The Effects of Neck Posture and Head Load on the Cervical Spine and Upper Extremities

by

Ebram Ibrahim, H.B.Sc.Kin

Department of Kinesiology
McMaster University
Hamilton, Ontario

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AUTHOR: Ebram Ibrahim (McMaster University)

SUPERVISOR: Dr. James R. Potvin

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ABSTRACT

Neck pain and injuries remain prevalent in many occupational categories. Risk factors include non-neutral neck postures and head loads. Most ergonomic tools do not account for the changes associated with these risk factors, or the effects that head position and load can have on the upper extremities. The purpose of this study was to investigate the effects of different neck postures and head loads on cervical discomfort and upper extremity functional integrity. Participants maintained flexed, extended, protracted, and neutral neck postures for a total of 4 minutes each. These trials were done both with and without a 3.68 kg head load. After each trial, measures of cervical discomfort, changes in hand sensation, hand and pinch grip strength, and holding forces were recorded. Cervical discomfort was found to increase in non-neutral postures and with the addition of a head load. Extension resulted in the greatest levels of discomfort, followed by flexion and protraction, with similar levels of discomfort, and neutral, which caused the least discomfort. Sternocleidomastoid activity increased in a loaded, non-neutral posture compared to an unloaded, neutral posture. These data could be implemented into current ergonomic tools to more comprehensively assess task demands and reduce the risk of injury.

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To God be all the glory and honor.

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CHAPTER 1 – INTRODUCTION

Proper task design is essential to reduce the risk of injury and the associated financial burden incurred by the employer. Nearly all work tasks involve an aspect of neck posturing to see the task or avoid an obstacle. In addition to supporting the head, the neck also houses and protects nerves travelling from the brain, through the spinal column, to the rest of the body. Therefore, great care must be taken to reduce the risks associated with neck injuries and pain as their implications may manifest in various other parts of the body. In a study of female automotive assembly workers, over a span of one year, 33% of workers reported neck pain (Zetterbeg et al., 1997). According to the Washington State Department of Labor and Industries in 2014, the neck category resulted in the tenth highest average injury cost, at $8,276 per injury. Bernard et al. (1997) conducted an extensive review of the occupational risk factors that may result in upper extremity or neck injuries. The review showed that there is either strong or sufficient evidence that posture, force and repetition are risk factors for the neck, as well as most segments of the upper extremity.

Numerous studies investigated the moment generating capacity of the neck and report strength values for different cervical postures for men, women, and different age groups (Chiu and Sing, 2002; Garces et al., 2002; Jordan et al., 1999; Stoll et al., 2000; Suryanarayana and Kumar, 2005; Vasavada et al., 2008). In the workplace, however, workers rarely maximally activate their neck muscles. Prolonged, static postures are more common and are reported to cause discomfort (Christensen & Knardahl, 2014; Sterud et al., 2014; Ohlsson et al, 1995; Hunting et al., 1980). This discomfort comes on quickly for workers, and is not immediately alleviated after the neck is relaxed (Keyserling et al., 1992).

Both non-neutral and neutral neck postures are reported to cause discomfort in the cervical region. Neck posture has a significant association with neck musculoskeletal disorders (MSDs) in occupational settings (Bernard et al., 1997). Non-neutral neck postures require increased muscular activity to stabilize the cervical joints when the center of mass of the head is not over the neck joints, thus causing a moment. This muscle activity causes an increase in spinal loading by compressing the cervical joints (Szeto et al., 2005). However, workers that have slight forward flexion of the neck exhibit lower muscle activity and report reduced levels of discomfort in occupations that involve prolonged sitting postures (Schuldt et al., 1985, Delleman, 1999). Reduced muscle activity, present in extreme working postures associated with dental work, may indicate a heavy reliance on the passive structures of the neck, such as tendons, ligaments and discs (Magnusson and Pope, 1998; Finsen et al., 1999). These non-muscular elements are at greater risk of failing (Keyserling et al., 1992).

Certain neck postures may not only increase the risk of neck injury, but they may also have ramifications for other parts of the body. Many studies show that certain neck postures can result in decreased H-reflex amplitude in the forearm muscles, as well as paresthesia in the fingers. These effects are similar to those seen due to nerve compression (Abdulwahab and Sabbahi, 1999, 2000; Cole et al., 2003; Yoo et al., 1992). As a consequence of these effects that are associated with neck posture, an individual may use more force than is necessary to complete a submaximal task if they are less acutely aware of the forces produced at the hand due to decreased sensation (Cole et al., 2003). If occupational tasks are designed with an ergonomically “acceptable” force requirement, but a worker uses more force than is required, due to the effects of possible nerve compression, the ergonomic and engineering safeguards on force levels will no longer be adhered to and may increase the risk injury.

In addition to supporting the moments caused by the weight of the head, certain occupational settings, such as tasks common to the military, require the worker to wear a helmet of considerable weight. Current military helicopter pilot helmets are equipped with night vision goggles, heads-up displays and a counterweight to offset the forward moment. These essential additions to the helmet increase neck compression, moment demands on the neck extensors, and result in pilots spending more time in flexion (Forde et al., 2011). The Canadian Armed Forces report that 80% of military helicopter pilots experience neck pain that they attribute to flying, and 10% report that the pain was so severe that they were no longer able to safely pilot the craft. They further report that the greatest limitation of flight duration is neck pain (Adam, 2004). Given these many issues, research is required to assess the effects of these loaded neck postures to reduce the risk of injury in work tasks that require helmet use.

In industry, many ergonomics recommendations are based on normative strength values for the different joints in the human body. With this knowledge, threshold limit values (TLVs) can be determined for different actions and applied in an occupational setting to reduce the risk of injury, as well as increase productivity and efficiency (Peebles and Norris, 2003; Dul & Neumann, 2009). TLVs that are used in ergonomics tools, such as the Mital and Snook tables (Mital, Nicholson, & Ayoub, 1993; Snook, 1978; Snook & Cirello, 1991), the Rapid Upper Limb Assessment (McAtammney & Corlett, 1993), the National Institute for Occupational Safety and health (NIOSH) Lifting Equation (NIOSH 1981), 3DSSPP (University of Michigan, Ann Arbor, MI), and Jack (Siemens, Ann Arbor, MI) all rely heavily on strength values to determine the acceptability and risk associated with different postures. Except for RULA, which takes neck posture into account, many of these tools lack a distinct emphasis on the neck that goes beyond simply recommending a strength limit, and none make quantitative calculations of actual neck loading. Also, passive tissues, such as tendons and ligaments, are not considered. In addition, these tools do not quantify the possible effects of posture on nerve cervical nerve root compression. Furthermore, there is currently no ergonomic tool that is able to assess the increased risk associated with the neck loading associated with wearing helmets.

Occupational settings will always involve non-neutral neck postures. A complete ergonomic recommendation must take both the muscular and non-muscular components, associated with different neck postures, into account. Current tools do not allow for such a recommendation. The effects of sustained neck postures, with and without a load such as a helmet, must be studied in isolation to further understand the complete effects of the cervical neck orientation in relation to the upper extremities. This research is required to specify the postures in which discomfort levels rise more rapidly, and their associated effects on other limbs. I anticipate that neck discomfort, a loss of tactile sensitivity at the fingers, and a reduction in maximal handgrip forces, will occur during different postural constraints. The neck is comprised of a series of complex joints at a particularly integral and mobile part of the body. It serves as the conduit for the spinal cord, and is the structure on which the perceptual organs of the head depend on for optimal performance. Focusing only on the muscular capabilities of the neck, while not considering the effects of neck posture on non-muscle elements, or the upper limbs, may not result in an ergonomic recommendation or redesign that reduces the incidences of neck or upper limb MSDs.

1.1 Purpose

The purpose of this study is to investigate the effects of neck posture and head load on both the neck and the upper extremities. The postures that will be considered will be neutral and maximum flexion, extension and protraction of the neck. The load will simulate helmets worn by military pilots, which are affixed with head-mounted displays, such as night vision goggles.

CHAPTER 2 - LITERATURE REVIEW

2.1 Anatomy of the Spine

The adult human spine, made up of twenty-four articulating vertebral segments, serves to support and allow for movements of the head, neck, upper limbs and torso. Furthermore, it operates as a protective channel through which the spinal cord travels and allows spinal nerves to exit from the foramen of each vertebrae. The spinal column can be sectioned off into four distinct regions based on their physical and functional characteristics. These regions are: 1) the cervical spine (C1-C7), which will be the focus of this thesis, 2) the thoracic spine (T1-T12), 3) the lumbar spine (L1-L5) and 4) the sacral spine (S1-S5) (Figure 2.1). The functional distinctions between the different regions of the spine are suggested by the "difference in the shape, size, and structure of…[their]…vertebrae and …[their]…intervertebral joints (Grant, 2002)."

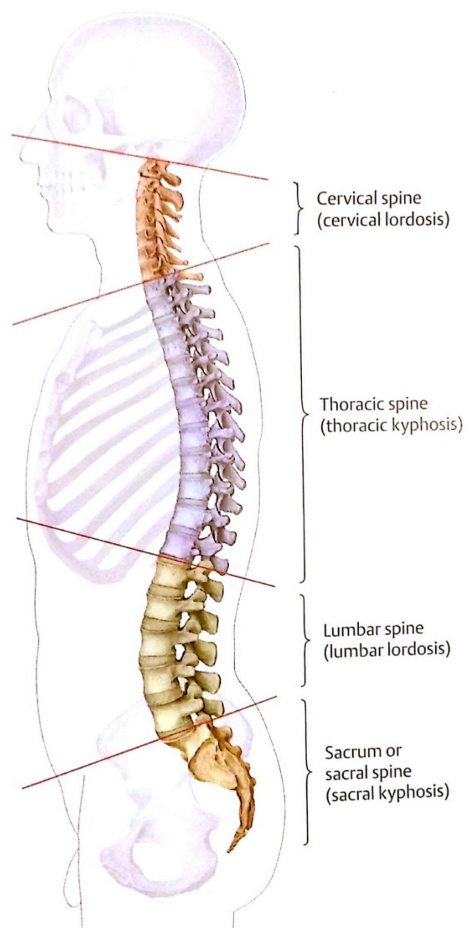


Figure 2.1. The four regions of the human spine (Seely et al., 2008)

2.3 The Cervical Spine

The cervical spine has the smallest vertebral bodies, as well as the largest spinal foramens through which the spinal nerve roots travel. The head, which houses the sensory organs and nerves for sight, smell, hearing and taste, is dependent on the cervical spine for both support and mobility. The cervical spine is essential for several activities of daily living, including directing the sensory organs towards aspects of the environment that would be most pertinent in a stable and safe manner. The cervical spine is able to serve all these functions due to the geometric characteristics of its vertebral bodies, which can be divided into three distinct units:

2.3.1 The Atlas (Cradle)

The atlas (C1) is the first point of bony contact between the skull and the spine. It has the largest vertebral foreman of all the cervical vertebrae. It does not have a spinous process, but rather, a posterior tubercle where the nuchal ligament is attached. The first cervical nerves exit over the posterior arch of the C1 vertebrae, on both sides of the posterior tubercle, under the posterior atlantooccipital membrane. The condyles of the occiput of the head are “cradled” by the superior articular facets of the atlas forming the atlanto-occipital joint. The geometry of the concave atlas and the convex occiput allows for flexion, and to a greater degree, extension (Table 2.1).

2.3.2 The Axis

The axis (C2) resides under the atlas to form the atlantoaxial joint that is secured by the transverse ligament. The odontoid process of the axis is the articulation point of the atlas above it. In addition to supporting the weight of the head, the atlantoaxial joint allows for a large range of axial rotation (Bogduk and Mercer, 2000). The lateral sections of the atlas and axis, and the anterior arch, interact with each other to allow for a large degree of voluntary cervical axial rotation (Grant, 2002) (Table 2.1).

2.3.3 The Column

The remaining segments of the cervical spine (C3 – C7) share the same basic morphological characteristics of a flat superior surface flanked by unicate processes and a concave inferior surface. However, C6 and C7 differ from the rest of the column in that their spinous processes are longer and the C6 spinous process is not usually divided into two parts. All vertebral segments are arranged on top of each other with intervertebral discs separating them. Intervertebral discs are cartilaginous pads that are subject to significant compressive loads and serve as shock-absorbers between vertebrae. These viscoelastic discs also hold adjacent vertebrae together while allowing slight mobility. Each disc is made up of a thick outer layer, called the annulus fibrosis, that encloses a gel-like center, called the nucleus pulposus. The geometry of the lower cervical column allows for axial rotation and lateral flexion.

2.4 Neck Musculature

The muscles responsible for movement and stability of the head and neck complex can be divided into the superficial and deep neck muscles (Figure 2.2). The superficial neck muscles, thought to be the prime movers of the neck (Jull et al., 2008), can be further divided into the anterior, posterior, and lateral muscles (Table 2.2). The superficial anterior group is responsible for flexion of the cervical spine, the posterior group for extension, rotation, and lateral flexion, and the lateral group for lateral flexion and extension. The deep cervical muscles are proposed to contribute to spine stability and slow movements (Bergmark, 1989).

Table 2.2: The three groups of superficial cervical muscles and their actions.

Group	Muscle	Action
Anterior	Longus capitis	Flexion
	Rectus capitis anterior	Flexion
Posterior	Longissimus capitis	Extension, rotation, lateral flexion
	Oblique capitis superior	Extension, lateral flexion
	Rectus capitis posterior	Extension, rotation
	Semispinalis capitis	Extension, rotation
	Splenius capitis	Extension, rotation, lateral flexion
	Trapezius	Extension, lateral flexion
Lateral	Rectus capitis lateralis	Lateral flexion
	Sternocleifomastoid	Rotation, extension, flexion

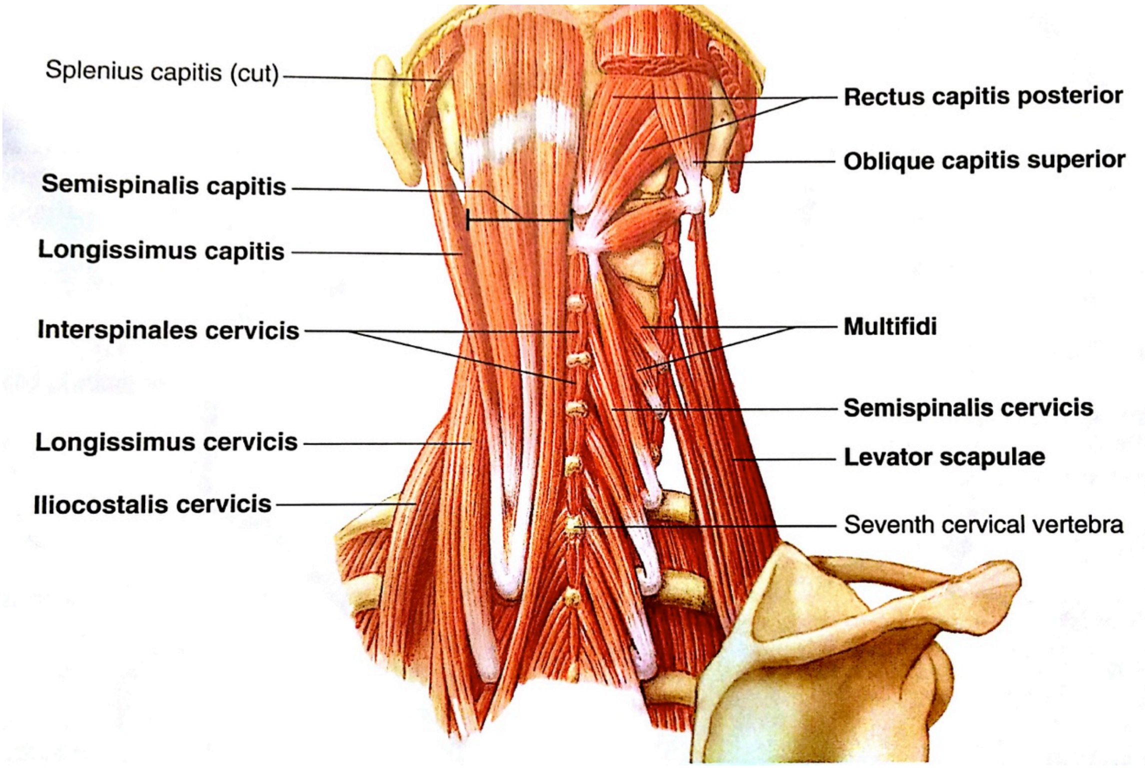


Figure 2.2: Deep muscles of the neck (Seely et al., 2008).

2.5 Neck Range of Motion

Chiu et al. (2001) used a Multi Cervical Rehabilitation Unit, designed to measure strength and neck ROM, to determine the range of motion (ROM) of 25 healthy participants (10 males, and 15 females) in flexion, extension, lateral flexion and axial rotation. Participants sat upright in a chair with restraints over their shoulders to isolate neck motion. Averaged across all participants, extension angle was only slightly greater than flexion angle by 0.3° ± 1.14°. Participants were also able to laterally flex to the left more than they were able to laterally flex to the right by 2.8° ± 0.1°(Table 2.1). These results were similar to those reported by Khulman (1993) and Penning and Wilmink (1987). White and Panjabi (1992) determined that the middle cervical spine (C4-C5) had the greatest contribution to neck ROM (Figure 2.3).

Table 2.1: Reported maximum ROM values of the neck from Chiu et al. (2001) on 25 healthy participants.

