ALTERATIONS IN NECK MUSCLE PERFORMANCE AND PRIOPRIOCEPTION WITH FATIGUE, ALTERED POSTURE AND RECURRENT NECK PAIN

By

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A thesis submitted in partial fulfillment of the requirements for the degree of

Masters of Health Sciences

University of Ontario Institute of Technology

July 2011

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ALTERATIONS IN NECK MUSCLE PERFORMANCE AND PROPRIOEPTION WITH FATIGUE, ALTERED POSTURE AND RECURRENT NECK PAIN

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ALTERATIONS IN NECK MUSCLE PERFORMANCE AND PROPRIOCEPTION WITH FATIGUE, ALTERED POSTURE AND RECURRENT NECK PAIN

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Abstract

Altered neuromuscular processing and motor output as both a risk and perpetuating factor for chronic neck pain is a relative new area of study. The cervical flexion relaxation response (FRR) is a reproducible and reliable marker of differences in neuromuscular function between neck pain patients and controls. Change in joint position sense (JPS) of upper limb joints has also been linked to chronic neck pain. Studies in this thesis sought to develop an experimental model in humans to investigate whether the FRR and JPS can be altered by fatigue and/or postural stress. Additionally a pilot study on the effect of three months of chiropractic treatment on the FRR was conducted. The studies revealed that muscular fatigue is a modulator of the FRR and may play a large role in spine stabilization. Minor postural alterations in the neck can impact joint position error at the elbow and 12 weeks of chiropractic care is a useful therapy to improve chronic and recurrent neck pain as well as improving the cervical FRR.

Keywords
Cervical Flexion Relaxation Ratio (Response), Fatigue, Joint Position Sense, Manipulation, Neck Pain
Statement of Originality
I hereby declare that this thesis is, to the best of my knowledge, original, except as acknowledged in the text, and that the material has not been previously submitted either in whole or in part, for a degree at this or any other University.
Acknowledgements

Thank you to my supervisor Dr. Bernadette Murphy whose guidance and support has been an integral part of where I am today. Your knowledge and experience was invaluable. I am truly grateful for all your help and encouragement.

To the chiropractors, Dr. Kelly and Kevin McAllister and Dr. Tarrah Sloane. Your time and dedication made this study happen. It would not have been as successful without you, Thank you!

To Sergiy Kudryavtsevith, your help with troubleshooting and setup of the subjects kept everything running smoothly and your sense of humor kept me relaxed throughout it all.

To all the subjects who so willingly took part in my studies, thank you. It could not have happened without you.

Lastly, to my family and friends, thank you so much for the love and support. You have helped to shape me into the person I am today and I am thankful that you are all a part of my life.
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Abbreviations

Absolute Error – AE
Activities of Daily Living – ADL
Analysis of variance – ANOVA
Cervical Extensors – CE
Chronic Low Back Pain – CLBP
Constant Error – CE
Flexion Relaxation Response – FRR
Joint Position Sense – JPS
Left and Right Cervical Extensors – LCE and RCE
Low Back Pain – LBP
Maximum Voluntary Contraction – MVC
McGill Pain Questionnaire – MPQ
Median Frequency – MedF
Mental Component Score – MCS
Neck Disability Index – NDI
Neck Pain – NP
Personal Digital Assistant – PDA
Physical Component Score – PCS
Present Pain Index – PPI
Root Mean Square – RMS
Seconds – s
Short Form 36 Questionnaire – SF-36
Short Form Pain Questionnaire – SF-MPQ
University of Ontario Institute of Technology – UOIT
Variable Error - VE
Visual Analogue Scale – VAS
Introduction

Chronic low back pain (CLBP) and neck pain (NP) are common medical problems in industrialized countries. Increases in technological usage, more specifically the use of computers when combined with increasing sedentary lifestyles, have given rise to a high incidence of chronic non-specific NP. Estimated occurrence of CLBP and NP are 60%-85% and approximately 67%, respectively[1]; [2]. Complex neuromuscular systems involving both active (muscle) and passive (vertebral bones, intervertebral disks, ligaments, tendons, and fascia) components help to govern movements in the cervical spine, including flexion and extension [3].

An emerging thought on the mechanisms that lead to musculoskeletal pain becoming chronic pain are alterations in the patterns of muscle activation following the original injury. For example, research on low back pain (LBP) has verified that during full trunk flexion individuals with LBP have an inability to display a flexion-relaxation response (FRR) [4, 5]. The term flexion-relaxation was first introduced by Floyd and Silver (1951) [6] and refers to a sudden onset of myoelectric silence in the erector spinae (ES) muscles of the back during standing, full forward flexion. Similarly, it appears that the absence of the myoelectric silence found in the cervical paraspinal muscles can be used as a marker to differentiate between healthy individuals and those with NP[7]. A recent study by Murphy & Marshall et al.[8] demonstrated high reliability as well as the ability of the FRR to discriminate NP patients from healthy controls. What has not been assessed in most NP intervention studies is whether the treatment is able to affect neuromuscular function. Research needs to examine what treatments can be used to improve the neuromuscular function and therefore decrease pain and disability in the
neck. There is only one study investigating the effect of neck treatment on the cervical FRR, but this included only a 4 week period of chiropractic care prior to an exercise intervention\cite{8}.

Additionally, there are no experimental studies attempting to create a model of how treatment may affect the FRR. The FRR is able to differentiate between patients with and without chronic or recurrent neck pain\cite{8}. As such it appears to be a marker of altered neuromuscular function. Chiropractors conventionally treat areas of joint dysfunction\cite{9}, which includes pain and muscle spasm as well as decreased mobility of the affected segments\cite{10, 11}. Patients often complain that their muscles feel fatigued or that their head feels heavy on their neck\cite{12}. An experimental model in humans to investigate whether the FRR can be altered by fatigue and postural stress would provide further insight into the mechanisms by which treatment may affect the FRR. It may also facilitate the understanding of the mechanisms underlying the development and perpetuation of spinal instability, chronic pain, and joint dysfunction in the cervical spine.

Another marker of altered neuromuscular function, in chronic neck pain patients is altered proprioception\cite{13} Proprioception is commonly used to describe the sensory feedback ascending towards the CNS generated by afferent receptors which provides orientation information about movement and position of the joints and muscles\cite{14}, an essential component of postural control\cite{15}. Proprioception is an important contributor to the neuromuscular control of movement \cite{16}. Joint position sense is one aspect of proprioception that relates to our awareness of joint angles and it can be measured experimentally by a subject’s ability to reproduce a joint position once it has been perturbed by the experimenter\cite{17}. A change in proprioception is one of the identified
problems in people with NP\cite{13}. The CNS builds an internal reference frame (body schema) from signals provided by proprioceptors\cite{13}, and this sensory information can be altered by changing the position of the head and neck. Perception of head position appears to play a large role in the organization of sensory information as shown by Knox and Hodges \cite{18, 19} revealing that perceived head and neck position affects the perceived positioning of the elbow joint. Research has suggested that maladaptive changes in proprioception and motor control are responsible for the individual subject’s symptoms and functional disturbances more so than the actual pain itself in those suffering from chronic long-term pain conditions\cite{13, 20}.

The research included in this thesis attempts to further our understanding of the neurophysiological changes that occur in neck pain. It includes experimental studies designed to extend our understanding of factors influencing joint position sense (JPS) and the cervical FRR in healthy subjects. It also includes a small pilot study to determine if three months of chiropractic care can influence the cervical FRR.

The aim of the clinical cervical FRR study was to use the cervical FRR as a marker for improved neuromuscular function. The following questionnaires were used to determine the deficits in NP patients; Neck Disability Index (NDI), Short Form 36 Questionnaire (SF-36), The Short Form McGill Pain Questionnaire, and Visual Analogue Scale (SF-MPQ).

Two experimental studies were also conducted to determine if the cervical FRR could be used as a marker for neuromuscular function which is experimentally
manipulated by fatigue interventions or whether it can be linked to clinical markers such as (JPS).

The aims of the experimental fatigue study was to determine whether exhaustion of the cervical muscles would alter the cervical FR ratio as well as alter the timing of the phases of the cervical FRR and what the impact of fatiguing the cervical extensor musculature had on recreating a previously presented angle at the elbow in a neutral head position. The experimental JPS study examined the affects that altered neck postures (flexion, flexion and rotation) had on recreating a previously presented angle at the elbow when compared to a neutral control position.

**Hypotheses**

**Clinical Study**

1. Three months of chiropractic care will significantly improve the cervical FRR ratios.

**Experimental Studies**

**Fatigue**

1. Maximal exhaustion of the cervical extensor musculature will alter the timing of the relaxation phase of the cervical FRR.

2. Fatiguing the cervical musculature will negatively impact the ability to reproduce a previously presented angle at the elbow.

**Joint Position Sense**

1. Altering the position of the head and neck will negatively impact the ability to reproduce a previously presented angle at the elbow.
Overview

The following research project is divided into three sections:

1. The literature review, with emphasis on:
   a. Internet Usage Amongst Canadian Households
   b. The Flexion Relaxation Response
   c. Muscle Fatigue
   d. Proprioception and Joint Position Sense
   e. Theoretical Models
   f. Strengths, Limitations, and Gaps in the Research

2. A manuscript for each specific study in the format specified for submission to SPINE.

3. All Figures and Tables

4. Appendices that include Advertisement Poster and Questionnaires
Section 1: Literature Review
Internet Usage Amongst Canadian Households

In industrialized countries, a majority of individuals have access to and frequently use computers/laptops, cell phones, personal digital assistants (PDA), and video games at work, school and in their personal lives. This increased use of technology can place a large strain on the paraspinal muscles of the neck as a result of constant cervical flexion.

A survey of characteristics of Canadian individuals using the internet by location and access was conducted by Statistics Canada and showed an increase of 12.4% (67.9 to 80.3%) of individuals using the internet from 2005-2009[21]. Internet locations were either at home, school, work, public library or other. These numbers were taken from a wide range of demographics including: (i) Household type (ii) Sex (iii) Age (iv) Level of education (v) Personal income quartile. Of these groupings both males and females under the age of 34 with a University degree in the highest quartile for income were among those using the internet the most (Table 1)[21]. Similarly, in 2000, approximately 4.7 million households in Canada were connected to the internet. Of these 4.7 million, 71% reported that at least one individual in the household was accessing the internet at least seven times per day[22].

The Cervical FRR

The experimental measure of the cervical FRR is an important point of interest because of the lack of research completed in the area. The FRR of the lumbar spine has been heavily researched [4-6, 23-26] as well as the effects of various therapeutic interventions [1, 4, 5]. The FRR however, has not been well studied in the cervical spine. The cervical FRR has been suggested to be a marker for altered neuromuscular function and can be used to discriminate between healthy and NP populations[8]. If an altered FRR can differentiate between NP patients and controls it may also be a marker of altered
neuromuscular function, which can be used to better understand the best form of intervention needed to diagnose and treat NP populations.

Complex neuromuscular systems involving both active (muscle) and passive (vertebral bones, intervertebral disks, ligaments, tendons, and fascia) components help to govern movements in the lumbar spine, including flexion and extension [3]. Based on biomechanical models of the spine, it has been proposed that spinal stabilization is the result of highly-coordinated muscle activation interacting with passive elements. [27] Instability of the lumbar spine has been suggested to be both a cause and a consequence of LBP.[27] The mechanisms underlying the FRR have been proposed to represent a shift in load-sharing and spinal stabilization from active structures to passive ligamentous and articular structures [24] [28]. Tension in the posterior ligaments and zygapophysial joints increases during trunk flexion to a level where the active extension moment generated by the posterior muscles of the spine is no longer needed [3]. This neuromuscular response is likely to be triggered by a growing mechanical load in the ligaments and disks of the lumbar spine.

Knowledge of the transfer of tissue loads in trunk and cervical flexion will help aid in the understanding of the mechanisms of injury, the biomechanics of normal trunk and cervical flexion, and the consequential pathogenesis of LBP and NP [3]. The majority of studies examining the lumbar FRR show an increase in load or a change in posture can delay the appearance of the FRR [23, 24, 29-31]. In a study by Murphy & Marshall (2006)[5], improvements in the FRR were attributed to improved relaxation rather than increases in the activity measured during the active movement phases,
providing support to a study by Neblett & Mayer et al. (2003) who found the same change after an exercise intervention.

**Phases of FRR**

Three major phases of movement in the FRR protocols of the cervical and thoracic spine (flexion, relaxation, and re-extension) are described in the literature. An upright anatomical starting position, (phase 1) (Figure 1a). Full flexion of the neck where the subjects chin rests on their chest (manubrium) (phase 2). When the head is maintained in full flexion, this is considered the relaxation moment (Figure 1b); where in healthy individuals we see the presence of the FRR. Lastly, a re-extension of the neck to the starting position (phase 3) (Figure 1c). The above phases are considered one movement trial when determining FRR. sEMG data is collected bilaterally throughout the trial with electrodes placed over the cervical extensor musculature, thus, allowing researchers to analyze the myoelectrical activity on the left and right sides of the body.

