Ball™) or a control exercise routine of floor exercises combined with either manipulation or non-manipulation, were able to increase the flexion relaxation ratio (FRR) for the erector spinae muscles at the L4-L5 vertebrae and at the T12-L1 vertebrae (Marshall & Murphy, 2008). In this particular study, the flexion relaxation ratio was calculated by dividing the maximum EMG activation level in the extension phase (Phase 4: See Figure 4) by the maximum of the fully flexed phase (Phase 3). The increase in FRR indicated a trend toward the restoration of normal FRP behaviour among the clinical population ($p < 0.05$: Marshall & Murphy, 2008). The lumbar ES muscles (at L4-L5) experienced the most timely improvement in performance; the FRR in these muscles improved after the first 4 weeks of intervention, whereas the ES muscles at T12-L1 only showed significant improvement in the long-term follow-up (nine months later) intervention conditions (Marshall & Murphy, 2008).

2.2.3 Modulating Factors of the Lumbar FRP

A modulating factor is an element that will cause an adaptation or adjustment in a system (Modulate: Merriam-Webster Unabridged Dictionary, 2005). In the case of lumbar FRP, several possible modulating factors have been investigated. These include the effects of loading (adding weight to the task) (Holleran et al., 1995) and movement speed (Steventon & Ng, 1995) on the onset and cessation angles for FRP. The speeds at which the participants are asked to perform the flexion-extension task may be a source of the differences seen in the FRP onset and cessation angles between studies in past literature. These are explained further in the following paragraphs. Some researchers requested that their participants perform the task in six seconds (Floyd & Silver, 1955), while others chose a task duration of five seconds (Portnoy & Morin, 1956), and still others suggested a duration of ten seconds (Kippers & Parker, 1984). It has been suggested that these methodological differences would affect the validity of the studies, and as such, the slow and fast flexion speeds should be compared to a natural rhythm speed (Stephenton & Ng, 1995). This comparison showed that speed had no effect on the critical point (i.e. onset angle) for FRP, and it was proposed that human movement may never occur at a rate that is fast enough to alter the stiffness of the ligaments and thus, would not affect the transfer of loads from the muscles to these ligaments (Stephenton & Ng, 1995). However, Sarti et al. (2001) examined the effect of speed and loading on FRP and found that while increasing speed from a slow pace to a fast pace, the onset angle changed from 69° of flexion to 79° of flexion respectively, thereby delaying the onset of FRP. The fast pace condition required the participants to perform both the flexion and extension phases in three seconds each, while the slow pace condition required the participants to perform both the flexion and extension in eight seconds each. In both conditions, participants were instructed to hold the fully flexed position (Phase 3) for a duration of one second (Sarti et al., 2001). However, time analyses on these data showed that participants took longer to execute the flexion phase (Phase 2) than the extension phase (Phase 4); they also held maximum flexion (Phase 3) longer in the fast condition than in the slow condition. The authors believed that since the duration of Phase 3 may be different between the slow and fast conditions, the passive elastic force generated might also be different due to a difference in the rate at which the muscles were loaded (Sarti et al., 2001). Muscle tissue is viscoelastic (i.e. it develops higher forces when loaded quickly and less force when loaded slowly), thus the change in the speed of movement would have caused differences in the force generated. Sarti et al. (2001) believed that the difference in elastic force developed between the fast and slow conditions was registered by mechanoreceptors, which caused the muscle activity of the erector spinae muscles to continue longer in the fast condition, thus delaying the onset of FRP.

The effect of restricting posterior movement of the pelvis as well as incorporating weights anteriorly and posteriorly to the pelvis has been studied as it relates to the lumbar FRP (Gupta, 2001). This study revealed that when posterior motion of the pelvis is restricted in flexion, the myo-electric silence is initiated much sooner (i.e. with a lesser magnitude of lumbar flexion) than when movement is not restricted. The cessation of the myo-electric silence also occurred sooner (immediately upon extension) as opposed to the general trend of ceasing after extension has already begun (Gupta, 2001). With load (10 kg) added in the participants' hands or strapped to their posterior pelvis, Gupta (2001) found that the onset angle increased (i.e. FRP occurred later), whereas Sarti et al. (2001) found that there was no significant effect of increased load on FRP. It was suggested that the inconsistencies seen between the studies might be due to two reasons. First, the differences may have arisen from slight variations in the position of the arms during flexion, as these slight variations can influence the bending moment that is acting on the spine (Sarti et al., 2001). Second, the participant selection criteria varied between the studies. While Gupta (2001) recruited participants from 18 to 49 years of age in a random sample that did not account for fitness level or health, Sarti et al. (2001) recruited participants from 18 to 25 years of age that were all physically fit. Since aging and fitness levels can influence mechanical conditions of the spine, these variables may account for some of the inconsistency that was observed between the studies (Sarti et al., 2001). Furthermore, since Sarti et al. (2001) recruited only physically fit males, the fit individuals may have been able to better compensate for the increased load (i.e. they were stronger and thus more able to handle the load without compensating for the weight by adjusting their posture), and thus a change in FRP was not seen in these individuals.

2.3 Cervical Flexion Relaxation Phenomenon (cFRP)

Similar to the lumbar paraspinal musculature, the cervical paraspinal musculature is also known to exhibit a myo-electric silencing when the neck is fully flexed (cFRP: Figure 9). Pauly (1966) was the first to observe myo-electric silencing in the cervical section of the semispinalis muscles. These authors examined the recruitment patterns of eight paraspinal muscles (semispinalis, spinalis, longissimus, iliocostalis, quadrates lumborum, multifidus, and gluteus maximus) during various exercises and movements using fine-wire EMG. Although myo-electric silencing of the semispinalis cervicis muscle was observed, they were not specifically looking for the cFRP – they did not

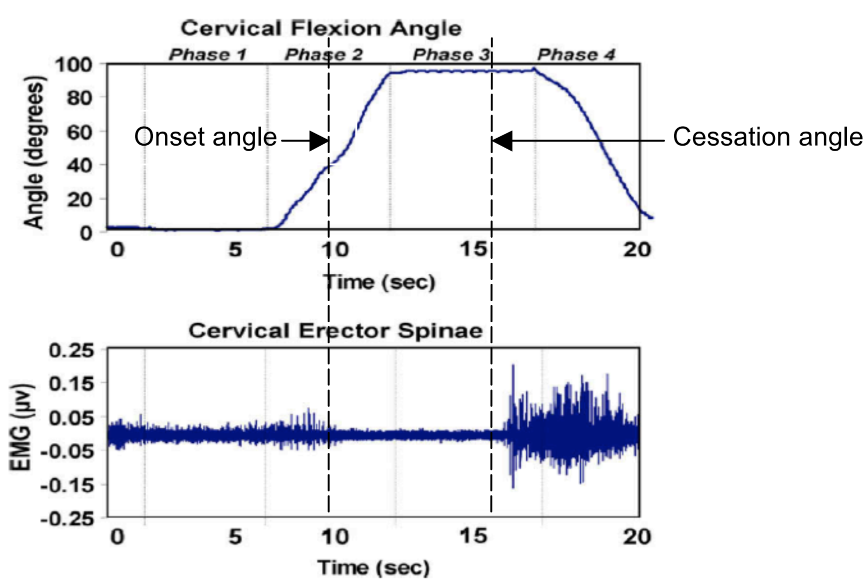

Figure 9: Kinematic and EMG analysis of the cFRP. Raw surface EMG trace for the cervical erector spinae and corresponding cervical flexion angle time history. Image: Adapted from Burnett et al., 2009, p. E232. Elsevier, Inc. (Toronto, ON).

investigate it any further, and did not use the term “cervical flexion relaxation phenomenon” to describe their observations (Burnett et al., 2009).

Since then, only a few studies have further investigated the cFRP (Meyer et al., 1993; Airaksinen et al., 2005; Burnett et al., 2009; Pialasse et al., 2009, 2010; Murphy et al., 2010). Meyer et al. (1993) conducted a study aimed to consistently evaluate cFRP. With the flexion motion standardized for the study, they were able to elicit cFRP in ten out of ten of the healthy participants. Airaksinen et al. (2005) examined the muscle activation patterns in the necks of one healthy individual and one individual with chronic neck pain. They found that in the healthy individual, a clear flexion relaxation rhythm was seen, whereas in the patient, this rhythm was blurred and difficult to distinguish (Airaksinen et al., 2005). Burnett et al. (2009) examined cFRP while controlling for sitting posture. Lumbar posture was standardized across participants by placing all participants in lumbo-pelvic sitting during the cervical flexion tasks. They employed various other methods of determining the presence or absence of cFRP including visual inspection of EMG tracings, but regardless of the criterion used, they were not able to elicit cFRP in 100 % of the participants (Burnett et al., 2009). They postulated that the discrepancy with previous studies (e.g. Meyer et al., 1993; Airaksinen et al., 2005) that reported cFRP in all participants was due to the previous studies’ reliance on visual analysis rather than using statistical analysis to determine whether FRP had occurred. It could also be due to the use of a different standardized lumbar posture than in previous studies (Burnett et al., 2009). Meyer et al. (1993) and Burnett et al. (2009) standardized the seated posture among all participants, however this posture differed slightly between the two studies. Furthermore, Meyer et al. (1993) restricted motion to the cervical spine, which may have resulted in the researchers identifying FRP in all participants.

2.3.1 Modulating Factors of the cFRP

Pialasse et al (2009) investigated the modulating effect of trunk flexion angle on the onset and cessation angles for cFRP. They found that while trunk posture (upright vs. 45° flexion) in a seated position did not influence the onset or cessation angles of the cFRP, trunk posture did influence the amplitude of the extension relaxation ratio (see Figure 4 for phase definitions). While this did not necessarily reflect the magnitude of the flexion relaxation phenomenon response, it did illustrate a marked effect that a change in trunk posture could have on the ERR of the cFRP in healthy individuals.

The effects of cervical loading and movement speed have also been investigated as they relate to cFRP. Eighteen healthy adults were asked to perform a complete cervical flexion task (achieve full cervical flexion, hold full flexion, then extend the neck to return to a neutral position) under three loading conditions and two different rhythms (Pialasse et al., 2010). The loading conditions included a condition where a 700 g load was strapped to the top of the participants' head, an unloaded condition, and a counterweighted condition where a 300 g counterweight was attached via pulleys to the back of the head. The two rhythm conditions consisted of different lengths of time that each phase of the cervical flexion task was held. The slow rhythm consisted of 5 seconds of flexion, 3 seconds held in full flexion, and 5 seconds of extension; the fast rhythm consisted of 2 seconds of flexion, 3 seconds of held full flexion, and 2 seconds of extension using a metronome to ensure a consistent pace (Pialasse et al., 2010). The magnitudes of the angles of onset and cessation and the EMG root mean squares (RMS) for each of the task phases were significantly higher in the loaded conditions, that is the FRP began later and ended sooner in the loaded condition. However, there were no changes in either the onset or the cessation angles or in the EMG RMS in any of the task phases, with increased movement speed (Pialasse et al., 2010). These results are similar to the previous findings regarding the effects of speed of movement and trunk loading on lumbar FRP.

To date, all cFRP studies have placed the participants in a seated posture during the cervical flexion movements. The modulating effect of standing postures on the cFRP has yet to be investigated. Many occupational tasks take place in a standing posture (e.g. assembly tasks, retail tasks, patient care, performing surgical procedures), some of which would require the worker to adopt varying magnitudes of cervical flexion for prolonged periods. Since prolonged neck flexion is a known risk factor for reporting neck pain (Ariens et al., 2000, 2001), understanding the behaviour of the cervical muscles when healthy individuals assume flexed cervical postures while standing (for example, by investigating of the presence of cFRP) is important.

Due to workstation layouts and variability in worker anthropometrics, workers may be required to adopt non-neutral (i.e. flexed or slumped) lumbar and/or cervical postures, whether seated or standing. As described above, Pialasse et al. (2009) examined the relationship between cFRP and trunk flexion angle; however this examination was conducted with participants in a seated posture and did not examine the effects of varying trunk angle on the cFRP in standing postures. Workers can often be seen assuming slumped postures at their workstations (i.e. shoulders rounded forward, neck extended and lumbar lordosis flattened). Slumped seated postures produce constant muscle activation in the lumbar erector spinae and myo-electric silencing of the thoracic erector spinae muscles during forward trunk flexion (Callaghan & Dunk, 2002), as well as increased muscle activity in the cervical paraspinal muscles (Caneiro et al., 2010). Different seated postures also produce significant changes in the curvature of the spinal segments: slumped seated postures place the cervical region in extension and the lumbar region in flexion, whereas upright (erect) seated postures produce the opposite trend (cervical spine in flexion, lumbar spine in extension) (Black et al., 1996). Since slumped postures promote increased cervical spine flexion compared to upright postures (Caneiro et al, 2010; Edmonston et al., 2011), and both prolonged neck flexion and prolonged sitting are known risk factors for reporting neck pain (Ariens et al., 2000, 2001), investigation of the effect of slumped postures on the cFRP is also warranted.

CHAPTER III

DESIGN AND METHODOLOGY

3.1 Participants

Seventeen participants (9 females, 8 males) were recruited for this study. Participants were recruited from the University of Windsor student population (mean age: 22.1 ± 2.0 years; mean height: 172.6 ± 12.6 cm; mean mass: 68.8 ± 15.2 kg). To be eligible, participants must have been free from back and neck pain at the time of participation, and must not have received medical treatment or taken any days off school or work due to neck or back pain in the 12 months preceding the collection date. Explaining the exclusion criteria to the participants and asking if these factors applied to them determined eligibility. Prior to participation, all participants read and signed an informed consent form, which was approved by the University of Windsor Research Ethics Board (Appendix A).

3.2 Data Acquisition

3.2.1 Electromyography

Originally, the intention was to collect muscle activity from 9 muscles bilaterally (18 recording sites in total – the muscles listed in Table 1 and the levator scapulae). The amplifier systems available for this research could collect up to 8 channels, thus the original electromyography (EMG) acquisition configuration for this study required three amplifiers. However, the levator scapulae muscles were removed from the collection protocol, as pilot trials showed substantial cross talk with the sternocleidomastoid

Table 1: EMG electrode placement locations for each muscle.

Muscle	Electrode location
Sternocleidomastoid (1)	Location of the largest muscle mass, parallel to the muscle fibres (Ferrario et al., 2006)
Cervical Paraspinal Muscles (2)	Over the largest mass at the C4 level, approximately 4 cm from the midline (Burnett et al., 2009)
Upper Trapezius (3)	Half the distance from the acromion process to the C7 spinous process (Zipp, 1982)
Upper Thoracic Erector Spinae (4)	Location of the largest muscle mass approximately 5 cm alteral from the spinous process at T4 (Burnett et al., 2009)
Lumbar Erector Spinae (5)	Location of the largest muscle mass approximately 4 cm from midline pf spine at L3 level (McGill, 1991; Mirka & Marras, 1993); Drake & Callaghan, 2006)
Rectus Abdominis (6)	3 cm lateral to the midline of the abdomen, 2 cm above the umbilicus (McGill, 1991; Mirka & Marras, 1993; Drake & Callaghan, 1996)
External Oblique (7)	15 cm from the umbilicus at the level of the umbilicus (McGill et al., 1996)
Internal Oblique (8)	Below the external oblique, superior to the inguinal ligament (McGill et al., 1996)

muscles. Subsequent data collections proceeded with the three amplifiers, but the two channels corresponding to the levator scapula muscles were simply discarded.