	Mean	SD
Flexion	68.0	6.2
Extension	68.3	7.3
Right lateral flexion	49.8	7.5
Left lateral flexion	52.6	7.6
Right rotation	78.0	6.4
Left rotation	77.2	7.6

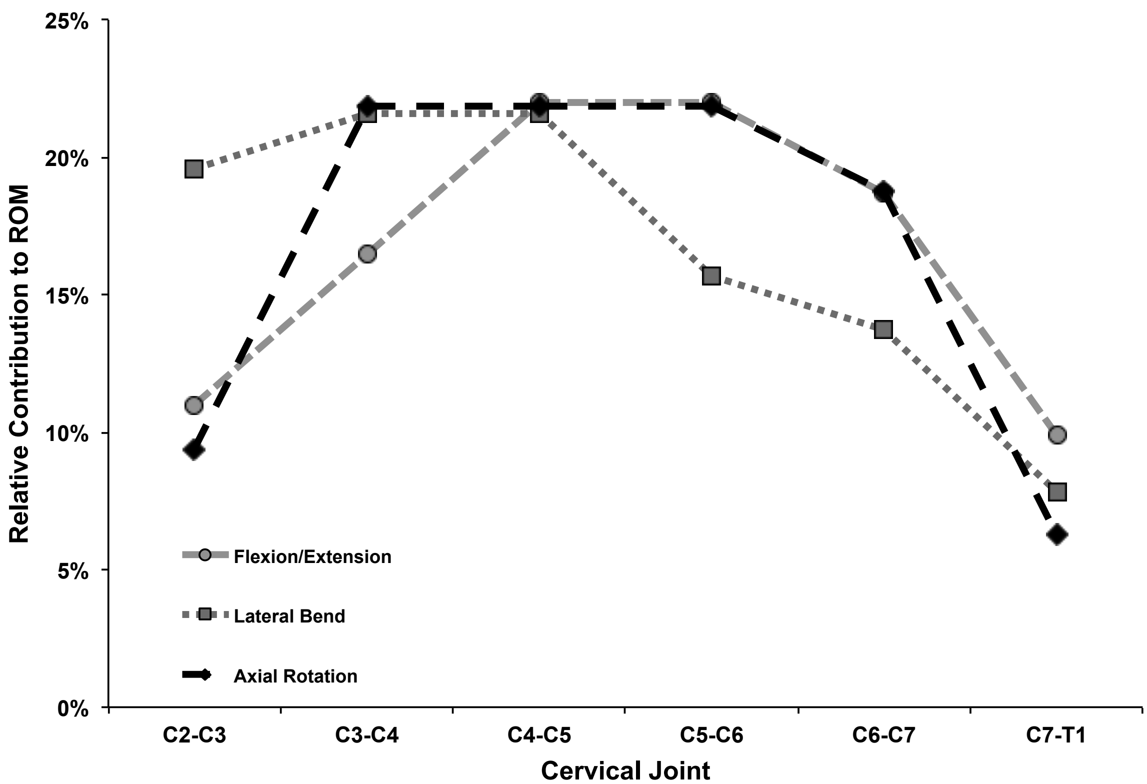


Figure 2.3: The contribution (in percentage) to neck ROM of each cervical joint for rotations about the flexion/extension, lateral bend, and axial rotation axes. Adapted from White & Panjabi (1992).

2.6 Spinal Nerves

There are 31 pairs of bilateral spinal nerves that exit from the spinal column. Eight of them originate from the cervical spine. The first pair exits between the occipital bone and the atlas, while the rest exit the vertebrae through the intervertebral foramen. Two spinal roots, the posterior and anterior roots, branch out of the spinal cord and then come together at the intervertebral foramen to form the spinal nerve. Outside of the vertebral columns, the spinal nerve roots branch into the dorsal and ventral rami, or the anterior and posterior branches, respectively. The posterior branches of the cervical spine innervate the structures of the neck that are found behind the intervertebral foramina (Bogduck, 1982). The anterior branches of the cervical spine make up the cervical plexus and the brachial plexus. The cervical plexus initiates with the spinal nerves that exit below C1 – C4, and can be spilt into a cutaneous (superficial) and motor (deep) branch. The cutaneous branch innervates the skin of the scalp, neck, chest and shoulder while the motor branch innervates certain muscles of the neck, diaphragm and shoulder. The brachial plexus includes spinal nerves C5 – T1 (Figure 2.4). The nerves that arise from this plexus include the axillary, musculocutaneous, radial, median and ulnar nerves. These nerves innervate muscles in the shoulders and upper limbs. Considering the level at which the brachial plexus nerves exit, it is conceivable that these nerves are mechanically affected by neck posture. The vertebral joints of the lower cervical spine (C5 – C7) contribute between 15 and 25% each to neck flexion, extension, and axial rotation (Figure 2.3). The most mobile section of the cervical spine may be an area where there is a higher risk of nerve impingement, possibly due to mechanical compression. A mechanical disruption to the brachial plexus would affect cutaneous sensitivity and the ability to move the upper limb.

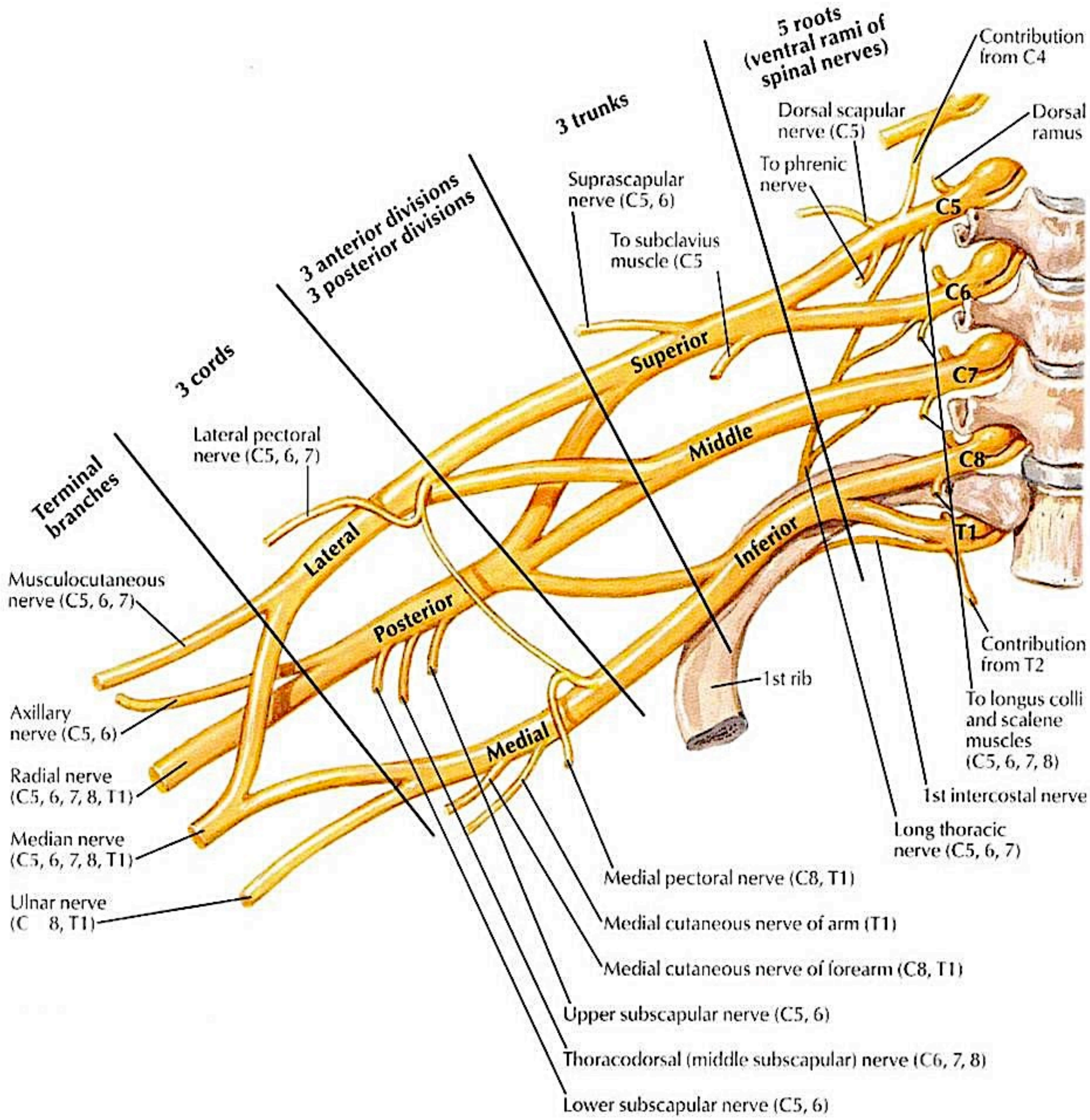


Figure 2.4: Spinal nerve roots exiting from C5–T1 that form the brachial plexus and it's associated nerves (Barbieri, 2013).

2.7 Neck injuries

Neck injuries affect a considerable number of workers and impose a significant financial burden on companies. Zetterberg et al. (1997) studied 564 car assembly workers (440 men and 124 women) and recorded self-reported incidences of neck injury, as well as the results of orthopedic examinations on the neck (Table 2.3). He reported that more than a third of females reported neck pain within the previous year and exhibited signs of myalgia, or muscle pain.

Table 2.3: Signs and symptoms of the neck from 564 auto assembly workers. A significant sex difference was only found in the number of orthopedic diagnoses of neck myalgia between men and women. Numbers in brackets represent the percentage of the total male or female participants (Zetterberg et al., 1997).

	Men	Women
Questionnaire on neck symptoms		
Last 12 months	143 (32%)	44 (36%)
Last 7 days	108 (14%)	16 (13%)
Orthopedic examination of neck		
Cervical spine (pain at examination)	49 (11%)	19 (15%)
ROM (side difference)	38 (8.6%)	8 (6.5%)
Myalgia	77 (18%)	43 (35%)

Bernard et al. (1997) systematically reviewed over 40 epidemiological studies on the effects of workplace demands on neck musculoskeletal disorders (MSDs). They found evidence that repetitive work and forceful exertions contributed to neck and shoulder MSDs. Furthermore, they found strong evidence that the neck and shoulder are at a significantly increased risk of MSDs when prolonged static loads, contractions, and extreme postures are required of a worker. Tension neck syndrome (TNS), associated with muscle fatigue, stiffness, and pain in the neck and shoulder, is a common MSD found in computer users - a task that typically involves prolonged neck and upper back postures (Mekhora, 2000). Posture, neck loads, repetitive work, and fatigue are risk factors for neck musculoskeletal injuries and pain (Finsen, 1999; Knight and Baber, 2004; Bernard et al, 1997; Sommerich et al., 2000; Winkel and Westgaard, 1992), as they are for most musculoskeletal disorders (MSDs). The upper back accounted for 3.3% (1,389) of all lost time claims in 2013 in Ontario according to the Workplace Safety and Insurance Board (WSIB). The Washington State Department of Labor and Industries (WSDLI) reported that, in the 2014 fiscal year, there were 1,364 neck injury claims incurring a total cost of $11.3 million USD, or an average of cost of $8,276 USD per claim. Neck injury claims are in the top ten of total incurred costs and average incurred costs. When considering these statistics, however, it should be noted that neck pain and injury may be significantly underestimated in worker’s compensation data, and likely contributes to all occupational categories (Haldeman et al., 2008). Zetterberg et al. (1997) recorded that maximum handgrip strength decreased in workers that had previously complained about neck pain. Cervical pain inhibits the maximal handgrip force that an individual would be able to produce due to the activation of the cervical muscles. For workers, this may lead to quality issues and/or the inability to complete certain tasks.

2.8 Neck Strength

Various studies quantified neck strength and discuss variables that would alter the force generating capacity of the neck, such as posture, gender and fatigue. It is extremely important to understand the functional capacity of the neck, so ergonomists can accurately determine acceptable loads. If neck strength demands eclipse the neck's moment generating capacity, injuries can arise. Furthermore, sustained submaximal static contractions, coupled with insufficient rest times, lead to muscle fatigue and are a risk factor for injuries and discomfort (Chaffin, Andersson, & Martin, 2006). Westgaard et al. (1986) reported that increased reports of worker neck and shoulder musculoskeletal injuries are correlated with increased static, submaximal activity of the upper trapezius. Establishing accurate, normative values for the strength of all joints in the body is extremely valuable for ergonomics decisions. Snook (1978) determined that, to significantly reduce the risk of lower back injuries, a job must be designed to be acceptable to at least 75% of the population. Knowing the mean and distribution of joint strength for particular muscle actions in a population allows for the design of a job that follows Snook's recommendation.

Chiu et al. (2002) used a Multi Cervical Rehabilitation Unit (MCRU) to record both the cervical strength and ROM of ninety-one healthy participants. They tested 45 men aged 20 – 84 years old, and 46 women aged 20 – 80 years old, to build a database of cervical strength as well as to determine variables that affect strength such as age, sex, and anthropometrics. Sitting restrained and upright in an adjustable chair, participants wore a head brace fitted with a load cell. They contracted as hard as possible against the brace with 10 seconds of rest between each contraction and 2 minutes rest between each neck action. Chiu et al. (2002) recorded 3 measurements each for flexion, extension, left lateral flexion, right lateral flexion, protraction, and retraction. They did not, however, record flexion and extension strength in a neutral neck posture. Rather, they recorded strength at 20° of flexion and extension for men, and at 40° of flexion and extension for women. Lateral flexion strength was recorded at 20° of lateral flexion. These values represented the highest strength compared to any other position. Chiu et al. (2002) reported that male isometric strength was 1.2 – 1.7 times greater than that of females. Postures between males and females, however, were not consistent in flexion and extension.

Kumar et al. (2001) conducted a study using 21 males and 19 females, with an average age of 24.4 and 23.9 years, respectively. They recorded maximal strength in eight different exertion directions. They reported that the neck was strongest in extension, with a progressive decrement in strength from posterolateral extension, lateral flexion, anterolateral flexion, to flexion, in both men and women. In accordance with numerous other studies (Chiu et al., 2002; Garces et al., 2002; Jordan et al., 1999; Stoll et al., 2000; Suryanarayana and Kumar, 2005), Kumar et al. (2001) found that males were able to produce greater neck moments than females in all directions. Vasavada et al. (2008) also collected the neck flexion and extension strengths of 35 males and 55 females, with an average age of 25.8 and 21.6 years, respectively. Female neck strength was 32% weaker in flexion and 20% weaker in extension, when compared to height matched males (Figure 2,5). To be considered “heighted-matched”, differences in standing height and neck length, between male and female pairs, had to be within 0.5 cm

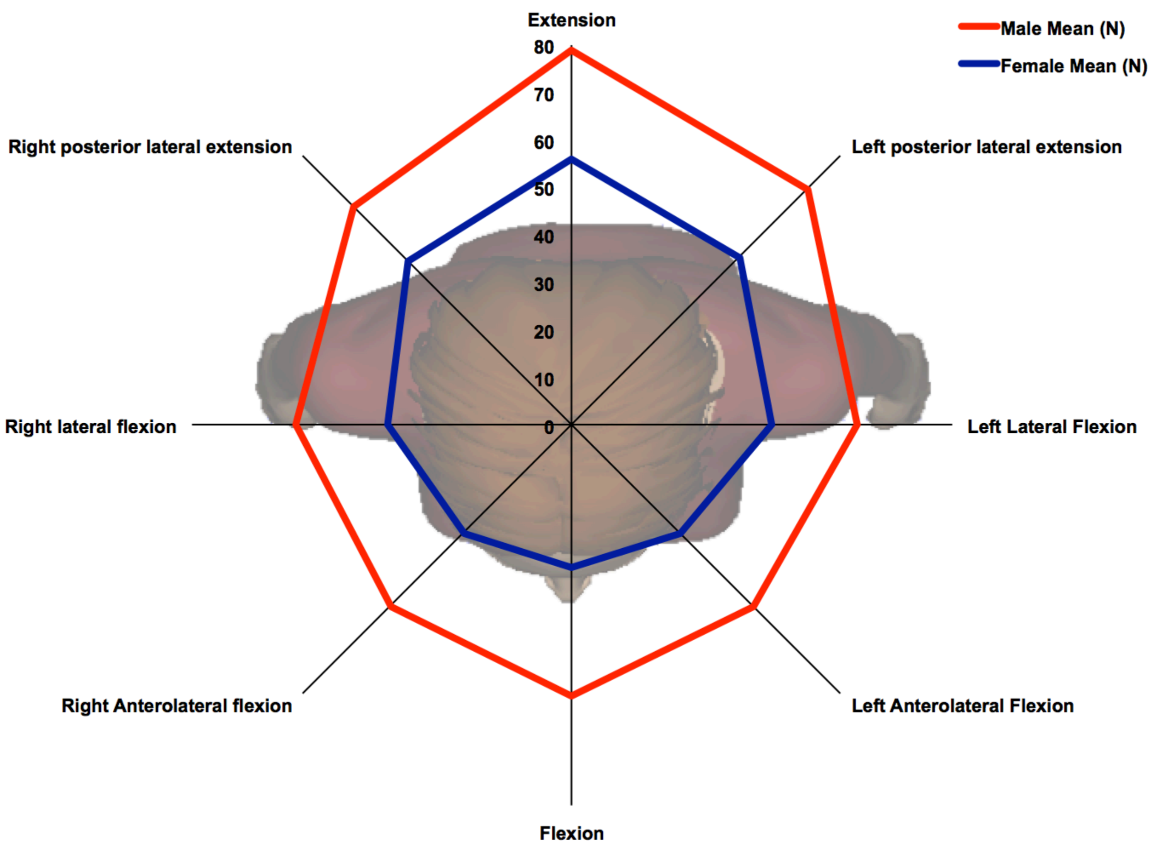


Figure 2.5: Representation of the average maximum strength values (Newtons) achieved by males (red) and females (blue) in various directions (Vasavada et al., 2008).

One issue with these studies is that Chiu et al. (2002), Kumar et al. (2001), and Vasavada et al. (2008) did not report neck moments or moment arms, which may not be consistent between the studies, considering the different apparatuses used. This makes it difficult to compare neck strength since locations of force application are dissimilar. Vasavada et al. (2001) recorded their neck strength data, as well as compiled data from previous studies, and reported the points at which they resolved the moments. A majority of the studies resolve the moment at the C4-C5 joint, or the C7-T1 joint and report similar values (Table 2.4).