**Criteria Defining FRR**

A number of methods have been used to determine the presence or absence of the FRR. From the articles obtained in this review, the criteria used to define the FRR were as follows: (i) Decreased muscle activation in phase 3 in comparison to phase 1 when visually or statistically analyzed.[32-35] (ii) Phase 3 muscle activation <3% of maximum voluntary contraction (MVC) or >1% MVC. [36] (iii) Phase 3 muscle activation <10% of peak muscle activation during the final phase back at neutral position[37] and lastly, (iv) a ratio of phase 3 or phase 1 / phase 2 muscle activation < 2. [33, 38, 39]

**Seated Postures of FRR**

A study by Black et al. (1993) [23] provided evidence that a variation of lumbar seated positions (comfortable, slouched, erect, forward inclined) may lead to differences
in cervical spine postures. Moreover, a significant difference in the motor activation of the trunk muscles of individuals with LBP has been reported when subjects are placed in a variety of lumbo-pelvic sitting postures.[34] This research has guided recent studies on cervical FRR to standardize the subjects in a neutral spine posture with support at the lumbar and lower thoracic spine, thus eliminating possible variability of onset and cessation angles of participants performing full flexion tasks at the cervical spine (Figure 2) [8, 32, 33, 40].

The myoelectric silence of the lumbar spine extensors muscles during a neutral upright standing or seated position has been researched by a number of biomechanical and clinical studies.[1, 41, 42] Recent research has begun to look at the same phenomenon in the cervical neck of those with NP.[8, 32, 33, 40] Activities of daily living (ADL) include a number of common movements that incorporate both full trunk and cervical flexion. Pain related fear and avoidance appears to be a large factor in the development of musculoskeletal pain becoming a chronic issue[43]. Constant activation of lumbar ES musculature among LBP patients represents the body’s attempt to stabilize the spinal structures protecting them from further injury and pain.[3] It has been suggested that neuromuscular control of spinal stability may be limited following prolonged flexion. [33, 44]

The onset and cessation of myoelectrical silence of the FRR is influenced by a number of factors including the velocity of flexion and extension, the coordination of the trunk and hip movements or the general laxity of the joints. Similarly, variables such as data analysis and interpretation, normalization techniques, patient population, recording
techniques, and protocols for task performance contribute to the differences seen between studies examining the FRR.[3, 24]

**Reliability and Reproducibility of FRR**

Watson et al.[39] developed a reliable and repeatable way of monitoring changes in the FRR between those suffering from CLBP and a healthy control group. The CLBP group demonstrated significantly higher myoelectric activity during forward flexion than healthy control subjects, [1, 33, 38] confirming that it is possible to determine the difference between CLBP patients and a healthy control by using FRR analysis. In a recent study by Murphy et al.[8] their results suggest that FRR can also be a useful measure in discriminating between NP and healthy controls similar to the results in CLBP patients. Given that the cervical FRR has been shown to be a reliable and reproducible method of discriminating between a healthy control and NP subjects, studies investigating the effects of treatments such as spinal manipulation and exercise interventions should be conducted to determine whether the cervical FRR can used as a marker for improved neuromuscular function and whether this correlates to improved neck pain. Previous research has demonstrated that chiropractic treatment can help to normalize altered patterns of muscle recruitment and sequencing suggesting that this is likely to be a fruitful area of research[40].

**Muscle Fatigue**

Muscular fatigue has been defined as an acute impairment of performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force [17], regardless of whether or not the task can be sustained [45]. Fatigue can be broken down into two categories: experienced fatigue, which is the difficulty in initiation of or sustaining voluntary activities and physiological
fatigue, which is an exercise induced reduction in maximal voluntary muscle force (MVC). The latter can be further broken down into peripheral fatigue: which is fatigue as a result of actual changes in nerves, muscles, and neuromuscular junctions because the body is not able to supply the contracting muscle with sufficient energy or other metabolites needed to meet the increased energy demands during physical work [46] and central fatigue; fatigue of the central nervous system (CNS) induced by a decline in motor neuronal output or “drive” of motor neurons or by direct inhibition of motor neurons due to altered input from muscle receptors [47, 48]. Continued drive to the muscle may put the neuromuscular junction or more likely the intracellular events associated with excitation-contraction coupling and actin-myosin interactions into a catastrophic state from which recovery is delayed or impossible [45]. It has been shown that exercise-induced local muscle fatigue adversely alters JPS, impairing neuromuscular control in the lower extremities [49-51]. Descarreaux et al. (2008) [52] found a significant effect of muscular fatigue on both FRR cessation and FRR onset angles of the lumbar erector spinae muscles, causing a shift of the FRR to appear sooner during the flexion movement and later during the extension movement. In healthy subjects, fatigue of the lumbar ES increases the myoelectric silence period during a flexion-extension task. This augmented silent period is produced from both a reduction in the onset angle of the FRR and a decreased FRR cessation angle [52] [53].

In a study by Olson and Solomonow (2004) [53], the effect of repeated cyclic lumbar flexion was examined and concluded that modifications in the EMG patterns along cycles may be caused by increasing muscular fatigue. In healthy people, fatigue results from repeated or sustained muscular activity and is common with exercise and the
ADL. Muscle fatigue in human performance can be defined as any exercise-induced decrease in maximal voluntary force or power produced by a muscle or muscle group [54]. The study of exercise-related fatigue does not explore the more cognitive aspects of fatigue, but rather examines the performance of the motor system, that is, how prior muscular activity impairs the ability to perform physical tasks or to produce muscle force [54].

An increase in myoelectric activity seen in LBP subjects may be a response to maintain adequate functional status. Spinal stability can be compromised by insufficient muscle force and inappropriate neuromuscular activation. Therefore, during full flexion, muscular fatigue may temporarily reduce spinal stability and consequently put previously-injured structures at risk [52].

To confirm that lumbar muscular fatigue is induced correctly, the rate of decline of median frequency (MedF) with time (Figure 3) was calculated for each individual[55, 56]. Specifically, in the study by Descarreaux & Lafond et al. (2008)[52], RMS and MedF were calculated from equally-spaced windows of 250 ms every 3 seconds (s) during the first 60s of the Sorenson test.

**Proprioception and Joint Position Sense**

In order to build a model of the relationship of changes in the cervical FRR to spinal stability, changes in the FRR need to be correlated to other markers of altered neuromuscular function such as proprioceptive awareness. JPS is one aspect of proprioception that relates to our awareness of joint angles and it can be measured experimentally by a subject’s ability to reproduce a joint position once it has been perturbed by the experimenter[17]. Proprioception is the awareness of the relative
orientations of body parts, both at rest and in motion. Sensations created within the body help contribute to this awareness and are fundamental to the normal control of human movement [57]. Proprioception is commonly used to describe the sensory feedback ascending towards the CNS generated by afferent receptors which contributes to the neuromuscular control of movement [16]. This provides orientation information about movement and position of the joints and muscles, [14] an essential component of postural control [15]. The neural input sent to the CNS is received from specialized nerve endings called mechanoreceptors which are located in the muscles, ligaments, capsules, joints, and tendons [17]. However, it has been suggested that only muscle spindles demonstrate an ability to modulate sensitivity to muscle stretch [15]. Muscle fatigue impairs proprioceptive and kinesthetic properties of joints by increasing the threshold of muscle spindle discharge, disrupting afferent feedback, and subsequently altering conscious joint awareness [17]. Therefore, altered somatosensory input due to fatigue could result in deficits in neuromuscular control as represented through deficits in postural control. Proprioceptive deficit has been associated with pain [58], injury [59], and muscle fatigue [16, 60]. In the cervical region, deficits include: range of motion [61], muscle function [62], and impairment in the postural control system. With respect to the postural control system, individuals with neck pain have demonstrated altered proprioception [63, 64], balance disturbances [65, 66], altered eye movement control [67, 68], and altered postural activity of cervical muscles [69]. It has been suggested that abnormal joint stress may alter the firing of cervical afferents with consequent changes in proprioceptive function[70]. The CNS relies on accurate sensory information about the position of the head to interpret the position of the upper limb segments [18, 71]. Thus, variation in
head position during an upper limb task could affect the interpretation of arm position and misdirect the movement [16]. Local muscular fatigue modifies the peripheral proprioceptive system by increasing the threshold for muscle spindle discharge. More specifically, in a state of local muscle fatigue, nociceptors are activated by metabolic products of muscular contraction. The metabolites have a direct impact on the discharge pattern of muscle spindles [72] and consequently, it is not surprising that local fatigue would confound muscle spindle sensibility inducing errors in JPS [17].

**Theoretical Models**

The scientific rationale which indicates why an impaired FRR may be a marker of altered neuromuscular function is based on the “Pain Adaptation Model” of Lund [73] and Panjabi’s “Model of Spinal Stability” [74, 75]. The “Pain Adaptation Model” describes dysfunctional characteristics of muscle as sometimes being a normal protective adaptation to avoid further pain and possible damage [73]. For example, in asymptomatic individuals exhibiting a normal FRR, the mechanism for silencing the erector spinae muscles during full trunk flexion has been proposed to be invoked by a stretch inhibition reflex. The stimulation of the stretch receptors of the posterior discoligamentous tissues during flexed posture acts to inhibit the erector spinae activity while allowing the passive components to provide the necessary extension moment [3, 26, 41].

Panjabi’s “Model of Spinal Stability” is composed of three stabilizing systems: the active system (contractile properties of muscle and tendon), passive system (vertebrae, passive stiffness of discs, spinal ligaments, joint capsules, passive components of muscle), and the neural control system. This neural component receives positional and
force feedback from both active and passive subsystems as well as integrating these for appropriate levels of muscle activation to balance destabilizing forces [74, 75]. It has been suggested that dysfunction or adaptation in one of the above systems will lead to changes in another.

**Spinal Manipulation**

Spinal manipulation most commonly involves a high velocity/low amplitude thrust to the specific spinal segment[40]. Spinal manipulation has been shown to lead to alterations in altered sensory processing [10, 11], reflex excitability [76-81], and altered motor excitability [82-84]. Various theories try to explain why this occurs. One theory is that spinal dysfunction leads to altered afferent input to the CNS [10, 11, 81], which in turn may lead to maladaptive changes in somatosensory processing, sensorimotor integration and motor control. This theory suggests that spinal manipulation can reverse these changes. In a study by Suter and McMorland 2002[85], they found an incomplete muscle activation of biceps muscles in chronic neck pain patients. After spinal manipulation at the level of C5/6/7 they found a decrease in biceps inhibition and an increase in elbow flexor strength. Spinal manipulation improved the muscle function, cervical range of motion, and pain sensitivity [85]. An individual’s normal movement patterns can be altered by joint dysfunction and/or muscle imbalances, perpetuating dysfunction and instability of the overstressed joints. The results of Suter and McMorland 2002[85] suggest that by restoring normal function to the joint and surrounding musculature it is possible to change the balance of inhibitory and excitatory inputs to the muscle and corresponding effects on motor neuron output.
**Strengths in the Research**

The research has provided conclusive evidence that lumbar and cervical FRR are reliable and reproducible measures that can be used to discriminate between healthy controls and CLBP patients [8, 41]. Research methods on lumbar FRR have covered both standing and a number of different sitting postures. It has been determined that for cervical FRR, the lumbar and lower thoracic spine need to be in a neutralized sitting position with the upper thoracic and cervical spine unsupported and able to freely move [86]. A wide variety of ages and populations has been used in the lumbar and cervical FRR studies and it has been found that it is consistently present in healthy controls and impaired in pain populations [4, 8, 25, 41]

**Limitations in the Research**

A limitation seen throughout many cervical FRR articles was an inappropriate age matching between healthy controls and pain patients. A number of studies examined pain patients who were on average over 20 years older than the healthy control groups. Many outlying variables may attribute to the pain in the older experimental group such as decrease in physical conditioning, compared to the young, healthy adult. Although highly dependent on each individual, it could be argued that overuse injuries from an additional 20 plus years of work, everyday life or mechanical damage from previous accidents or injuries would be present in the older experimental group. There were no age specific control studies or high risk populations groups that were specifically investigated. Therefore, a need for research examining a younger population of individuals is required. Many JPS articles examined lower limb proprioception and examined a subject pool of older populations as pertaining to gait and falls in the elderly.
Gaps in the Research

There has not been a lot of research conducted on the cervical FRR. Recently, the cervical extensor muscles were shown to exhibit a consistent FRR in healthy control subjects [8]. The measurement was highly reproducible four weeks apart in both the healthy control and chronic NP patients [8]. This research will allow for further investigations into determining what, if any, types of treatment can help improve pain in the cervical neck. Larger studies can now be applied to determine if the cervical FRR can be used as a clinical measure useful for the chronic NP populations. An increase in technology has lead to an increase in the amount of hours either at work, school or during personal time spent at a desk on a computer, using a PDA, or cell phone. Research needs to look at therapeutic interventions for NP individuals who rely on computers for their jobs/schooling. There are currently no studies found that examine if the cervical FRR is a marker of neuromuscular function which can be experimentally manipulated by interventions such as fatigue or if changes in the cervical FRR can be correlated with other clinical markers such as JPS.