Muscle activity was recorded from eight muscles bilaterally, using three differential AC amplifiers of 115 dB common mode rejection ratio (at 60 Hz), a gain capability of up to 15,000, and a 10-1,000 Hz analog band-pass filter (Model AMT-8, Bortec Biomedical Ltd, Calgary, AB, Canada). EMG signals were digitized at a rate of 2048 Hz through a 16-bit analog-to-digital conversion card (NI USB-6216, National Instruments, Austin, Texas, USA). Two surface electrodes (Kendall Soft-E, H59P; Tyco/Healthcare, Mansfield, Maryland) were placed over each of the muscles (interelectrode distance = 20 mm). The electrodes are self-adhesive, however to ensure that they remained adhered for the duration of the collection, the electrodes on the neck were reinforced with medical-grade tape (Hypafix: BSN Medical, Hamburg, Germany). The pre-amplifiers were also affixed to the skin using medical-grade tape. The target muscles and specific electrode placement sites are listed in Table 1 and displayed in Figure 10a. Additional reference (ground) electrodes were placed over the anterior superior iliac spine, and bilaterally over the acromion processes.

3.2.2 Electrogoniometers

Cervical range of motion was recorded using a biaxial electrogoniometer sampled at 2048 Hz (SG Series, Biometrics Ltd., Virginia, USA). Additional electrogoniometers were placed over the thoracic and lumbar regions of the spine, respectively, to monitor thoracic and/or lumbar motion during the cervical flexion trials. These were affixed to the skin over C3-T2 (ensuring that the device spanned the joint at C7), T4-T11 (ensuring that the device spanned as many thoracic intervertebral joints as possible), and L1-sacrum (ensuring that the device spanned all lumbar intervertebral joints), respectively (Figure 10b), using two-sided tape applied to the underside of the endblocks of the electrogoniometer to affix it to the skin. Medical-grade tape (Hypafix: BSN Medical, Hamburg, Germany) was then applied over the endblocks to further adhere the device to the skin as well as to prevent excessive movement of the device. Once all electrogoniometers and EMG electrodes were affixed to the participants' skin, the cervical flexion trials began.

3.3 Experimental Protocol

Participant height and mass were measured using an extensible measuring tape and a bathroom scale, respectively. Once the demographic data (participant height, mass, age, and sex) were recorded, participant instrumentation followed. EMG electrodes were applied first. This process consisted of removing any body hair from the skin beneath the electrode using a clean, disposable razor. This helped to maximize the contact between the electrode and skin. The skin was then cleansed using rubbing alcohol and the electrodes were affixed to the skin.

3.3.1 EMG Normalization

Raw (i.e. unprocessed) EMG data are typically highly variable between participants, as well as within participants between trials, due to several factors such as skin thickness, subcutaneous fat, electrode placement, and muscle fibre composition

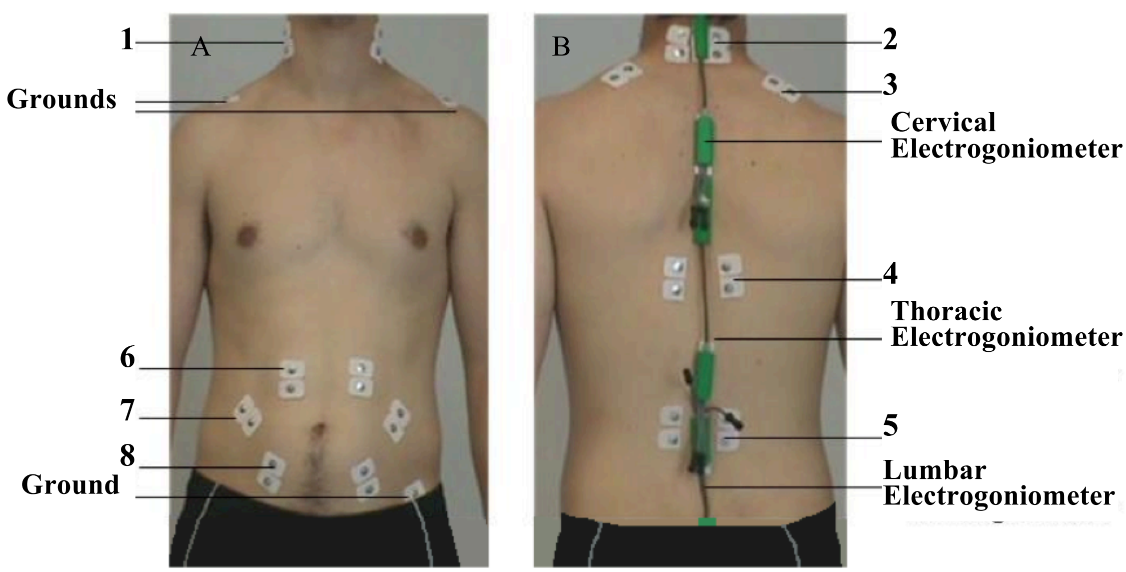

Figure 10: EMG electrode and electrogoniometer placement locations. A) Anterior view. B) Posterior view. The muscles corresponding to numbers 1-8 are listed in Table 1. The Hypafix has been removed in order to enhance the visibility of the instruments.

(Winter, 2005). EMG data normalization enables the comparison of muscle activity levels between participants. Before collecting the MVCs, participants were asked to lie on their back on a massage table for 30 seconds. They were instructed to completely relax their bodies, to close their eyes, and breath slow deep breaths. This process allowed the collection of the resting baseline activity levels for each muscle. In order to normalize the EMG channels for data analysis, maximum voluntary isometric contractions (MVCs) were obtained. These exercises required the participant to achieve a maximal exertion for each target muscle. Isometric contractions were used to ensure that a change in muscle length did not affect the force generation of the muscle. The procedures for obtaining MVCs from each muscle are listed in Table 2. Three MVC repetitions were collected from each muscle.

3.3.2 Electrogoniometer Placement

Once the MVCs were collected, the participants were instrumented with the electrogoniometers while in an upright position. As with the EMG electrodes, the process to apply the electrogoniometers may have required a section of hair be removed for each of the electrogoniometer adhesion sites. The electrogoniometers were zeroed on a flat surface immediately prior to the instrumentation so that the spinal angles were measured in absolute terms (as opposed to relative to the participant's neutral position).

3.3.3 Cervical Flexion Trials

Participants performed two sets of movements; one while seated in a chair, and another set while standing (subsequently referred to as the "postures"). In each set, participants completed three repetitions of each of the following movements (for a total of

Table 2: MVC protocol for every muscle examined.

Muscle Group	Electrode location
Upper Trapezius	The participant attempted to complete a shoulder shrug motion in a seated position while being resisted by the researcher (Zipp, 1982).
Cervical Paraspinal Muscles	The participant was seated while attempting to extend their head and neck against resistance to the back of the participant's head (Greig, 2005).
Sternocleidomastoid	The participant was seated while attempting to flex their neck against resistance applied by the researcher to the participant's forehead (Greig, 2005).
Upper and Lower Erector Spinae Muscles	Using a "beck-extension bench" the participant positioned him/herself in such a way that they were lying prone, with only their hips and ankles supported by the bench to prevent fatigue. Upon strating the collection, the participants crossed their arms over their chest and dipped down to form a slight flexion about their hips. The researcher applied a downward force to their back as the participant extended upward (Mirka & Marras, 1993).
Rectus Abdominis, Internal and External Oblique Muscles	A "sit-up" posture was used to normalize these abdominal muscles. The participants were restrained as they attempted to perform flexion and twisting exertions. The participants were asked to sit on the bench with the knees bent up and the feet under a crossbar to provide support. The participants were asked to cross his/her arms over their chest. The participants were asked to flex forward, to try to twist to the left and right, as well as to bend left, and bend right against resistance provided by the researcher (Mirka & Marras, 1993).

9 trials in each posture; i.e. a total of 18 collection trials): full cervical flexion with the trunk upright (0° trunk inclination), full cervical flexion in moderate trunk inclination (45° trunk inclination), and full cervical flexion in a slumped thoracic posture (these are referred to as the “conditions”) (Figure 11). The order of presentation of the postures and conditions as well as the trials within each condition (repetition 1, 2, 3) was randomized. Participants were asked to reach their maximum range of cervical flexion in 5 seconds, hold their position at maximum flexion for 3 seconds, and then move back to the starting position in 5 seconds (Pialasse et al., 2010). Standardized timing of movement through

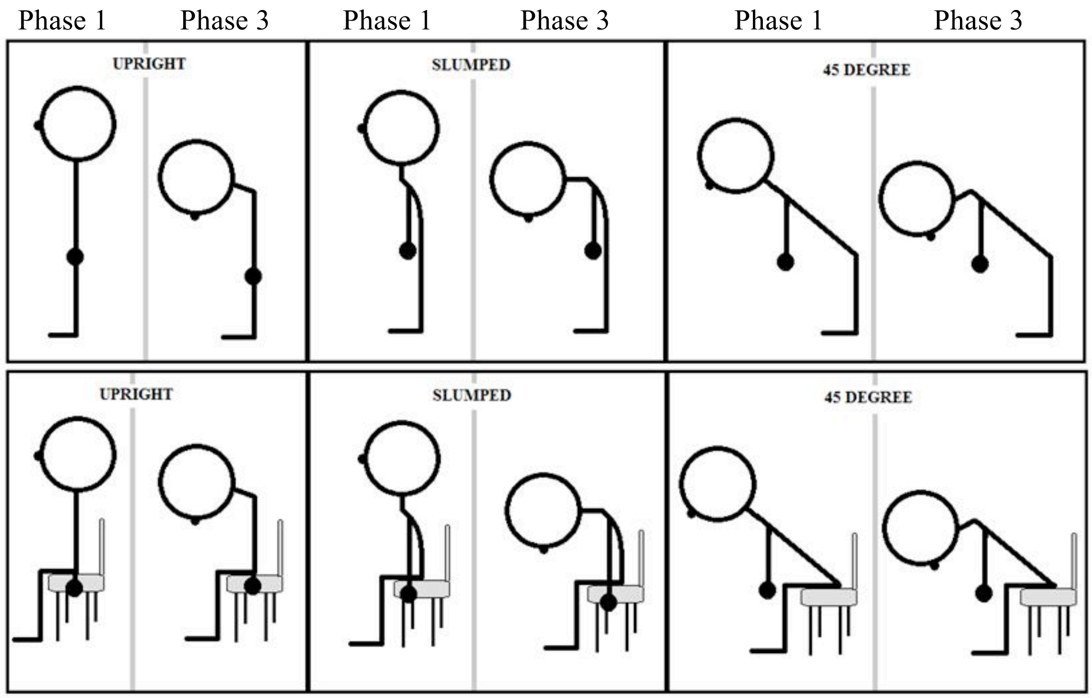

Figure 11: The six posture-condition combinations in both Phase 1 (starting position) and Phase 3 (held flexion).

the range of motion were achieved via audible metronome and verbal cues, wherein the participants were told when to start flexing, when to hold the posture, and when to return to their starting position. The cervical electrogoniometer trace was visually monitored on a computer screen through each trial, and if at any point the trace showed a jerky movement or an inconsistent speed, the trial was repeated. A minimum of thirty seconds rest was allotted between each trial. Participants were given two practice trials prior to the initiation of the data collection, to help them learn to perform the flexion-extension task at the desired pace.

To reduce the between- and within-participants variability in trunk inclination angles during the 45° inclination trials, the participants were placed in the desired posture using a template (Figure 12). The template consisted of a clear sheet of acetate with two lines that intersected at a 45^{o} angle. One line was arranged vertically to represent zero

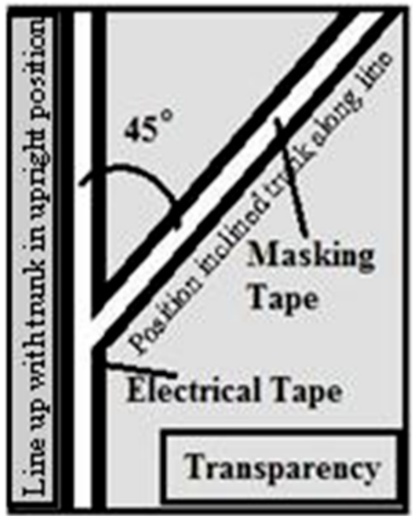

Figure 12: Representation of template used for trunk positioning

degrees of trunk inclination, according to a global coordinate system (i.e. vertical with respect to the room). The other line corresponded to the desired 45^{o} trunk inclination angle. The intersection of the two lines was placed over the hip joint and the participant was asked to incline their trunk to the desired 45^{o} angle. The angles from the thoracic and lumbar electrogoniometers associated with the desired posture were noted. These angles became the reference angles for the subsequent 45^{o} inclination trials in order to ensure that the participant was maintaining the desired posture. The lumbar and thoracic angle traces were monitored on a computer screen throughout every 45^{o} inclination trial to ensure participants maintained the lumbar and thoracic spinal angles associated with the desired trunk inclination angle. This was procedure was performed for both the seated and standing 45^{o} inclination trials. All participants were able to maintain the desired posture throughout all 45° inclination trials in both seated and standing postures. If there was any doubt about the angle of the trunk segment for the participant at any time, a protractor was used to verify the angle seen.

A pilot study was conducted to determine whether standardization of the slumped postures was warranted. Ten male and 10 female participants were instrumented with the electrogoniometer configuration described above. Participants were asked to perform three repetitions of a slumped posture (held for five seconds) while both seated and standing. Baseline data with the participants assuming upright-seated and upright-standing postures were also collected, and the magnitude of the deviation from upright (i.e. difference from upright) for each slumped posture was evaluated. Deviations from upright posture were highly variable between participants; some exhibited very little deviation from upright, where others exhibited drastic changes (Table 3). Given the substantial variability of the data, standardizing spinal postures in the slumped trials of the cervical FRP study might have forced participants to assume spinal angles that may be far outside their natural slump. Edmonston et al. (2011) reported an increase in CPS muscle activation when participants were told to assume a guided slumped seated posture, compared to when participants self-selected a comfortable neutral position. Therefore, it was decided that the best course of action would be to allow participants to assume their natural slumped posture during the slumped cervical FRP trials, to avoid affecting the muscle activation patterns of the cervical spine, and possibly the presence or EMG parameters of the cFRP.

3.4 Data Processing

The rectus abdominis, internal oblique, and external oblique EMG data were collected as part of a larger study, and were not the focus of the present study. Therefore, only data from the cervical paraspinal (CPS), upper trapezius (UTR), and thoracic erector

Table 3: Mean (SD) angles and mean (SD) deviations from upright obtained form the pilot study examining whether there is a consistent slumped posture for males and females in sitting and standing.

	Male (*n*=10)		**Female (*n*=10)**	
	Absolute Angle (°)	**Difference from upright (°)**	**Absolute Angle (°)**	**Difference from upright (°)**
Cervical				
Slumped Seated	-18.8 (13.8)	-7.6 (10.0)	-15.7 (18.9)	-11.8 (14.3)
Upright Seated	-11.2 (11.5)		-6.1 (9.3)	
Slumped Standing	-9.8 (11.5)	1.7 (9.8)	-7.8 (12.4)	-4.4 (6.8)
Upright Standing	-11.5 (13.6)		-3.4 (10.1)	
Thoracic				
Slumped Seated	16.8 (8.9)	6.7 (10.9)	9.3 (5.9)	3.2 (5.9)
Upright Seated	10.1 (7.1)		6.0 (13.7)	
Slumped Standing	12.6 (6.5)	5.9 (7.1)	9.6 (16.7)	4.3 (9.3)
Upright Standing	6.7 (8.5)		5.3 (12.8)	
Lumbar				
Slumped Seated	6.2 (7.9)	13.1 (12.5)	2.0 (9.4)	6.7 (10.1)
Upright Seated	-6.9 (10.9)		-4.0 (7.1)	
Slumped Standing	-18.8 (7.7)	-3.3 (11.4)	-19.6 (9.3)	-1.5 (6.6)
Upright Standing	-15.4 (13.8)		-18.0 (5.4)	

spinae (TES) muscles were analyzed in terms of cFRP. Data from the sternocleidomastoid and lumbar erector spinae muscles were low-pass filtered and normalized according to the procedures described in Sections 3.4.1 and 3.4.3, but were not examined for cFRP.