Non-neutral neck postures also have a significant effect on cervical strength (Salo et al., 2006). Flexion strength, recorded from participants in a neutral neck posture, was greater than the strength reported from Jordan et al. (1999) and Chiu et al. (2002), where participants' necks were slightly flexed. Extension strength follows this same pattern. Neck demands, while in particular postures or performing certain tasks, can be compared to neck strength data to determine whether a particular job exceeds the capacity of the structures of the neck. However, it is not likely that a job would require a maximal neck exertion in any direction by a worker. Instead, sustained, submaximal contractions are common and present in most workplace environments. Tools like the maximum acceptable effort (MAE) equation (Potvin, 2012) are helpful in this regard to determine the maximum acceptable efforts for repetitive tasks. An MAE, as a percentage of the maximum voluntary effort (MVE) (e.g. 22% MVE), is calculated for a particular duty cycle assuming an 8-hour workday. The task demands of submaximal, occupational work can be assessed using the MAE equation. Exceeding this recommendation may lead to injuries and discomfort associated with muscle fatigue.

Table 2.4: Table from Vasavada et al. (2001) compiling maximum neck moment data (Nm) from other studies, as well as their own data, and the points of moment resolution, or the defined axis, for various actions.

	No. and Gender of Subjects	Point of Moment Resolution	Extension Moment	Flexion Moment	Axial Rotation Moment	Lateral Bending Moment
Berg et al [2]	17 F		23 ± 8	13 ± 5	8 ± 3	
Choi and Vanderby [5]	10 M	C4–C5	28 ± 3	18 ± 3		17 ± 3
Harms-Ringdahl and Schüldt [10]	10 F	C7-T1	29			
		mastoid	11			
Jordan et al. [13]	50 M	C7–T1	55 ± 14	30 ± 9		
	50 F	C7–T1	48 ± 15	21 ± 8		
Lee and Ashton-Miller [14]	9	C4–C5	29 ± 7	19 ± 4		
Leggett et al [15]	53 M	Thyroid cartilage	38			
	20 F		22			
Mayoux-Benhamou et al [16]	5 M, 10 F	C7–T1	53 ± 12			
Moroney et al [18]	10 M	C4–C5	30 ± 15	12 ± 7	10 ± 3	15 ± 8
	4 F	C4–C5	17 ± 7	6 ± 3	6 ± 2	8 ± 4
Pollock et al [20]	14 M, 5 F	Thyroid cartilage	34 ± 10			
Queisser et al [21]	12 M	C7–T1	60 ± 9			
Current study	11 M	C7–T1	52 ± 11	30 ± 5	15 ± 4	36 ± 8
		C4	35 ± 8	19 ± 4	14 ± 4	25 ± 6
		mastoid	24 ± 7	13 ± 3	15 ± 4	17 ± 5
	5 F	C7–T1	21 ± 12	15 ± 4	6 ± 3	16 ± 8
		C4	15 ± 8	10 ± 2	6 ± 3	10 ± 5
		mastoid	10 ± 5	6 ± 1	6 ± 3	6 ± 3

Note. Moments in Nm (mean and standard deviation) reported at the neutral position. Points of moment resolution defined in Methods except C4–C5 (center of C4–C5 intervertebral disc) and thyroid cartilage. Berg et al [2] did not define the point of moment resolution in their study. Because Leggett et al [15] and Pollock et al [20] did not explicitly define neutral position, it was assumed to be the average of the two middle positions of the range reported. The moments reported by Harms-Ringdahl et al [10] include the moment caused by the weight of the head. The moments reported by Queisser et al [21] were measured with subjects in the supine position, and the weight of the head was subtracted.
M = males; F = females.

2.9 Neck Posture

In an extensive review of the literature, Bernard et al., (1997) recorded 27 studies that report a strong association with neck posture and neck MSDs in occupational tasks. Non-neutral neck postures impose significant demands on the muscles and tendons of the neck to ensure stability of the head, which results in an increase in spinal loading (Szeto et al., 2005). Neck flexion is reported to cause neck discomfort and upper limb disorders (Ohlsson et al, 1995; Hunting et al, 1980). Forward flexion of the neck results in 3 to 6 times the load on the C7-T1 joint when compared to a neutral posture (Finsen et al., 1999)

Delleman (1999) reported that neck postures should be within 0°-25° of flexion to reduce the level of discomfort in workers. Both the International Organization for Standardization (ISO) and the European Committee for Standardization (EN) recommend a slightly flexed neck in occupational settings (ISO 11225 and EN 1005-4, respectively), citing decreased muscle activity (Schuldt et al.,1986). This same phenomenon is seen in the extreme ranges of motion of the neck. For example, with extreme flexion, there is a significant decrease in neck muscular activity (Magnusson and Pope, 1998).

Finsen et al. (1999) recorded the muscle activity associated with the neck in postures related to dental work. They recruited seven female dentists to work on patients for an average 6 hour day in two common postures, one associated with working in the mouth of the patients and the other handling dental equipment. Both postures involved some degree of forward flexion. EMG was recorded from the splenius muscles. They observed that the mechanical load on the neck was four times higher than what the EMG would suggest. While it is possible that other muscles were recruited, this may point to heavy reliance on the passive structures of the neck. Prolonged postures, such as extreme neck flexion, can lead to discomfort within 15 minutes of sustained exposure, and sustained discomfort well after the posture is discontinued (Keyserling et al., 1992). Kilbom et al. (1986), report that extended phone use, which involves lateral bending to hold the phone between the head and shoulder, is associated with an increased risk of neck injuries when compared to neutral.

While muscle demands are a good indication of possible risk of injury and pain, non-muscular elements must also be considered. Ligaments, bones and nerves are in close proximity to the cervical neck, and the disruption of any one of these components may result in discomfort or injury. While slight flexion of the neck may be considered preferable in occupational settings, due to the resulting decrease in muscular activity, the effects of sustained flexion may manifest themselves in damage to the passive structures of the neck.

2.10 Nerve compression

Neck posture and cervical dysfunction have significant effects on the upper extremities (Abdulwahab and Sabbahi, 2000; Quintner, 1989; Sabbahi and Abdulwahab, 1999; Skubick et al., 1993). Abdulwahab and Sabbahi (1999, 2000) investigated the effect of neck postures on the flexor carpi radialis (FCR) muscle. In 1999, they studied the change in the FCR H-reflex due to possible cervical nerve root compression, caused by acute neck postural changes. The H-reflex is the refractory response of a muscle after the afferent sensory fibers of the innervating nerve are externally stimulated. A change in latency or amplitude of the H-reflex while the participant remains stationary may, in part, be due to some change in the nerve that innervates the limb. They had twenty-two healthy participants that were seated and guided into end ranges of neck flexion, extension, rotation, lateral bend, protraction and retraction. The participants maintained each position for 30 seconds. They tested and recorded the FCR H-reflex after each 30-second bout, as well as in a neutral neck position. Abdulwahab and Sabbahi (1999) found that all head positions, excluding flexion, caused an increase in H-reflex amplitude. The authors postulated that this was indicative of increased spinal excitability and mechanical decompression of the cervical nerve root. Flexion resulted in an H-reflex of significantly lower amplitude when compared to the neutral posture.

In 2000, Abdulwahab and Sabbahi again looked at the effects of neck postures, specifically protraction and retraction, the FCR H-reflex. They built on their previous work by including a clinical population and a subjective rating of pain. The healthy group consisted of 10 controls and the patient group, who suffered from cervical pain, was made up of 13 participants. They instructed both groups to sit upright on a chair and read for 20 minutes, which was then followed with 20 repetitions of practitioner-assisted neck retractions. Neck retractions are recommended to treat cervical neck pain (McKenzie, 1983). The H-reflex of the FCR was recorded throughout the reading and neck retraction trials. Participants rated their pain on a visual analog scale before reading, after reading and after the neck retractions. In both groups, the H-reflex amplitude decreased after reading and then increased after the neck retractions, although the differences were only significant in the patient group. However, only the patient group showed significant changes in the H-reflex amplitude. The patient group also reported that reading increased cervical and radicular pain.

The findings agree with their previous 1999 study on the effects of neck posture on the H-reflex recorded from the FCR. Their results, however, differed for neck protraction, which is a posture common to several everyday tasks such as reading. It is possible that, in the initial 1999 study, an acute 30-second hold of the neck in the end range of motion for protraction was not sufficient to elicit any changes. Furthermore, pure protraction may not have been a posture that affects the cervical nerves. The provocation of a possible neural change by instructing the participants to read is more indicative of an occupational setting and, therefore, provided data that are more applicable to use. Both studies show that flexion had an adverse effect on motor neuron excitability and caused increases in radicular and cervical pain. According to the second study, protraction has the same effect. Extension, lateral bend, and rotation result in the opposite, an increase in H-reflex amplitude and a decrease in cervical pain.

Abdulwahab and Sabbahi (1999) hypothesized that mechanical compression of the median nerve in the neck can be one of the possible causes of a change in the H-reflex signal. They thought that neck retraction has a mechanically de-compressive effect on impinged nerve roots in the cervical spine. That is to say that, with neck protraction, the opposing motion results in a compression of the cervical nerve roots. The authors attribute cervical nerve root compression, during neck protraction and flexion, to the bulging of the nucleus pulpous, similar to its behavior in the lumbar spine.

In studies of the lumbar spine, flexion and extension resulted in a migration of the nucleus pulposus (Fennell et al., 1996). In flexion, they observed that the nucleus pulposus moved posteriorly in the disc, while it moved anteriorly during extension. Abdulwahab and Sabbahi (1999, 2000) predicted that this same interaction, between flexion/extension and nucleus pulpous migration, occurs in the cervical spine. They contend that the posterior translation of the pulposus mechanically compresses the cervical spinal root, which results in the decreased H-reflex amplitude in flexion and protraction. In extension and retraction, the opposite occurs and the spinal root is decompressed. This would explain the immediate changes seen in the FCR H-reflex and radicular pain. However, findings from the lumbar spine, on which nucleus pulposus migration research is done, cannot be applied to the cervical spine as the types of injuries, dimensions and changes due to age of the cervical and lumbar intervertebral discs are dissimilar. Also, the existence of the nucleus pulposus in the cervical intervertebral discs, while present in infants and young children, does not persist into adulthood as in the lumbar spine (Bland and Boushey, 2001; Mercer and Bogduk, 1999; Oda et al., 1988).

In a study of 155 human cadaveric cervical vertebrae, with age at time of death ranging from 6 days to the mid 80 years, Oda et al (1988) took 15 mm thick segments of the vertebrae and analyzed them using x-ray photography. Given the wide range in age, the developments of the segments within the cervical discs could be observed. The nucleus pulposus, made up of notochord cells in early development nearly completely disappears by the age of 25 and is, instead, composed of fibrocartilage and dense fibrous tissue. Thus, in later years, the pulposus is no longer a soft gelatinous material, but rather, a large collagenous web with very different material characteristics.

While the nucleus pulposus may, indeed, drastically migrate in the lumbar spine, as mentioned by Abdulwahab and Sabbahi (1999) and McKenzie (1983), it is far less likely to do so in the cervical spine. Although the nucleus pulposus may not be responsible for the effects of cervical neck posture on the arm, the findings of Abdulwabab and Sabbahi are similar to the effects seen in limbs due to nerve compression. Discomfort, forearm muscle weakness, and reduction in tactile sensitivity of the digits are symptoms association with cervical nerve root compression, typically seen in adults over 40 years of age (Persson et al., 1997).

Cole et al. (2002) studied the effects of acute compression on the median nerve in the carpal tunnel. They studied 8 participants (4 females, and 4 males), free of any nerve injury or disease. Participants placed their hands in a device that would ensure dorsal veins remain uncompressed and allow for adjustable pressure on the median nerve using a clamp. With the participants' hands in the device, they stimulated the participants' median nerves distal to the compression location and recorded their sensory nerve action potentials (SNAPs) from the digital nerve of their index fingers. The authors set external compression pressure on the median nerve to induce a 25%, 50% and 75% reduction in the amplitude of the SNAPs of the digital nerve compared to the SNAPs when there was no external compression. During each condition, they recorded the tactile sensitivity of the thumb and index fingers, and finger grip force required to lift a 4 N object of the participants at the different compression pressures. However, finger grip strength and tactile sensitivity did not respond in unison throughout the various trials. At 75% of the uncompressed SNAP, they recorded reduced sensitivity but grip forces did not change compared to 100% of SNAP. At 50% of SNAP, there was an increased loss of tactile sensitivity and an increase in grip force by 55%. At 25% of SNAP, participants described the areas innervated by the median nerve as numb. Also, grip force increased to 50% of their original uncompressed trial. These results show that decreased sensitivity, and increased grip force, are markers of direct nerve compression, and similar phenomena seen at the hand during certain neck postures may be indicative of mechanical compression of the median nerve. If this nerve compression occurs at the cervical level, the effects of neck posture are not limited to the neck, but also to the areas of the body innervated by the cervical nerves.

During an upper extremity task, in a posture that impinges the cervical nerve roots, the afferent signal from the muscles would be hindered. This will cause to the brain to increase efferent activity so as to ensure the completion of a task. Due to the blocking of the afferent signal, because of cervical nerve impingement, and sensation of numbness in the hands, the individual may not be sure if they have the object firmly in their grasp. The individual is likely to grasp the object more firmly, more than is required, to ensure a secure hold. The force they exert will be a greater percentage of their MVE and further increases the risk of injury, due to the build up of metabolites associated with fatigue (Fitts, 1994). Neck posture is a critical variable in reducing occupational risk factors, both to the neck and the upper extremities.

2.11 Effects of cervical spine motion on the neuroforaminal dimensions of human cervical spine

To have a greater clinical understanding of cervical injuries and pathologies, Yoo et al. (1992) conducted a study on the change in cervical neuroforaminal space with changes in cervical neck posture. They hypothesized that irritation or mechanical compression of the nerve roots may occur if certain cervical postures cause the intervertebral foramen to narrow, constricting the area around the spinal nerve roots. This would likely affect the innervated limbs over time. The researchers used the C2-T1 specimens from 5 freshly frozen human cadavers that were between 35-70 years old. The specimens were free of injuries, diseases or any previous surgical interventions. They secured, and controlled, the kinematics of the C2 and T1 vertebrae, while vertebrae C3 to C7 retained their natural motion. Four 2.5 lbs weights hung from transverse pins in C2 to simulate normal spinal compression. Using finely graded circular blunt probes, Yoo et al. (1992), recorded the size of the largest probe that could pass through the foramen without forcing movement of the facet joints. They tested the specimens in flexion alone, extension alone and flexion and extension in combination with 20° axial rotation.

When compared with neutral posture, the foramen size significantly decreased in extension and significantly increased in flexion when angles were 20° or greater. In extension, with 20° of ipsi/contra-lateral bend, foramen size decreased when compared to foramen size with pure rotation. In contrast, foramen size increased in flexion with 20° of ipsi/contra-lateral bend (Figure 2.6).

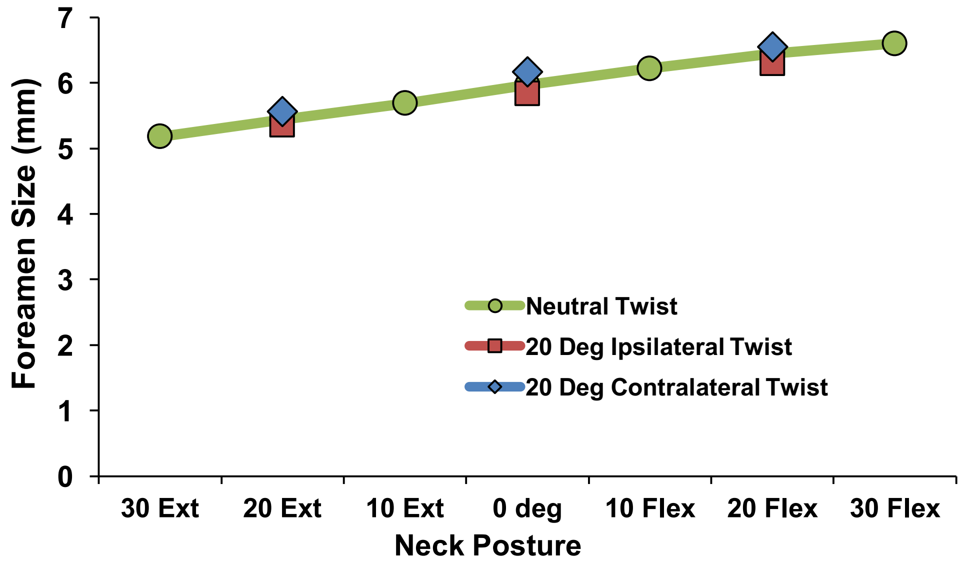


Figure 2.6: Graph adapted from Yoo et al. (1992) showing the foramen size of human cadavers in response to different neck postures in mm.

Yoo et al. (1992) state that spinal nerve roots, compared to peripheral nerves, have less epinerial protection from connective tissue and, therefore, have a higher predisposition to mechanical compression. According to their findings, this mechanical compression is more likely to occur in neck extension due to the decreased cervical foramen size. C5 has a significantly smaller foraminal opening than C7 and C6 in both flexion and extension postures. Mechanical compression of nerve roots is therefore most likely to occur in the C5 foramen during extension than at any other cervical foramen. Parethesia of the ipsilateral extremity may be related to postures that tend to reduce foramen size. These findings are contrary to the findings from Abdulwahab & Sabbahi (1999, 2000) who observed symptoms associated with mechanical compression in flexion, a posture that Yoo et al. (1992) state allows for greater liberty of the nerve root in the foraminal space. Flexion, seen to reduce spinal excitability, is a posture that increases foraminal space, and therefore mechanical compression of the nerve root is less likely to be the cause of a decreased FCR H-reflex amplitude. For these studies to be harmonized, mechanical compression of the spinal nerve root, at the location of the vertebrae, might not be the cause of the symptoms seen in the upper limb. Mechanical nerve root compression in the foraminal space may not be a valid explanation for the findings of Abdulwahab & Sabbahi (1999, 2000) in flexion considering the effect of this posture on foraminal size recorded by Yoo et al. (1992).