If the cervical FRR can be used as a marker for improved neuromuscular function in the cervical musculature, it may help provide a better understanding of the mechanisms by which different treatments for NP work and may suggest which patients need different or additional treatments to those they have previously received.
*All figures and tables are listed in the appendices in the order at which they appear throughout the thesis. Relevant figures and tables are also imbedded within each manuscript. To maintain continuity of labeling, the figure and table numbers remain the same in each manuscript.
Section 2: Manuscript 1 (Clinical Flexion Relaxation Response Study)

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Abstract

Background: The flexion relaxation ratio (FRR) has shown reliability and reproducibility in distinguishing between symptomatic and asymptomatic individuals with chronic/re-current low back pain (LBP) and neck pain (NP). However, no research has examined the effects of a period of chiropractic care lasting longer than 4 weeks of treatment in chronic/re-current NP individuals. The objective of the study was to determine whether 12 weeks of chiropractic care would significantly improve the FRR and therefore improve pain and impairment in those with chronic and re-current NP.

Methods: 11 male and female participants with chronic/re-current NP persisting for more than 3 months with no history of mechanical neck injuries and had not received chiropractic care in the 1 month prior to the first data collection were used. All subjects received 12 weeks of chiropractic care. The cervical neck FRR was examined using sEMG at weeks 1 (baseline), 6, and 12 along with outcome measures: Neck Disability Index (NDI), The Short Form- 36 (SF-36), and The Short Form McGill Pain Questionnaire (SF-MPQ). A repeated measures analysis of variance (ANOVA) was used to evaluate the changes in FRR over the 12 week period.

Results: Significant changes in the FRR were found between baseline and 12 week measures (p=.017) as well as from 6 weeks to 12 weeks (p=.036) but no significance was found from baseline to 6 weeks. There were no significant changes in other outcome measures.

Conclusions: The FRR of the cervical extensor musculature showed a significant improvement over 12 weeks of chiropractic care in NP subjects suggesting the FRR can be a useful marker of improved neuromuscular function following treatment.
Introduction

Chronic low back pain (CLBP) and neck pain (NP) are common medical problems in industrialized countries. Estimated occurrence of CLBP and NP are 60%-85% and approximately 67%, respectively[1]; [2]. Individuals with chronic and/or recurrent NP have an inability to relax their cervical extensor muscles and demonstrate an increase in muscle activity during full forward flexion of the neck [8]. The FRR is a measure of the ability to relax the cervical extensors during full forward flexion at the neck or lumbar spine[8, 87]. Watson et al. [39] developed a reliable and repeatable way to monitor changes in the FRR between CLBP and healthy controls. To measure the FRR, the FR ratio is utilized, which takes the maximal cervical extensor muscular activation (the concentric phase of extensor contraction) and divides it by the amount of activation present during relaxation at full forward flexion. In 1993, Meyer et al [32] established that a consistent FRR similar to that in the low back was demonstrated in the cervical paraspinal muscles. However, to reproduce this FRR, the thoracolumbar region must remain stabilized allowing for only flexion in the cervical region[32]. This ratio has been shown to be a reproducible and reliable measure of distinguishing between symptomatic and asymptomatic individuals in the cervical spine as well [8].

Exercise and chiropractic involving spinal manipulation (high velocity and low amplitude thrusts to a specific spinal segment) may improve impaired neuromuscular patterns, as the techniques appear to help normalize altered patterns of muscle recruitment and sequencing as well as helping to improve joint instability and dysfunction often present in musculoskeletal impairments and chronic/recurrent pain [8, 85]. In a study by Marshall & Murphy [4] significant changes were found in the lumbar
FRR over an 8 week exercise intervention using a Swiss ball. In a separate study [88], Marshall & Murphy found long-term changes for the feed-forward activation of the deep abdominals after therapeutic interventions which included exercise and manipulation. Interestingly, a significant improvement in the onset latency of the deep abdominal muscles during rapid limb movement only occurred at 12 month follow-up even though the trend was there at the end of the 12 week intervention period. This suggests that neuromuscular factors such as feed-forward activation may be able to act as markers of the nervous system alterations that occur in chronic and recurrent pain, and that even with successful treatment interventions with respect to pain and disability scores, it can take several months for the nervous system adaptations to normalize.

While the cervical FRR is a reliable measure able to discriminate between patients with and without chronic neck pain [8], there has only been one study to date which looked at the effect of treatment on the FRR and this study only included 4 weeks of chiropractic care in a group of people with a lifetime history of chronic neck pain. The researchers suggested that a longer period of care may have been needed to produce lasting changes in the cervical FRR.

The aim of this study was to determine whether 12 weeks of chiropractic care could significantly improve the FRR ratio and therefore improve pain and impairment of the cervical neck in those suffering from chronic and/or recurrent NP.

**Design**

**Clinical FRR Study**

This study was designed as a pilot study examining the effects of 12 weeks of chiropractic care, where NP subjects were required to attend 12 weeks of Chiropractic
care after passing an initial assessment, meeting the inclusion/exclusion criteria performed by registered chiropractors. During these 12 weeks, outcome measures were assessed at baseline, 6 weeks, and at week 12.

**Study Sample**

The target population for the clinical FRR study consisted of 11 subjects, 4 male and 7 female aged 18 years and older with chronic or recurrent NP. Participants must have been suffering from NP for a minimum of three months prior to study start but have no previous mechanical injury (car accidents, whiplash) of the cervical spine, and no chiropractic treatment within the 4 week period prior to the beginning of the study.

Subjects were recruited via advertisements at the local university and college campus (Appendix 1), and presentation lectures to Health Science students.

**Methods**

All experiments were carried out in the University’s Human Neurophysiology and Rehabilitation laboratory. The chiropractic care was performed at the university’s Health Center clinic or at the chiropractors’ off campus clinic. Ethical approval was initially obtained from the research ethics board (REB) at The University of Ontario Institute of Technology (UOIT). Ongoing approval of all changes was addressed as the study progressed (File# 07-073). Informed consent for each participant was collected in accordance to Tri-Council guidelines in Canada with full disclosure of risks and benefits prior to the beginning of the study. Three Questionnaires were also completed prior to each data collection.
Cervical FRR

Participants were asked to sit in a lumbar supported chair with no upper thoracic or cervical support (Figure 2). The participant’s spine area was prepared by abrading the electrode placement site using 3M Red Dot trace Prep 2236 and then wiping the area with BSNmedical Medi-Swabs. sEMG electrodes (meditraceTM 130 ECG Conductive Adhesive Electrodes) were then attached to the right and left cervical extensor (LCE and RCE) muscles 2cm apart running parallel to the spine in the direction of the muscle fibers. A ground electrode was placed over the right clavicle. The electrodes were placed over the belly of the muscle, approximately 2cm from the spinous process at the level of C4 allowing for the monitoring of changes in muscular activity of the FRR throughout the test (Figure 4). A sampling rate of 2000Hz was used and was filtered using a 3-pole Butterworth with cutoff frequencies of 20-1000Hz.

Figure 2: Proper seated posture; Lumbar supported chair with no cervical or upper thoracic support. Legs crossed at the ankle with arms on lap.
Figure 4: Example EMG data during the flexion relaxation phenomenon showing the corresponding change in cervical spine angle. Note that the EMG trace between lines A and B represents the neck flexion phase, the trace between lines B and C represents the relaxation phase and the 3 second phase between lines C and D represent the re-extension phase when the participant is returning their neck to neutral.

**Assessment**

Participants were asked to complete three FRR trials. sEMG of the LCE and RCE musculature as described previously were monitored as the subjects moved through the three phases that make up the FRR (Figure 1a-c). A metronome set at a pace of 1 beat per second was used as well as the experimenter counting to the beat. Subjects practiced the movements until both the subject and experimenter were comfortable with the ability of the subject to consistently reproduce the movement. After this practice, three final trials were collected and used as final data.
Figure 1a-c: The phases of the flexion relaxation response. (1a) Flexion Phase; neutral starting position to full flexion of the cervical spine. (1b) Relaxation Phase; full flexion of cervical spine maintained. (1c) Extension Phase; re-extension from full flexion back to neutral position.

**Questionnaires**

1. The Neck Disability Index (NDI) is a 10-item self-administered questionnaire designed to assess the impact of NP on activities of daily living, including both work and lifestyle activities. It has been shown to be both reproducible and reliable [89] (Appendix 2). The NDI is the oldest and most strongly validated instrument for assessing self-reporting of disability due to NP. It has strong and well documented convergent and divergent validity with other instruments as well as high reliability and strong internal consistency [90].

2. The Short Form McGill Pain Questionnaire (SF-MPQ) [91] which includes the Present Pain Index (PPI) and Visual Analogue Scale (VAS) of the original McGill Pain Questionnaire (MPQ). The PPI and VAS are two horizontal lines, 100 mm in length, anchored by word descriptors at each end. The subject marks on the line the point that he/she feels represents his/her perception of his/her current pain and greatest experienced pain in the previous week (Appendix 2). In a study by de Boer & van Lanschot & Stalmeier et al., (2004)[92] the VAS was an instrument shown to have good validity, and excellent reliability when assessing quality of
The SF-MPQ has been shown to be a useful tool in measuring pain similar to that of the original MPQ where the MPQ takes too long to administer. The SF-MPQ was shown to be a highly reliable measure of pain with a high intra-class correlation coefficient [93].

3. The Short Form (36) Health Survey (SF-36) consists of two major subscales with eight further scales and is the most widely used instrument designed to measure health-related quality of life. It is a generic measure of health status as opposed to one that targets specific age, disease or treatment groups [94] (Appendix 2). In a study by Jenkinson & Wright & Coulter, (1993) [95] reliability and validity of the SF-36 were examined and shown to be excellent.

**Repeated Measures**

A baseline sEMG measurement of the cervical FRR of the paraspinal musculature was taken from NP subjects. The NP group then underwent 12 weeks of chiropractic care. Holidays, vacations, and exams, were issues that arose that caused a decrease in compliance for chiropractic treatment. Where participants missed consecutive chiropractic treatments for these reasons, additional appointments were added, to ensure that participants would have had a similar number of treatments sessions as those able to be treated consecutively for 12 weeks. Treatment frequency was based on the clinical judgment of the treating clinicians, however it generally consisted of twice weekly initially for the first 2-4 weeks, tapering to once every two weeks by the end of the twelve weeks. Three patients needed an additional two weeks added to their treatment due to entire weeks of missed treatments. Treatment depended on the presenting complaint but included some aspect of neck manipulation or mobilization for most participants. At weeks 6 and 12 of chiropractic care, a cervical FRR sEMG measurement of the
paraspinal muscles was taken. At each of the three stages: baseline (pre treatment), 6 weeks, and 12 weeks, the NDI, SF-MPQ, and the SF-36 questionnaires were administered.

**Chiropractic Treatment**
Participants received high velocity, low amplitude spinal manipulation for 12 weeks by a registered chiropractor in a private practice clinic. Based on the clinician’s experience and clinical judgments, subjects were treated 1 or 2 times per week, depending on the subject’s symptoms and responses to treatment. Manipulations focused on cervical and upper thoracic spine with treatment to the lumbar spine as needed. High velocity, low amplitude manipulation delivered to joints showing tenderness to palpation and restricted range of motion were targeted as well as myofasical trigger points in the cervical muscles and mobilization of the shoulder, wrist and elbow were treated as needed.

**Data Analysis**
Analysis of the results for the clinical study was conducted using the computer software program SIGNAL 4.03(CED), IBM SPSS Software 19(SPSS) and Microsoft Office Excel 2007(Excel). sEMG data was collected using the computer software SIGNAL. The RMS of the maximal activity for a 1-second period within the three second time frame of each the relaxation phase and the re-extension phase were calculated and then exported to a previously created spreadsheet in Excel. The flexion-relaxation ratio was calculated by dividing the maximal activity during the re-extension phase by the activity during the relaxation phase. The average of the 3-trials performed was used to determine the flexion-relaxation ratio of both the left and right cervical extensor muscles (LCE, RCE).
and week 12 for all participants were analyzed in SPSS by means of a repeated-measures analysis of variance (ANOVA) examining cervical FRR with a priori contrasts. Significance was set at $P \leq 0.05$. A repeated-measures analysis of variance was utilized to analyze the participant’s perception of change through the questionnaires they filled out at baseline, week 6, and week 12.