3.4.1 Residual Analysis

The EMG and electrogoniometer data were subjected to a residual analysis for each channel. A residual analysis is used to find the optimal cut-off frequency for subsequent low-pass filtering of the data by determining which frequency would include the most useful data, while eliminating the most noise (Winter, 2005). Independent samples *t*-tests were run to determine whether the frequencies differed significantly between genders. In all cases except for the left cervical paraspinal muscle, the t-tests revealed that there were no significant differences ($p > 0.05$) between males and females. Consequently, the cut-off frequencies were grouped for these muscles. The optimal cut-off frequencies for each muscle are listed in Table 4. The frequencies obtained by the

Table 4: Optimal low-pass filter cut-off frequencies (Hz) used for all electrogoniometers and muscles determined by the residual analysis. There were no significant differences between sexes except for in the left CPS muscle, where different frequencies were used for males and females.

Channel	Optimal Cut-off Frequency (Hz)	
	Left	***Right***
Cervical Electrogoniometer	5.65	
Thoracic Electrogoniometer	5.60	
Lumbar Electrogoniometer	6.02	
Sternocleidomastoid	1.32	1.22
Cervical Paraspinal	0.87(M) 1.13(F)	0.93
Upper Trapezius	1.06	0.84
Thoracic Erector Spinae	0.89	0.83
Lumbar Erector Spinae	0.87	0.86

residual analysis are smaller than what is commonly used (e.g. 2 Hz: Sommerich et al., 2000; 4 Hz: Burnett et al., 2009); however these values are directly applicable to the data for the current study. Had the larger frequencies from previous studies been used, a larger amount of noise could potentially have been included in the data, which could have influenced the filtered EMG amplitudes, and potentially the outcome of the study.

3.4.2 Electrogoniometer Processing

All EMG and electrogoniometer data were processed using customized LabView software (LabView 8.6, National Instruments; Austin, Texas, USA.) Electrogoniometer data were low-pass filtered using a dual-pass, 4^{th}-order Butterworth filter with the cut-off frequencies as specified by the residual analysis (Winter, 2005). The filtered goniometer traces were then zeroed and normalized to percent of maximum flexion (%MF).

To zero the goniometer trace, the mean angle in the starting posture (Phase 1) was obtained. This value chosen to represent the participants' neutral posture, and was subtracted from every data point in the filtered angle trace. This allowed each participant to start at "zero degrees of flexion". To express the angle data as %MF, the maximum flexion angle of each trace was recorded, and every data point in the angle trace was expressed as a percentage of this maximum value. The trace was then marked with the locations of the beginning and end of each of the phases for use in calculating the flexion relaxation ratios, and the sample number associated with these locations were recorded (Figure 13).

3.4.3 *EMG Processing*

Raw MVC data were full-wave rectified and low-pass filtered with a dual-pass, 4th-order Butterworth filter at the optimal cut-off frequencies specified by the residual analysis for each channel. The peak of the filtered EMG data from each of the three MVC trials was obtained for each channel, and the peak for each channel became the normalization factor for all subsequent trials, for that channel.

Some of the cervical flexion trials contained unexpected spikes in the data, which did not appear to be related to the cervical motion and lasted less than 500 samples (~244 ms). Trials containing these spikes were first processed by clipping out the spikes and splicing the trace back together. The trials were then low-pass filtered using a dual-pass, 4th-order Butterworth filter at the optimal cut-offs specified by the residual analysis for each channel. The filtered EMG data were then normalized and expressed as a percent of maximum voluntary contraction (%MVC). That is, every EMG data point in the trial was divided by the MVC value for each muscle, and then multiplied by 100 to express the

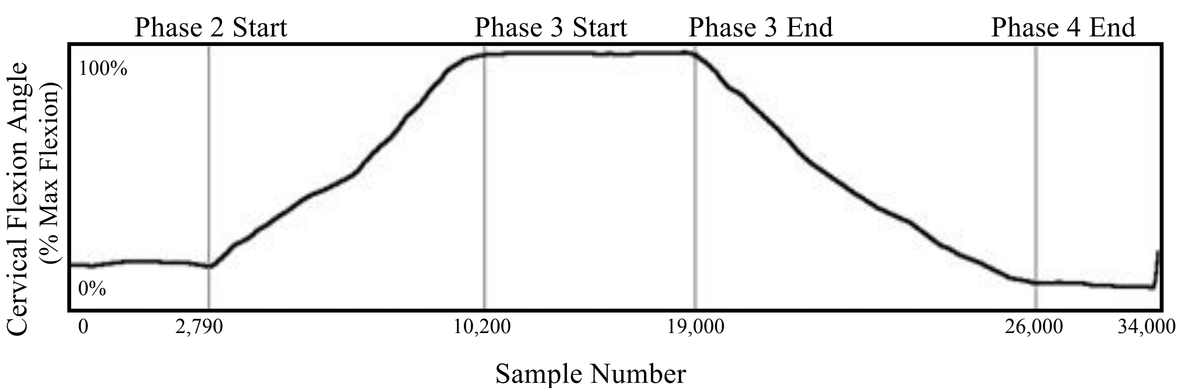

Figure 13: Screen capture of the LabView goniometer trace, used to determine phase separation points. Black line: cervical electrogoniometer trace. Vertical gray lines indicate phase separation points: start of Phase 2 (flexion phase), start of Phase 3 (hold phase), end of Phase 3/start of Phase 4 (extension phase), end of Phase 4.

data points as %MVC.

3.4.4 Calculation of Flexion (FRR) and Extension (ERR) Relaxation Ratios

For each cFRP trial, the sample numbers associated with the start and end points of the cFRP phases were located in the EMG traces, and the filtered, normalized EMG data (CPS, UTR, and TES only) were separated into the four phases. The peak muscle activation was calculated for Phase 2 and Phase 4, and the mean muscle activation was calculated for Phase 3. These values were then to calculate the FRR and ERR for each cFRP trial, as follows:

$$FRR = \frac{Phase\ 2\ peak\ EMG}{Phase\ 3\ mean\ EMG} \tag{1}$$

$$ERR = \frac{Phase\ 4\ peak\ EMG}{Phase\ 3\ mean\ EMG} \tag{2}$$

3.4.5 Criteria for Determination of the Presence of cFRP

An ERR or FRR greater than 1 indicates that the peak EMG in Phase 4 or Phase 2 (respectively) is greater than the mean EMG in Phase 3. Once the ERRs and FRRs were calculated for each trial, binary coding (1 = 'FRP', 0 = 'no FRP') was used to signal whether the ratios indicated the presence of FRP. Previous studies have used a minimum FRR of 1.0 as the criterion to establish the presence of FRP (Watson et al., 1997; Colloca & Hinrichs, 2005, Alschuler et al., 2009). However, this did not appear to be stringent enough, as it would have included any ERRs that were even slightly greater than 1.0 in the analysis (Figure 14). For example, trials with an ERR of 1.01 would have been coded

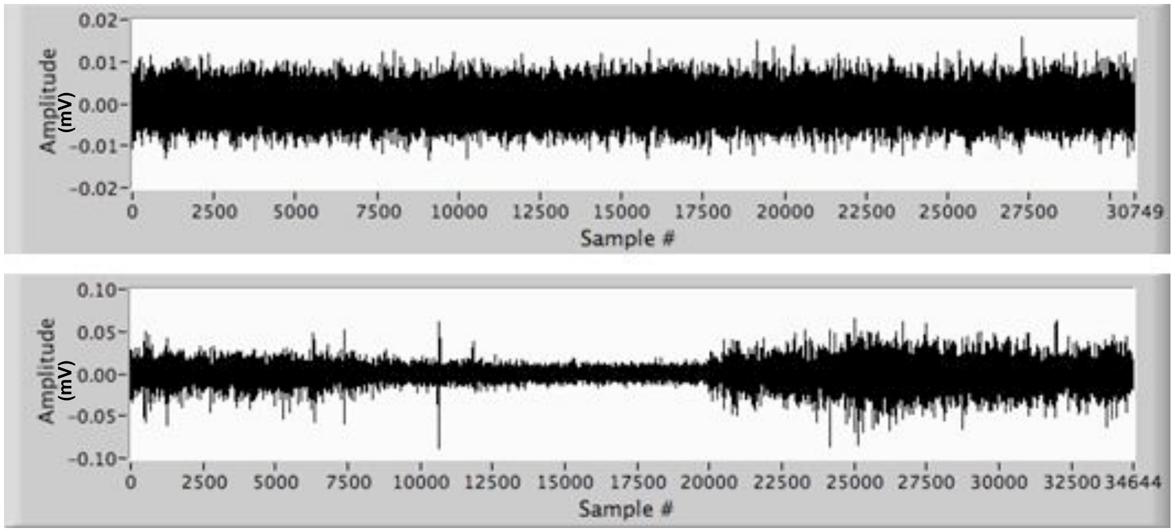

Figure 14: EMG traces for the right CPS muscle from two different cervical flexion trials. The bottom trace illustrates the characteristic FRP trace, and the corresponding FRR and ERR were 3.4 and 4.7, respectively. The top trace does not show the characteristic pattern for FRP, but would have been considered positive for FRP if only the criteria of ERR ≥ 1.0 was used for determining the presence of FRP (FRR = 1.06, ERR = 1.03).

as 'FRP', when visual inspection of the trial EMG clearly indicated otherwise. For this reason, the following criteria for establishing the presence of FRP were adopted:

- FRR > 1.1, AND
- ERR > 1.1, AND
- trial EMG trace showed the characteristic bimodal pattern of FRP (Burnett et al., 2009).

The two ratios were used to flag EMG traces potentially exhibiting FRP. Upon visual inspection, any trace that did not show the characteristic pattern was excluded from further analysis. Figure 15 shows a graphical representation of the process used for determining whether FRP was present or not.

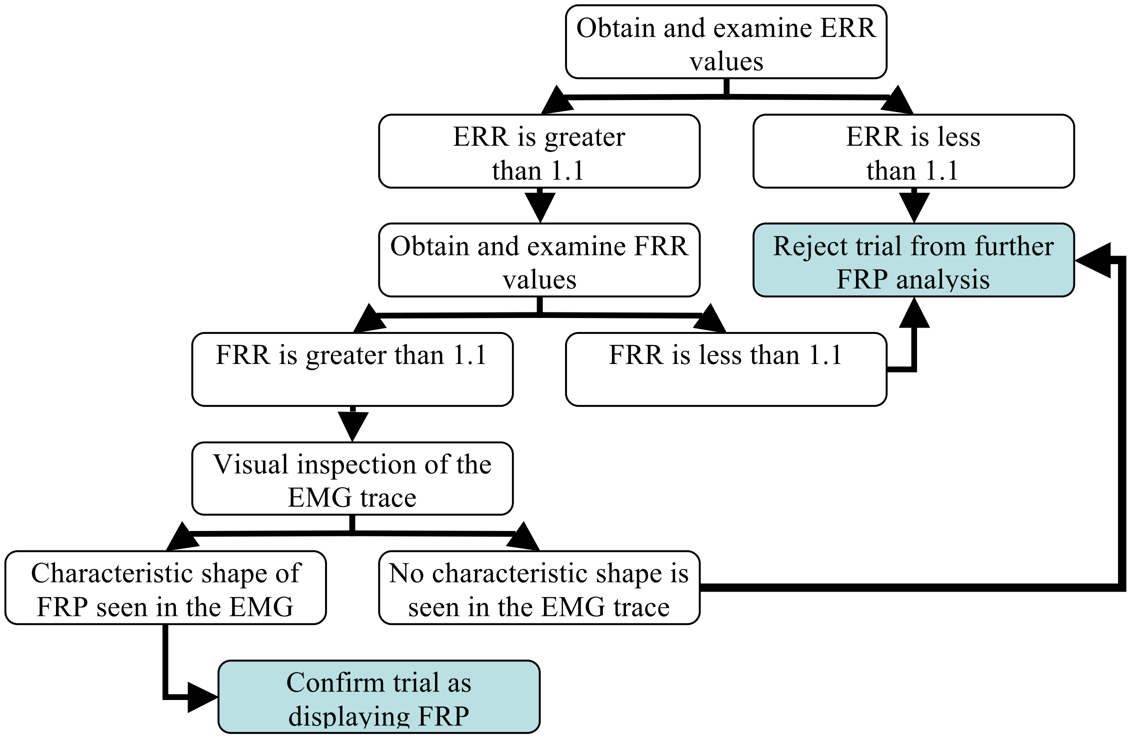

Figure 15: Flow-chart of the decision process for determining the presence of cFRP.

3.4.6 Calculation of Onset and Cessation Angles

To determine the onset and cessation of myo-electric silence, the raw EMG traces of all trials that met the criteria for FRP were visually examined using customized LabView software. The raw EMG traces were displayed on the computer screen, and the researcher visually inspected the traces to locate the point at which she believed the muscle activity ceased (i.e. FRP onset) and resumed (i.e. FRP cessation). To facilitate this process and allow the researcher to pinpoint the onset and offset points as accurately as possible, the software program allowed the researcher to zoom in on a 50-sample window of the trace where she believed the onset or offset occurred. This allowed for the determination of whether the muscle was on or off within a small range of sample points.

The sample number at which muscle activity ceased and where it recommenced were recorded. The sample numbers at these points were then located on the corresponding normalized cervical angle traces (Figure 16). From there, the normalized (%MF) cervical angle at FRP onset and cessation were determined. Since the trace consisted of approximately 35,000 samples, a deviation from the actual onset or cessation angle by 50 samples in either direction did not translate to more than one tenth of a degree when applied to the electrogoniometer trace.