2.12 Head load

The effect of head loads is also an area that demands attention. Wearing a helmet will protect the head, but the weight of the helmet results in altered muscular activity, increased incidence of pain, higher perception of discomfort, increased risk of neck injuries and accelerated time to fatigue. Knight and Baber (2004) studied the effects of adding a weight to the head on neck muscle activity in different postures. They had twenty participants, ten with a front-loaded helmet, and 10 with a counter balanced helmet, maintain common neck postures such as 30° of flexion and extension. Increased loading on the head caused an increase in musculoskeletal activity, necessary to maintain stability, In extension, although neck EMG activity was reduced, both groups reported increased perceptions of pain and discomfort when compared to neutral. They did not show evidence of fatigue in the neck muscles due to a short static posture (10 s) but Chaffin (1973) did show evidence of neck muscle fatigue due to prolonged (< 2 hours) static neck flexion.

In a survey of helicopter pilots in the Canadian armed forces, 80% of pilots experience neck pain that they attributed to flying (Adam, 2004). Of those that reported pain, 10% reported that the pain was so severe that their ability to safely pilot the helicopter is compromised or non-existent. This poses tremendous occupational and flight safety concerns. The helicopter pilots surveyed had to wear night vision goggles (NVGs) and heads-up displays (HUDs) as part of their headgear during all flights. The combined weight of all the necessary head gear, including a counterweight to offset the NVGs and HUDs that are part of the anterior aspect of the helmet was 36 N. This counterweight is added to reduce the flexing moment caused by the anterior load. This leads to a decrease in trapezius activity, but an increase in sternocleidomastoid activity, a form of co-contraction that is necessary to stabilize the cervical structure and consequently, causes increased spinal compression. (Harrison et al., 2007; Knight and Baber, 2004)

In a study by Forde et al. (2011), of 10 male Canadian Air Force helicopter pilots with full headgear and counterweights, they recorded flight missions and assessed the pilots for postural and spinal loading data. They used 3D rigid linked-segment model to determine rotations at the C7 level while the pilots completed full missions in a helicopter simulator. They found that pilots wearing full headgear spent less time in extended and neutral postures, and significantly more time in mild and severe flexed neck postures. Neck compression and neck muscle extension moments were found to significantly increase with full head gear compared to wearing no NVGs. Time that the pilots spend in mild (10-30°) or severe flexion (>35°) is especially concerning considering that workers who spend more than 66% of their work cycle in flexion are 2.6 times more likely to develop neck pain (Anderson et al., 2003).

In addition to the loading and flexion moments they cause, NVGs decrease the range of vision that a pilot would have and, thus, require the pilot to compensate by directing their head more directly towards pertinent parts of the environment. These same effects are also seen in paramedics using head mounted displays (Knight and Baber, 2004). The increased weight of the helmet, in addition to decreased range of peripheral vision, results in compensatory actions that may lead to a greater risk of neck pain and injury. An increase in head loads alone leads to increased pain and discomfort, as well as a deviation from neutral head posture (Knight and Baber, 2004). The specific postures in which discomfort levels arise, as well as the associated effects in other limbs, still requires directed research and will find its applicability in ergonomic recommendations for combat pilots, first responders and other occupations that involve the use of a helmet.

2.13 Hypothesis

1. Prolonged flexion, extension, and protraction of the neck, at the extreme ranges of motion, will result in a greater degree of discomfort and decreased hand and pinch grip forces, when compared to neutral. In static postures, at the extreme ranges of motion, continuous bilateral muscle activity will be required to stabilize the head-neck joint (Panjabi et al., 2001). Maintaining these muscular contractions will result in fatigue and discomfort (Mekhora, 2000). Upper limb exertions result in increased and altered activity of the muscles of the neck. A maximal handgrip or pinch grip will cause increased muscle activity at the neck, which participants will want to avoid due to existing cervical discomfort. (Falla et al. 2004). To prevent further discomfort, they will limit their maximal exertions and not be able to exert similar forces in neck flexion, extension, and protraction compared to a neutral posture.
2. Mechanical compression of the spinal nerve roots, exiting from C4–C7 (the most mobile of the cervical vertebrae in flexion/extension) (Grant, 2002), will result in numbness felt at the areas of the hand innervated by the median and ulnar nerves during neck extension and increase lift forces for the same task. During neck extension, the intervertebral foramen is narrowed, increasing the risk of nerve root impingement (Yoo et al., 1992). This may lead to mechanical compression of the spinal nerve roots, which will reduce maximal handgrip forces, increase lift forces, and further manifest in reduced sensation of the hand due to the decreased ability of the efferent and afferent signals to pass the compressed nerve.

3. Wearing a weighted helmet will amplify the reduction in maximal handgrip and pinch grip forces of unloaded neck postures observed in extension, flexion, and protraction. A weighted helmet will necessitate increased EMG of the cervical muscles to stabilize the head-neck joint (Harrison et al., 2007; Knight and Baber, 2004; (Green & Brown, 2004; Hendriksen & Holewijn, 1999; Newman, 1997). The increased submaximal activity of the muscles will lead to a greater degree of discomfort in the neck and, therefore, will decrease hand and pinch grip forces, in all postures when compared to the unloaded conditions Falla et al., 2004).

4. Wearing a weighted helmet will not cause a further change in lift forces compared to the unloaded neck extension posture. Potential mechanical compression of the cervical nerve roots is related to posture, and not related to head load (Grant, 2002; Yoo et al., 1992).

CHAPTER 3 - METHODS

3.1 Participants

Sixteen right-handed, healthy, university-aged females were recruited from the McMaster community. Participants had an average age of 22.9 ± 1.9 (Table 3.1). Participants had no history of musculoskeletal injuries or disorders to the upper extremities and neck. Prior to the start of the protocol, the participants were asked to read and sign a consent form. This study has ethics approval from the McMaster Research Ethics Board (2014-250).

Table 3.1: Anthropometric data of the participants included in this study (n=16).

	Height (cm)	Weight (kg)	Age(yrs)
Mean	164.9	62.4	22.9
SD	6.6	10.0	1.8
Min	152.4	45.9	21.0
Max	177.8	80.2	26.0

3.2 Instrumentation and Data Acquisition

We used a custom, manually adjustable tilt board to control the angle of the neck.
An adjustable footrest at the base of the tilt board allowed participants to retain their position on the board (Figure 3.1).

We recorded neck angle using a 6-degree of freedom 3Space Fastrak system (Polhemus, Colchester, VT). The Fastrak system uses a magnetic field to track the orientation and position of individual sensors in three-dimensional space. One Fastrak sensor was attached to the top of headgear and another to the upper sternum of the participants for a total of two Fastrak sensors. These kinematic data were collected at a sampling rate of 30 Hz, which is defined by the Fastrak system. Online visual feedback, pertaining to neck and head posture, was provided to the researcher so that they can alert participants if their neck deviates from the intended posture.

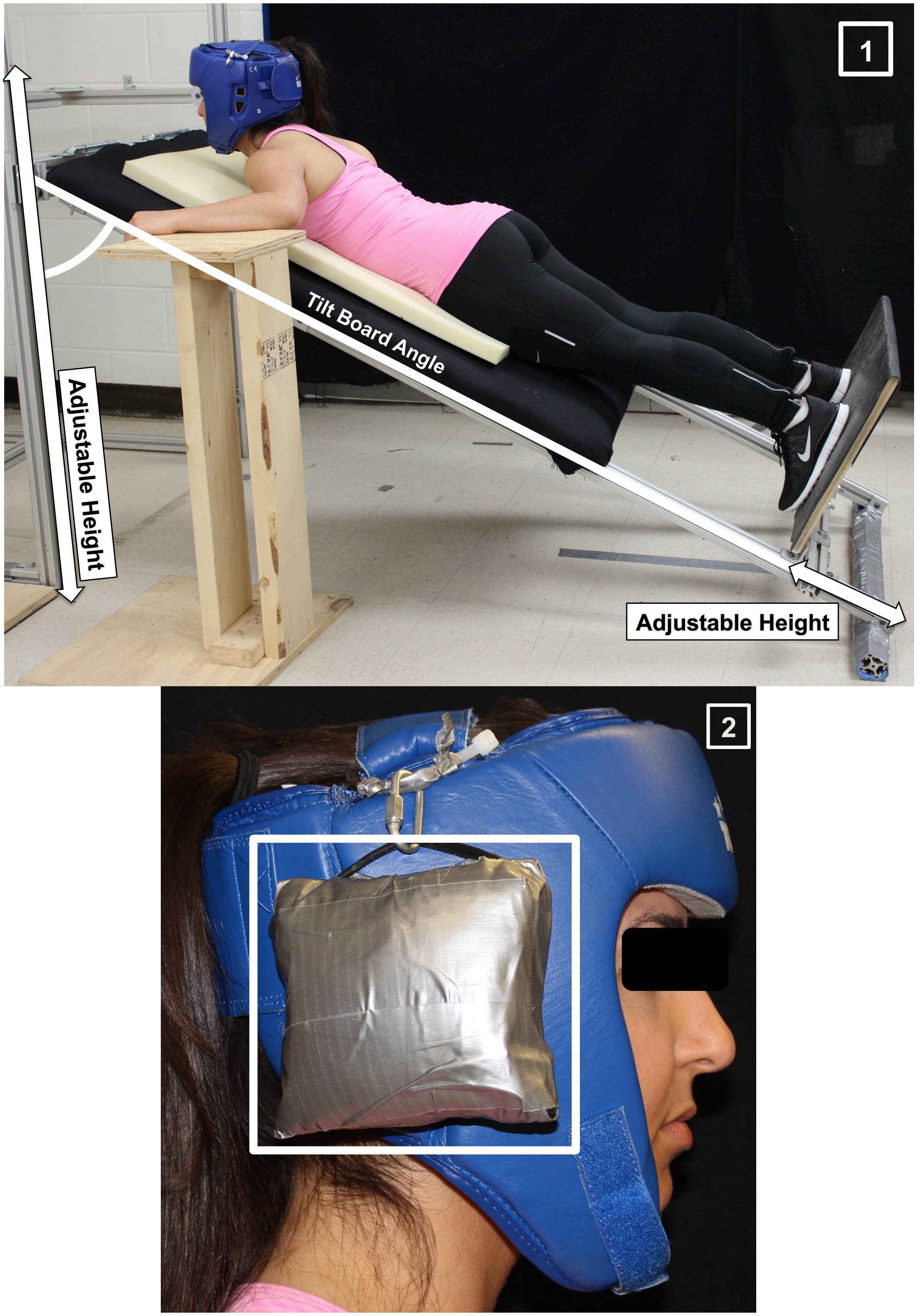


Figure 3.1: 1. Tilt board tilted at 52°. Foot rest near the bottom of the board was adjusted to the participant's height. The height of the top of the board as well as the bottom of the board was adjusted to facilitate different angle requirements. 2. Load attached to the side of the helmet.

Force data was collected using an s-type load cell (100lb max, Omegadyne Inc., Laval, QC, Canada) and a hand grip dynamometer (MIEMedical Research limited, Leeds, UK).
Neck strength force data for flexion, extension, and protraction was collected using a tri-axial load cell (500 lb XYZ Sensor, Sensor Development Inc, Lake Orion, MI), which was attached to an adjustable horizontal length of slotted rail (80/20 Inc, Columbia City, IN) (Figure 3.4). The horizontal length of slotted rail was fastened between two vertically oriented slotted rails. This set-up ensures adjustability to accommodate for the different sitting heights of participants.

Surface EMG (10-1000 Hz; CMRR>115 dB at 60 Hz; input impedance ~10 GΩ; AMT-8, Bortec Biomedical Ltd., Calgary, AB) was collected bi-laterally from 3 muscles of the cervical neck: sternocleidomastoid (SCM), erector spinae (ES), and upper trapezoid (UT).
We prepared the electrode sites by scrubbing the area with alcohol prior to the placement of the disposable Ag-AgCl surface electrodes (MediTrace Mini ECG electrodes, Kendall, Mansfield, MA, USA) over the muscle belly along the fiber direction with an inter-electrode distance of 2.0 cm. Electrode placements were confirmed using palpation and manual resistance tests Table 3.2.

Table 3.2: Physical location of the electrode placements for each muscle.

Muscle	Location
Erector Spinae	Immediately lateral to the spinal column at the level of C2/C3
Sternocleidomastoid	Over muscle belly, about 1/3 of length rostral to sternal attachment
Upper Trapeius	Over muscle belly, about C6–C7 level and dorsal to insertion on lateral third of clavicle

We collected all force and EMG data 2000 Hz with custom LabVIEW software (National Instruments, Austin TC) using a PC compatible computer and converted by a 12-bit A/D card (National Instruments, Austin TX).

A Borg Rating of Perceived Exertion Scale was used to determine the participant's level of perceived discomfort. The purpose of the Borg scale is to detect a change in discomfort which may be influenced by the different neck positions and loading over time. A schematic of the hand was supplied to the participants so that they can point out areas of perceived numbness (Figure 3.2).

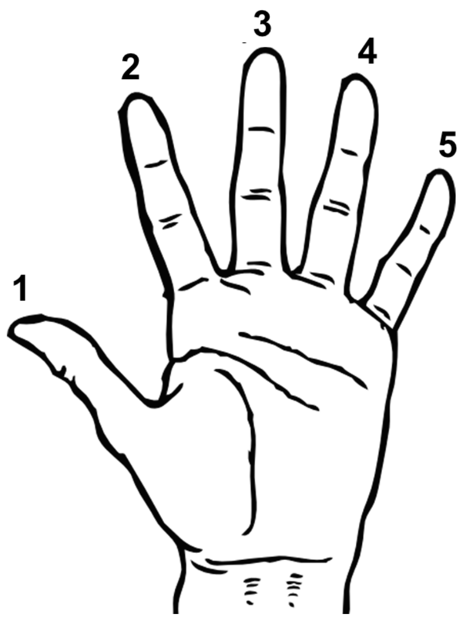


Figure 3.2: Participants were shown this figure and asked to denote areas where they perceive numbness. Options are the first, second, third, fourth, and fifth fingers, as well as the palm (http://www.tabs4acoustic.com/images/uploads/images/Hand.png)

3.3 Experimental Procedures and Protocol

During the first session, age and anthropometric measurements of height (cm) and weight (kg) were recorded. Height was used to properly adjust the foot rests of the tilt board so that the participant may comfortably lied on it such that their chin is beyond the end of the board when face down and in neck extension.

Subjects wore a securely fitted padded leather helmet (295 g) for the duration of the study. Necessary adjustments to the size of the helmet will be made to ensure a comfortable and secure fit. Fastrak sensors were attached to the top of the helmet and to the participant's sternum. Surface EMG electrodes were affixed to the skin (Figure 3.3). With the subject in a neutral standing posture, the online kinematic data from the Fastrak sensors was used to record maximum voluntary ROM (in degrees), from a neutral neck posture, for flexion, extension, and protraction. The participant was instructed to slowly flex, extend, laterally bend, twist, protract and retract their neck as far as they can and hold their posture for each action for at least 3 seconds (Figure 3.4). They were asked to complete each action twice. The largest relative angle, between the head and the sternum, was calculated and used to normalize angle data to the maximum ROM for each direction.

A quiet EMG trial was conducted prior to any collections to remove the signal bias from each EMG channel. Static MVC trials in flexion, extension, and protraction were conducted in a seated position, with the participant's feet flat on the ground, to determine EMG activity. Participant neck MVCs in flexion, extension, and protraction were recorded using a custom-mounted, height adjustable load cell (Figure 3.4) in conjunction with EMG recordings. MVC trials required the participant to either isometrically: a) flex, b) extend, c) laterally bend to the right or d) laterally bend to the left against the load cell with their heads with as much force as possible. They were instructed to ramp up their force application to their maximum, hold it for two seconds, and then ramp down. Between each neck action, they were given at least one minute of rest to ensure that there are no residual effects of fatigue. Two trials were conducted for each neck action and, if the trials were within 10% of each other, then the higher force value was recorded. If they are not within 10% of each other, then a third trial was collected. This resulted in a minimum of 8 neck MVCs. The maximal EMG from the MVC determination were used to normalize the EMG signals from the collection trials.