**Results**

Of the 13 subjects who began chiropractic treatment, 2 were removed from the study due to non-compliance of treatments due to time commitments. Both subjects only completed their baseline data collection and 2 chiropractic treatments. One subject’s initial FRR was actually in the “healthy range”. They were kept in the study as the subject was deemed to have neck pain by the chiropractic assessment. The final study size was 11 subjects with 7 women and 4 men.

The mean baseline FRR values are expressed as mean ± SD and were $2.39 \pm 1.19$ for the RCE and $2.06 \pm 1.14$ for the LCE. At weeks 6 and 12 of treatment the RCE FRR values were $2.44 \pm 1.76$, $2.82 \pm 1.2$ and the LCE was $2.49 \pm 1.45$, and $3.16 \pm 1.44$ respectively. See Table 2 for individual FRR results. Significance was found between baseline and 12 week measures ($p=.017$) as well as from 6 weeks to 12 weeks ($p=.036$) but no significance was found from baseline to 6 weeks.

The mean score for the NDI at baseline, 6 weeks, and 12 weeks were $12.56 \pm 1.44$, $8.89 \pm 1.59$, and $9.11 \pm 1.74$ respectively. The SF-36 mean scores were broken up into physical component scores (PCS) and mental component scores (MCS) and the average values at each stage were as follows: PCS – 46.42, 50.3, 48.06 and MCS – 51.21, 52.65,
53.12 respectively. The McGill Pain Questionnaire mean scores were 11.91 ±7.94, 8.09±6.25, and 9±8.11 respectively. There were no significant changes in the scores of any of the 3 questionnaires.

**Table 2**: FR ratio of the RCE and LCE for each subject

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Baseline</th>
<th>6 week</th>
<th>12 week</th>
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<tr>
<td></td>
<td>RCE</td>
<td>LCE</td>
<td>RCE</td>
</tr>
<tr>
<td>1</td>
<td>RCE</td>
<td>4.26</td>
<td>4.28</td>
</tr>
<tr>
<td>2</td>
<td>RCE</td>
<td>1.29</td>
<td>1.17</td>
</tr>
<tr>
<td>3</td>
<td>RCE</td>
<td>1.49</td>
<td>1.59</td>
</tr>
<tr>
<td>4</td>
<td>RCE</td>
<td>3.11</td>
<td>2.97</td>
</tr>
<tr>
<td>5</td>
<td>RCE</td>
<td>2.28</td>
<td>1.98</td>
</tr>
<tr>
<td>6</td>
<td>RCE</td>
<td>4.15</td>
<td>3.29</td>
</tr>
<tr>
<td>7</td>
<td>RCE</td>
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</tr>
<tr>
<td>8</td>
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</tr>
<tr>
<td>9</td>
<td>RCE</td>
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</tr>
<tr>
<td>10</td>
<td>RCE</td>
<td>2.76</td>
<td>1.47</td>
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<tr>
<td>11</td>
<td>RCE</td>
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<td>0.92</td>
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<tr>
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<td>1.76</td>
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<tr>
<td>Overall Avg</td>
<td>2.25</td>
<td>2.47</td>
<td>2.99</td>
</tr>
</tbody>
</table>

Table 2: RCE and LCE FRR average data for each subject; 1The average FR ratio score at baseline, week 6, and week 12 for each subject of both the LCE and RCE. 2Combined LCE and RCE average FR ratio for the entire group.

**Discussion**

The initial average FRR scores suggest impairment close to the disability ratio of

- 2. Disability range in the cervical neck is less than that of the lumbar spine (ratio of 4)
due to the relative size difference of the muscles responsible when performing a flexion and extension moment of the spine. A positive trend of improved FRR from baseline to 6 weeks was demonstrated. However, significant results were seen at the 6 week to 12 week mark and for the total duration of treatment, baseline to 12 weeks. This is important as it provides a potential timeframe for clinicians and patients pertaining to when a notable benefit from chiropractic intervention can be seen. It is also important because it is the first study to show an improving profile over time, suggesting that once pain has become chronic, a longer period of care may be needed to reverse the neuromuscular alterations associated with chronic neck pain. Panjabi’s “Model of Spinal Stability” consists of three stabilizing systems (passive, active, and neural) working together to provide sufficient stabilization of the spine. It has been postulated that when one of these systems is impaired it leads to changes in another. If the FRR represents an attempt by the central nervous system to stabilize the spine in the face of ongoing spinal dysfunction, then its improvement could be considered a marker of successful treatment. Previous work on the cervical FRR of “healthy control” subjects showed an FR ratio of 4.09±1.58 at baseline and 4.27±1.71 after 4 weeks of chiropractic treatment [8]. Although the subjects in the current study significantly improved many did not reach an FR ratio of 4 similar to that in the “healthy controls” study stated previously. This may be because although there was significant improvements in the FR ratios, subjects were not 100% symptom free by the end of treatment. Murphy et al. 2010[8] did not find a significant change in the FR ratio from baseline to 4 weeks in neck pain subjects, which is similar to the findings of this current study, in that there was no significant change of FR ratios from baseline to 6 weeks. However, the findings of this current study demonstrated a
significant change in the FR ratio from both 6 weeks to 12 weeks and baseline to 12 weeks. This highlights the fact that 4-6 weeks of spinal manipulation may not be a sufficient amount of time to improve the altered neuromuscular patterns in those suffering from chronic/recurrent neck pain. Murphy et al.’s previous study included only 4 weeks of manipulation and showed only a small effect size (0.636) which indicated that 64 participants would have been needed for future work. This current study suggests that 4 weeks is not enough time and that in fact in a chronic or recurrent pain group, 12 weeks or even more treatment may be required to begin to address the issues that lead to the altered FRR in the first place.

**Figure 5:** Improving trend of the FRR at baseline (1) 6 weeks (2) and 12 weeks (3) during 12 weeks of spinal manipulation. Significance was seen from baseline to 12 weeks and from 6 weeks to 12 weeks

The FRR has been comprehensively examined in the low back erector spinae. Individuals with CLBP have demonstrated significantly higher myoelectric activity during forward flexion when compared to healthy controls. Recently, Murphy et al. [8] found that the FRR can be a useful and reliable measure in
discriminating between cervical NP and healthy controls similar to the results in CLBP patients. This current study has shown that 12 weeks of chiropractic manipulation significantly improved the FRR ratio in chronic and/or recurrent NP individuals. Larger studies are needed in the future as well as follow up data collection post treatment to see if the improved impairment of the cervical FRR is maintained post chiropractic care.

Although self perceived levels of functional disability were low at baseline according to the questionnaires, an improvement was still seen across the 12 weeks of treatment for most individuals. The NDI scores of some subjects placed them in the mild disability category at the onset of the study. These subjects were suffering from recurrent neck problems and it is possible that their pain at the time of the first data collection was not severe. Murphy et al. [8] showed that the FRR is a reliable measure for neck pain patients even in the absence of pain and in cases of mild disability. Improvements in the FRR after chiropractic manipulation are similar to work previously done in the lumbar spine [4, 5, 88] but this is the first to show significant changes in the cervical spine.

**Strength of Study**

This clinical study is one of the first to examine neuromuscular function of the cervical FRR through a longer term chiropractic care intervention. There is currently no evidence of the effect of long term care on the cervical FRR. There is a need for research to look at what treatments can be used to improve the neuromuscular function and therefore help to decrease pain and disability in the neck. Previous studies examining NP, more specifically the cervical FRR have only examined pain populations in mid-age to older populations [8] whereas this study was able to look at a younger population consisting mainly of students.
Limitation of Study
This study only looked at pain in the cervical spine. However, referred pain from back or shoulder injuries could have a direct impact on the pain associated in the neck. Research is dependent on participant’s willingness to regularly visit the chiropractor for 12 weeks. Holidays, vacations, and exams, were issues that arose that caused a decrease in compliance for chiropractic treatment. However, make-up chiropractic treatments were added for those who missed consecutive appointments due to previously mentioned issues. Data collection also occurred at variable time intervals following the last chiropractic treatment, immediately after for some participants and up to a week later for others. For future larger studies it is recommended that data collection occur at a standard time after the participant’s most recent chiropractic treatment. Over the course of the week many factors may arise that would place stress on the participants neck (exercising, school work, exams, assignments, jobs) and it is important to standardize the timing of data collection in relation to treatment to minimize variability due to external factors. Another limitation is the need for a long term follow up at 3 or 6 months to see if the improvements in the FRR persist or even continue to improve [88].

Conclusion
The FRR of the cervical extensor musculature showed a significant improvement over 12 weeks of chiropractic care in NP subjects, suggesting the FRR can be a useful marker of altered neuromuscular function.
Manuscript 2 (Reliability of Joint Position Sense and Altered Head Positioning)

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Abstract

Background: It has been shown that participants without a history of neck pain or injury reduced their accuracy of elbow joint position sense (JPS) by changing their head and neck position while lying in a supine position. The aim of this study is to examine the effects of altered neck postures (flexion, flexion and rotation) on recreating a previously presented angle at the elbow when compared to a neutral control position while in an upright seated posture.

Methods: 17 healthy subjects participated in this study which measured the accuracy of JPS at the elbow. Accuracy of the elbow JPS was measured under 4 head posture conditions: Neutral 1, Neutral 2, Flexion (10°), Flexion and Rotation (10°, 30°). Target and rest angle were passively presented in concession with the neck in neutral. The subject was then asked to actively reproduce the target angle with his/her head in one of the test positions. 3 different angles were tested at each head position.

Results: The variable error (VE) and absolute error (AE) showed increases in JPS error when the head position was changed to flexion or flexion and rotation, however these changes were not deemed significant (p≤0.05). The constant error (CE) while in the flexed and rotated head position showed a significant decrease in accuracy of elbow joint angle reproduction (p=0.03).

Conclusions: The results suggest that there was a significant decrease in CE during the flexed and rotated head position (P=0.03) but no significant AE or VE changes in any of the test positions. These results differ from similar studies; however large methodological differences may be the reason for this. Future research in a larger healthy population is needed to verify whether a change in head position during a seated position will affect JPS.
Introduction

Proprioception is the awareness of the relative orientations of body parts, both at rest and in motion. Sensations created within the body help to contribute to this awareness and are fundamental to the normal control of human movement [57]. Proprioception is commonly used to describe the sensory feedback ascending towards the central nervous system (CNS) generated by afferent receptors which contributes to the neuromuscular control of movement [16]. This provides orientation information about movement and position of the joints and muscles [14], an essential component of postural control [15]. Joint position sense is one aspect of proprioception that relates to our awareness of joint angles and it can be measured experimentally by a subject’s ability to reproduce a joint position once it has been perturbed by the experimenter[17]. Integrated information from multiple sensory inputs is required to understand both the target position and body position relative to other body segments and objects in space. These sensory inputs include proprioceptive, visual, and vestibular information[19, 96]. It has been proposed that body position is affected by body schema and not just dependent on local proprioceptive input [19].

Knox and Hodges, 2005 [19] showed that participants without a history of neck pain or injury reduced their accuracy of elbow JPS when the position of their head and neck was changed passively. The accuracy of a target repositioning movement is reliant on the ability of the CNS to integrate the somatosensory, vestibular, and visual information regarding the current body position. By placing the subject’s head in full flexion or full rotation, it was argued that the CNS could have been put into an overload of computational capacity which resulted in an increase in JPS error of the upper limb [19].
The neural input sent to the CNS is received from specialized nerve endings called mechanoreceptors which are located in the muscles, ligaments, capsules, joints, and tendons [17]. However, it has been suggested that only muscle spindles demonstrate an ability to modulate sensitivity to muscle stretch [15]. Muscle fatigue impairs proprioceptive and kinesthetic properties of joints by increasing the threshold of muscle spindle discharge, disrupting afferent feedback, and subsequently altering conscious joint awareness. Therefore, altered somatosensory input due to fatigue could result in deficits in neuromuscular control as represented through deficits in postural control.

Altered neck postures, similar to fatigue is an example of altered afferent input to the body schema (map) that could potentially alter upper limb proprioception. Individuals rely heavily on computer technologies for school, work and in their personal life to complete assignments, correspond with others and simply for enjoyment. This increased use of technology can place a large strain on the paraspinal muscles of the neck as a result of the constant cervical flexion. This constant flexion may bring about NP and disability which will decrease performance at work or school, possibly resulting in worker/student absenteeism and a decrease in quality of life. Consequently, both individuals and companies could lose time, money and learning opportunities because of injury. A limitation of the Knox and Hodges (2005) [19] study was that it was done with participants lying down, meaning that this may not generalize to everyday life situations such as prolonged postural alterations that accompany computer use.

Therefore the aim of this study was to examine the effects of altered neck postures (flexion, flexion and rotation) on recreating a previously presented angle at the elbow when compared to a neutral control position, with the participants in a seated position.
Design
This aspect of the thesis was a pilot study where individuals currently free from neck pain participated in a repositioning task of a previously presented angle at the elbow joint after manipulation of head positioning/orientation. This study consisted of a onetime data collection period.