3.5 Statistical Analysis

All statistical analyses were executed using SPSS Statistics 19 (IBM Corporation: Somers, NY). Using Exploratory Data Analysis (EDA), the dependent variables were checked for normality and homogeneity of variance prior to each step of the statistical analysis. Data were considered normally distributed if the following conditions were met (Tabachnick & Fidell, 2007):

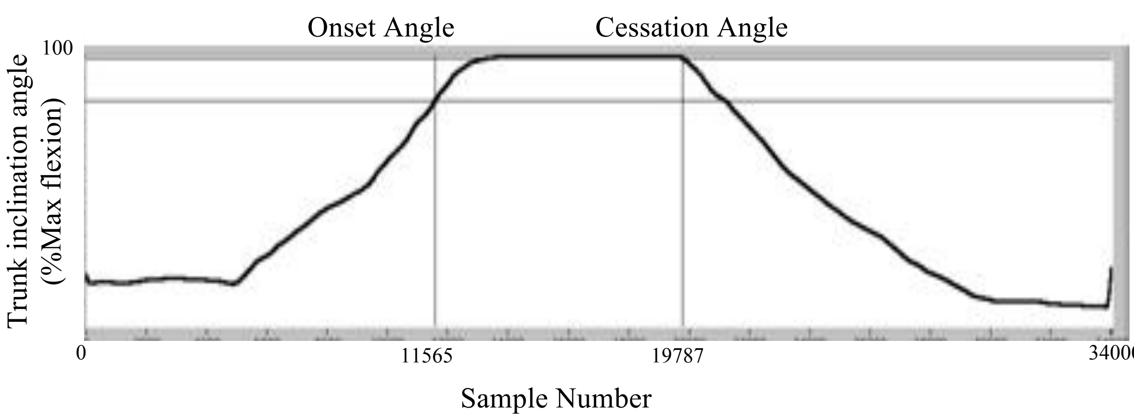

Figure 16: Screen capture showing the LabView program used for determining the onset and cessation angles for cFRP. Black line: cervical electrogoniometer trace. Vertical gray lines show locations of the point of cessation of EMG activity (onset angle), and the point of resumption of EMG activity (cessation angle) as determined from visual analysis of EMG traces.

$$\frac{estimate\ of\ skewness}{standard\ error\ of\ skewness} < 3.29 \quad (3)$$

$$\frac{estimate\ of\ kurtosis}{standard\ error\ of\ kurtosis} < 3.29 \quad (4)$$

Estimates of skewness and kurtosis and their respective standard errors were calculated using the 'Explore' command in SPSS. Data were considered to meet the assumption of homogeneity of variance if the largest group variance was less than 10 times larger than the smallest group variance (Tabachnick & Fidell, 2007). When these assumptions were violated, the data were transformed by taking the square root, natural logarithm, and/or inverse of the dependent variable, and the transformed data were re-explored to determine if the transformation resolved the violation (Tabachnick & Fidell, 2007). Since data transformations make interpretation of the transformed data difficult, the original data were used in the subsequent analyses, but the alpha level was adjusted to compensate for the degree of violation of the assumptions of normality/homogeneity of variance. A moderate violation can be corrected using the square root or the natural logarithm of the data transformations. A severe violation requires that the data be transformed using the inverse of the numbers in the data set. When alpha is originally set to $p = 0.05$; untransformed data with moderate violations can be analyzed using $p = 0.025$, and severe violations can be analyzed using $p = 0.01$ (Tabachnick & Fidell, 2007).

In this study, each participant performed three cervical flexion trials ("trial": trial 1, trial 2, trial 3) in each trunk posture condition ("condition": upright, 45^{o}, slumped), in both seated and standing postures ("posture": seated, standing). EMG data were collected from eight muscles bilaterally, although only three were of primary interest in this study:

cervical paraspinal muscles (CPS), upper trapezius (UTR), and thoracic erector spinae (TES). Data from left and right sides were compared to determine whether these data could be grouped ("side": left, right). Data from males and females were compared to determine whether there were any sex differences in FRR and onset and cessation angles ("sex": male, female). Thus, the design of the study was a 2 (side) x 2 (sex) x 2 (posture) x 3 (condition) x 3 (trial) mixed analysis of variance (ANOVA) with repeated measures. However, although the data were collected in a balanced manner, not every participant exhibited FRP in every trial. Thus, the data sets within each side and sex were not balanced across postures, conditions, and trials. Since cases with missing data are automatically removed from the analysis in repeated measures ANOVA, statistical comparisons were executed using Linear Mixed Modeling [LMM: analysis of variances with both fixed and random effects (Delval et al., 2008)]. Unlike repeated measures ANOVA, LMM allows comparisons of unbalanced data sets without removing entire cases with missing data, and thus was the most appropriate choice for this data set.

For both ERR and onset angle, the initial model included participant, sex, side, posture, and condition, which were modeled as fixed factors. The ERR and onset angle for each trial were input into SPSS, but trial number was not included in the model, as the randomized presentation of the trials made trial effects unlikely. Participant was also modeled as a random factor using a scaled identity covariance structure. With LMM, the modeling proceeds in an iterative, step-down approach. The initial model including all fixed and random factors is run, and the output provides an omnibus test of the main effects and all higher-order interactions for each fixed factor, estimates of covariance parameters (Wald *Z*) for the random factor, and information criteria to indicate the fit of the model. Pairwise comparisons of the levels of the main effects are also included. Fixed factors with non-significant interactions and main effects are removed from the model, and the model is re-run. Information criteria from each iteration of the model are compared, to determine which model fits the data the best.

Prior to each model run, the data were checked for violations of normality and homogeneity of variance, and alpha levels were adjusted where necessary. The details concerning each exploratory data analysis and the parameters specified in each LMM run, for both ERR and onset angle, are described in the results section. The cessation angles exhibited a very small range of data, and as such were not normally distributed and did not meet the assumption of homogeneity of variance. Data transformation did not resolve the violations, and since LMM requires these assumptions to be met, non-parametric options were explored. The Friedman test is the non-parametric equivalent to the repeated measures ANOVA, but it also removes cases with missing data from the analysis. Due to a lack of appropriate options, cessation angle data were not analyzed statistically. Instead, descriptive statistics (means & standard deviations) and general trends were reported.

CHAPTER IV

RESULTS

In total, 612 cFRP trials were collected (17 participants, 18 trials per participant, right and left sides). Of these, 291 trials (right and left sides combined) met the criteria of both FRR and ERR > 1.1 in the CPS muscles. After visual inspection, 189 of those trials were confirmed as exhibiting cFRP. Overall, the CPS muscles exhibited FRP in 30.8 % of all trials, either unilaterally (14.2 %) or bilaterally (16.7 %). cFRP was confirmed in only 9 trials in the upper trapezius (1.5 % of all trials), and no participants exhibited cFRP in the thoracic erector spinae muscles. Since the upper trapezius and thoracic erector spinae muscles did not show FRP in enough trials to perform statistical analyses they were excluded from further evaluation. For the remainder of this document, all analyses will be described for the CPS musculature only.

4.1 Extension Relaxation Ratio (ERR)

Since the order of presentation of the postures and conditions were randomized, it is unlikely that trial effects were present. As verification, repeated measures ANOVAs (sex x posture x condition x trial) was conducted using the ERRs from every trial (data split into right and left sides), including those which did not meet the criteria for ERR (i.e. visual inspection and ERRs > 1.1). No trial effects were evident within any side, sex, posture, or condition ($p > 0.05$). A visual inspection of the ERRs for the three trials in a posture-condition combination revealed that the ERRs remained very similar (little variability) for each participant over the three trials in each posture-condition combination (Appendix B). This, coupled with the randomized presentation of the trials, makes it unlikely that trial effects were present within the ERR data set.

The first iteration of the LMM modeled side, sex, posture, and condition as fixed factors, and participant as a random factor. Exploratory data analysis (EDA) of the ERRs grouped by the fixed factors revealed violations of homogeneity of variance in some groups. Transforming the data by taking the inverse of the ERRs resolved the non-homogeneity in all cases. Since this violation could be considered severe (i.e. requiring an inverse transformation to resolve the non-homogeneity of variance: Tabachnick & Fidell, 2007), the alpha level was reduced to 0.01. The omnibus test for the nested terms showed no significant interactions of any of the fixed factors ($p > 0.01$: Table 5). There was a significant main effect of condition [$F(2,154.5) = 14.28$, $p = 0.000002$]. When collapsed across sex, side, and posture, ERR was significantly higher in the 45° trunk

Table 5: Results from linear mixed model iteration #1 for ERR comparisons. There was a significant main effect of condition (i.e. trunk posture) on ERR ($p < 0.01$). There were no other significant main effects or interactions.

Source	Numerator df	Denominator df	F	Sig.
Sex	1	6.74	0.71	0.43
Side	1	152.13	2.42	0.12
Posture	1	148.21	0.37	0.54
Condition	**2**	**154.45**	**14.28**	**0.000002**
Sex * Side	1	152.13	0.03	0.87
Sex * Posture	1	148.21	$4E^{-04}$	0.98
Sex * Condition	2	154.45	1.36	0.26
Side * Posture	1	147.71	0.15	0.70
Side * Condition	2	149.66	2.36	0.10
Posture * Condition	2	149.56	0.43	0.65
Sex * Side * Posture	1	147.71	0.01	0.91
Sex * Side * Condition	2	149.66	0.02	0.98
Sex * Posture * Condition	2	149.56	1.38	0.26
Side * Posture * Condition	2	149.20	0.43	0.65
Sex * Side * Posture * Condition	2	149.20	0.58	0.56

inclination condition (3.05 ± 0.88) than in both the upright (2.34 ± 0.51) and slumped (2.66 ± 0.84) conditions (p = 0.000001 and p = 0.002, respectively). This means that the muscle activation in Phase 4, increased with an increase in trunk inclination angle. ERR did not differ significantly between the upright and slumped conditions (p = 0.073). Random variance related to participants was not significant (Wald Z = 1.32, p = 0.182). The mean (± SD) ERR values for each condition are represented graphically in Figure 17. Since the first model revealed no significant main effects of sex, side, or posture, these factors were removed from the model, and a second iteration of LMM was run that modeled condition as a fixed factor and participant as a random factor. A comparison of the Akaike's Information Criterion (AIC) between the two models, revealed the AIC in Model 1 (411.54) was lower than the AIC in Model 2 (424.30). A lower AIC indicates a

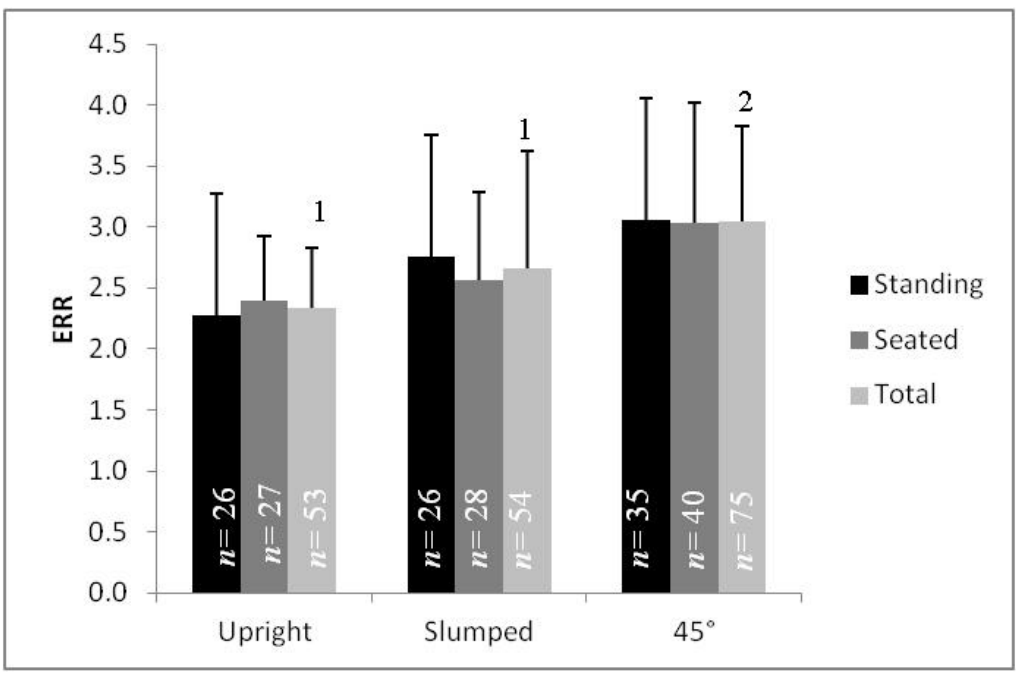

Figure 17: Comparison of ERR values between postures and conditions. There were no significant differences between postures within any condition. Significant differences between conditions (collapsed across postures) are indicated by the different numbers above the bars ($p < 0.01$).

better model fit, thus the results generated by Model 1 were used.

4.2 cFRP Onset Angles

As in the ERR analysis, there were not enough data points to determine whether a trial effect existed for the onset angles. Because the order of presentation of the trials within each posture and condition were completely randomized, a trial effect is unlikely for this data.

The first iteration of the LMM modeled side, sex, posture, and condition as fixed factors, and participant as a random factor. EDA of the onset angles grouped by the fixed factors grouped by the fixed factors revealed many violations to the assumptions of normality and homogeneity of variance. Since one of the groups had a very small sample size (n = 2), this was not resolved regardless of the transformation level used. When gender was removed as a factor and the data were re-grouped according to side, posture, and condition, all groups met the assumptions of normality and homogeneity of variance. This trend continued as side and posture were also removed. It was therefore determined that for these analyses, except for the four-way analysis when an alpha of 0.01 was required, an alpha level of 0.05 would be used.

The omnibus test for the nested terms showed no significant interactions of any of the fixed factors ($p > 0.01$: Table 6). There were no significant main effects or interactions in this model ($p > 0.05$). Therefore, a second iteration of the LMM was run. Initially, the intention was to remove the side factor first. However, an EDA revealed none of the groups displayed normality or homogeneity of variance, regardless of the data

Table 6: Results from linear mixed model iteration #1 for onset angle comparisons. There were no significant main effects or interactions in this model iteration.

Source	Numerator df	Denominator df	F	Sig.
Sex	1	7.83	0.14	0.72
Side	1	157.10	$3E^{-03}$	0.96
Posture	1	148.85	0.10	0.76
Condition	2	153.65	2.02	0.14
Sex * Side	1	157.10	0.03	0.87
Sex * Posture	1	148.85	0.19	0.67
Sex * Condition	2	153.65	2.05	0.13
Side * Posture	1	148.50	0.31	0.58
Side * Condition	2	149.90	0.41	0.66
Posture * Condition	2	149.80	2.91	0.06
Sex * Side * Posture	1	148.50	3.42	0.07
Sex * Side * Condition	2	149.90	0.07	0.93
Sex * Posture * Condition	2	149.80	0.09	0.92
Side * Posture * Condition	2	149.56	0.15	0.86
Sex * Side * Posture * Condition	2	149.56	0.53	0.59

transformations used. Therefore, the sex factor was removed instead, and the EDA was run once again, resulting in all groups displaying normality and homogeneity of variance. Thus, the second iteration of the LMM was run which modeled side, posture, and condition as fixed factors, and participant as a random factor. A comparison of the Akaike's Information Criterion (AIC) between the two models revealed the AIC in Model 1 was lower than the AIC in Model 2. A lower AIC indicates a better model fit, however the alpha level used for Model 1 had to be lowered due to non-normal data distributions and violations of the assumption of homogeneity of variance. Thus, the results generated by Model 2 were used.

The omnibus test for the nested terms in Model 2 showed no significant interactions of any of the fixed factors ($p > 0.05$: Table 7). There was a significant main effect of condition [$F(2,165.7) = 3.1$, $p = 0.05$]. When collapsed across sex, side, and posture, onset angle was significantly lower in the 45° trunk inclination condition (75.0° ± 15.1°) than in the upright condition (84.8° ± 16.9°) ($p = 0.01$). This means that FRP

Table 7: Results from linear mixed model iteration #2 for onset angle comparisons. There was a significant main effect of condition (i.e. trunk posture) on onset angle ($p < 0.05$). There were no other significant main effects or interactions.

Source	Numerator df	Denominator df	F	Sig.
Side	1	168.98	$1E^{-03}$	0.98
Posture	1	161.37	0.25	0.62
Condition	**2**	**165.69**	**3.06**	**0.049**
Side * Posture	1	161.07	0.03	0.86
Side * Condition	2	161.61	0.37	0.69
Posture * Condition	2	162.64	2.61	0.08
Side * Posture * Condition	2	160.86	0.07	0.93

began sooner in the 45° trunk inclination condition than in the upright condition. Onset angle did not differ significantly between the slumped (76.7° ± 12.6°) and upright conditions (p = 0.14), or the 45° trunk inclination and slumped conditions (p = 0.07). Random variance related to participants was not significant (Wald Z = 1.6, p = 0.12). The mean (± SD) onset angle values for each posture and condition are represented graphically in Figure 18.