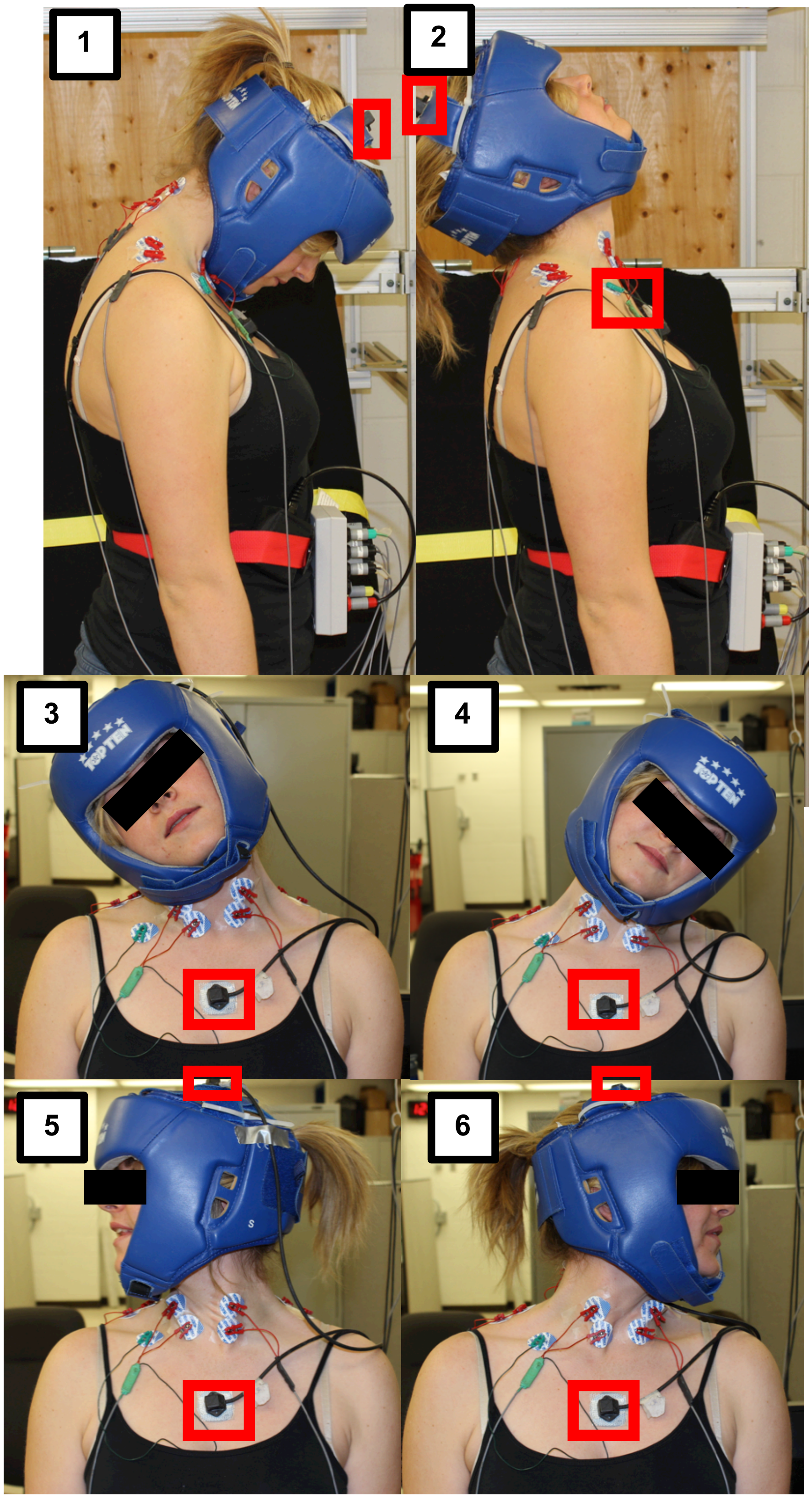


Figure 3.3: Maximal ROM posture in 1) flexion, 2) extension, 3) right lateral bend, 4) left lateral bend, 5) right axial twist, and 6) left axial twist. Sensors are outlined in red where visible. Sensor 1 is on the top of the head and sensor 2 is on the sternum.

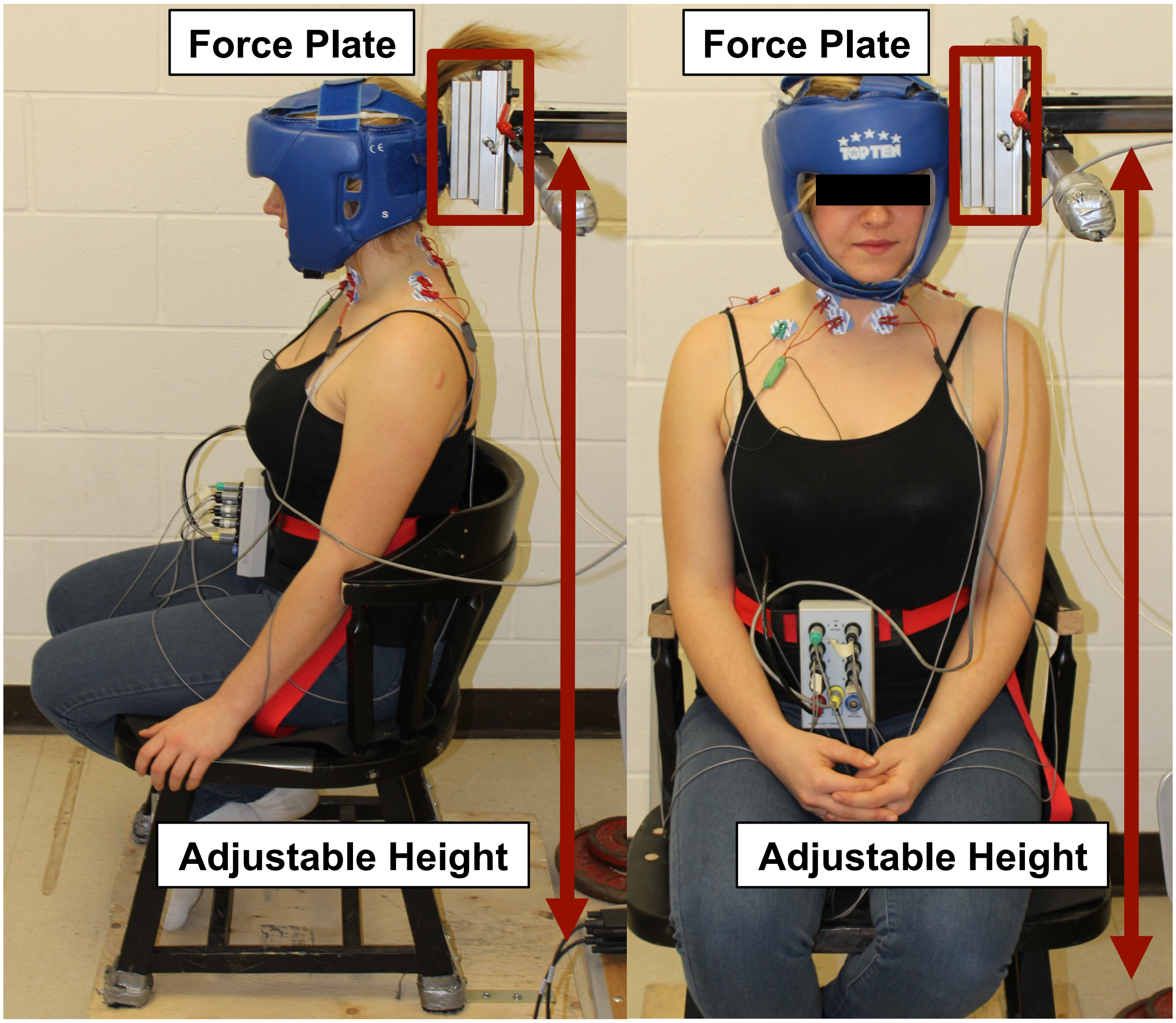


Figure 3.4: The load cell is affixed to a height adjustable support. Participants sat on the chair and pushed up against the load cell while wearing a padded helmet. The chair was adjusted to accommodate the different neck actions. In flexion, participants pushed against the load cell with their forehead. 1. In extension, they pushed with the back of their head (as shown). 2. In lateral bend, they pushed with the side of the head (as shown).

There were 2 independent variables:

1. Load
    - With load
    - Without load
2. Posture
    - Neutral
    - Flexion
    - Extension
    - Protraction

Loaded conditions required the addition of 3.68 kg of lead shot to the participants' helmet. The unloaded conditions did involve the use of the lead shot, but the participants wore the helmet. The order of presentation of two conditions was randomized between participants. Within these conditions, the postures that the participant was required to get into were: neutral, flexion, extension, and protraction at 100% of the participants ROM for each action. The postures within the loaded and unloaded conditions were block randomized between participants. The postures involving flexion and extension required the participants to lie down on the tilt board that was titled to the maximum angle that they achieved for each posture relative to the vertical (e.g. 60° of flexion had the board tilted up 30° from the ground but 60° from the vertical) (Figure 3.5). Participants adopted a supine posture when in flexion, and a prone posture when in extension. In the protraction conditions, they were seated upright in a chair (Figure 3.6). Conditions with neutral postures were done with the participant standing. While on the tilt board, or seated in the chair, participants were told to keep their heads at the same relative angle that was achieved during the maximal ROM trials for the neck posture being recorded.

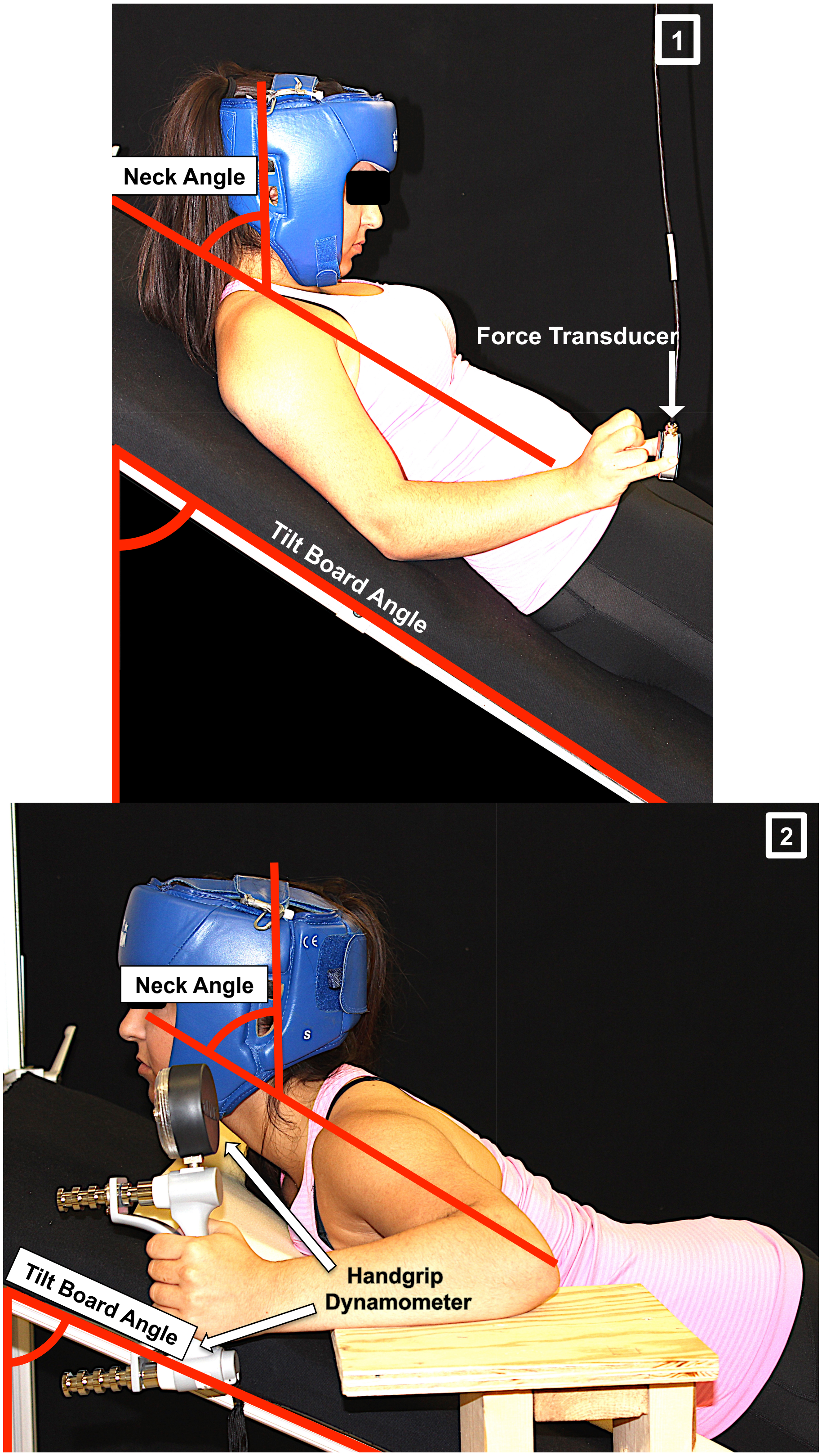


Figure 3.5: Example of a participant lying on the tilt board in: 1) neck flexion and 2) neck extension. The tilt board is set to the max angle of the neck in flexion and extension, relative to the vertical.

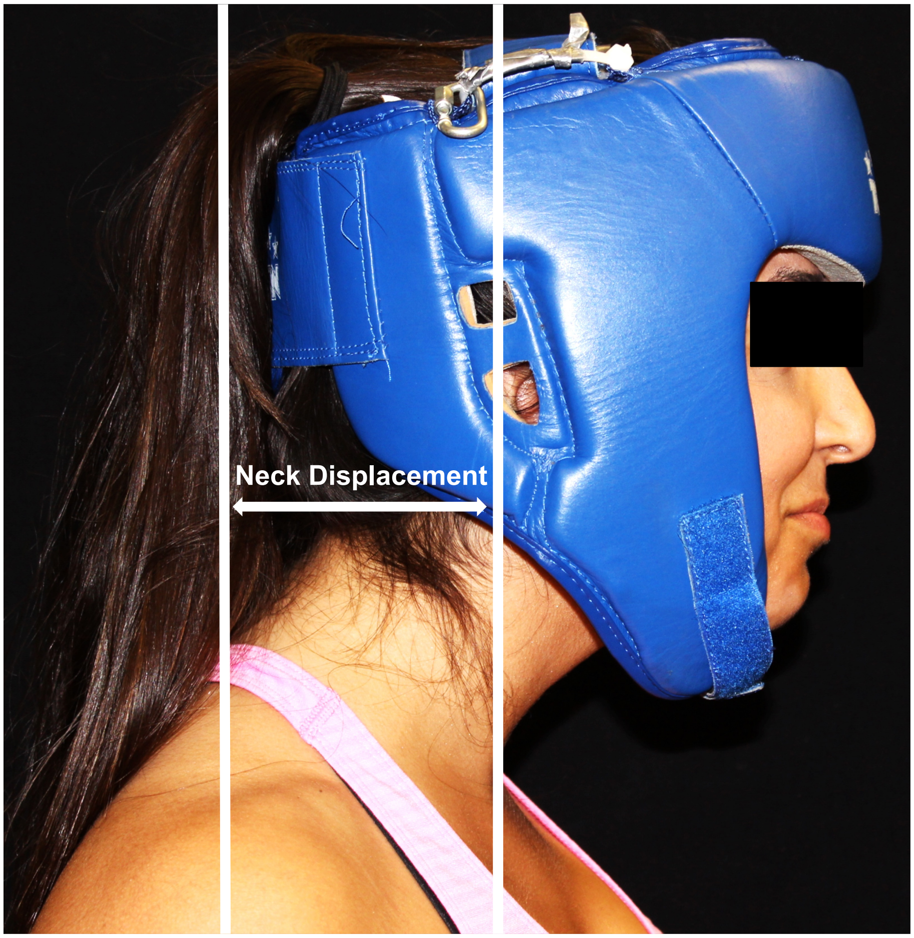


Figure 3.6: The participant is seated upright in the chair and protracted maximally.

For each condition, postures were held for 4 minutes, after which the participants reported their ratings of perceived discomfort, as well as areas of numbness on their hands. Following these prolonged trials, forces were also recorded for the maximal right hand grip, and pinch grip forces. There were two different types of pinch grips. One required the index finger and thumb, while the other required the little finger and thumb. The forces required to lift a weighted transducer (750g) were also recorded using the same two pinch grips.

Maximal grips and the lifting task forces were recorded with the right forearm horizontal to the floor at the participant's side. The lifting tasks were always recorded prior to the maximal grip tasks. There were 8 trials of prolonged postures; four while wearing the loaded helmet, and four without the load.

For each participant, there was six data collection sessions. Neutral postures, both loaded and unloaded, and the loaded flexed posture were collected during the same session. EMG activity of the SCM, UT, and ES were only recorded with these postures in that session (Table 3.3). The remaining five conditions were collected during their own sessions. The order of the sessions was randomized and ROM determination was carried out at the start of the first session.

Table 3.3: There were a total of eight separate conditions consisting of four postures and two loading conditions. Postures and loading conditions during which EMG was continuously recorded are denoted with "EMG."

		Postures			
		Neutral	Flexed	Extended	Protracted
Loading	Unloaded	EMG			
	Loaded	EMG	EMG		

3.4 Data Analysis

Independent variables include neck posture, head load, and duration of trial.
Dependent variables will include average neck EMG activity over time, pinch and hand grip force levels, lifting task forces, perceived numbness and perceived discomfort.

EMG signals from the SCM, UT, and ES were processed using a bandpass 6^{th} order Butterworth filter from 20 to 500 Hz. The signals were used to calculate the average EMG activity for every 10 seconds of the total trial time. The filtered EMG signals was full wave rectified, smoothed with a half second moving average and then normalized to their respective MVCs to determine percent activation levels.

Position and orientation data from the 2-channel Fastrak system was calibrated to degrees (°). Force signals from the s-type load cell and force plate was smoothed with a half second moving average and the voltage outputs calibrated to Newtons.

3.5 Statistical Analysis

For each of the measured variables (maximal hand and pinch grip force, transducer lift force, Borg scale score, perceived numbness, and ROM) recorded after 4 minutes of a sustained posture, a 4 x 2 repeated measures ANOVA was performed. The independent variables were posture (neutral, flexion, extension, and protraction) and load (no load, with load). The neutral posture with no load will be the control condition.

A separate 2 x 2 x 2 ANOVA will be run for average EMG for each muscle (SCM, UT, ES) on both right and left sides. The factors for these ANOVAs include 2 loads (no load and with load), 2 postures (neutral and flexion), and two time points (first and last ten seconds of each trial). There was a total of 6 ANOVAs run for this dependent variable.

Chapter 4 - Results

Main effects and interactions are presented if both the p-value was less than 0.05 and if the ω^2 value was greater than 1% (Table 4.1 & 4.2). For each of the independent variables, only the highest order significant effect will be presented and discussed.

Table 4.1: Summary of the p-values for each ANOVA of the independent variables of discomfort, handgrip, pinch holds, and max pinches. P-values under 0.05 are bolded and highlighted. Values that are highlighted in green represent the variables that are the highest order significant effect with a ω^2 value greater than 1%.

	Discomfort	Force		
		Max Grip	Pinch Hold	Max Pinch
Posture	**< 0.01**	0.130	0.205	0.893
Condition	**< 0.01**	0.467	0.071	0.237
Pos * Con	0.353	0.750	**0.028**	0.236
Finger			**< 0.01**	**< 0.01**
Pos * Fin			0.259	**0.039**
Con * Fin			0.580	0.976
Pos * Fin * Con			0.316	0.319

Table 4.2: Summary of the p-values for each ANOVA of the independent variables of muscle activity. P-values under 0.05 are bolded and highlighted. Values that are highlighted in green represent the variables that are the highest order significant effect with a ω^2 value greater than 1%.