Study Sample
The target population for the experimental studies consists of a healthy population of 17 male (n=11) and female (n=6) subjects aged 18 years and older with no previous history of mechanical NP/spinal injury or chiropractic intervention of the cervical region.

Subjects were recruited via presentations in Health Science lectures at the local university. Ethical approval was initially obtained from the research ethics board at The University of Ontario Institute of Technology. Ongoing approval of all changes was addressed as the study progressed (File# 07-072). Informed consent for each participant was collected in accordance to Tri-Council guidelines in Canada with full disclosure of risks and benefits prior to the beginning of the study. Participants were asked to sit in a lumbar supported chair with no upper thoracic and cervical support.

Methods
Participants were seated in a lumbar supported chair with no upper thoracic and cervical support. The subject’s right arm was placed in a sling which was attached to a cable secured into concrete walls on either side of the lab. This allowed the subject to have their arm in approximately 80° abduction, eliminating fatiguing of the shoulder and neck musculature (Figure 6). The experiment was conducted using The 3D Investigator™ Motion Capture System (Northern Digital Instruments, Waterloo, Ontario, Canada (NDI) Figure 7)). The 3D investigator (Optotrack) is a motion sensor detection
system that allowed the experimenter, through specific calculations, to monitor angle changes at the elbow, as well as angle changes in neck flexion and rotation. The Optotrack detects smart markers™ (Figure 8a) that are placed on the subject’s body. These smart markers™ can be placed into pre-formed plastic bodies of three, creating a rigid body (Figure 8b). The rigid body can be referenced to imaginary markers which are digitized by the experimenter using a pointer tool (Figure 9), allowing for calculations to be made measuring the change in positioning of the rigid body in relation to the digitized points. For the purpose of this study, a total of 12 smart markers™ were made into 3 rigid bodies that were placed on the inion of the skull, upper arm and wrist (Figure 10). As well as a total of 12 imaginary, digitized points were created. NDI First Principles software (version 4.03) was used to collect and calculate changes joint angles.

Figure 6: The supportive sling (arrows) was set up to allow for approximately 80° of abduction at the shoulder to help eliminate muscle fatigue and postural discomfort.
Figure 7: The 3D Investigator™ Motion Capture System (Northern Digital Instruments, Waterloo, Ontario, Canada (NDI))

8a      b

Figure 8: Smart markers (a) which are detected by the 3D Investigator™ Motion Capture System relaying positional information of the markers to the computer. (b) Pre fabricated rigid body which houses the sensory markers creating smart markers.
Figure 9: Pointer tool which allowed for the creation of digitized imaginary markers which were referenced to the stationary smart markers enabling measurement of angle changes.

Figure 10: The set up for the experimental studies consisted of 12 smart markers™ that were made into 3 rigid bodies that were placed on the inion, upper arm and wrist.

The JPS task was measured by the subject’s ability to reproduce a previously presented angle at the elbow. Throughout each experimental condition the subject was asked to keep his/her eyes closed to minimize any external sensory cues. Four different head/neck placements were used for each participant (neutral, neutral, flexion, flexion and rotation). Neutral consisted of head straight and eyes closed. Flexion was 10° of cervical flexion and flexion/rotation was 10° of cervical flexion and 30° of cervical rotation. The experimenter was responsible for placing the subject’s head in the above positions and was able to visually confirm that these angles were reached in real time on the computer monitor. A target angle range of 80°-100° of elbow flexion and a rest angle
range of 70°-80° and 100°-110° were used. These ranges were chosen to eliminate additional cues from soft tissue stretch and apposition at the end of a range[97]. All angles used were determined and recorded prior to beginning of data collection. The subject’s arm was passively moved to a target angle between 80° and 100° of elbow flexion and held in that position for 3 seconds. His/her arm was then moved passively to a rest target between 70°-80° and 100°-110° of elbow flexion and held for another 3s. At this point, if completing the neutral protocol the subject was asked to actively recreate the target angle previously presented. For the flexion or flexion/rotation protocol the subject’s head was placed into the desired position prior to recreation of the previously presented joint angle at the elbow. All passive movements were performed at a velocity between 5° and 25°/sec, helping to limit the predictability and timing of the task. Movement towards the target and rest angle is performed actively, as it could be argued that movement time and muscle activity would provide additional cues for repositioning.

**Data Analysis**

Analysis of the results for this experimental study was conducted using the computer software program IBM SPSS Software 19 (SPSS) and Microsoft Office Excel 2007 (Excel). The accuracy of the angle reproduction was measured using three parameters for each condition, as done by Knox et al[19]. These measures consisted of Constant Error (CE), which is the difference between the reproduced and the previously presented target angle taking into account the direction and magnitude of error; Variable Error (VE), which is the standard deviation of the mean constant error; and Absolute Error (AE), which is the difference between the reproduced and previously presented target angle regardless of sign. Accuracy between conditions was measured using a
repeated measures analyses of variance (ANOVA) with a priori contrasts to the initial neutral head posture condition. Significance was set at $P \leq 0.05$.

**Results**

In the Neutral position, when participants were asked to reproduce a previously presented angle, the mean Absolute Error was 3.74° (95% confidence interval: 2.99-4.89). This was not different from the second Neutral trial with a mean absolute error of 3.99° (95% confidence interval: 3.05-4.93) ($P=0.64$). No significant difference in absolute error was found when the head was placed into a flexed or a flexed and rotated position when compared to both Neutral 1 and Neutral 2 positions.

In the Neutral position, participants were asked to reproduce a previously presented angle, the mean Constant Error was -0.52° (95% confidence interval: -1.6-0.55). This was not different from the second Neutral trial with a mean Absolute Error of -0.43° (95% confidence interval: -1.92-1.06) ($P=0.869$). However, when participants had to actively reproduce the elbow angle with their head in a flexed and rotated position the constant joint position error increased ($P=0.03$). There was no increase in error during the head flexion position ($P=0.619$). The Variable Error similar to the absolute error showed an increase in joint position error when a change in head position was introduced, however the increase was not significant.
Figure 11a-c: Absolute, Constant, and Variable JPE for each condition. Error bars represent the standard deviation. Note that absolute error, variable error, and constant error all showed an increase in the flexed/rotated head position which was significant for the constant error condition. *P≤0.05
Discussion

The results of this study show that a flexed and rotated position of the head and neck affected direction of accuracy of elbow JPS target repositioning. Participants tended to overshoot the intended target angle at the elbow when their head was in a flexed and rotated position when compared to the neutral position. There were no significant increases in absolute or variable error during head repositioning even though error was greater in these positions relative to the neutral trials. These results are different to those of Knox and Hodges, 2005[19]. This is probably due to methodological differences between the studies. In the current study, subjects were sitting up in a lumbar supported chair with no cervical support as opposed to lying supine on the floor. The degrees of flexion and rotation were 10° and 30°, respectively, instead of full flexion and rotation. A seated position was selected instead of supine position in order to mimic more realistic, everyday life situations. There are several times throughout the day at school, work, or at home when people are seated and need to reach for something where as very few situations when you are lying down. Lying supine with the arm supported by a sling can be an awkward and unfamiliar feeling. Correspondingly, neck flexion while supine is similar to performing an abdominal curl, which places strain on the cervical neck and contraction of the abdomen. None of these issues occur in the seated position. 10° of flexion and 30° of rotation were selected instead of full flexion and rotation because 10° and 30° are similar neck postures to those adopted by individuals working on computers (especially laptops). 10° of flexion represents the slight bend in the cervical neck needed to look at a laptop computer screen while typing. 10° of flexion and 30° of rotation represents a slight bend and rotation towards something beside the computer screen such as a student’s notebook.
**Strengths of the Study**

This study is the first to examine the affects of altered head position on elbow JPS while seated. The use of the NDI Optotrak improved the accuracy of measuring the change in elbow joint angle in the seated posture. This allowed us to examine the effect of changes in neck position on elbow joint position in a seated position, where upper limb movements are most likely to occur in day to day living, and distorted upper limb joint position sense could have consequences on upper limb performance accuracy. The study indicated that even the small amount of neck flexion and rotation that would be seen with using a laptop computer is able to affect elbow joint position sense.

**Limitations of the Study**

Some subjects were not comfortable with their arm shoulder in complete external rotation, especially individuals with a high amount of upper body musculature. The sling was attached to a cable which allowed us to move the subject’s arm forward slightly to accommodate for this uncomfortable position. Another limitation was making sure that the subject’s arm remained in the same plane during the target and repositioning phases. A visual inspection was performed during the movement to ensure that there was not a large deviation from original plane. Transitional learning may have also been an issue. Although subjects were allowed practice trials before data collection, the neutral trials were always first and there may have been some transitional learning as subjects worked their way through to the flexion and flexion/rotation trials becoming more aware and confident with the repositioning movements. Finally, when the experimenter let go of the subject’s hand in between the rest angle and re-creation of the target angle there was some deviation from the rest angle as the subject contracted to begin their active movement, which may have affected repositioning accuracy.
Conclusion
The constant error during a flexed and rotated head position while recreating a previously presented angle at the elbow was significantly different that with the head in a neutral posture (P=0.03). This has potential implications for industry where peoples work require manipulation of objects with their upper limb while their head is flexed and rotated as well as clinicians, who may treat people with repetitive strain disorders of the neck and upper limb. Further studies with larger numbers of subjects are needed to confirm and extend these findings.
Manuscript 3: (Fatigued Flexion Relaxation Response / Joint Position Sense)

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Abstract

Background: Previous research of the FRR in the low back has postulated that muscles during a state of fatigue are unable to provide sufficient stability of the spine, and fatigue is also known to impair lumbar spine proprioception, but little work has been done in the cervical spine. The aim of this study is to determine whether neck muscular fatigue affects upper limb joint position sense (JPS), specifically, accuracy of angle recreation at the elbow joint. The second aim is to determine if muscular fatigue alters the timing of the phases of the cervical FRR, in particular, the onset and cessation of the myoelectric silence period during a FRR task.

Methods: 17 healthy subjects participated in the JPS study consisting of two conditions: neutral head position no fatigue, and fatigued. Fatigue was induced by the same method as above. Constant Error (CE), Variable Error (VE), and Absolute Error (AE) were used to determine the accuracy of movements. 9 healthy subjects participated in the FRR study examining altered timing of FRR phases. This study consisted of 3 cervical neck FRR tasks under 2 different conditions: neutral head position no fatigue, and fatigued. Fatigue was induced by a 30s maximal isometric contraction resisting against a wall mounted force transducer. Cervical neck flexion angle was monitored throughout FRR task. The cervical neck flexion angle corresponding to the onset and cessation of myoelectrical silence was compared using a repeated measures ANOVA.

Results: A significant effect of muscular fatigue was found for both FRR onset and cessation angle changes (p=0.035; p=.004), respectively. There were no significant changes in CE, VE, AE between neutral JPS and neutral fatigued JPS.

Conclusions: This study suggests that muscular fatigue is a modulator of the FRR which
may play a large role in the insufficient stabilizing of the spine and surrounding structures when injured or fatigued.
Introduction

Panjabi’s “Model of Spinal Stability” is composed of three stabilizing systems: the active system (contractile properties of muscle and tendon), passive system (vertebrae, passive stiffness of discs, spinal ligaments, joint capsules, passive components of muscle), and the neural control system which receives positional and force feedback from both active and passive subsystems as well as integrates these for appropriate levels of muscle activation to balance destabilizing forces [74, 75]. It has been suggested that dysfunction or adaptation in one of the above systems will lead to changes in another. It has been postulated that the stabilizing muscles in the low back (LB) during a state of fatigue are unable to sufficiently stabilize the vertebral units and therefore must transfer load-sharing to passive structures earlier in trunk flexion, thus, increasing the myoelectric silence period during a FR task [52]. This premature decrease in spinal stability puts previously-injured structures at risk due to insufficient muscle force production and inappropriate neuromuscular activation.

Gandevia [45] defines muscular fatigue as “a loss in the capacity for developing force and/or velocity of a muscle, resulting from muscle activity under load and which is reversible by rest”. Physiological fatigue can be further broken down into peripheral: fatigue as a result of actual changes in nerves, muscles, and neuromuscular junctions because the body is not able to supply the contracting muscle with sufficient energy or other metabolites to meet the increased energy demands during physical work [46] and central fatigue: fatigue of the CNS induced by a decline in motor neuronal output or “drive” of motor neurons or by direct inhibition of motor neurons due to altered input from muscle receptors [47, 48]. Continued drive to the muscle may put the
neuromuscular junction or more likely the intracellular events associated with excitation-
contraction coupling and actin-myosin interactions into a catastrophic state from which
recovery is delayed or impossible [45]. Descarreaux et al. (2008)[52] found a significant
effect of muscular fatigue on both FRR cessation and FRR onset angles for all muscles.
Myoelectric relaxation appeared sooner during the flexion movement and later during the
extension movement. In healthy subjects, fatigue of the lumbar erector spinae (ES),
increases the myoelectric silence period during a flexion-extension task. This augmented
silent period is produced from both a reduction in the onset angle of the FRR and a
decreased FRR cessation angle [52] [53].