4.3 cFRP Cessation Angles

The cessation angles were very similar within all postures and conditions, and between males and females on both the right and left side. When grouped by posture and condition, the largest mean cessation angle was found in the slumped standing condition (98.2° ± 1.4°) followed closely by the 45° standing condition (98.0° ± 0.62°) (Figure 19). The smallest mean cessation angle was found in the upright seated condition (95.8° ±1.4°). When grouped by posture, the mean cessation angle for the standing postures were slightly larger than those in the seated postures (97.9° and 97.0° for standing and seated, respectively). When the data were grouped by side, sex, posture, and condition, the lowest recorded cessation angle value occurred among the males on the right side in the seated 45° trunk inclination condition (70.5°); the largest recorded cessation angle

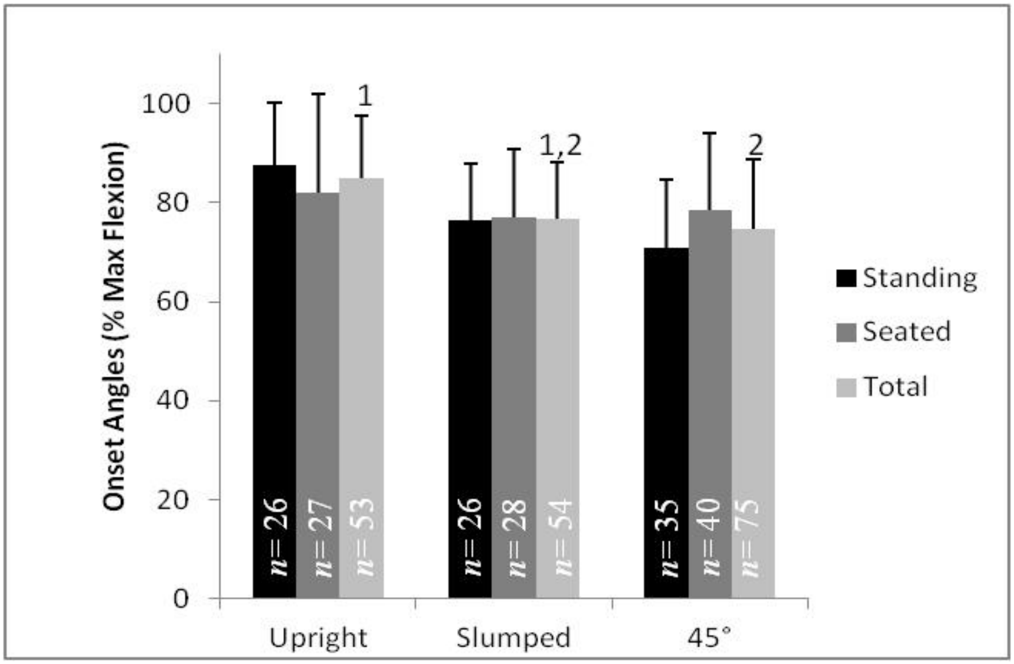

Figure 18: Comparison of onset angles between postures and conditions. There were no significant differences between postures within any condition. Significant differences between conditions (collapsed across postures) are indicated by the different numbers above the bars ($p < 0.01$).

was 100° and was recorded in several side/sex/posture/condition groups. The means, standard deviations, and ranges for each of the dependent variables by posture and condition are provided in Table 8 and the descriptive statistics for the cessation angles are shown graphically in Figure 19.

4.4 Summary of Results

Overall, FRP was observed in the CPS muscles unilaterally in 11 participants (64.7 %), and bilaterally in 8 participants (47.1 %), across all postures and conditions. cFRP was confirmed in only 10 trials in the upper trapezius (1.6 % of all trials), and no participants exhibited cFRP in the thoracic erector spinae muscles; thus all subsequent analyses were executed for the CPS muscles only. There were no significant differences

Table 8: Means, standard deviations and ranges for all dependent variables (grouped by posture and condition).

	Posture	Condition	Mean	Standard Deviation	Maximum	Minimum
ERR	Standing	Upright (*n*=26)	2.3	0.5	3.3	1.6
		Slumped (*n*=26)	2.8	1.0	6.2	1.5
		45° (*n*=35)	3.1	0.8	4.9	1.6
	Seated	Upright (*n*=27)	2.4	0.5	3.7	1.7
		Slumped (*n*=28)	2.6	0.7	4.7	1.9
		45° (*n*=40)	3.0	1.0	6.0	1.7
Onset Angle	Standing	Upright (*n*=26)	87.6°	12.7°	100.0°	59.9°
		Slumped (*n*=26)	76.5°	11.4°	100.0°	56.5°
		45° (*n*=35)	70.9°	13.9°	99.2°	43.6°
	Seated	Upright (*n*=27)	82.0°	20.0°	99.8°	40.0°
		Slumped (*n*=28)	77.0°	13.9°	97.0°	47.9°
		45° (*n*=40)	78.6°	15.4°	99.8°	48.0°
Cessation Angle	Standing	Upright (*n*=26)	97.5°	3.3°	100.0°	84.7°
		Slumped (*n*=26)	98.0°	4.1°	100.0°	79.6°
		45° (*n*=35)	98.0°	1.6°	100.0°	94.1°
	Seated	Upright (*n*=27)	96.1°	5.8°	99.8°	73.7°
		Slumped (*n*=28)	98.0°	2.6°	100.0°	91.1°
		45° (*n*=40)	97.4°	4.8°	100.0°	70.5°

in ERRs or onset angles between the left and right CPS muscles, or between males and females, within any of the body postures or trunk conditions. Body posture (i.e. seated vs. standing) was found to have no effect on ERR values for the different conditions, and as such they were grouped by posture and compared across trunk conditions. Mean grouped ERR values were significantly larger in the 45° trunk inclination condition than in both slumped and upright conditions, but did not differ significantly between the slumped and upright conditions. In other words, the muscle activity in Phase 4 (extension) was highest in the 45° condition and lowest in the upright and slumped conditions when compared to the muscle activity in Phase 3 (flexion phase). Mean grouped onset angles were

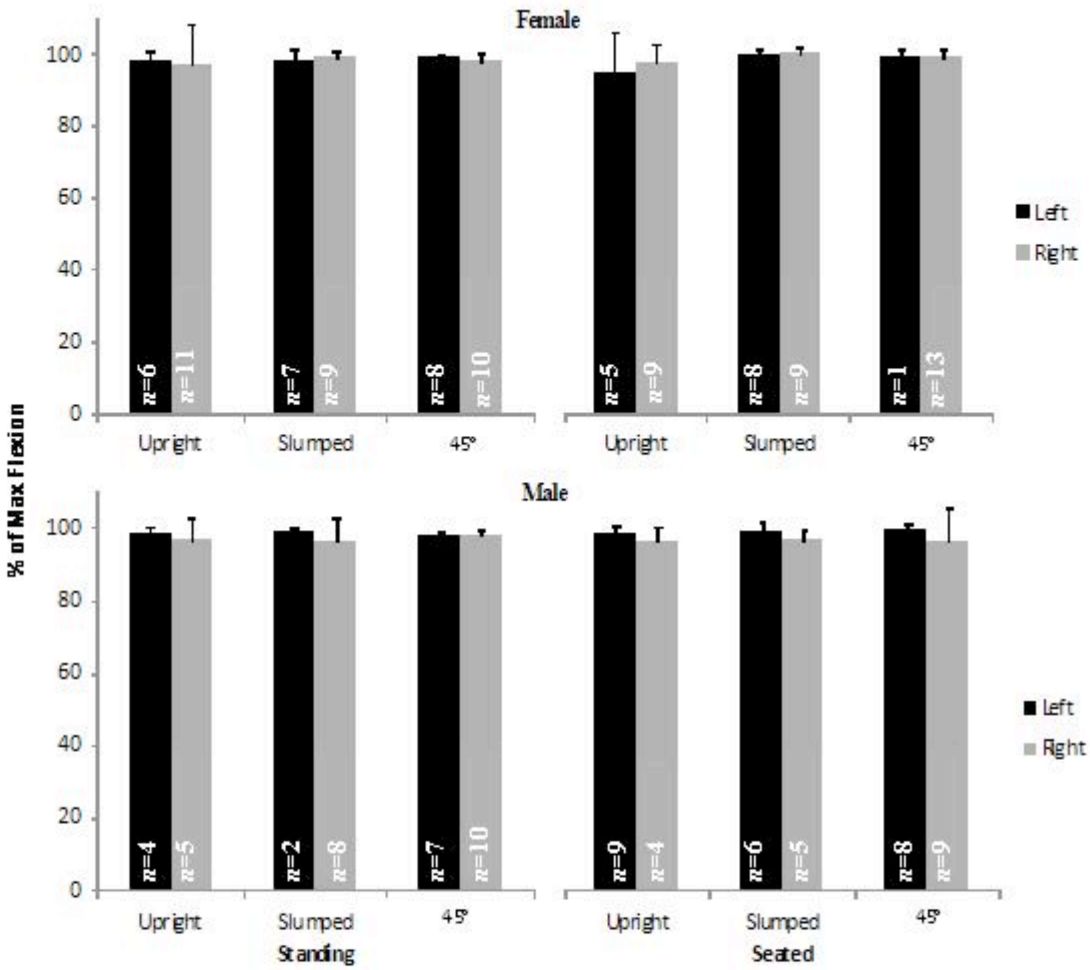

Figure 19: Mean (SD) cessation angles for all postures and conditions across left and right sides, for males and females.

significantly lower in the 45° condition than in the upright condition, but did not differ significantly between the slumped and upright conditions, or the 45° and slumped conditions. There was very little difference in the cessation angles between or within postures and conditions, although the minimum values were more variable than the maximum values. No statistical comparisons were made on the cessation angles, as the range of cessation angles was very narrow (70.5° - 100.0°) and the data did not meet assumptions of normality.

CHAPTER V

DISCUSSION

The purpose of this study was to evaluate the presence of the cervical flexion relaxation phenomenon in both seated and standing postures, and to investigate the potential modulating effect of non-neutral trunk postures (i.e. slumped and flexed 45°) on the magnitude of the extension relaxation ratio (ERR) and the onset and cessation angles of the cervical FRP. To date, only a handful of studies have examined the flexion relaxation response in the cervical muscles (Meyer et al., 1993; Airaksinen et al., 2005; Burnett et al., 2009; Pialasse et al., 2009, 2010; Murphy et al., 2010), thus the knowledge base for this phenomenon is still rather limited, especially when compared to that in the lumbar spine. All of the previous cervical FRP studies have taken place in seated postures, and very little research has examined the modulating factors of the cervical FRP. The results of the present study expand the current knowledge base by being the first to document the presence of cervical FRP in both seated and standing postures. This is also the first study to examine the modulating effect of slumped postures on the kinematic and EMG parameters of the cervical FRP.

5.1 Specific Aim I: cFRP in Upright Seated and Standing Postures

Hypothesis I (Accepted): The flexion relaxation phenomenon would be observed in the dorsal cervical paraspinal musculature, in both upright seated and upright standing postures.

The findings of the present study supported this hypothesis. In the upright standing task, cervical FRP was observed unilaterally in 7 out of 17 participants (41.2%), and bilaterally in 4 participants (23.5 %). In the upright seated task, cervical FRP was observed in unilaterally in 11 participants (64.7 %) and bilaterally in 6 participants (35.3 %). In comparison, Pialasse et al. (2009) reported evidence of cervical FRP in 84.2 % of participants unilaterally, and 67.4 % of participants bilaterally in an upright seated neck flexion task. The difference in the incidence of FRP between the two studies may be related to the more stringent criteria used to classify FRP in the current study. Generally, the FRR cut-off to denote the existence of FRP has been set at 1.0 (Watson et al., 1997; Colloca & Hinrichs, 2005; Alschuler et al., 2009). In the present study, a cut-off of 1.1 was used and both the ERR and FRR ratios had to meet these criteria for a muscle to be considered positive for exhibiting FRP. If one of the ratios was not positive for FRP, then that trial was rejected from further processing. This occurred in 321 trials (52.5 %). Once all of the trials showing both an FRR and ERR of 1.1 or greater were identified (n = 291), these trials were further inspected to visually identify the characteristic FRP EMG pattern (Floyd & Silver, 1955; Burnett et al., 2009). When the data from the current study were re-coded using a criterion of ERR ≥ 1.0, the incidence of FRP was greater than 95% for all trials and all conditions. However, this criterion did not appear to be stringent enough, as it included any ERRs that were even slightly greater than 1.0 in the analysis. For example, the ERR for the trial shown in the upper trace in Figure 14 was 1.06. Using a criterion of ERR > 1.0, this trial would have been coded as 'FRP', when visual inspection of the trial EMG clearly suggests otherwise. By contrast, the FRR and ERR for the trial in shown in the lower trace in Figure 14 were 3.4 and 4.7, respectively; and the EMG trace clearly shows the characteristic FRP pattern.

Burnett et al. (2009) examined the effectiveness of various criteria for determining the presence of FRP, and reported a large variability in the incidences of FRP between the different criteria. Depending on the method used, the researchers found that between 0 % and 65 % of the participants exhibited FRP. Using a visual analysis of the EMG traces to identify the characteristic FRP pattern, 25 % of the participants were deemed as having exhibited FRP. When the criterion used was Phase 3: Phase 2 > 1.0, 80 % of the participants exhibited FRP (Burnett et al, 2009). These results coincide with the current study, whereby simply employing the FRR to identify FRP resulted in more than 95 % of participants exhibiting FRP, but using visual analysis to confirm the presence of FRP brought the incidence down to approximately 65 %. This suggests that the criteria used in the present study, while conservative, were not excessively stringent.

In this study, cFRP was observed in the CPS muscle unilaterally more often than bilaterally. This was not unexpected, as Pialasse et al. (2009) also reported a higher incidence of cFRP unilaterally. These authors suggested the unilateral presentation of cFRP could be explained by methodological differences between sides, such as electrode placement or the execution of the movement. A second explanation to the unilateral appearance of the FRP could be explained by the handedness of the participant. While this data was not collected, it is possible that differences in muscle strength and motor control between the dominant and non-dominant sides of the body could have altered muscle activation patterns in such a way that their dominant side would display FRP while their non-dominant side would not. Another explanation advanced by Pialasse et al. (2009) was that the unilateral FRP might represent an underlying asymptomatic injury. In addition to symptomatic neck pain patients, a lack of FRP has also been observed among individuals with injuries in the asymptomatic phase (Watson et al., 1997; Colloca & Hinrichs, 2005). While the inclusion criteria of the present study were very stringent so as to prevent anyone with serious neck/back pain or a history of serious neck/back pain in the last year from participating, the exclusion criteria may not have eliminated all incidences of pain. If the participants had neck pain in the past year that did not prevent them from attending school or work, or if they experienced neck/back pain but did not seek medical attention for it, they would have been included in the present study as long as they were currently asymptomatic. This could have resulted in the inclusion of participants who had recently experienced a bout of neck pain, or were in the asymptomatic phase of a mild neck injury, which, as suggested by Pialasse et al. (2009), might explain the observation of unilateral cFRP in the present study.

The objective of this portion of the study was to determine whether the cFRP could be elicited in both standing and seated postures. Many occupational tasks take place in both seated and standing postures and involve neck flexion, which is a known risk factor for pain if the flexion is held for prolonged periods (Ariens et al., 2000, 2001). Since up to 14% of workers experience neck pain that is severe enough to interfere with their daily activities (Côté et al., 2009a), describing the behaviour of the neck muscles in these postures in healthy individuals is a necessary step towards the development of viable neck injury mechanisms. Data from this study could also be compared to similar data from a group of patients with neck pain, to investigate the clinical significance of the cFRP; similar to the work that has been done to establish the clinical significance of the lumbar FRP. With further research, the cFRP could eventually be used as a clinical aid to guide and monitor neck injury rehabilitation.