	Sternocleidomastoid	Erector Spinae	Upper Trapezius
Side	**0.014**	0.568	0.540
Condition	**< 0.01**	0.112	**0.300**
Side * Con	**0.047**	0.330	0.094

4.1 Discomfort

There was a main effect of Posture on the level of reported discomfort ($p<0.01$). The post hoc analysis revealed: extension was higher than neutral ($p<0.01$), flexion ($p<0.05$) and protraction ($p<0.05$); flexion > neutral ($p<0.01$) and protraction > neutral ($p<0.05$) (Figure 4.1). There was also a significant main effect of Condition with discomfort for loaded > unloaded ($p<0.01$). Post hoc analysis revealed that loaded conditions resulted in 1.8 times more discomfort than unloaded conditions (Figure 4.2).

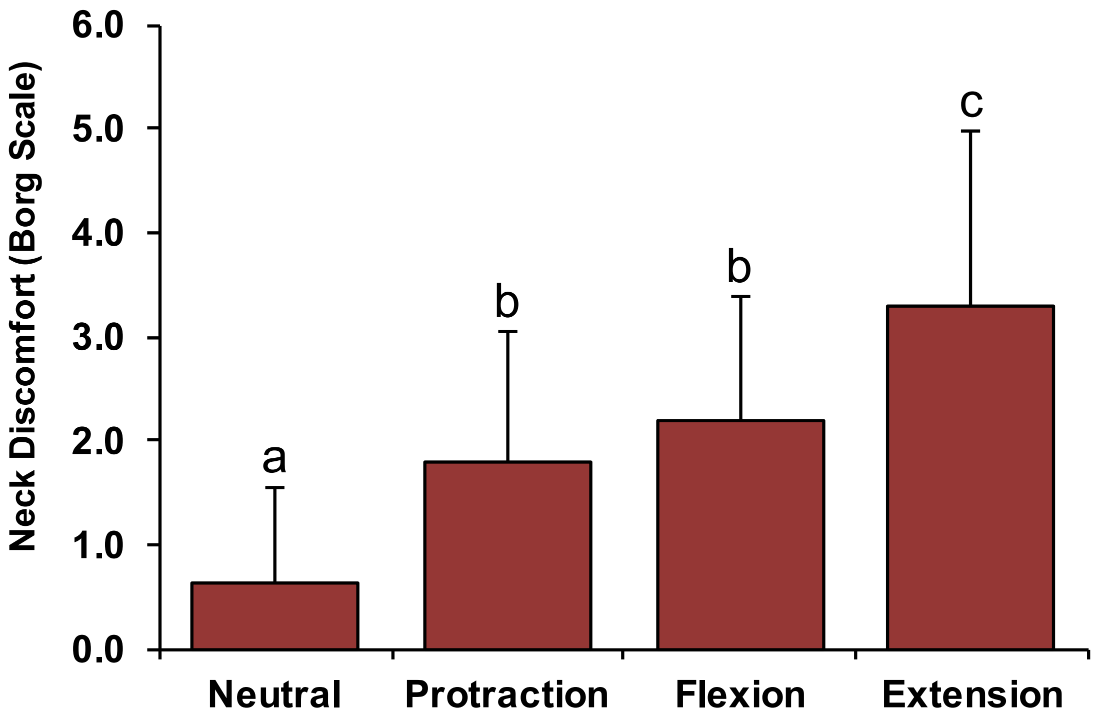


Figure 4.1: The main effect of Posture on the level of perceived discomfort by participants ranked from lowest to highest. Significantly different means are indicated with different letters ($p<0.05$). Standard deviation bars are displayed.

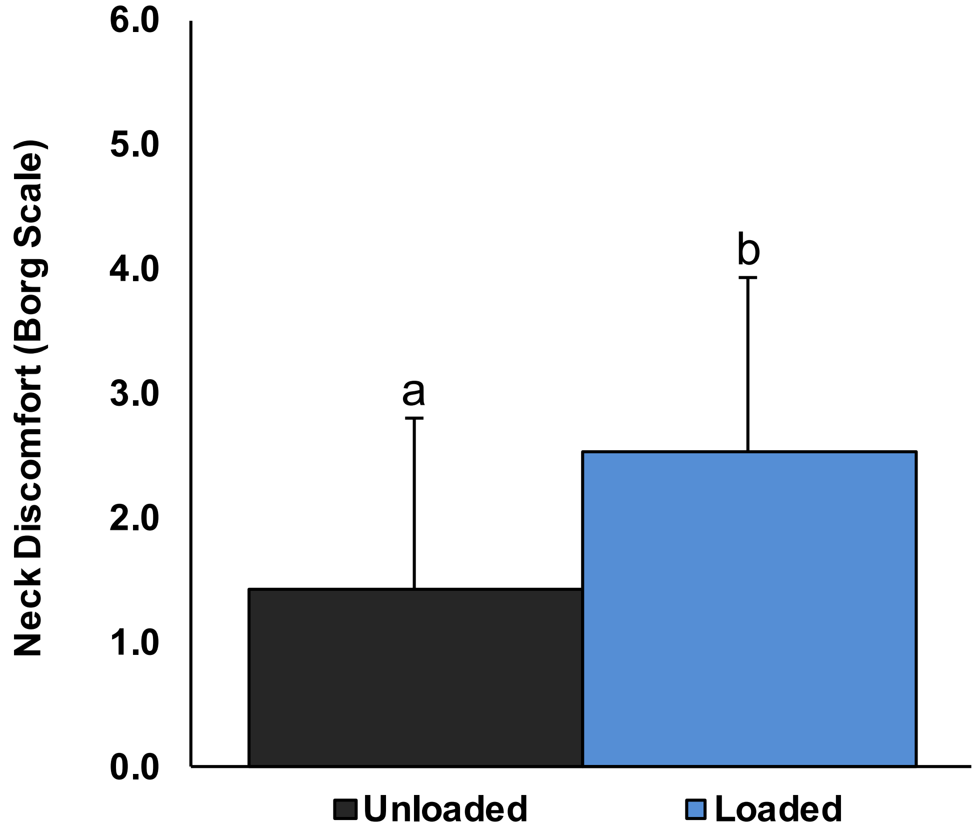


Figure 4.2: The main effect of Condition on the reported perceived discomfort. Significantly different means are indicated with different letters. Standard deviation bars are displayed.

4.2 Pinch Holds

There was a main effect of Finger on the holding forces ($p<0.01$). Forces during the thumb-index finger pinch were 1.5 times greater than with the thumb-little finger (Figure 4.3). The Posture*Condition interaction was significant but post-hoc analysis revealed no significant differences for the means that were compared.

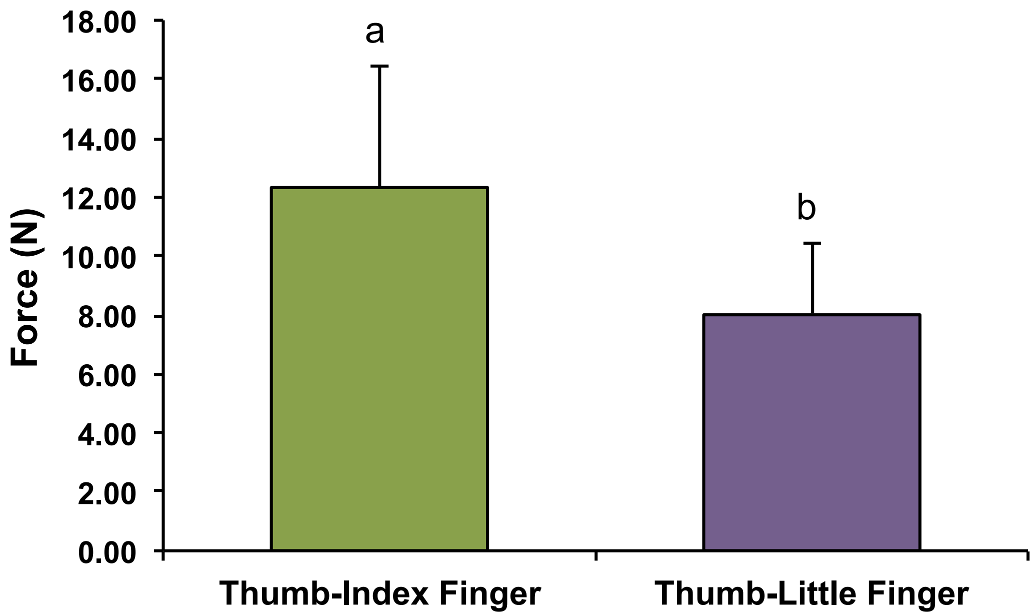


Figure 4.3: The main effect of Finger on the forces recorded during the holding task. Significantly different means are indicated with different letters. Standard deviation bars are displayed.

4.3 Max Pinches

There was a main effect of Finger on the max pinch grip forces ($p<0.01$). Max pinch forces with the thumb-index finger max were 45% greater than with the thumb-little finger (Figure 4.4).

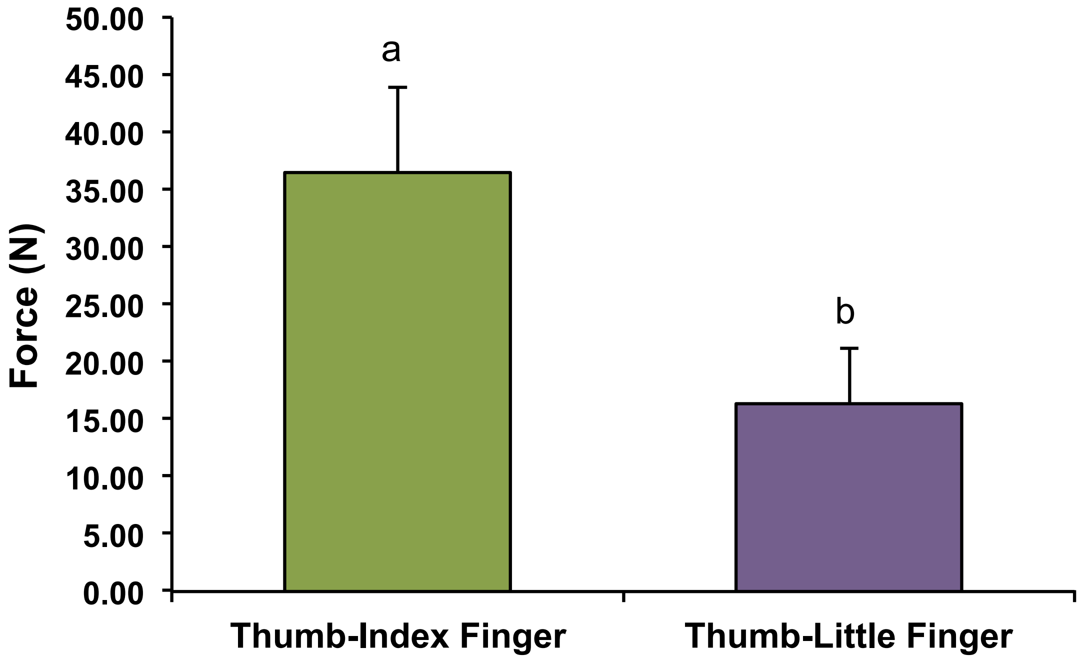


Figure 4.4: The main effect of Finger on the forces recorded during the max pinch task. Significantly different means are indicated with different letters. Standard deviation bars are displayed.

4.3 Muscle Activity

There was a main effect of Condition on SCM muscle activity ($p<0.01$). The post-hoc analysis revealed that SCM activity during flexion-loaded (13.0%±9.7%) was greater than both neutral-loaded (2.2%±1.9%)($p<0.01$) and neutral-unloaded (2.3%±2.4%) ($p<0.01$) (Figure 4.5). ES and UT activity did not have a significant effect of Condition, but did follow the same trend and increased in the loaded conditions when compared to neutral-unloaded condition. There was also a main effect of Side on SCM activity ($p<0.05$). The post-hoc analysis revealed that the right SCM was 1.71 times more active than the left SCM.

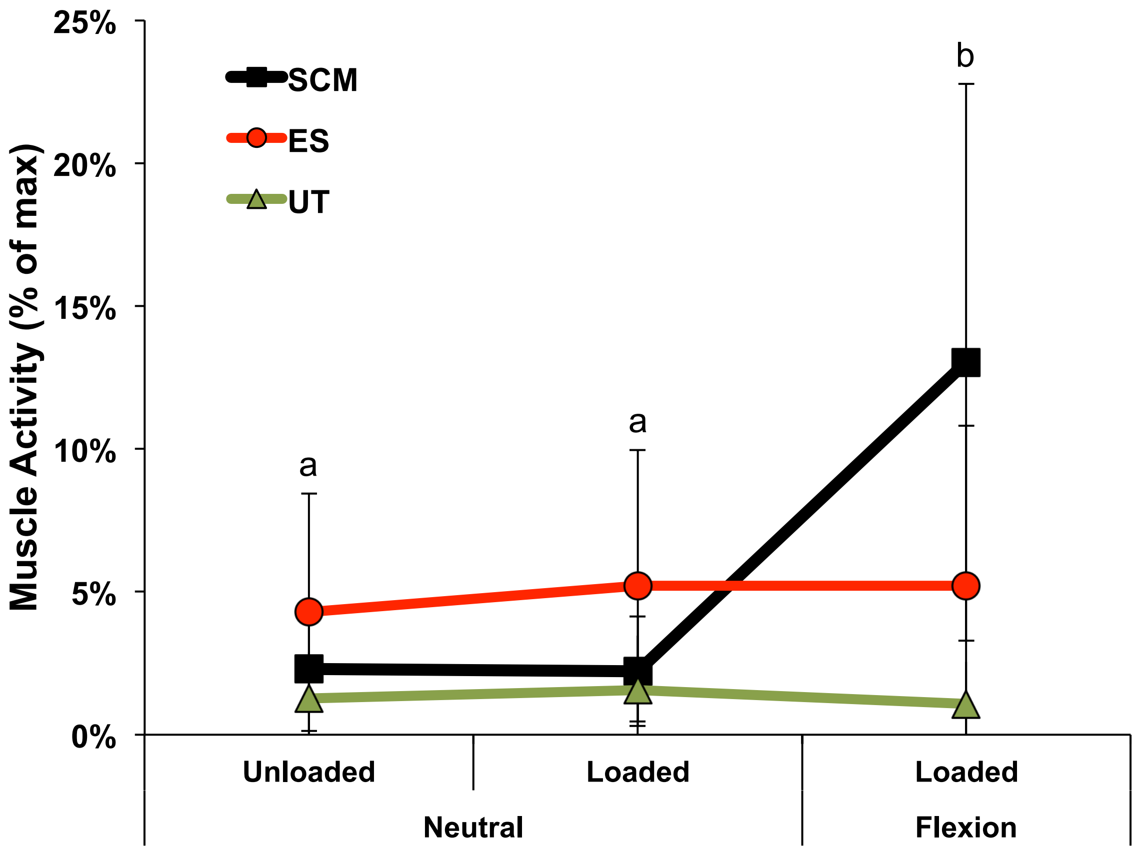
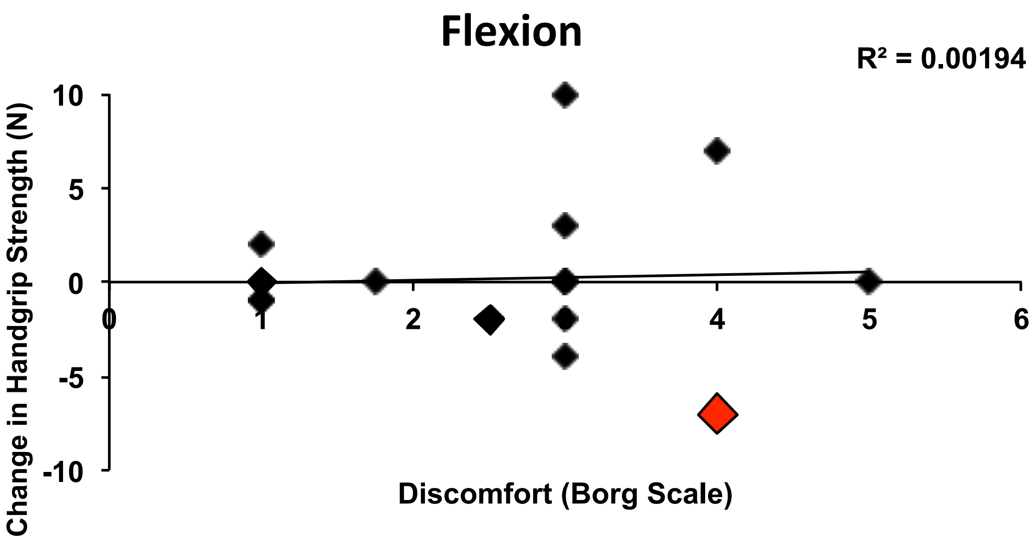
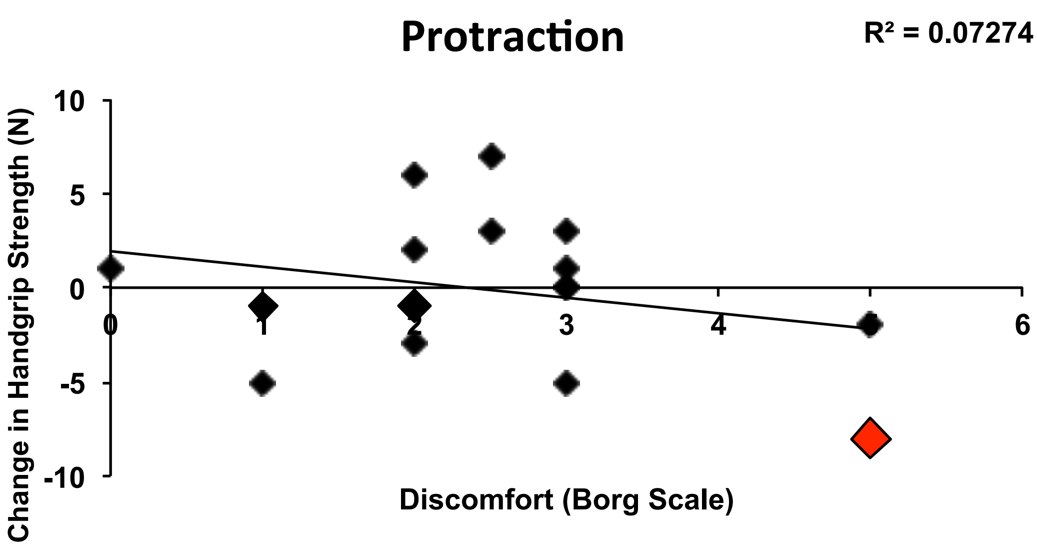


Figure 4.5: Mean muscle activity (% of max) for the SCM, ES, and UT across conditions for which EMG was recorded (neutral-unloaded, neutral-loaded, and flexion-loaded). Significantly different means in SCM activity (shown in black) are indicated with different letters. ES and UT activity did not show significant differences in response to the different conditions.