Studies have shown that exercise-induced local muscle fatigue negatively alters
joint position sense (JPS) in young healthy adults, impairing neuromuscular control in the
lower extremities [49-51]. JPS has been defined as an aspect of proprioception that
relates to our awareness of joint angles and it can be measured experimentally by a
subject’s ability to reproduce a joint position once it has been perturbed by the
experimenter[17]. Previous work has shown that goal directed tasks such as accuracy of
end-point error in a pointing task is affected by changes in head and neck position [98-
101]. Knox and Hodges, 2005[19] exhibited a reduced accuracy of elbow joint position
sense by changing the head and neck position in participants with no history of any neck
pain. Muscle fatigue in the knee of elderly male subjects showed a diminished JPS [17].
Therefore if fatigue is an example of altered afferent input which affects neuromuscular
control, we might expect changes in JPS in conjunction with the FRR.

Spectral analysis of electromyographic (EMG) recording can be used to evaluate
the rate of myoelectrical fatigue using the median frequency of the EMG signal. The
median frequency of the power spectrum will undergo a compression towards lower
frequency as a function of time during an isometric muscle contraction [102-104].
Median frequency begins to decrease almost immediately in a sustained contraction.
Indications that metabolic fatigue of the muscle are present are reflected in the median
frequency decrease prior to the subject’s failure to maintain the required level of force
[103]. It has been shown that individuals with a higher rate of myoelectrical fatigue in
the LB also had impaired FRRs[104].

The aim of this study was to examine the impact of fatiguing the cervical extensor
musculature on the FRR and on the timing of the phases of the FRR. Due to the know
associations between fatigue and JPS in the lower limb [17, 50, 51], it was also
considered important to examine the level of impact that fatiguing the cervical extensor
musculature had on recreating a previously presented angle at the elbow in a neutral head
position.

**Design**

This study consisted of a onetime data collection period. Study participants
recruited were currently free from neck pain and participated in a repositioning task of a
previously presented angle at the elbow joint during an upright, lumbar-supported seated
posture, with fatigue and no fatigue of the cervical extensor musculature as the
experimental conditions. The same subjects also participated in FRR movements while
their cervical extensors were in fatigued and non-fatigued states.

**Study Sample**

The target population for the experimental study consisted of a healthy population
of 16 male (n=11) and female (n=6) subjects aged 18 years and older with no previous
history of mechanical neck pain (NP)/spinal injury or chiropractic intervention of in the cervical region.

Subjects were recruited via advertisements around the local college and university campuses. Ethical approval was initially obtained from the research ethics board at The University of Ontario Institute of Technology. Ongoing approval of all changes was addressed as the study progressed (File# 07-072). Informed consent for each participant was collected in accordance to Tri-Council guidelines in Canada with full disclosure of risks and benefits prior to the beginning of the study.

Methods
Participants were asked to sit in a lumbar supported chair with no upper thoracic and cervical support. The cervical spines of each participant were prepped by abrading the electrode placement site using 3M Red Dot trace Prep 2236 and then sterilizing the area with BSNmedical Medi-Swabs. sEMG electrodes (meditraceTM 130 ECG Conductive Adhesive Electrodes) were then attached to the right and left cervical extensor (CE) muscles 2cm apart running parallel to the spine in the direction of the muscle fibers as well as a ground electrode was place over the right clavicle. The electrodes were placed over the belly of the muscle approximately 2cm from the spinous process at the level of C4 allowing for the monitoring of changes in muscular activity of the FRR throughout the test (Figure 4). A sampling rate of 1024Hz was used with a bandpass filter of 10-500Hz.

Joint position sense was measured using The 3D Investigator™ Motion Capture System (Northern Digital Instruments, Waterloo, Ontario, Canada (NDI)) (Figure 7). The 3D investigator (Optotrack) is a motion sensor detection system that allowed the
experimenter, through specific calculations, to monitor angle changes at the elbow, as well as, angle changes in cervical neck flexion and rotation. The Optotrack detects smart markers™ (Figure 8a) that are placed on the subjects’ body. These smart markers™ can be placed into pre-formed plastic bodies of three, creating a rigid body (Figure 8b). The rigid body can be referenced to imaginary markers which are digitized by the experimenter using a pointer tool (Figure 9). Thus, allowing for calculations to be made measuring the change in positioning of the rigid body in relation to the digitized points. For the purpose of this study a total of 12 smart markers™ were made into 3 rigid bodies that were placed on the inion, upper arm and wrist (Figure 10). As well as a total of 12 imaginary, digitized points were created. NDI First Principles software (version 4.03) was used to collect and calculate changes joint angles.

Figure 4: Example EMG data during the flexion relaxation phenomenon showing the corresponding change in cervical spine angle. Note that the EMG trace between lines A and B represents the neck flexion phase, the trace between lines B and C represents the relaxation phase and the 3 second phase between lines C and D represent the re-extension phase when the participant is returning their neck to neutral.
Figure 6: The supportive sling (arrows) was set up to allow for approximately 80° of abduction at the shoulder to help eliminate muscle fatigue and postural discomfort.

Figure 7: The 3D InvestigatorTMMotion Capture System (Northern Digital Instruments, Waterloo, Ontario, Canada (NDI))
Figure 8a-b: Smart markers (a) which are detected by the 3D InvestigatorTM Motion Capture System relaying positional information of the markers to the computer. (b) Pre fabricated rigid body which houses the sensory markers creating smart markers.

Figure 9: Pointer tool which allowed for the creation of digitized imaginary markers which were referenced to the stationary smart markers enabling measurement of angle changes.

Figure 10: The set up for the experimental studies consisted of 12 smart markers™ that were made into 3 rigid bodies that were placed on the inion, upper arm and wrist.
**FRR vs. Fatigued FRR**

sEMG data was collected using Lab Chart 7 while changes in joint angle were simultaneously collected using NDI First Principles software. Utilizing both programs allowed the experimenter to monitor changes in the timing of the subjects’ muscular activity when compared to the phases of the FRR. Participants were asked to complete three FRR trials. sEMG of the left and right cervical musculature as described previously was monitored as the subject moved through the three phases that make up the FRR. A metronome was used at the pace of 1 beat per second as well as the experimenter counting to the beat. Subjects practiced the movements until both the subject and experimenter were comfortable with the ability of the subject to consistently reproduce the movement. After this practice, three final trials were collected and used as final data. To ensure that the subject’s movements were consistent the experimenter monitored the degrees of flexion and rotation via the real time output of angle changes from the NDI software used. Participants were then asked to perform a maximal isometric contraction of the cervical extensor musculature. A strap was secured around their head and attached to a wall mounted force transducer (Figure 12). Subjects were asked to maintain a 100% isometric MVC resisting cervical extension against the strap for duration of 30 seconds or until failure prior to the 30 second mark. The sEMG electrodes were attached to the right and left cervical extensor (CE) muscles 2cm apart running parallel to the spine in the direction of the muscle fibers. The electrodes were placed over the belly of the muscle approximately 2cm from the spinous process at the level of C4 allowing for the monitoring of changes in the timing of the phases of the FRR when compared to the change in angle. Muscular fatigue was assessed through spectral analysis of the sEMG data (fast fourier transform). To confirm that muscular fatigue was induced the rate of
decline of the median frequency (MedF) with time was calculated through equally spaced windows of 250 milliseconds every 3 seconds for the duration of the 30 second fatiguing task as done by Descarreaux et al. [52]. Immediately after the fatigue task three additional FRR trials were completed.

![Figure 12: A 30 second 100% isometric MVC of the cervical extensors was accomplished by a strap that was secured around the subjects head and attached to a wall mounted force transducer.](image)

**JPS Neutral vs. Neutral Fatigued**

The JPS for the Neutral head position task compared to the fatigued Neutral head position task was measured by the subject’s ability to reproduce a previously presented angle at the elbow. Throughout each experimental condition the subject was asked to keep their eyes closed to minimize any external sensory cues. With their arm resting in a sling to prevent muscular activation and fatigue in the upper limb, a target angle range of 80°-100° of elbow flexion and a rest angle range of 70°-80° and 100°-110° were used. These ranges were chosen to eliminate additional cues from soft tissue stretch and apposition at the end of a range[97]. All angles used were determined and recorded prior to beginning of data collection. The subjects arm was passively moved to a target angle between 80° and 100° of elbow flexion and held in that position for 3 seconds(s). Their
arm was then moved passively to a rest target between 70°-80° and 100°-110° of elbow flexion and held for another 3s. At this point, for both the fatigued and non-fatigued protocols the subject was asked to actively recreate the target angle previously presented. 3 trials with varying angle changes were utilized for each the fatigued and non-fatigue protocols. All passive movements were performed at a velocity between 5° and 25°/sec, helping to limit the predictability and timing of the task. Movement towards the target and rest angle is performed actively as it could be argued that movement time and muscle activity would provide additional cues for repositioning.

Subjects were fatigued for a second time in exactly the same process as they were fatigued for the FRR fatigue aspect of the study. Immediately following the fatigue process the subject’s right arm was placed back into the support sling and the experimenter performed 3 additional neutral head position repositioning tasks at the elbow.

Data Analysis

FRR vs. Fatigue

Analysis of the data for the FRR vs. FRR Fatigue was conducted using the IBM SPSS Software 19(SPSS), Lab Chart 7, and Microsoft Office Excel 2007(Excel). sEMG data was collected using the computer software Lab Chart. The RMS of a one second period within the three second time frame of each the relaxation phase and the re-extension phase was calculated and then exported to a previously created spreadsheet in Excel to determine the average FRR (left and right CE) of the three trials. The same was done for the Fatigue FRR data. All data were analyzed in SPSS by means of a repeated-
measures analysis of variance (ANOVA) examining any changes in the FRR during normal and fatigued conditions.

The total flexion angle of the cervical neck corresponding to the onset and cessation of the myoelectrical silence during normal and fatigued states was analyzed using a repeated measures ANOVA comparing the normal and fatigued results. Statistical significance was set to $P \leq 0.05$.

**JPS Neutral Head Position vs. Fatigued Neutral Head Position**

The CE, VE, and AE were calculated and the accuracy between conditions was measured using a repeated measures analyses of variance (ANOVA). Statistical significance was set a $P \leq 0.05$.

**Results**

9 subjects were used when measuring the onset and cessation of muscle activity during normal and fatigued FRR. 5 subjects had high amounts of muscle activation throughout the test, to the point that either onset or cessation of the silenced periods was indistinguishable. An additional 3 subjects were not used for this aspect of the study as the motion sensors were not visible to the camera during certain parts of the movement eliminating the ability to measure angle change in relation to onset and cessation of muscle silence.

For all subjects a rate of decline in MedF/time over the 30 second fatigue task were observed, representing muscular fatigue induction prior to the FRR task. There was no statistical difference between the amplitude of the fatigued FRR and either the Neutral1 and Neutral2 FRR.
A significant effect of muscular fatigue was found for both FRR onset and
cessation angles on the cervical extensors. The angle related to the onset angle of
myoelectric silence was significantly reduced after the fatigue task at the C4 level (36 ±
2.614 vs. 32.45 ± 1.909) (p=0.035) (95% confidence interval 30.65-41.36 and 28.53-
36.36). The angle related to the cessation angle of myoelectric silence was significantly
reduced after the fatigue task at the C4 level as well (35.8 ± 2.612 vs. 32.8 ± 2.167)
(p=0.04) (95% confidence interval 30.45-41.15 and 28.38-37.26). This shows that fatigue
of the cervical extensors did produce a shift in the FRR, muscular silence appearing
sooner in the flexion moment and continuing longer during the extension moment.

There was no statistical significance found in the constant error (CE), variable
error (VE), and absolute error (AE) between the ability to re-create the elbow angle in the
neutral neck position between the fatigue and non-fatigue states. There was a trend
towards significance in the CE.
Figure 13a-b: Effect of fatigue induced on total neck angle at FRR onset and FRR cessation. Note a significant change was found between the non-fatigued and fatigued trails for both the onset and cessation angles. *P≤0.05

**Discussion**

The results of this study show that fatigue does not have a significant effect on the FR ratio. However, muscular fatigue of the cervical extensors does alter the timing of the phases of the FRR increasing the myoelectric silence period during a flexion-extension task of the cervical neck. Several studies in the LB have shown the same increase in
muscular silence period during a flexion-extension task [26, 52, 53]. The results of this study are similar to those of Descarreaux [52] who used isometric contraction to fatigue the LB musculature in comparison to studies which used prolonged cyclic lumbar flexion to fatigue the LB musculature[26, 53]. It has been shown that the stabilizing capacity of passive articular tissues can be significantly reduced during a period of cyclic or static flexion produced by the development of creep in the lumbar viscoelastic tissues[26, 105, 106]. However, to independently test the effect of fatigue on the FRR, an isometric contraction was used to maximally fatigue the cervical extensor muscles eliminating the possibility of creep in the spinal ligaments. The speed of the flexion and extension movement was maintained at a constant pace by a metronome to eliminate unconscious increases or decreases in the speed of the movement.