5.2 Specific Aim II: Modulating Effect of Trunk Inclination Angle

Hypothesis IIa (Accepted): The ERR would increase with increases in trunk inclination angle, in both the seated and standing postures.

The results of the present study supported this hypothesis. In both seated and standing postures, ERRs were largest in the 45° condition and lowest in the upright conditions, with ERRs for the slumped condition falling in between. In other words, the muscle activity in Phase 4 was highest in the 45° condition and lowest in the upright condition. Since there were no significant differences in ERRs between seated and standing postures for any of the trunk conditions, ERRs were grouped by posture and compared across trunk conditions. Grouped ERR values were significantly larger in the 45° condition (3.05 ± 0.88) than in both slumped (2.66 ± 0.84) and upright (2.34 ± 0.51) conditions ($p < 0.01$). This is in agreement with Pialasse et al. (2009), who also reported larger ERRs with 45° trunk inclination.

The larger ERR in the 45° condition was driven by an increase in paraspinal muscle activity. During trunk inclination, the perpendicular distance from the centre of rotation of the neck to the vector representing the force of gravity acting through the centre of mass of the head (i.e. the moment arm) increases. The larger moment arm increases the moment about the centre of rotation of the neck, and requires the CPS to generate more force to overcome the effect of gravity on the mass of the head. This would result in increased muscle activity since muscle force production is related to EMG amplitude (Hamill & Knutzen, 2003). Indeed, Phase 4 peak CPS EMG amplitudes were larger in the 45° condition than in the upright condition. The ERR is the ratio of the peak

EMG in Phase 4 to the mean EMG in Phase 3; thus, the larger peak EMG amplitude in Phase 4 would have driven the increase in the ERR in the condition with greater trunk inclination (45°). This is not a positive finding when it is considered in the context of work tasks in industry that require trunk inclination. If workers were required to adopt inclined trunk postures, the moment about the centre of rotation of their necks would increase, requiring the muscles to generate more tension to overcome the effect of gravity on the mass of the head and maintain their neck postures. This would place a greater demand on the neck muscles, which could cause them to fatigue sooner. This fatigue could increase the likelihood of injuries occurring in these muscles.

Hypothesis IIb (Rejected): There would be no effect of trunk inclination angle on onset and cessation angles for cervical FRP in the seated and standing trials.

The data from the present study do not support this hypothesis. The onset angles were significantly lower in the 45° condition than in the upright condition ($p = 0.000001$). That is, FRP occurred sooner in the 45° condition than in the upright condition. This is in contrast to Pialasse et al. (2009), who reported no significant difference in onset angles in the 45° condition compared to the upright condition. However, Pialasse et al. (2009) used a trunk supporting apparatus for their 45° condition, while participants in the present study were required to actively maintain the 45° of trunk inclination (i.e. their trunks were unsupported). If the participants in the present study were focusing on maintaining the 45° trunk inclination posture as they were instructed; then perhaps their attention was diverted away from the muscles of the neck and these muscles were able to achieve FRP sooner since they were no longer the main focus of the participant. While there is no supportive literature on the idea that focusing on one muscle would cause subconscious relaxation in another, a similar theory has been used in cancer treatment and pain management. Distraction techniques have been used in the treatment of the side effects of chemotherapy by encouraging the patient to focus on progressive muscle relaxation (i.e. focusing on one muscle group at a time and consciously relaxing them) rather than the nausea and anxiety that they are experiencing (Vasterling et al., 1993). The attention required for this task is substantial enough that the side effects and anxiety are diminished, until the attention has been redirected (Vasterling et al., 1993). This supports the idea that while an individual is focusing on one intrinsic process; another is able to occur without conscious perception of it. In the case of cFRP, if the muscles are able to rest longer they would not likely fatigue as quickly and this could help in preventing muscle injury.

In a healthy spine, the FRP could be considered a protective mechanism for the dorsal paraspinal muscles during tasks involving spine flexion, as it allows the muscles to transfer of the load-bearing task to the passive elements of the spine. However, this could actually put the posterior lumbar ligaments and the intervertebral disc at risk of injury. McGill & Kippers (1994) demonstrated that full trunk flexion increases the loads in the interspinous and supraspinous ligaments and posterior annulus of the intervertebral disc, and Solomonow et al. (2003) demonstrated that prolonged lumbar flexion induced creep in the posterior lumbar ligaments as well as muscle spasms in the lumbar erector spinae. Creep occurs when a viscoelastic tissue (such as a ligament) is stretched and held at a constant load (Hamill & Knutzen, 2003). Over time, this constant load causes deformation (i.e. lengthening) of the tissue. Providing the tissue is not deformed beyond its elastic limit, it will return to its original shape. However, if the elastic limit is exceeded, the tissue will not return to its original shape and there will be some residual deformation after the force is removed. Residual deformation in a ligament will affect the stability of its associated joint, leaving the joint susceptible to injury (Hamill & Knutzen, 2003). Thus, while FRP may be a protective mechanism for the muscles when flexed postures are held for short durations, it may put the ligaments and other viscoelastic tissues at greater risk of injury if the posture is held for prolonged periods.

Neck flexion in the present study was held for a very short duration (approximately 3 seconds), and may not necessarily represent what happens when the posture is held for longer durations. However, the findings of this study indicate that cervical FRP and thus, the transfer of load bearing from the active muscles to the passive elastic components of the spine, occurred earlier in an inclined, unsupported trunk posture than in an upright posture. In the context of work tasks, this suggests that if workers must adopt postures involving cervical flexion and moderate unsupported trunk inclination, the posterior cervical ligaments might be at increased risk of injury due to the earlier transfer of load bearing from active to passive cervical tissues. However, this has yet to be investigated.

The cessation angles were not suitable for statistical comparisons due to severe violations of the assumptions of normal distribution and homogeneity of variance. Table 6 outlines the range of values obtained for the cessation angles (70.5° - 100.0°). There was very little difference in the cessation angles between or within postures and conditions. This is not surprising, because previous FRP research has shown that the FRP cessation occurs slightly before extension begins, which would mean that it would generally occur at approximately 100 % of maximum flexion. The minimum values were more variable than the maximum values. This was likely due to any small bobbling that may have occurred towards the end of Phase 3 prior to extension (due to movement hesitation), or may be associated with movement generated by muscles other than the CPS (e.g. multifidus) that occurred before the CPS activity resumed to contribute to the neck extension. Explanations for trends seen in cessation angles were not found in any of the FRP literature, and they will not be discussed further.

5.3 Specific Aim III: Comparison of Kinematic and EMG Parameters of cFRP in Standing and Seated Postures

Research Question #1: What effect, if any, does body posture (seated or standing) have on the magnitude of the ERR, onset angle, and cessation angle of the cervical FRP?

Statistical analysis revealed no significant main effects or interactions of posture on the magnitude of the ERR (all $p > 0.05$). When collapsed across all other factors, the magnitude of the ERR in the standing posture (2.7 ± 0.8) was not significantly different than in the seated posture (2.7 ± 0.8) ($p = 0.54$). Prior to beginning data collection for the current study, it was anticipated that higher ERR magnitudes might be observed in the seated trials than in the standing trials. The basis for this prediction came from the research of Callaghan & McGill (2001), who found that lumbar and thoracic erector spinae muscle activation was greater in a seated posture than in standing. While these authors did not investigate muscle activity levels in the neck, the origins of the cervical erector spinae overlap with the insertions of the thoracic erector spinae (Tortora, 2005). Therefore, it was thought that the increase in muscle activation observed in the thoracic erector spinae might translate to the cervical musculature as well. An increase in CPS muscle activity when seated might result in higher muscle activation in Phase 4, potentially resulting in higher ERR values when compared to standing (assuming Phase 3 showed the expected relaxation). Mean Phase 1 (i.e. starting posture) CPS EMG amplitudes were calculated for every trial in which the presence of FRP was confirmed; and the absolute value of the difference between the seated and standing Phase 1 mean EMG was calculated in every case where FRP was observed in both the seated and standing trials for that condition. This comparison revealed minimal differences between the Phase 1 CPS muscle activation in seated and standing, in each trunk condition. The largest difference was seen between the seated and standing 45° conditions, where the standing posture showed an average absolute difference in muscle activation levels of 2.9 %MVC ± 4.8 %MVC (n = 30) from the seated condition. Average absolute differences were 0.9 %MVC ± 1.2 %MVC (n = 17) in the upright condition, and 1.1 %MVC ± 0.9 %MVC (n = 24) in the slumped condition. Thus, it appears that the differences in CPS muscle activity between seated (ERR: 2.7 ± 0.8) and standing (ERR: 2.7 ± 0.8) postures were not large enough to have an effect on cFRP.

When collapsed across all other factors, the mean onset angle was slightly larger in the seated posture (79.1° ± 16.4°) than in the standing posture (77.6° ± 14.5°), but this difference was not statistically significant (p = 0.62). Mean Phase 1 (i.e. starting posture) cervical, thoracic, and lumbar angles were calculated for every trial in which the presence of FRP was confirmed; and the absolute value of the difference between the seated and standing Phase 1 mean angle was calculated in every case where FRP was observed in both the seated and standing trials for that condition (n = 58). This comparison revealed small differences between the mean seated and standing Phase 1 angles (collapsed across trunk conditions) in the cervical (6.1° ± 5.0°) and thoracic (5.3° ± 3.8°) regions, but a large difference in the lumbar region (17.8° ± 11.0°). This is to be expected, as the lordosis of the lumbar spine flattens in seated postures (Black et al., 1996). Appendices C, D, and E contain the initial (Phase 1) spinal angles for every posture and condition, for each individual participant.

Combined with the lack of difference in ERRs between seated and standing postures, these findings imply that body posture does not have a modulating effect on the cFRP. This suggests that whether a task is taking place in a seated posture or a standing posture, the cervical ligaments could be placed at risk of injury due to the increase in their load-bearing role during cFRP. This reinforces the importance of employing ergonomic interventions in work tasks in order to minimize the occurrence of neck flexion, whether workers are seated or standing. Efforts should be made to accommodate workers with workstations that allow them to perform a task at eye-level, which would reduce the amount of time spent in a flexed posture, thereby relieving the load on the ligaments. The lack of difference in the kinematic and EMG parameters of the cFRP between seated and standing postures also suggests that the findings of previous research examining the cFRP in seated postures can also be applied to standing postures. Future cFRP studies may not have to examine cFRP in both seated and standing postures, so that more focus can be applied to the modulating factors specifically.

5.4 Specific Aim IV: Modulating Effect of Slumped Posture

Research Question #2: What effect, if any, does a slumped posture have on the magnitude of the FRR, onset angle, and cessation angle of the cervical FRP?

Cervical FRP was observed in 28.4 % and 26.5 % of the seated and standing slumped trials, respectively. Interestingly, the ERR and onset angles in the slumped condition were not significantly different from those in the upright condition. Previous studies (Caneiro et al., 2010; Edmonston et al., 2011) found significantly higher muscle activity in a slumped posture. This led to the belief that the muscle activation in Phase 4 would be higher, potentially increasing the ERR during slumped postures. Also, because of the increase in neck flexion found in these studies, it was expected that FRP would begin sooner as the flexion task would begin with the neck already in a flexed position. Contrary to the findings of Caneiro et al. (2010) and Edmonston et al. (2011), Phase 1 mean CPS muscle activation was higher in the upright condition (18.1 %MVC ± 20.7 %MVC; n = 34) when compared to the slumped condition (16.6 %MVC ± 18.6 %MVC; n = 48). However, the small difference here does not seem to have been substantial enough to affect the CPS muscle's ability to achieve FRP, nor to significantly alter the magnitudes of the ERR and onset angles. The slumped condition may not alter the inclination of the trunk enough to cause the moment arm (i.e. perpendicular distance from the centre of rotation of the neck to the vector representing the force of gravity acting through the centre of mass of the head) to deviate excessively from that seen in the upright condition. Since the starting posture for both the upright and slumped conditions in the present study involved an upright head and essentially vertical body posture, gravity would be acting downward through the cervical spine for the two conditions. This would result in little or no modulating effect of slumped posture.

The lack of significant differences in the kinematic and EMG parameters of the cFRP between upright and slumped postures is interesting, given that slumped postures place the cervical spine in flexion, and prolonged neck flexion is a risk factor for reporting neck pain (Ariens et al., 2000, 2001). However, in this study the slumped postures were held for a very short duration – only for the duration of the cervical flexion task (approximately 13 seconds). Perhaps if the slumped postures were held for a much longer period of time (e.g. 10 minutes), changes in the ERR or onset angle would have been elicited related to the development of creep in the viscoelastic tissues of the neck. For example, Solomonow et al. (2003) investigated the effects of static flexion of the trunk on the lumbar FRP. Participants performed full trunk flexion tasks before and after a 10-minute period of static trunk flexion, and the onset and cessation angles of the lumbar FRP were recorded. They found that creep developed in the viscoelastic tissues that supported the trunk during the silencing of the erector spinae, and that FRP onset and cessation angles were both larger after the prolonged flexion task; meaning FRP began later in the flexion phase and ended earlier in the extension phase following 10 minutes of static trunk flexion (Solomonow et al., 2003). Although it is likely that the cervical paraspinal muscles would exhibit similar behaviour after a period of static neck flexion, no research in this area has been conducted to date. Future work could investigate changes in cFRP parameters after participants maintain flexed or slumped postures for prolonged periods.

5.5 Limitations

The exclusion criteria relied on a truthful self-report by the participants of no neck or back pain, and there is no means of definitively stating that the participants were entirely truthful in their self-reporting. However, since the participants were not promised any kind of reward for participation and they did not directly benefit from participation in this study, they had no reason to falsify this information and there was no reason to suspect their honesty.

Physical activity prior to participation was not controlled for in this study. A strenuous workout prior to participation may have influenced muscle recruitment and ability to produce a maximum voluntary contraction. The participants were asked immediately prior to participation if they were currently experiencing any pain at all (delayed onset muscle soreness included). If they answered yes, then they were asked to reschedule and return at a later date when the pain has cleared up, if they answered no, then the collection was able to proceed.

The electrogoniometers used in this study were found to have a large amount of noise in the collected signal. This is likely due to the age of the converter as well as the environmental factors (i.e. an increase in the temperature of the electrogoniometers, caused by the participant wearing them for 30 minutes from start to finish) that are known to affect electrogoniometer signals. This was corrected by filtering all of the data at the frequency determined by the residual analysis to ensure that the processing for this instrument was appropriate for the data. Also, to further reduce the effects of noise and possible calibration inconsistencies, the electrogoniometer data were expressed as a percentage of maximum flexion within each trial.

A statistical limitation to this study is that the cessation angle data were unable to be analyzed due to severe deviations from the normal distribution and violations of the assumption of homogeneity of variance. Instead, means, standard deviations, and data ranges were reported. However, no other FRP studies reported trends in cessation angles, likely for the same reason. Visual inspection of the means and standard deviations revealed the data did not vary substantially, and thus statistically significant differences were not expected.

The sample size ($N = 17$) of the present study was relatively small and as such, the results obtained in this study may not be applicable to the general population. Power analyses were conducted before beginning collections, and again post-collection. The pre-collection power analysis revealed a minimum total sample size of 10 participants (i.e. five males and five females) was necessary to achieve greater than 80% statistical power to detect a medium effect size. The post-collection power analysis revealed that the inclusion of 17 participants yielded a large degree of statistical power (98%), and thus the sample size was adequate for this study.