4.4 Individual Subject Case Studies – Discomfort and Handgrip Strength

There were some interesting case studies that emerged from the data. In certain participants and conditions, an inverse relationship between neck discomfort and handgrip strength was observed (Figure 4.6). Not all participants showed this relationship, although there was a slight trend, most notably observed in extension (R^2=0.19) in the loaded conditions (Figure 4.6). Participant 6 showed a relationship between handgrip strength and neck discomfort across all 3 non-neutral postures studied. Participant 6's handgrip strength decreased from what was recorded in a neutral-unloaded posture with increased discomfort. Participants 1 and 3 only showed this relationship in the extended posture.





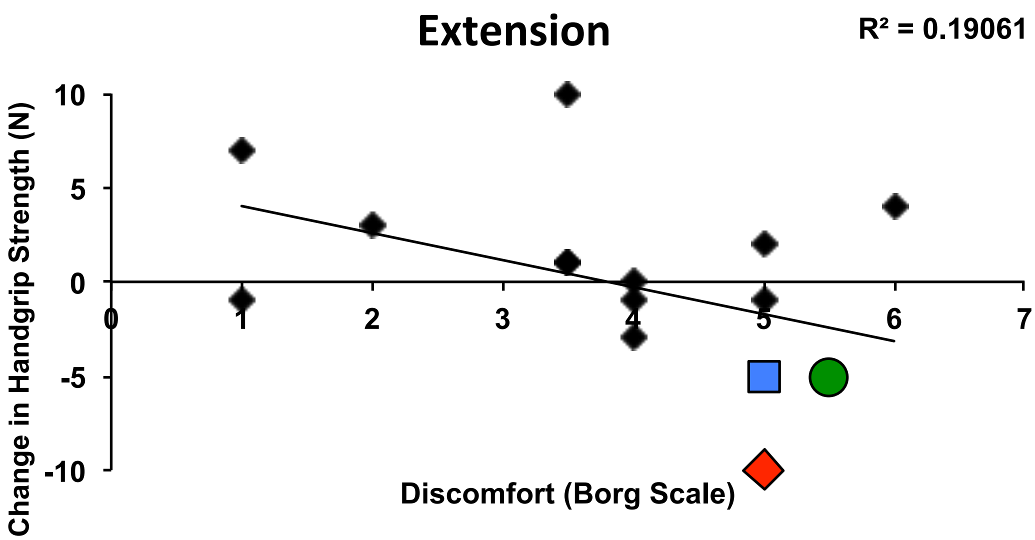


Figure 4.6: The relationship between Handgrip Strength and Discomfort for all participants in the loaded conditions. The change in Handgrip Strength represents the change from the values recorded while in a neutral posture. The blue, green, and red markers denote participants 1, 3, and 6, respectively.

Chapter 5 - Discussion

This study contributes unique data to the literature related to the isolated effects of head load and neck postures, as well as their combined effects. This study identified the postures and loading conditions that resulted in the greatest levels of perceived discomfort reported by the participants, and this is very important for the development of an ergonomics tool that assigns risk to the neck. Extension caused the highest levels of discomfort, followed by both flexion and protraction, which had similar levels of discomfort. As expected, a neutral posture caused the lowest levels of discomfort in this study. In addition, loaded conditions caused greater discomfort than unloaded conditions across all postures. These effects point to postures and conditions that should be avoided, or accounted for in ergonomic evaluations. By using these data, ergonomic tools can be improved, and a screening tool can be created that would calculate the risk score associated with different neck posture and load demands. These tools would used to reduce the risk of neck injury and pain in the workplace.

5.1 Discomfort

5.1.1 Posture

Non-neutral postures caused significantly greater discomfort than a neutral posture, which supported the hypothesis. Considering the recorded increase in muscle activity in a non-neutral posture, it is possible that this activity may account for the increase in discomfort. In addition to the static muscle activity that leads to fatigue and discomfort over time, muscle activity also reduces venous return, decreasing the removal of waste products, which may exacerbate these effects (Mekhora, 2000). Discomfort was 1.7 times greater in extension than flexion and protraction, and 5 times greater than a neutral posture. Yoo et al., (1992) reported that extension, at the end range of motion, may lead to compression of cervical nerve roots which might also contribute to the high discomfort levels recorded.

In non-neutral neck postures, gravitational demands result in increased muscle activity (Vasavada et al., 2015). If this muscle activity is sustained beyond prescribed time limits, the risk of injury and pain increases (Jensen et al., 1993; Veiersted, et al, 1990). The results of this study complements previous literature by adding that, even after removing gravitational moment demands, different neck postures cause different degrees of discomfort in a distinct and graded manner. The postures tested in the current study were at the extreme ranges of motion for each participant, such that the discomfort associated with these postures may not only be due to sustained muscle activity. Neck muscle activity, resulting from various non-neutral postures, does not satisfy the moment requirements to maintain these postures and underestimates tissue load (Finsen et al., 1999). This may be due to unexpected and different muscle load-sharing strategies, where the muscles being recorded are not contributing as much as expected. However, it also may point to the extensive use of the passive structures of the neck, such as the nuchal and longitudinal ligaments, to sustain different postures. Furthermore, the moment generating capacity of the neck musculature is decreased in non-neutral postures (Garces et al., 2012), placing a heavier reliance on passive tissues to support the neck. At near-end, or end, range of motion, there is an increased risk of injury to passive structures due to extreme stress or strain (White & Panjabi, 1992). It is these passive structures that, if stretched, could be contributing to the discomfort experienced by the participants.

5.1.2 Head load

Increased head load further exacerbates the effects of reduced muscle capacity in non-neutral postures. In occupations that require helmet use, the muscles are less able to cope with the amplified stability and posture demands, which may lead to a reduced higher rates of fatigue. As a result, passive structures would then be engaged to a higher degree to ensure the integrity of the cervical neck in non-neutral and loaded postures if muscles are unable to generate the necessary moments. Increased and excessive cervical passive structure reliance, for stability and support, may account for the nearly two-fold increase in discomfort in loaded conditions compared to unloaded conditions.

Canadian helicopter pilots in the Canadian Armed Forces are required to wear night vision goggles and heads-up displays as part of their headgear during all flight, in addition to a counterweight to offset the front-weighted helmet (Adams, 2004). The mass of the helmet increases spinal compression, as well as cervical instability, requiring increased sternocleidomastoid activity to stabilize the head-neck joint (Harrison et al., 2007; Knight and Baber, 2004). High G forces (deceleration and acceleration forces on the body due to flight maneuvers) apply heavy loads and increase stress on the cervical spine (Green & Brown, 2004; Hendriksen & Holewijn, 1999; Newman, 1997). These forces, as well as head position and helmet mass, are directly implicated in the acute neck injuries that pilots endure while operating the craft (Green & Brown, 2004, Green, 2003).

In-flight G forces are associated with causing compression fractures, tears to ligaments, and bulging of intervertebral disks (AGARD, 1994; Schail, 1989; Andersen, 1985). In addition to these loads, pilots also maintain non-neutral neck postures for a majority of their flight time (Anderson et al,. 2003). Coakwell et al., (2004) reported that F-16 pilots require 15° of forward neck flexion to fly the craft. This causes increased cervical instability, as well as decreased muscle capacity to stabilize the spine and support the head load during flight maneuvers. The authors hypothesize that this may put increased stress on the ligaments and put pilots at a higher risk of both acute and chronic neck injuries. This is supported by the observation that military pilots are, in some cases, unable to safety perform their duties due to cervical pain or injury (Netto & Burnett, 2006; Anderson, 1998).

5.2 Muscle Activity

SCM activity increased significantly in the flexion-loaded condition, supporting the hypothesis that muscle activity would increase in non-neutral and loaded postures. However, the ES and UT did not show significant increases in activity. There was a trend (but insignificant) towards an increase in these two muscle's activity recorded in both the neutral-loaded and flexion-loaded conditions compared to unloaded-neutral.

One of the limitations of this study is that participants stood while completing the maximum neck ROM tasks requiring them to maximally flex and extend their necks. I used these values to set the tilt-board to the appropriate angle. Recording maximum ROM in this way may allow for gravity to aid in increasing the neck ROM beyond what they would have been able to achieve if gravity did not cause a moment that would aide them (as was the case in my experimental conditions). Therefore, during the flexion-loaded condition, participants likely needed their neck flexors (ie. the monitored SCM) to achieve the same angles as during the max ROM trial. This may explain the large increase in SCM activity when loaded in flexion. However, this does present new data in that the extensors were not the most active muscles in flexion, which is not true for most other studies (Vasavada et al., 2015). This points to other structures that may be contributing to recorded neck discomfort. Rather than discomfort caused by muscle demands, the observed discomfort may be associated with cervical nerve root irritation or mechanical compression due to the narrowing of the intervertebral foramen (Yoo et al., 1992, Eubanks, 2010). The stretch of passive structures, such as tendons, ligaments, and discs, which are heavily relied on, may also contribute to neck discomfort (Finsen et al., 1999; Keyseling et al., 1992; Kilbom et al., 1986).

It is also possible that some of the increase in muscle activity was necessitated by increased instability in the cervical spine caused by the added head load. This is seen in the flexion-loaded condition and, to a much lesser extent, in the neutral-loaded condition. A neutral cervical spine has low stiffness (Panjabi et al., 2001) and a non-neutral posture further increases instability.

To counter this effect, cervical muscles would play an important role in stabilizing the cervical spine, through co-contraction of the neck muscles (McGill et al., 2003). Adding a load to the head, which may shift the center of mass of the head higher, amplifies cervical instability requiring increased neck muscle activity to stabilize the neck. The increased SCM activity observed in this study may be activity that was not contributing to the maintenance of the required posture but, rather, to the stability of the cervical spine.

Muscle activity recorded on the right side of the neck and upper back was higher than on the left. Every effort was made to place the loads symmetrically. However, the placement of the weights may have created a larger moment on one side of the neck rather than the other, even though participants did not report that this was the case. It is more likely that, due to sleeping patterns and work postures, participants developed muscle load-sharing strategies, or favored using muscles on one side of their neck than the other.

In a study of female office workers, Johnson et al., (2008) also observed higher right cervical muscle activity, compared to left, for individuals with neck pain. Chiu et al., (2002) hypothesized that frequent use of the right hand to complete tasks, by right-handed individuals, and the associated neck muscle activation on the right side, may lead to neck musculature that is more developed on the right side than the left. To this point, it should be noted that participants in this study were exclusively right handed. Muscles on the right side of the neck are, therefore, better able to cope with increased activity, more resistant to fatigue, and would be preferentially activated over muscles on the left (Falla et al., 2004, Nederhand et al., 2000). Assuming symmetrical loading, it is possible that the recorded superficial muscles were preferentially activated on the right side of the neck to reduce stress on more fatigable intrinsic neck muscles. If the muscles on the left side of the neck were not as well developed, the requisite activity may have been shared more equally between the superficial and deep muscles to stabilize the head-neck joint. It is possible that, if the posture was held for a longer duration than in the current study, superficial muscle activation may have increased on the left side as well to reduce deep muscle activation (Falla et al., 2004; Falla et al., 2004). If left-handed individuals were recruited for this study, it is likely that, while sustaining the extreme neck postures, left cervical muscle activity would be significantly higher than right cervical muscle activity.

Potvin (2012) developed an equation to calculate the Maximum Acceptable Effort (MAE) that is recommended given different Duty Cycles (DC), or the total effort duration divided by the cycle time ($MAE = 1 – DC^{0.24}$). If required effort is already known, the equation can be rearranged to determine the Maximum Acceptable DC (MADC) ($MADC = [1 – Effort]^{4.167}$). To determine the MADC for the condition with the highest muscle activity (SCM during flexion-loaded), the recorded muscle activity, pooled from both sides of the neck, 13.0% was input into the MADC equation (Equation 3) giving a value of 0.56. This translates into a recommendation that the flexion-loaded condition should not be held for more than 33.6 s per minute, continuously throughout a work day, even though the head was upright and there was no gravitational moment about the cervical spine.

Non-neutral neck postures, while standing or sitting, would result in even higher required neck extensor activity, to counteract the gravitational moment demands that are not present in this study. This would further reduce the acceptable amount of time that an individual can maintain a loaded, flexed posture per minute. The ES activity was the highest, of the three muscles recorded, for the neutral-unloaded (4.3% MVE) and neutral-loaded conditions (5.2% MVE). Thus, the maximum acceptable duty cycle would be 0.833 (ie. 50 s/min) for neutral-unloaded, and 0.800 (ie. 48 s/min) for neutral-loaded. Both neutral-unloaded and neutral-loaded conditions can be maintained by individuals for 14.4 to 16.4s longer per minute than a flexion-loaded condition, and remain within maximum acceptable effort recommendations to reduce the risk of pain and injury.

Prolonged non-neutral neck postures increased the level of cervical muscle activity. The addition of a head load in both neutral and non-neutral postures also increases cervical muscle activity. Thus, it is likely that the compressive forces on the cervical spine were increased due to the increased muscle activity in non-neutral and loaded neck postures. Based on these data, it was concluded that occupations that require non-neutral neck postures (e.g. office work, overhead assembly, pilots) and helmet use (e.g. welders, military pilots, paramedics), increase the risk of pain and injury due to compressive forces on the cervical spine.

5.3 Max Pinches

These current data did not support the hypothesis that forces, recorded during maximal pinches, would decrease with non-neutral postures and load. In fact, acute changes in neck posture and head load did not have any effect on maximal pinches. Discomfort did not seem to have an effect on the max pinch task with either task (thumb-index or thumb-little finger) and there was no quantified indication of loss of tactile sensitivity that may point to compressed cervical nerves (Cole et al. 2002). It is likely that the time spent in each posture was not sufficient to cause changes.

As expected, maximal thumb-little finger max pinch forces were 44.8% of maximal thumb-little finger pinch forces. This trend agrees with previous literature, where thumb-little finger max pinch forces were 47% of thumb-index finger max pinch forces, and the recorded values for thumb-index and thumb-little finger max pinches were 103% and 98%, respectively, of previously reported values (Swanson et al., 1970).

5.4 Holding Tasks

Previous literature suggested that direct nerve compression would result in an increase in exertion levels during a hand task (Cole et al., 2003). However, I found no significant increase in holding forces, after prolonged extension, regardless of the loading condition and, therefore, the data did not support the hypothesis. Perhaps the degree of cervical nerve compression, if any, was not sufficient to elicit a functional consequence at the effectors.

Interestingly, holding forces with the thumb-index finger were greater than those with thumb-little finger. It is possible, but unlikely, that a notch on the force transducer allowed for a better grip with the thumb-little finger pinch than the thumb-index pinch. It is more likely that participants used more force to pinch with their thumb-little finger because they were not confident that they would not drop the force transducer. The holding task required nearly 50% of the participants' maximum thumb-little finger max pinch force, as opposed to only 34% of their maximum thumb-index max pinch force to hold the 750 g transducer.

Force variability increases with exertion level (Christou et al., 2002) and participants may have been unable to determine and maintain the relatively high force level required to efficiently hold the transducer during the thumb-little finger hold. Furthermore, due to the short holding time (~ 5 seconds), it is possible that participants were not concerned with efficient use of their muscles during the thumb-little finger hold, but more concerned with not dropping the transducer. Perhaps if the holding time was longer, or if the holding task was repeated many times with breaks in-between, pinches force would have decreased as participants became more accustomed to the mass of the transducer and are more concerned with reducing fatigue.

5.5 Case Study

While not all participants displayed a trend, participant 6 had a distinct inverse relationship between handgrip strength and discomfort across the three non-neutral postures that were studied (Flexion, extension, and protraction) (Figure 4.6). Participants 1 and 3 also showed this relationship, but only in extension. Across all participants, neck extension caused the strongest trend between handgrip strength and discomfort (R^2=0.19). Perhaps with more participants, this trend would more clearly be observed.

Grip strength is an objective index of functional integrity of the upper extremity (Myers et al., 1980). Upper extremity tasks, such as a handgrip task, activate cervical musculature (Falla et al., 2004). The decreased handgrip strength seen in these participants may be related to the activation of neck muscles during the handgrip task (Woldstad & Nicolade, 2001; Falla et al., 2004; Zetterberg et al., 1997). Pain and discomfort may inhibit muscle activation in the affected area.

In spite of this, the current study does show that non-neutral neck postures and head loads result in cervical discomfort. If the cervical muscles are fatigued, or causing pain, handgrip strength may be limited by the extent to which individuals are willing to activate their neck muscles (Zetterberg et al., 1997). If individuals prevent themselves from activating their cervical muscles, or from activating them to pre-discomfort levels, due to pain and discomfort during a handgrip task, then their maximal handgrip strength would decrease.