The results of this study are consistent with Panjabi’s theoretical model of spinal stability which suggests that if one of the 3 stabilizing systems (active, passive, neural) is in a state of dysfunction then the other 2 systems will compensate. This is seen with the shift in the phases of the FRR creating a longer silenced period. When the cervical extensors are in a situation of maximal exhaustion, they transfer the load-sharing to the passive structures of the neck (vertebrae, passive stiffness of discs, spinal ligaments, joint capsules, passive components of muscle), and the neural control system. The neural system receives positional and force feedback from both active and passive subsystems as well as integrates this information for appropriate levels of muscle activation to balance destabilizing forces [74, 75] earlier during a forward flexion movement and later during the extension movement. This explains the early onset and delayed cessation of muscular silence when compared to the angle change in the neck.
The fact that there was no statistical significance when comparing the neutral JPS elbow joint angle re-creation to the fatigued JPS elbow joint re-creation may be an artifact of the low number of subjects used. Future work should use a larger number of subjects before concluding that neck muscle fatigue has no impact on elbow joint position sense.

**Strength of the Study**

This study is the first to show an altered timing in the phases of the FRR as produced by muscular fatigue in the cervical neck. An increased muscular silenced period modulated by fatigue is similar to studies already completed on the LB. The implications of this research show that the cervical FRR could be used as a marker for neuromuscular function which is experimentally manipulated by fatigue interventions. Future research needs to be done on a larger population.

**Limitations of the Study**

There were some methodological issues which need to be addressed in future research. Some subjects were not comfortable with their arm in complete external rotation, especially individuals with a high amount of upper body musculature. The sling was attached to a cable which allowed us to move the subjects arm forward slightly to accommodate for this uncomfortable position. Another limitation was making sure that the subjects arm remained in the same plane during the target and repositioning phases. A visual inspection was performed during the movement to ensure that there was not a large deviation from original plane. Transitional learning may have also been an issue. Although subjects were allowed practice trials before data collection, the neutral trials were always first and there may have been some transitional learning as subjects worked their way through to the fatigue trials becoming more aware and confident with the
repositioning movements. When the experimenter let go of subjects hand in between the rest angle and re-creation of the target angle there was some deviation from the rest angle as the subject contracted to begin their active movement. Finally, this study was done in conjunction with the JPS study (manuscript 3). Future research should look at fatigue of the FRR separately because the subjects arm needed to be maintained in the sling so the Optotrak could still see the markers. The arm placement in the sling for this extended period of time may have caused excess muscle activation in the trapezius muscles.

Conclusion

The results indicate that muscular fatigue is a modulator of the FRR which may play a large role in the insufficient stabilizing of the spine and the structures surrounding the cervical neck when injured or fatigued. The FRR can be used as a marker or neuromuscular function which can be manipulated by experimental fatigue interventions. These results could significantly impact the creation and management of chronic and recurrent NP rehabilitation programs.

Thesis Summary

Altered neuromuscular processing and motor output as both a risk and perpetuating factor for chronic neck pain is a relative new area of study. Research of the cervical FRR is also a relatively new area of study but has been shown to be a reproducible and reliable marker of differences in neuromuscular function between neck pain patients and controls. Study 1 demonstrated that 12 weeks of chiropractic care is a useful therapy to improve chronic and/or recurrent NP. Study 3 demonstrated that muscular fatigue is a modulator of the FRR which was seen through the increase in the onset and cessation of the myoelectric silence period during the FRR. Muscular fatigue
may play a large role in the insufficient stabilization of the spine and the surrounding structures. These preliminary results need to be extended in both science and clinical studies, but this type of work could significantly impact the creation and management of chronic and re-current NP rehabilitations program.

Study 2, the JPS study was the first to look at changes in elbow joint recreation accuracy in altered head postures while seated. The notable finding of this study was that even a fairly minor postural alteration of the neck, similar to when viewing a laptop screen was enough to impact the ability to recreate a previously presented angle at the elbow. Several limitations were described with the design use, and future research needs to take into account the limitations stated previously as well as collecting fatigue and non-fatigue data on separate days.

Individuals rely heavily on computer technologies for school, work and in their personal life to complete assignments, correspond with others and simply for enjoyment. This constant use of computers can lead to NP and disability which may decrease performance at work or school, possibly resulting in worker/student absenteeism and a decrease in quality of life. Consequently, both individuals and companies could lose time, money and learning opportunities because of injury. These studies suggest that the chronic postural alterations can impact upper limb performance and that fatigue can have a negative impact on the stabilization mechanisms of the neck.

By better understanding the mechanisms by which different forms of treatment can be used for NP, the impact on the amount of time and money saved on worker/student absenteeism due to neck injury and possible preventative measures of
NP/disability will be seen. This pilot study will help to provide data for future larger studies examining the use of the cervical FRR for clinical interventions on those with chronic and/or recurrent NP. Future research needs to examine whether improvements in the FR ratio persist post chiropractic care in the absence of manipulation. The effect of fatigue on JPS needs to be examined in a larger study with more subjects before it is concluded that neck muscle fatigue does not have an effect on JPS. Similarly, a larger study needs to be conducted on the effects of postural changes of the head on JPS to confirm the present findings. Once these experimental findings are confirmed, this work could be extended to ergonomic applications examining the effect of both fatigue and altered neck postures on upper limb joint position sense and its relationship to the cervical FRR.
References


**Figures**

*Figures 1a-c:* The phases of the flexion relaxation response. (1a) Flexion Phase; neutral starting position to full flexion of the cervical spine. (1b) Relaxation Phase; full flexion of cervical spine maintained. (1c) Extension Phase; re-extension from full flexion back to neutral position.

*Figure 2:* Proper seated posture; Lumbar supported chair with no cervical or upper thoracic support. Legs crossed at the ankle with arms on lap.

*Figure 3:* Example data of the rate of decline of median frequency with time (MedF/Time) during the isometric fatiguing task.
Figure 4: Example EMG data during the flexion relaxation phenomenon showing the corresponding change in cervical spine angle. Note that the EMG trace between lines A and B represents the neck flexion phase, the trace between lines B and C represents the relaxation phase and the 3 second phase between lines C and D represent the re-extension phase when the participant is returning their neck to neutral.

Figure 5: Improving trend of the FRR at baseline (1) 6 weeks (2) and 12 weeks (3) during 12 weeks of spinal manipulation. Significance was seen from baseline to 12 weeks and from 6 weeks to 12 weeks
Figure 6: The supportive sling (arrows) was set up to allow for approximately 80° of abduction at the shoulder to help eliminate muscle fatigue and postural discomfort.

Figure 7: The 3D InvestigatorTMMotion Capture System (Northern Digital Instruments, Waterloo, Ontario, Canada (NDI))
Figure 8a-b: Smart markers (a) which are detected by the 3D InvestigatorTM Motion Capture System relaying positional information of the markers to the computer. (b) Pre fabricated rigid body which houses the sensory markers creating smart markers.

Figure 9: Pointer tool which allowed for the creation of digitized imaginary markers which were referenced to the stationary smart markers enabling measurement of angle changes.
Figure 10: The set up for the experimental studies consisted of 12 smart markers™ that were made into 3 rigid bodies that were placed on the inion, upper arm and wrist.
Figure 11a-c: Absolute, Constant, and Variable JPE for each condition. Error bars represent the standard deviation. Note that absolute error, variable error, and constant error all showed an increase in the flexed / rotated head position which was significant for the constant error condition. *P≤0.05
Figure 12: A 30-second 100% isometric MVC resisting against cervical extension was accomplished by a strap that was secured around the subject's head and attached to a wall mounted force transducer.
Figure 13: Effect of fatigue induced on total neck angle at FRR onset and FRR cessation. Note a significant change was found between the non-fatigued and fatigued trails for both the onset and cessation angles. *$P \leq 0.05$
### Table 1: Internet use by individuals, by selected characteristics

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<td></td>
<td>2005</td>
<td>2007</td>
<td>2009</td>
</tr>
<tr>
<td>% of individuals&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Internet users</td>
<td>67.9</td>
<td>73.2</td>
<td>80.3</td>
</tr>
<tr>
<td>Household type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single family households with unmarried children under age 18</td>
<td>80.9</td>
<td>86.4</td>
<td>91.1</td>
</tr>
<tr>
<td>Single family households without unmarried children under age 18</td>
<td>62.5</td>
<td>67.5</td>
<td>76.4</td>
</tr>
<tr>
<td>One-person households</td>
<td>48.7</td>
<td>53.0</td>
<td>63.1</td>
</tr>
<tr>
<td>Multi-family households</td>
<td>78.8</td>
<td>80.6</td>
<td>86.4</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>68.8</td>
<td>74.1</td>
<td>81.0</td>
</tr>
<tr>
<td>Females</td>
<td>67.8</td>
<td>72.3</td>
<td>79.7</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34 years and under</td>
<td>88.9</td>
<td>93.1</td>
<td>96.5</td>
</tr>
<tr>
<td>35 to 54 years</td>
<td>75.0</td>
<td>79.8</td>
<td>87.8</td>
</tr>
<tr>
<td>55 to 64 years</td>
<td>53.8</td>
<td>60.8</td>
<td>71.1</td>
</tr>
<tr>
<td>65 years and over</td>
<td>23.8</td>
<td>28.8</td>
<td>40.7</td>
</tr>
<tr>
<td>Level of education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than high school</td>
<td>31.2</td>
<td>43.2</td>
<td>50.7</td>
</tr>
<tr>
<td>High school or college</td>
<td>72.0</td>
<td>76.8</td>
<td>83.4</td>
</tr>
<tr>
<td>University degree</td>
<td>89.4</td>
<td>92.5</td>
<td>94.7</td>
</tr>
<tr>
<td>Personal income quartile&lt;sup&gt;3,4,5,6&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest quartile</td>
<td>58.7</td>
<td>68.8</td>
<td>76.2</td>
</tr>
<tr>
<td>Second quartile</td>
<td>56.9</td>
<td>60.7</td>
<td>69.9</td>
</tr>
<tr>
<td>Third quartile</td>
<td>71.3</td>
<td>75.5</td>
<td>83.1</td>
</tr>
<tr>
<td>Highest quartile</td>
<td>83.2</td>
<td>87.9</td>
<td>92.1</td>
</tr>
</tbody>
</table>

Table 1: Internet use by individuals, by selected characteristics:

Household type, Sex, Age, Level of education, Personal income quartile.
1. Internet access from any location includes use from home, school, work, public library or other, and counts an individual only once, regardless of use from multiple locations.
2. Percent who have used the Internet for personal, non-business reasons in the past 12 months. The target population for the Canadian Internet Use Survey (CIUS) has changed from individuals 18 years of age and older in 2005 to 16 years of age and older in 2007.
3. Canadian Internet use survey (CIUS) divides income into quartiles or four equal groups based on the respondent's personal income, each representing 25% of the income spectrum from highest to lowest.
4. In 2005, the lowest quartile is less than or equal to $13,000, the second quartile is from $13,001 to $26,999, the third quartile is from $27,000 to $45,999 and the highest quartile is from $46,000 and higher.
5. In 2007, the lowest quartile is less than or equal to $12,000, the second quartile is from $12,001 to $27,999, the third quartile is from $28,000 to $48,999 and the highest quartile is from $49,000 and higher.
6. In 2009, the lowest quartile is less than or equal to $10,000, the second quartile is from $10,001 to $29,999, the third quartile is from $30,000 to $49,999 and the highest quartile is from $50,000 and higher.