The participant pool was restricted to a convenience sample of current students at the University of Windsor. As a result, the mean age of the participants (22.1 ± 2.0 years) was lower than the mean age of the working population. This may limit the generalizability of this data to a workplace setting, and to the population as a whole since the strength of the association between age and neck pain peaks between the ages of 40-

59 years (Coté et al., 2009a). However, many students are employed at least part-time throughout their studies; they also spend a large amount of time seated at a desk or computer. Prolonged sitting and prolonged neck flexion are known risk factors for neck pain (Ariens et al., 2000, 2001). Therefore, the use of students as the participant group may still have provided a fair representation of the postures assumed and the risk factors encountered in the workplace. Expanding the scope of this cFRP research to include industry should be considered in the future.

The chair used in the seated posture was not height adjustable due to the fact that most adjustable chairs have wheels, and the influence of chair motion throughout a trial may have added unnecessary variability to the data. This being said, it is possible that the participants at the extremes of height may have had hip and knee angles that deviated from 90°. This may have changed their lumbo-pelvic postures, which may have changed baseline activity in postural muscles and possibly impacted some participants' abilities to achieve FRP. Future studies could employ a height adjustable chair with locking mechanisms on the wheels to investigate the effect of chair height on lumbo-pelvic angle. However, this did not appear to have an effect on the cFRP in the present study, as the individuals at either end of the height spectrum (tallest individual: 193.0 cm, and smallest individual: 157.5 cm) both exhibited FRP.

CHAPTER VI

CONCLUSIONS

The purpose of this study was to determine whether the cervical flexion relaxation phenomenon exists in standing, and whether it's kinematic and EMG parameters are modulated by trunk posture. It was confirmed that cFRP does occur during standing, and its kinematic and EMG parameters did not differ significantly with seated postures. This study also found that, while moderate unsupported trunk inclination modulated the cFRP, slumped postures did not. To date, very little research on the cFRP has been conducted. The findings of this exploratory study broaden the knowledge base in this largely under-researched area.

Based on the results of this study, the following conclusions can be drawn:

I) The flexion relaxation phenomenon was elicited from the cervical paraspinal muscles in both seated and standing postures, with approximately equal frequencies between the two postures.

II) The extension relaxation ratio (ERR) increased with a moderate trunk inclination angle (45°), in both seated and standing postures.

III) cFRP occurred sooner (i.e. at a smaller onset angle) with a moderate trunk inclination angle (45°), in both seated and standing postures.

IV) There was no effect of posture (sitting or standing) on the magnitudes of the ERRs or the onset angles.

V) The cessation angles showed little variability between sides, sexes, postures or conditions.

VI) cFRP was observed in seated and standing slumped postures.

VII) Slumped postures (whether seated or standing) had no effect on the kinematic (i.e. onset angles) or EMG (i.e. ERR) parameters of the cervical FRP.

Based on the results of this study, there are possible directions for future research:

I) Future cFRP research would benefit from the use of fine-wire, in-dwelling EMG electrodes rather than surface EMG. This would allow the researchers to target various individual paraspinal muscles specifically, rather than grouping them together as the "cervical paraspinal muscles". This could provide a more detailed analysis of how each muscle individually contributes to cFRP.

II) Future cFRP research may benefit from the investigation and quantification of the changes in moment arms from the centre of rotation of the neck to the vector representing the force of gravity acting on the centre of mass of the head; the effects these changes might have on cervical muscle activity, and how these will bring about changes in cFRP. If the relationship between the demands on the cervical muscles and changes in cFRP parameters can be defined, the effects of various postures and conditions could be anticipated. This may provide further insight into the mechanisms underlying occupational neck pain.

III) Investigating the time-varying presence of FRP during occupational tasks in industry is a possible direction in which to continue this work.

IV) Future work could investigate changes in cervical FRP parameters after participants maintain flexed or slumped postures for prolonged periods, to identify the development of creep in the posterior cervical ligaments as well as changes in the muscle activation patterns (e.g. Solomonow et al., 2003).

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APPENDICES

APPENDIX A

Research Ethics Board-approved Consent to Participate in Research

University of Windsor

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: Cervical flexion-relaxation phenomenon during upright standing and modulating effect of trunk flexion angle.

You are asked to participate in a research study conducted by Tara Diesbourg and Dr. Nadia Azar, from the Department of Kinesiology at the University of Windsor. This study will serve as Tara's Masters Thesis project.

If you have any questions or concerns about the research, please feel to contact Dr. Nadia Azar at 519.253.3000 ext 2473

PURPOSE OF THE STUDY

This research study will try to answer the following questions:

1) Does the Flexion-Relaxation Phenomenon (FRP) exist in the muscles of the neck?
2) Is the FRP in the neck affected by trunk flexion angle?

PROCEDURES

Participation in this study should require one visit lasting no more than 2 hours.
This study will involve the following components:

1) 8 pairs of electrodes will be attached over various muscle groups. These electrodes will be placed bilaterally on your abdomen, back, chest, shoulder, and neck. Reference electrodes will also be placed over your left shoulder blade and collarbone.

2) 3 electrogoniometers will be affixed to the skin over three spinal segments. These segments are located in your neck, your mid-back, and your low-back and the electrogoniometers will span these sections almost entirely.

3) Three main tasks will be performed to elicit maximal contraction from the muscle groups; (i) the abdominal muscle groups will be contracted against resistance during a modified bent-knee sit-up, (ii) the back muscles will be contracted against resistance during a back extension, (iii) the neck muscles via flexion and extension exercises

4) You will be asked to perform nine time-controlled trials involving some bending at the neck and hips, as well as some sitting and standing. These trials will be repeated three times each.

5) All of the exercises will be performed in a Kinesiology laboratory on campus of the University of Windsor.

POTENTIAL RISKS AND DISCOMFORTS

1) There is always a risk of muscle, joint or other injury in any physical task. However, the risks in this study are not anticipated to be greater than those encountered in the regular activities of daily living, manual work. You will be advised to terminate the testing session if you experience moderate discomfort or at any time feel that you can no longer continue.

2) Maximal voluntary contractions of the muscles will be performed in order to normalize the levels of muscular activity. Possible discomfort (muscle soreness or stiffness) could result from the tasks during the collection of data. However, none of the tasks should be of any greater risk than that involved with daily/work/exercise type activities. Any soreness/stiffness is normal and usually disappears in a few days.

3) Some individuals may experience mild skin irritation/redness from the tape and/or adhesive used to attach the electrodes and the electrogoniometers to your skin. This is similar to the irritation that may be caused by a bandage

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and typically fades within two to three days. The portable part of the electrical recording systems is battery operated and isolates the participant from the main electrical lines. There is no risk of electrical shock.

4) If the participant has an allergy or sensitivity to rubbing alcohol, we ask that this is indicated to the researchers. Rubbing alcohol will be used to clean the skin prior to electrode attachment. As this is a mandatory step in the procedure, the individuals will not be allowed to participate in the study.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

This study will measure the strain placed on the neck during various work-related tasks and the muscle activation patterns that are associated with it. The results of this study will be useful in the design/re-design of workplace tasks to ensure the safety of all employees involved.

PAYMENT FOR PARTICIPATION

There will be no payment for participation in this study.

CONFIDENTIALITY

Each participant will be assigned a randomly generated three-letter identification code known only to the primary researcher and therefore your identity can not be determined by anyone other than the primary researcher. When the results of the study are presented, personal information such as you name, age, height, weight, and gender will not be released. Only average age, height, and weight values per gender groups will be presented.

Following data collection and analysis, all data will be stored and retained indefinitely on secure computers to which only the primary researcher and assistants will have access. Raw data are valuable for future studies, and therefore the data collected in this study will not be destroyed. However, if future researchers use these data, only gender, age, weight, and height will be associated with the data, not your name. Your name and identification code will only be recorded by the primary researcher and will remain only with the primary researcher to insure confidentiality.

If you agree to the use of digital video and/or still image data, only censored photos or video data will be used in publications or presentations, where your face/head will be obscured to protect your identity. These data will also use the three-letter identification code, but will only be accessible by the primary researcher.

Each data collection session will be videotaped in order to assist data analysis. Please refer to the attached video-taping consent form for approving the videotape recording. If you do not wish to be videotaped you may withdraw from the study or you may proceed with the study and the collection session will NOT be videotaped

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don=t want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

The findings of this study will be made available if you are interested in the results. It is anticipated that the results will be available within one calendar year. Please contact Tara Diesbourg or Dr. Nadia Azar for further information

Date when results are available: **May, 2011**

SUBSEQUENT USE OF DATA

This data will be used in subsequent studies.

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH SUBJECT/LEGAL REPRESENTATIVE

I understand the information provided for the study ***Muscular activity during cervical flexion: Modulating effects of task-related postural constraints.*** as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

______________________________ ____________
Signature of Subject Date

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

APPENDIX B

ERR values for right and left CPS, for each participant. Bolded values are those that met all three criteria (ERR and FRR ≥ 1.1, confirmed by visual inspection), italicized values are those that met the criteria of ERR and FRR ≥ 1.1 but were rejected by visual inspection.

		Left CPS						Right CPS					
		Seated			Standing			Seated			Standing		
Participant #	Sex	Upright	Slumped	45°	Upright	Slumped	45°	Upright	Slumped	45°	Upright	Slumped	45°
1	F	**2.77**	**2.25**	**4.13**	*2.98*	**2.58**	**3.23**	**2.48**	**2.15**	**3.29**	**2.27**	**2.65**	**3.17**
1	F	*2.46*	**2.27**	**2.24**	3.24	**3.04**	**3.54**	**2.15**	**2.24**	**2.17**	**1.89**	**2.63**	**3.06**
1	F	**2.36**	**2.61**	**4.29**	*2.40*	**2.34**	**4.87**	**1.76**	**2.20**	**4.70**	**2.02**	**2.04**	**4.07**
2	F	1.06	1.05	1.05	1.06	1.07	1.06	1.02	1.01	1.02	1.03	1.05	1.04
2	F	1.05	1.04	1.05	1.03	1.05	1.03	1.06	1.03	1.03	1.02	1.04	1.06
2	F	1.03	1.04	1.04	1.07	1.06	1.07	1.04	1.03	1.05	1.06	1.00	1.04
3	F	1.09	1.07	1.11	1.06	1.13	1.07	1.08	1.15	1.19	1.08	1.10	1.02
3	F	1.06	1.13	1.13	1.13	1.12	*1.14*	1.04	1.14	1.18	1.02	1.13	*1.17*
3	F	1.08	1.13	1.16	1.07	1.09	1.15	1.11	1.15	1.20	1.05	1.11	1.21
4	M	1.05	1.02	1.09	1.04	1.03	1.05	*2.20*	**1.89**	**3.23**	**1.91**	1.63	**2.84**
4	M	1.03	1.07	1.07	1.09	1.03	1.05	**2.45**	**2.12**	**1.93**	**2.20**	**2.17**	**3.22**
4	M	1.05	1.05	1.03	1.07	1.07	1.04	**1.80**	**2.16**	**3.44**	**2.02**	**2.00**	**3.69**
5	M	*3.70*	3.32	*4.91*	3.34	2.69	**2.87**	*1.87*	*2.92*	*4.40*	**2.40**	**4.29**	*2.56*
5	M	**3.43**	2.83	1.87	**2.11**	3.54	*3.39*	**3.25**	*3.17*	2.09	**1.74**	2.53	*3.95*
5	M	2.24	2.78	*3.70*	*2.72*	4.23	*3.68*	**3.13**	*2.91*	**3.56**	*2.07*	*4.52*	**3.35**
6	F	*1.95*	**4.68**	**3.96**	**2.98**	**3.52**	**3.33**	**1.65**	**3.82**	**3.21**	**3.25**	**3.32**	**3.04**
6	F	**2.75**	**3.71**	**3.04**	1.58	**4.17**	**3.53**	**2.33**	**2.76**	**2.85**	1.61	**3.84**	**3.51**
6	F	**2.84**	**3.74**	**2.95**	**2.78**	**3.13**	**3.36**	**2.19**	**3.58**	**2.14**	**2.74**	**2.90**	**2.98**
7	F	*1.17*	1.39	*1.41*	1.35	*1.40*	1.29	1.06	1.06	1.33	1.07	1.10	1.06
7	F	*1.36*	1.45	1.26	1.33	1.36	1.36	1.07	1.11	1.12	1.09	1.11	1.40
7	F	1.45	1.25	1.26	1.24	**1.48**	1.32	1.08	1.09	*1.44*	1.06	1.14	1.12
8	M	1.22	1.16	1.40	1.49	0.67	1.24	1.83	*1.10*	1.12	1.58	0.40	*1.43*
8	M	1.01	1.73	0.96	1.08	1.16	1.13	1.07	1.70	0.62	1.01	0.82	*1.28*
8	M	1.02	1.26	1.29	1.11	0.73	1.59	0.90	0.86	1.35	1.13	0.52	1.42
9	F	1.10	1.30	1.53	1.21	1.31	1.24	2.94	2.84	**5.98**	**2.27**	3.58	**3.79**
9	F	1.12	1.41	*1.21*	1.19	1.20	*1.24*	**2.34**	4.59	2.85	**2.24**	2.68	*3.46*
9	F	1.04	*1.22*	*1.32*	*1.12*	1.32	1.26	1.94	2.87	**3.39**	**1.94**	3.69	2.85
10	F	1.59	**2.20**	2.22	**3.12**	1.59	*4.20*	**2.05**	**2.78**	**2.86**	*2.74*	**2.74**	**4.06**
10	F	1.85	**2.11**	2.16	**2.96**	*2.42*	*2.38*	*1.94*	**2.51**	**3.96**	2.21	**3.00**	**3.34**
10	F	*1.39*	**2.49**	2.57	**2.49**	*1.92*	3.70	*2.31*	*2.59*	**3.20**	*2.31*	**2.07**	**4.58**
11	F	1.30	1.92	**2.93**	*1.72*	*1.85*	**2.58**	1.35	2.09	2.85	1.83	1.73	1.75
11	F	*1.58*	1.63	**1.76**	1.70	1.94	**2.35**	1.58	1.61	2.08	1.78	*2.65*	2.31
11	F	**2.00**	**1.85**	**3.41**	**2.01**	**2.62**	**1.64**	2.01	1.84	**2.90**	2.02	1.52	1.87
12	F	1.50	2.21	1.72	**1.59**	*1.39*	1.46	1.54	1.23	1.42	**1.92**	1.49	*1.44*
12	F	*1.54*	1.89	1.67	**2.70**	1.78	1.89	*1.21*	*1.41*	*1.30*	**1.83**	*1.42*	1.18
12	F	**1.67**	1.99	**3.03**	*2.49*	1.93	1.80	*1.45*	1.35	**2.32**	**1.84**	*1.45*	*1.33*
13	M	1.11	0.82	1.35	0.49	1.06	*1.37*	1.01	0.74	1.37	0.50	0.98	*1.15*
13	M	1.02	1.07	1.32	0.88	1.21	1.34	0.95	1.23	1.89	0.99	0.95	1.78
13	M	1.18	1.02	*1.69*	0.87	*1.49*	*1.44*	0.94	1.07	1.34	0.92	1.32	1.09
14	M	*2.79*	1.05	1.16	1.32	**1.32**	*2.26*	*2.92*	1.03	1.18	1.58	1.48	*2.43*
14	M	*1.14*	1.41	*1.31*	*1.21*	*1.66*	1.27	1.34	1.21	1.26	1.37	1.76	1.20
14	M	*1.96*	1.23	*1.49*	*1.40*	*1.29*	1.53	2.13	1.12	1.46	1.43	1.40	1.87
15	M	**3.05**	1.35	**1.87**	**1.44**	1.57	0.92	2.31	1.13	1.04	1.01	1.03	1.06
15	M	**2.19**	**1.93**	**2.27**	**1.60**	1.48	**2.37**	*1.23*	0.99	*2.26*	*1.68*	1.06	0.99
15	M	**2.72**	**2.25**	**1.70**	**2.59**	*1.69*	1.36	*1.62*	1.08	1.06	1.08	1.13	0.93
16	M	**2.52**	*2.94*	**3.46**	*2.35*	*3.16*	3.28	*1.75*	*2.20*	**2.21**	*1.38*	**1.84**	**2.59**
16	M	*2.41*	**3.03**	**2.59**	*2.27*	3.00	**3.87**	1.80	*2.05*	**1.79**	*1.48*	**2.26**	**2.33**
16	M	**2.44**	**2.73**	**3.50**	**3.02**	2.64	3.42	*1.59*	**1.99**	**2.13**	**1.75**	**2.07**	**2.62**
17	M	**2.21**	**1.89**	*1.78*	1.41	**2.28**	**1.84**	1.77	**1.90**	**3.77**	1.25	**6.15**	**1.88**
17	M	**2.14**	1.65	**2.59**	*1.87*	1.77	1.83	**1.83**	**1.90**	**2.50**	*1.68*	**1.78**	**1.89**
17	M	1.73	**1.92**	**2.26**	*2.14*	1.53	**2.18**	1.45	*1.68*	**5.53**	*1.68*	1.61	**2.19**

APPENDIX C

Cervical angles in Phase 1 of the cervical flexion task (i.e. starting postures).