Statistics, Canada. Last modified 2010/09/27
Table 2: FR ratio of the RCE and LCE for each subject

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Baseline</th>
<th>6 week</th>
<th>12 week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RCE</td>
<td>LCE</td>
<td>RCE</td>
</tr>
<tr>
<td>1</td>
<td>RCE</td>
<td>4.26</td>
<td>4.28</td>
</tr>
<tr>
<td>2</td>
<td>RCE</td>
<td>1.29</td>
<td>1.17</td>
</tr>
<tr>
<td>3</td>
<td>RCE</td>
<td>1.49</td>
<td>1.59</td>
</tr>
<tr>
<td>4</td>
<td>RCE</td>
<td>3.11</td>
<td>2.97</td>
</tr>
<tr>
<td>5</td>
<td>RCE</td>
<td>2.28</td>
<td>1.98</td>
</tr>
<tr>
<td>6</td>
<td>RCE</td>
<td>4.15</td>
<td>3.29</td>
</tr>
<tr>
<td>7</td>
<td>RCE</td>
<td>2.91</td>
<td>2.52</td>
</tr>
<tr>
<td>8</td>
<td>RCE</td>
<td>0.55</td>
<td>0.71</td>
</tr>
<tr>
<td>9</td>
<td>RCE</td>
<td>2.19</td>
<td>2.25</td>
</tr>
<tr>
<td>10</td>
<td>RCE</td>
<td>2.76</td>
<td>1.47</td>
</tr>
<tr>
<td>11</td>
<td>RCE</td>
<td>1.27</td>
<td>0.92</td>
</tr>
<tr>
<td>Average 1</td>
<td>2.39</td>
<td>2.10</td>
<td>2.44</td>
</tr>
<tr>
<td>Stdev</td>
<td>1.19</td>
<td>1.09</td>
<td>1.76</td>
</tr>
<tr>
<td>Overall Avg 2</td>
<td>2.25</td>
<td>2.47</td>
<td>2.99</td>
</tr>
</tbody>
</table>

Table 2: RCE and LCE FRR average data for each subject; 1 The average FR ratio score at baseline, week 6, and week 12 for each subject of both the LCE and RCE. 2 Combined LCE and RCE average FR ratio for the entire group.
Appendix

Appendix 1: Advertisement Poster for Subject Recruitment

INVITATION

Do you suffer from neck pain or repetitive strain injury (RSI)?

Have you had neck pain for at least 3 months? Do you suffer from neck pain or RSI? Are you between the ages of 18 and 50?

If so, you may be eligible to participate in a research study entitled “The neurophysiological effects of spinal manipulation” to determine whether your brain processes information differently and whether treatment can change this processing pattern.

If you are a suitable candidate you will receive chiropractic treatment sessions at a reduced rate to compensate you for the time involved in coming to the University of Ontario Institute of Technology to participate in this research.

As part of this research we will collect some information about the electrical signals from your neck and arm muscles as well as from the parts of your brain that control these muscles. To do this we will use a special stimulator over a nerve at your wrist and measure the way that your brain responds to this stimulation.

If you would like to know more about this study, please contact:

Ian Barker or Diana Gray
Email: ianbark@yahoo.com diana.gray@uoit.ca
**Appendix 2: Questionnaires**

**Neck Disability Index (NDI)**

<table>
<thead>
<tr>
<th>The Neck Disability Index</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck Pain Intensity</td>
<td></td>
</tr>
<tr>
<td>○ I have no pain at the moment.</td>
<td>○ I can concentrate fully when I want to.</td>
</tr>
<tr>
<td>○ The pain is very mild at the moment.</td>
<td>○ I can concentrate fully when I want to with no difficulty.</td>
</tr>
<tr>
<td>○ The pain is moderate at the moment.</td>
<td>○ I have no difficulty in concentrating when I want to.</td>
</tr>
<tr>
<td>○ The pain is fairly severe at the moment.</td>
<td>○ I have a slight degree of difficulty in concentrating when I want to.</td>
</tr>
<tr>
<td>○ The pain is very severe at the moment.</td>
<td>○ I have a slight degree of difficulty in concentrating when I want to.</td>
</tr>
<tr>
<td>○ The pain is the worst imaginable at the moment.</td>
<td>○ I cannot concentrate at all.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Personal Care (e.g. washing, dressing)</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>○ I can look after myself normally without causing extra pain.</td>
<td>○ I can do as much work as I want to.</td>
</tr>
<tr>
<td>○ I can look after myself normally but it causes extra pain.</td>
<td>○ I can only do my usual work, but no more.</td>
</tr>
<tr>
<td>○ I am painful to look after myself, and I am slow and careful.</td>
<td>○ I can do most of my usual work, but not more.</td>
</tr>
<tr>
<td>○ I need some help, but manage most of my personal care.</td>
<td>○ I cannot do my usual work.</td>
</tr>
<tr>
<td>○ I need help every day in most aspects of self care.</td>
<td>○ I cannot do any work at all.</td>
</tr>
<tr>
<td>○ I do not get dressed, I wash with difficulty, and stay in bed.</td>
<td>○ I cannot do any work at all.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lifting</th>
<th>Driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>○ I can lift heavy weights without extra neck pain.</td>
<td>○ I can drive my car without any neck pain at all.</td>
</tr>
<tr>
<td>○ I can lift heavy weights, but I get extra neck pain.</td>
<td>○ I can drive my car as long as I want, with slight pain in my neck.</td>
</tr>
<tr>
<td>○ Neck pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned, for example on a table.</td>
<td>○ I can drive my car as long as I want, with moderate neck pain in my neck.</td>
</tr>
<tr>
<td>○ Neck pain prevents me from lifting heavy weights, but I can manage if they are conveniently positioned.</td>
<td>○ I cannot drive my car as long as I want, because of moderate pain in my neck.</td>
</tr>
<tr>
<td>○ I can lift only very light weights.</td>
<td>○ I can hardly drive at all because of severe pain in my neck.</td>
</tr>
<tr>
<td>○ I cannot lift or carry anything.</td>
<td>○ I cannot drive my car at all because of the pain in my neck.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reading</th>
<th>Sleeping</th>
</tr>
</thead>
<tbody>
<tr>
<td>○ I read as much as I want, with no pain in my neck.</td>
<td>○ I have no trouble sleeping.</td>
</tr>
<tr>
<td>○ I read as much as I want, with slight pain in my neck.</td>
<td>○ My sleep is hardly disturbed (less than 1 hr sleeplessness).</td>
</tr>
<tr>
<td>○ I read as much as I want, with moderate pain in my neck.</td>
<td>○ My sleep is mildly disturbed (1-2 hrs sleeplessness).</td>
</tr>
<tr>
<td>○ I cannot read as much as I want, because of moderate pain in my neck.</td>
<td>○ My sleep is moderately disturbed (3-5 hrs sleeplessness).</td>
</tr>
<tr>
<td>○ I cannot read at all because of severe pain in my neck.</td>
<td>○ My sleep is greatly disturbed (5-7 hrs sleeplessness).</td>
</tr>
<tr>
<td>○ I cannot read at all because of pain in my neck.</td>
<td>○ My sleep is completely disturbed (7 hrs sleeplessness).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Headaches</th>
<th>Recreation</th>
</tr>
</thead>
<tbody>
<tr>
<td>○ I have no headaches at all.</td>
<td>○ I am able to engage in all my recreational activities, with no neck pain at all.</td>
</tr>
<tr>
<td>○ I have slight headaches which occur infrequently.</td>
<td>○ I am able to engage in all my recreational activities, with some pain in my neck.</td>
</tr>
<tr>
<td>○ I have moderate headaches which occur infrequently.</td>
<td>○ I am able to engage in most, but not all of my usual recreational activities because of pain in my neck.</td>
</tr>
<tr>
<td>○ I have moderate headaches which occur frequently.</td>
<td>○ I am able to engage in few of my usual recreational activities, because of pain in my neck.</td>
</tr>
<tr>
<td>○ I have severe headaches which occur frequently.</td>
<td>○ I cannot engage in any recreational activities because of pain in my neck.</td>
</tr>
<tr>
<td>○ I have headaches about all the time.</td>
<td>○ I cannot engage in any recreational activities at all because of pain in my neck.</td>
</tr>
</tbody>
</table>

The Short Form McGill Pain Questionnaire - SF-MPQ

**The Short Form McGill Pain Questionnaire**

Subject Information: The following form presents words that may describe the neck pain that you experience. Please tick any words that apply to your neck pain under the heading of None, Mild, Moderate, Severe.

<table>
<thead>
<tr>
<th>Patients Name</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>None (0)</th>
<th>Mild (1)</th>
<th>Moderate (2)</th>
<th>Severe (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throbbing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shooting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stabbing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sharp</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cramping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gnawing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot - burning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aching</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Splitting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tiring - Exhausting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fearful</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sickening</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Punishing - Cruel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. How much pain are you experiencing right now?

No Pain _______________________________ Worst Pain

2. What is the greatest level of pain you have experienced in the last week?

No Pain _______________________________ Worst Pain

Melzack (1975)
SF-36 QUESTIONNAIRE

Name: ___________________________ Ref. Dr: ___________________________ Date: ______

ID#: ___________________________ Age: ______ Gender: M / F

Please answer the 36 questions of the Health Survey completely, honestly, and without interruptions.

GENERAL HEALTH:
In general, would you say your health is:
☐ Excellent ☐ Very Good ☐ Good ☐ Fair ☐ Poor

Compared to one year ago, how would you rate your health in general now?
☐ Much better now than one year ago
☐ Somewhat better now than one year ago
☐ About the same
☐ Somewhat worse now than one year ago
☐ Much worse than one year ago

LIMITATIONS OF ACTIVITIES:
The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports.
☐ Yes, Limited a lot ☐ Yes, Limited a Little ☐ No, Not Limited at all

Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf.
☐ Yes, Limited a Lot ☐ Yes, Limited a Little ☐ No, Not Limited at all

Lifting or carrying groceries.
☐ Yes, Limited a Lot ☐ Yes, Limited a Little ☐ No, Not Limited at all

Climbing several flights of stairs.
☐ Yes, Limited a Lot ☐ Yes, Limited a Little ☐ No, Not Limited at all

Climbing one flight of stairs.
☐ Yes, Limited a Lot ☐ Yes, Limited a Little ☐ No, Not Limited at all

Bending, kneeling, or stooping.
☐ Yes, Limited a Lot ☐ Yes, Limited a Little ☐ No, Not Limited at all

Walking more than a mile.
☐ Yes, Limited a Lot ☐ Yes, Limited a Little ☐ No, Not Limited at all

Walking several blocks.
☐ Yes, Limited a Lot ☐ Yes, Limited a Little ☐ No, Not Limited at all

Walking one block.
☐ Yes, Limited a Lot ☐ Yes, Limited a Little ☐ No, Not Limited at all
Bathing or dressing yourself  
☐ Yes, Limited a Lot  ☐ Yes, Limited a Little  ☐ No, Not Limited at all

PHYSICAL HEALTH PROBLEMS:
During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

Cut down the amount of time you spent on work or other activities  
☐ Yes  ☐ No

Accomplished less than you would like  
☐ Yes  ☐ No

Were limited in the kind of work or other activities  
☐ Yes  ☐ No

Had difficulty performing the work or other activities (for example, it took extra effort)  
☐ Yes  ☐ No

EMOTIONAL HEALTH PROBLEMS:
During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

Cut down the amount of time you spent on work or other activities  
☐ Yes  ☐ No

Accomplished less than you would like  
☐ Yes  ☐ No

Didn't do work or other activities as carefully as usual  
☐ Yes  ☐ No

SOCIAL ACTIVITIES:
Emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

☐ Not at all  ☐ Slightly  ☐ Moderately  ☐ Severe  ☐ Very Severe

PAIN:
How much bodily pain have you had during the past 4 weeks?

☐ None  ☐ Very Mild  ☐ Mild  ☐ Moderate  ☐ Severe  ☐ Very Severe

During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

☐ Not at all  ☐ A little bit  ☐ Moderately  ☐ Quite a bit  ☐ Extremely
ENERGY AND EMOTIONS:
These questions are about how you feel and how things have been with you during the last 4 weeks. For each question, please give the answer that comes closest to the way you have been feeling.

Did you feel full of pep?
☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little bit of the time
☐ None of the time

Have you been a very nervous person?
☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little bit of the time
☐ None of the time

Have you felt so down in the dumps that nothing could cheer you up?
☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little bit of the time
☐ None of the time

Have you felt calm and peaceful?
☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little bit of the time
☐ None of the time

Did you have a lot of energy?
☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little bit of the time
☐ None of the time
Have you felt downhearted and blue?

- All of the time
- Most of the time
- A good bit of the time
- Some of the time
- A little bit of the time
- None of the time

Did you feel worn out?

- All of the time
- Most of the time
- A good bit of the time
- Some of the time
- A little bit of the time
- None of the time

Have you been a happy person?

- All of the time
- Most of the time
- A good bit of the time
- Some of the time
- A little bit of the time
- None of the time

Did you feel tired?

- All of the time
- Most of the time
- A good bit of the time
- Some of the time
- A little bit of the time
- None of the time

SOCIAL ACTIVITIES:
During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives, etc.)?

- All of the time
- Most of the time
- Some of the time
- A little bit of the time
- None of the time
GENERAL HEALTH:
How true or false is each of the following statements for you?

I seem to get sick a little easier than other people
☐ Definitely true  ☐ Mostly true  ☐ Don't know  ☐ Mostly false  ☐ Definitely false

I am as healthy as anybody I know
☐ Definitely true  ☐ Mostly true  ☐ Don't know  ☐ Mostly false  ☐ Definitely false

I expect my health to get worse
☐ Definitely true  ☐ Mostly true  ☐ Don't know  ☐ Mostly false  ☐ Definitely false

My health is excellent
☐ Definitely true  ☐ Mostly true  ☐ Don't know  ☐ Mostly false  ☐ Definitely false