		Cervical Goniometer Angle (°)					
		Upright		Slumped		45°	
Participant #	Sex	Seated	Standing	Seated	Standing	Seated	Standing
1	F	-4.4	-0.2	-32.9	-26.3	-22.3	-28.2
1	F	-1.4	-4.5	-36.9	-24.3	-30.7	-37.4
1	F	-3.1	-2.5	-34.2	-40.2	-23.7	-39.4
2	F	-2.9	-8.2	-19.1	-9.9	-15.3	-19.6
2	F	-6.8	-8.8	-28.7	-17.4	-16.7	-14.4
2	F	-9.7	-10.7	-15.1	-4.6	-14.9	-16.1
3	F	-3.6	-4.1	-28.7	-12.8	-7.9	-13.9
3	F	5.9	-1.4	-25.1	-14.0	5.0	-10.9
3	F	1.6	-3.0	-24.4	-8.8	-3.1	-6.1
4	M	0.3	-7.8	-1.2	3.5	-5.4	3.5
4	M	-6.1	-4.3	-13.6	-0.7	-6.2	-1.6
4	M	-3.9	-6.0	-8.7	-0.2	2.9	-6.6
5	M	-2.8	2.4	-13.3	-3.7	-3.5	19.4
5	M	-3.9	-1.2	-23.8	-1.6	-14.9	-19.0
5	M	-4.0	0.6	-21.5	-11.0	-17.1	-21.5
6	F	-1.6	0.6	-19.1	-19.1	-15.8	-18.5
6	F	1.4	3.6	-14.2	-17.1	-10.0	-29.5
6	F	2.4	5.8	-17.9	-15.4	-9.0	-19.3
7	F	-27.6	-24.3	-35.4	-28.2	-29.9	-15.5
7	F	-25.3	-26.6	-43.9	-24.6	-31.5	-23.4
7	F	-28.4	-25.5	-45.9	-38.8	-22.9	-23.2
8	M	-38.6	-30.4	-31.9	-22.1	-36.7	-44.8
8	M	-41.9	-45.1	-33.8	-24.9	-44.4	-54.2
8	M	-30.8	-45.9	-33.3	-28.9	-40.3	-54.9
9	F	-0.5	-0.5	-36.5	-10.1	-25.7	-16.5
9	F	-2.1	0.3	-32.3	-12.4	-25.5	-13.2
9	F	-2.0	0.7	-37.1	-20.1	-29.5	-24.2
10	F	-3.7	0.9	-8.7	-5.4	-19.3	-4.2
10	F	-7.1	0.4	-14.9	-3.6	-24.6	-14.7
10	F	-3.7	-1.9	-17.9	-8.3	-24.6	-10.1
11	F	8.6	10.4	-3.8	0.8	13.7	-3.5
11	F	8.4	10.6	-11.7	1.4	0.2	-7.9
11	F	8.9	7.1	-4.7	3.9	2.2	-2.4
12	F	0.1	3.1	-11.9	-11.9	-22.1	-16.8
12	F	1.6	0.8	-9.8	-10.2	-23.2	-23.9
12	F	0.1	2.5	-17.3	-8.2	-19.8	-30.0
13	M	-12.0	-15.4	-22.4	-22.6	-14.9	-33.3
13	M	-15.8	-19.0	-32.0	-17.8	-30.6	-32.9
13	M	-15.4	-19.6	-23.0	-20.4	-27.0	-22.0
14	M	-17.8	-14.0	-18.3	-20.1	-19.0	-24.5
14	M	-16.1	-17.8	-34.5	-26.6	-23.9	-27.5
14	M	-17.8	-16.5	-26.4	-16.5	-23.5	-25.3
15	M	11.5	-5.9	-3.5	-11.3	-14.0	-15.7
15	M	7.8	7.4	-11.0	-13.9	-6.6	-7.6
15	M	5.3	4.8	-10.9	-2.3	-6.0	-2.9
16	M	-6.9	-6.3	-8.4	-11.3	-9.4	-14.2
16	M	-7.4	-6.5	-10.9	-9.7	-6.9	-10.6
16	M	-5.4	-6.1	-10.4	-7.2	0.1	-6.0
17	M	-1.1	1.4	-10.8	-2.0	-23.3	-20.4
17	M	6.2	-1.4	-1.6	-0.1	-19.4	-18.5
17	M	1.9	3.1	-3.2	-1.3	-21.5	-11.2

APPENDIX D

Thoracic angles in Phase 1 of the cervical flexion task (i.e. starting postures).

		Thoracic Goniometer Angle (°)					
		Upright		Slumped		45°	
Participant #	Sex	Seated	Standing	Seated	Standing	Seated	Standing
1	F	-3.1	4.0	19.0	20.0	9.6	14.8
1	F	-0.6	5.5	20.0	18.3	14.7	17.7
1	F	3.7	3.0	20.1	18.1	13.6	12.2
2	F	4.1	21.1	11.5	29.2	8.3	5.4
2	F	6.2	21.5	18.0	27.5	10.1	4.9
2	F	0.5	14.6	12.6	29.3	6.6	8.4
3	F	12.3	23.8	22.0	32.2	16.6	19.9
3	F	15.2	22.9	22.0	32.4	15.3	19.0
3	F	17.0	21.5	18.5	30.7	16.7	21.4
4	M	24.0	35.3	42.2	29.5	27.7	29.5
4	M	22.6	31.0	39.1	42.4	26.0	30.8
4	M	23.6	37.1	37.8	43.9	26.8	27.9
5	M	3.4	13.1	20.9	22.3	22.0	2.9
5	M	2.2	9.6	22.0	23.7	9.6	4.7
5	M	6.0	11.4	20.6	24.8	14.5	6.3
6	F	7.9	6.7	20.6	26.4	14.8	11.3
6	F	10.6	3.5	25.0	25.9	13.2	9.9
6	F	5.9	8.4	20.2	25.9	16.6	6.4
7	F	25.0	27.7	34.6	36.4	23.4	33.9
7	F	24.2	29.1	35.0	38.4	25.2	27.8
7	F	23.6	27.1	34.3	36.4	25.5	30.7
8	M	17.3	30.0	32.2	38.0	22.3	23.1
8	M	26.4	32.6	28.6	37.5	34.0	25.2
8	M	23.1	30.4	31.9	37.2	34.2	23.7
9	F	14.6	25.7	41.3	36.0	32.2	27.5
9	F	14.1	23.0	42.6	38.6	34.1	22.0
9	F	18.0	18.4	42.7	38.4	32.0	27.6
10	F	15.7	23.3	22.7	34.2	21.4	18.9
10	F	16.2	24.0	23.3	32.9	26.9	22.8
10	F	18.0	24.0	27.6	33.6	21.3	21.6
11	F	8.9	13.3	21.8	22.7	16.1	23.6
11	F	10.5	14.9	23.1	23.1	18.6	22.9
11	F	9.8	12.4	22.6	21.6	22.9	21.8
12	F	1.5	10.9	2.6	20.3	-1.1	4.9
12	F	3.2	12.9	4.1	20.6	3.4	3.3
12	F	4.6	9.9	15.7	18.7	1.0	0.1
13	M	0.3	11.6	14.8	17.9	3.9	10.9
13	M	2.5	8.7	17.9	16.6	4.3	15.3
13	M	0.7	3.7	17.5	17.2	7.9	9.5
14	M	22.8	24.2	20.6	29.6	17.5	20.1
14	M	20.9	23.5	24.2	18.6	19.7	25.7
14	M	21.9	22.3	22.4	26.6	17.9	18.3
15	M	15.2	30.3	26.7	34.3	19.4	24.7
15	M	17.0	28.9	29.8	34.2	18.0	29.0
15	M	15.7	29.6	28.5	32.3	22.0	26.4
16	M	17.8	19.7	21.0	31.2	17.2	17.9
16	M	17.2	22.9	20.8	29.5	17.3	20.0
16	M	18.2	23.0	21.4	27.5	20.2	22.1
17	M	26.4	30.5	31.1	33.2	28.3	27.7
17	M	24.4	24.9	26.2	32.5	27.8	24.9
17	M	29.2	28.2	24.0	34.0	26.3	24.3

APPENDIX E

Lumbar angles in Phase 1 of the cervical flexion task (i.e. starting postures).

		Lumbar Goniometer Angle (°)					
		Upright		Slumped		45°	
Participant #	**Sex**	**Seated**	**Standing**	**Seated**	**Standing**	**Seated**	**Standing**
1	F	-7.5	-17.7	-16.1	-21.6	13.3	5.5
1	F	-12.1	-18.7	-7.0	-22.6	9.1	3.4
1	F	-7.1	-27.1	-14.1	-24.3	9.3	3.4
2	F	-0.7	-31.7	13.2	-12.1	13.0	-4.3
2	F	-6.7	-31.2	13.0	-15.8	14.2	-4.3
2	F	4.2	-26.7	13.1	-16.3	12.2	-4.2
3	F	-4.7	-31.9	8.4	-35.7	6.0	-6.4
3	F	-7.8	-32.3	9.3	-35.9	4.6	-5.4
3	F	-7.1	-31.2	7.6	-38.9	4.8	-6.3
4	M	13.8	-10.4	7.3	5.0	17.2	5.0
4	M	12.6	-8.2	17.6	-15.7	16.4	5.2
4	M	12.4	-10.2	16.4	-15.7	16.5	4.7
5	M	12.6	-7.3	18.4	-9.9	17.9	12.8
5	M	10.8	-6.5	-17.7	-17.3	17.7	7.5
5	M	14.0	-6.9	17.9	-15.0	19.1	2.3
6	F	9.8	-8.0	12.1	0.9	11.3	10.3
6	F	7.4	-7.0	11.5	-2.2	11.8	9.7
6	F	7.4	-8.0	12.9	-1.9	12.5	8.2
7	F	0.3	-31.6	2.4	-25.0	6.8	-14.6
7	F	3.1	-28.1	4.5	-40.8	6.1	-15.1
7	F	3.8	-28.1	4.8	-30.9	6.3	-13.5
8	M	14.8	-8.4	15.5	-10.5	14.9	17.0
8	M	9.9	-7.7	14.9	-11.6	15.0	17.8
8	M	7.5	-7.9	13.4	-9.5	16.9	16.5
9	F	-4.4	-38.0	0.9	-31.9	7.2	-8.1
9	F	-5.9	-35.3	0.6	-24.6	7.2	-9.1
9	F	-7.8	-36.5	-3.5	-26.1	6.8	-9.6
10	F	-2.5	-40.2	-1.8	-30.3	1.5	-1.3
10	F	-5.9	-39.3	-0.2	-40.8	1.8	-15.1
10	F	-8.8	-40.9	-0.9	-38.6	1.7	-15.1
11	F	-12.2	-48.2	1.6	-44.1	2.0	-8.2
11	F	-11.7	-43.7	1.7	-47.6	2.9	-8.7
11	F	-7.1	-45.3	-4.3	-48.9	5.1	-8.3
12	F	-3.0	-33.3	8.0	-34.6	10.0	7.6
12	F	-4.4	-32.4	5.7	-33.7	12.0	9.7
12	F	-5.2	-31.4	-3.4	-39.1	10.8	10.0
13	M	-0.3	-24.6	0.8	-29.1	5.5	-2.7
13	M	0.8	-27.5	-0.8	-27.7	4.6	-1.1
13	M	-0.6	-24.1	-5.2	-27.6	3.6	-3.3
14	M	13.4	-15.0	19.6	-12.6	23.2	16.7
14	M	11.4	-10.9	21.1	22.4	21.1	15.5
14	M	12.4	-14.1	20.4	-11.8	22.8	15.7
15	M	-5.7	-30.9	3.3	-31.7	0.5	-4.6
15	M	-4.3	-30.1	1.8	-32.9	-0.6	-4.7
15	M	-4.1	-30.7	0.2	-26.2	-1.1	-5.7
16	M	17.4	-0.7	19.6	-5.1	20.4	9.6
16	M	15.4	-2.8	17.9	-4.9	20.3	8.6
16	M	15.2	-3.5	23.1	-3.5	18.9	7.4
17	M	2.4	-12.5	11.3	-10.3	19.3	12.9
17	M	9.1	-7.3	15.6	-9.8	15.7	12.7
17	M	1.2	-9.0	15.6	-10.3	16.1	13.3

VITA AUCTORIS

Having grown up in Essex County, Tara Diesbourg attended École Élémentaire Saint Michel and moved on to attend Cardinal Carter Catholic Secondary School in Leamington, Ontario. She has always had a passion for medical sciences and had always dreamed of someday becoming a doctor. She followed her passion and combined it with her love for sports when she enrolled in the Honours Bachelor of Human Kinetics program at the University of Windsor in Windsor, Ontario. In second year, she was given the opportunity to take part in the co-operative education program which provided her with experience in several fields including chiropractic care, rehabilitation, recreation therapy, and special needs care.

Tara decided that while she had clinical experience, she was lacking research experience. This led her to enroll in the Masters of Human Kinetics program at the University of Windsor. It was then that her passion for research began to emerge. She is now enrolled as a PhD student at Queen's University, pursuing a doctoral degree in Biomechanics. Her areas of interest include forces and mechanisms that cause injury in the tissues of the neck and back with a specific focus on the Flexion Relaxation Phenomenon (FRP) which she plans to broaden by introducing different populations to her subject pool. Tara is currently working on several manuscripts focusing on FRP in the lumbar spine in coupled postures, as well as a manuscript focusing on standardizing postures for future studies using a slumped posture.

Conference presentations include:

Diesbourg, T.L., Drake, J.D.M., Azar, N.R. (2011) Cervical flexion relaxation phenomenon during upright standing and the modulating effect of trunk flexion angle. Ontario Biomechanics Conference (Not Peer Reviewed). March, 2011.

Diesbourg, T.L., Azar, N.R., Drake, J.D.M. (2011) Standardizing slumped postures for males and females in sitting and standing. Ontario Biomechanics Conference (Not Peer Reviewed). March, 2011.

Diesbourg, T.L., Drake, J.D.M., Axar, N.R. (2010) Effect of coupled postures on lumbar muscle activity: Does the flexion relaxation phenomenon persist? Canadian Society for Biomechanics Biennial Conference (Peer Reviewed). June, 2010)