Participant 6 is of further interest due to being the only participant that reported numbness or decreased sensation in all fingers of the right hand during the extension-loaded condition. This may point to cervical nerve compression contributing to reduced handgrip strength in extension. Yoo et al. (1992) reported that cervical foramen size decreases in extension (Figure 2.6). Perhaps, participant’s 6’s cervical foramen is particularly small and there is sufficient mechanical compression of the nerve by the vertebrae to cause an effect on the areas innervated by the compressed nerve. These effects include parethesia, weakness in the upper extremities, and cervical pain (Eubanks, 2010), all of which were observed in this participant.

Participants 1, 3, and particularly 6, may represent a subset of the population whose upper extremity functional integrity is negatively affected with increased neck discomfort due to prolonged posture demands and cervical spine loading. It is possible that some individuals are more susceptible to prolonged and/or repetitive neck posture demands that could lead to a greater degree of discomfort due to sustained muscle activity that leads to fatigue and more prolonged stressed on the passive tissues of the neck. This increased discomfort may translate into more pronounced decreases in handgrip strength. Furthermore, cervical nerve compression may cause similar effects on neck discomfort and motor dysfunction in the upper extremities. A lack of handgrip strength may lead to a decrease in product quality. In addition, workers may not be able to accomplish certain upper extremity tasks due to unattainable force requirements.

A short, 4 minute deviation of neck posture, combined with head loading, was sufficient to cause neck discomfort and possible cervical impingement in some participants to precipitate a reduction in their handgrip strength. Based on this, it may be possible for employers to use this same 4-minute test to identify individuals that should not be placed in occupational settings that require a non-neutral or loaded posture. By matching more susceptible workers to workstations that don't require deviated neck postures, the risk of avoidable pain and discomfort can be reduced for these most vulnerable workers, and product quality will not suffer.

5.6 Lateral Bend

In a studied conducted in parallel with mine, Webb (2015) studied the effects of neck right lateral bend on neck discomfort and the distal upper extremities.
Participants laid on their side on the same adjustable tilt board, with their neck maximally laterally bent to the right for 4 minutes. Similar to the results presented in this paper, non-neutral and loaded postures resulted in significantly greater discomfort when

compared to a neutral-unloaded posture (laterally bent-loaded > laterally bent-unloaded > neutral-loaded > neutral-unloaded). Furthermore, discomfort was higher on the right side, compared to the left. Increased discomfort levels coincided with increased EMG activity of the SCM, Splenius Capitis (SC), and the UT. However, Webb observed no changes in handgrip strength, pinch hold forces, or max pinch forces.

5.7 Applications

This study attempted to determine the effects of extreme postures and load on neck discomfort and upper extremity functional ability, and to determine the aspects of certain task demands that need to be carefully considered for elevated risk of injury or pain in occupational contexts. It is clear that non-neutral neck postures, and the addition of a head load, caused discomfort; however, there was no indication of interacting effects of load and posture. Furthermore, extension caused the greatest discomfort, followed by protraction and flexion.

These findings are extremely important to consider during ergonomic evaluations and task design. It is anticipated that these data, will be combined with that of Webb (2015) and the MAE equation of Potvin (2012) to create an ergonomic tool for the neck. A multiplier for different postures and load will be developed that would determine a risk score. If this risk score is beyond a certain threshold, then the task would be deemed unacceptable. The ultimate goal is to have this neck risk assessment method incorporated within current ergonomic tools and software, and allow users to more fully address occupational demands on the body, and evaluate the risk associated with different neck postures and head loads.

Furthermore, based on these data, it is possible that a placement tool can be created for those individuals who have an increased sensitivity to neck pain and discomfort to the degree that it affects functional ability of their upper extremities. To that end, a short test could be developed, similar to the protocol in this study, to identify these individuals. Those identified could be placed in work environments that do not have extensive postural and load requirements on the head and neck. This would decrease the risk of injury and pain to the most susceptible individuals as well as ensure the quality of the product or successful completion of a task. However, much more data are required to determine if such a test could predict those that would ultimately claim injuries and discomfort in the neck region during work.

This study also highlights the need for ergonomic assists and redesigns for jobs that require helmets. Center-weighted head loads are important to reduce muscle demands when in a neutral posture, otherwise a constant flexion or extension moment will be applied on the neck (Harrison et al., 2007). Head loads, that are not center-weighted, would cause greater a moment about the C7-T1 and increased cervical muscle activity required to counteract this moment.

However, not all occupations requiring a helmet use a counter-weighted helmet, including; welders, or laparoscopic surgeons who use front-loaded helmets and Head-Up Displays (HUDs). HUDs require constant neck extensor activity to maintain a neutral posture, which may further increase the level of neck discomfort and would accelerate fatigue. In fact, discomfort values would likely be higher than what was observed in this study. Current military helicopter pilot helmets have a counterweight to ensure that there is no moment about C7-T1 while in neutral to reduce neck extensor activity. Center-weighted helmets still will cause alternated muscle activity, pain, discomfort, and an increased risk of neck injuries (Knight and Baber. 2004).

To reduce moment demands in non-neutral and loaded postures, an ergonomic assist should be developed to support the neck, thereby reducing muscle demands, time to fatigue, and the risk of pain or injury. To this end, Ibrahim & LaDelfa (2015) recently recommended a spring-assisted neck support to assist surgeons who use front-weighted Head Mounted Displays (HMDs) during laparoscopic surgery. The main advantage of that proposed system, over a constant mass counterweight, is that it applies scalable extension counter-moment that increases or decreases with neck angle. Such a system would support the head and aide neck stability, reducing cervical muscle moment demands and the associated risks.

5.8 Limitations

While this study provided important and novel data, certain limitations need to be addressed.

1. Participants were exclusively university aged, right-handed females with little to no experience in manufacturing or occupations that require helmet use. A study with a broader population base and, perhaps, participants with more experienced in manufacturing or the military, would need to be conducted to record more applicable effects.
2. The posture demands for this study were not representative of occupational posture demands. Few, if any, occupational tasks require an individual to maintain extreme neck postures.
3. Tasks were presented in a predictable order. Maximal pinches always followed the holding tasks, and the handgrip task always followed the maximal pinch. It is possible that participants ignored the pain felt at their neck, during the handgrip task, because they knew it signified the end of the trial and, thus, the recorded handgrip strength was higher than expected across different levels of discomfort. A randomized task order, or multiple task requirements throughout a longer trial, would be more representative of an actual occupational task. This may result in more drastic effects of neck posture and load on the upper extremities and neck discomfort.
4. Tasks demands were only repeated once. If tasks requirements are repeated more than once per session, (ex. completing each task three times) different strategies to reduce fatigue and cope with discomfort may arise. Participants may favor muscular efficiency more than a more secure grip on the force transducer during the pinch hold task

5.9 Further Directions

Future studies should focus on more repetitive posture demands on the neck, that more closely mimic occupational task demands. By having a realistic duty cycle (ie. the percentage of time an individual is engaged in an effort (Potvin, 2012)) there may be an accumulation of discomfort due to insufficient rest breaks, as well as due to the irritation of the cervical nerve root, especially during extension (Yoo et al., 1992). This may have a more pronounced effect on functional upper extremity strength decrease.

The current study focused on neck postures that were at end range of motion to observe the effects on discomfort and the upper extremity in extreme cases. Future studies should focus on neck postures in the sub-maximum range of motion to determine if there is a range from neutral, in which the risk of discomfort or injury is not significantly increased. Furthermore, I studied flexion, extension, and protraction while Webb (2015) studied of lateral flexion. Future studies should also consider neck twist, as well as a combination of these postures such as the effects of combined flexion and twist. Perhaps certain postures, such as a combination of neck extension and neck twist, will have greater effects on discomfort, since neck muscles are no longer bilaterally contributing to the same action, and foramen size may dramatically change.

The possible magnifying effect of vibration, on neck injury risk, is another area of concern that should be further studied. There is currently insufficient evidence that vibration is a risk factor for the neck. It is known that skull vibration may cause vestibular changes as well as nausea (Karlberg et al., 2002; Lackner et al., 1974). However, various studies document the implications that vibration at the neck has on gait and the lower limb. (Andersson & Magnusson, 2002; Bove et al., 2001; Rossi, 1985). Andersson & Magnusson (2002) reported that cervical vibration causes anterior and posterior sway of the body, leading to the compensatory activation of lower extremity muscles. Direct neck vibration also led to gait perturbations, causing deviation of path trajectory and undershooting a pre-determined distance (Bove et al., 2001). Ultimately, significant vibration is present for many occupations that involve the use of heavy machinery. Thus, the effects of vibration on task completion, neck discomfort, and upper extremity functional performance requires further study.

Finally, the effects of neck postures and head loads on the performance of skilled tasks should be studied. Head position is an essential aspect for the organization of sensory information for joint position sense (JPS) of the upper limb (Paulus and Brumagne, 2008). A change in neck posture will change an individual’s perception of their limbs and body, and affect the performance of upper-limb goal directed tasks. (Roll et al., 1991). Neck muscle fatigue can alter upper limb proprioception (Zabihhonesseinian et al., 2015). Upper limb JPS is impacted due to the altered afferent input from fatigue resulting from neck posture and pain. Various authors agree that accuracy in pointing tasks suffer from changes in head and neck position (Fookson et al., 1998; Berger et al., 1998). These effects may be exacerbated with neck pain and discomfort (Knox et al., 2006).

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Appendix A

Letter of Information and Consent

The Effects of Neck Posture on the Upper Extremities

Investigators: Dr. James Potvin, Ebram Ibrahim, & Michele Webb

Principal Investigator: Dr. James Potvin
Department of Kinesiology
McMaster University,
Hamilton, Ontario, Canada
potvinj@mcmaster.ca
(905) 525-9140 ext. 23004;

Student / Co-Investigator: Ebram Ibrahim
Department of Kinesiology
McMaster University,
Hamilton, Ontario, Canada
ibrahe@mcmaster.ca
(647) 401-8477

Student / Co-Investigator: Michele Webb
Department of Kinesiology
McMaster University,
Hamilton, Ontario, Canada
webbma@mcmaster.ca

Research Sponsor: Auto 21

Purpose of the Study
The goal of this study is to develop an ergonomics tool for assessing the injury risks present for the neck during work tasks. This tool will take into account the effects that certain neck postures have on the arm and hand. The data collected in this study will be extremely useful to ergonomists and can be added to existing ergonomic tools. We hope that it will be used as a starting point for more refined and safe occupational workstation design. Currently, very important ergonomic decisions are based on insufficient research concerning the neck and its effect on the upper extremities. This research will go a long way towards improving the accuracy of ergonomic tools, thus lowering the incidence of work-related musculoskeletal injuries.

Procedures involved in the Research
Participation in this study will take place in the McMaster Occupational Biomechanics Laboratory in the Ivor Wynne Centre, room A108. This study will involve 2 sessions over 2 days with each session lasting

about 2 hours. Before study commencement, physical characteristics such as your age, weight, and height will be measured.

Principal investigators will be Ebram Ibrahim and Michele Webb, one of which will be present for all data collection.

Session 1 – Orientation and baseline measurements:
The maximal or greatest range of motion (ROM) of your neck will be recorded in 6 different directions. Bending your neck forward **(flexion)**, bending your neck backwards **(extension)**, bending your neck to each side **(lateral bend)**, pushing your chin forward **(protraction)**, and pulling your chin backwards **(retraction)**. To do this, two sensors will be taped onto your neck and head and will be tracked in 3-D space by use of an electromagnetic source. You will not feel this electromagnetic source at all, and it will put you at no risk whatsoever. These sensors will be affixed to the appropriate locations for both sessions. This system will be connected to a custom program that will display the angles in real time on a LCD screen in front of you.

Force data will be collected using a digital pinch and hand grip tool. You will be asked to pinch and grip a handle with as much force as you can with your arm bent at 90° on your side while standing straight. Two trials for each grip will be conducted and if the forces are not within 10% of each other, a third trial will be run. The average of the two trials that are within 10% of each other will be recorded as the max pinch and hand grip strength.

During this session, you will also be able to get into some of the postures and familiarize yourself with the equipment that will be used in the second session

Session 2 – Data Collection of Full Protocol:
In addition to using the Fastrak system, surface electromyography (EMG) will be collected on certain muscles found around your neck and shoulders. EMG involves placing electrodes with a weak adhesive over the muscle sites on your skin. The muscle sites will be around your throat, upper back, and shoulders. All wires from the Fastrak system as well as the electrodes will be safely, and securely, bundled together and fastened to remove any choking hazard. The electrode sites will be prepared by scrubbing the area with alcohol prior to the placement. Maximal trials on each muscle will be recorded by the investigator asking you to flex, extend, and bend your neck to the side with as much force as possible. While you do this, you will be seated and wearing a helmet that is in a fixed position and records your force. These max trials will be collected using precautions that have been proven to ensure your safety and comfort.

You will be comfortably and securely fastened to a **custom, manually adjustable,** inversion table which can be tilted to different angles. You will be tilted to 50% and 100% of your measured max ROM angle for the neck action being tested (Figure 1). You will be told to maintain your eyes level with a horizontal line and will receive visual feedback from the monitor in front of you to maintain the desired neck posture.

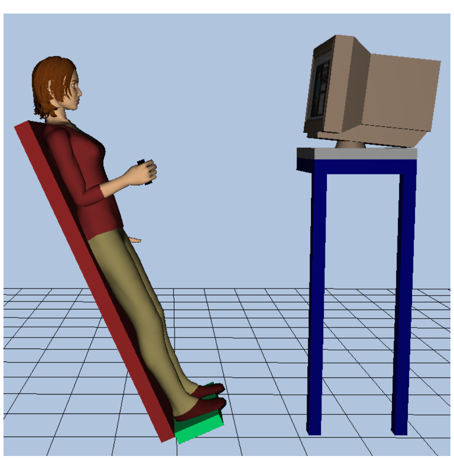

Figure 1: Participant lying on their back on the inversion board. The inversion board is set to an angle of 24°. Neck flexion angle is also 24°. The computer monitor displays real time angle data from the neck. The right arm is flexed 90° and the hand grip dynamometer in black is grasped by the participant.

There will be one trial for each neck position. Each trial will last 5 minutes with another 5 minutes rest in between trials. A tactile vibrator will be used to measure finger sensitivity to touch at the end of every trial. To do this, your fingers will be placed on a small device and the mechanical vibrator will stimulate your finger with a short and small vibrations. You will simply state if you feel the vibration on your finger or not. Pinch and hand grip strength will be recorded immediately after every trial. A discomfort scale will be administered to you at the end of each trial where you will be able to pick a value from 0 – 10 with 0 meaning no discomfort and 10 meaning extreme discomfort. After the rest period and prior to the start of each trial, max pinch and hand grip strength while standing straight with your right arm bent at 90° will be recorded to ensure no lasting effects of the neck posture you were in. If the recorded strength is not close enough to the originally calculated max pinch and hand grip strength, then the rest period will be extended to make sure that there are no lasting effects of the neck posture or due to fatigue. Furthermore, greatest range of motion tests for your neck will be recorded again to ensure that you are able to retain it. Depending on the results of these measures, the rest period may be extended.

After this, the same protocol will be run except this time you will be asked to wear a different non-stationary helmet weighing 1.95 kg.

The orientation session will take place on one day while the collection session will take place on another. It is important that you give a complete maximal effort for every trial during the sessions.

You will be able to remove all the Fastrak sensors, the EMG electrodes, the helmet, and get off the inversion board at any time if you choose to do so.

Potential Harms, Risks or Discomforts:
As this is a study that measures physical exertion, force production and involves a sustained neck posture, there exists a possibility of localized muscle fatigue in the neck, forearm, and shoulder. This would be due to maintaining your neck posture for 5 minutes, the exertion of force and the recruitment of muscle to produce that force. This discomfort, if present, will be similar to what may be felt after lifting weights at the gym. These types of force production trials of the neck and hand have been used extensively in previously studies with no injuries being reported by the researchers. It should be noted that you will be in complete control of your neck posture, as well as how much force is being applied or produced. You will be free to take a break or stop participating at any time if you feel uncomfortable or tired. You will be given ample rest between conditions and will be free to end a session if you feel it is necessary. We may ask you to return for more than three sessions if you do not feel comfortable performing the current protocol as it is designed.

Potential Benefits:
Although there will be no direct benefits to you, this study will result in the improvement of the ergonomic tools & software available to ergonomists. With a more accurate ability to predict the full effects of neck postures, ergonomists can help reduce occupational musculoskeletal injuries by designing safer jobs.

Payment or Reimbursement:
You will be reimbursed with a $5 Tim Horton’s gift card for each hour. The study will involve a maximum of two data collection sessions, each for a maximum of 90 minutes. You may keep the compensation if you choose to withdraw.

Confidentiality:
You will be assigned a randomly generated participant code known only to the investigators; thus, your identity cannot be determined by anyone other than the investigators. Your personal information including name, age, and physical characteristics will be kept anonymous on all documents using the coding system. The information obtained in this study will be used for research purposes only and will be kept in a locked cabinet or stored on a password-protected computer for a maximum of 10 years. As mentioned previously, the infrared cameras will only record the movement of the reflective markers so the participants’ confidentiality will be maintained.

Participation and Right to Withdraw:
Your participation in this study is strictly voluntary. If you choose to volunteer, you have the right to withdraw from the study without any consequence at any time either before or during the testing sessions

until approximately July, 2015. If you choose to withdraw, all of your digital data will be permanently deleted from the computers and all paperwork will be shredded, unless you indicate otherwise

Information about the Study Results:
Results from this study can be expected by September of 2015 (approximately). You may obtain information about the results of the study by contacting one of the investigators, or by leaving your email address on a confidential form to which the final results will be mailed.

Information about Participating as a Study Participant:
If you have questions or require more information about the study itself, please contact Ebram Ibrahim (ibrahe@mcmaster.ca; 647-401-8477) or Michele Webb (webbma@mcmaster.ca).
This study has been reviewed and has received ethics clearance from the McMaster Research Ethics Board. If you have concerns or questions about your rights as a participant or about the way the study is conducted, you may contact:

McMaster Research Ethics Board Secretariat
Telephone: (905) 525-9140 ext. 23142
c/o Office of Research Services
E-mail: ethicsoffice@mcmaster.ca

CONSENT

I have read the information presented in the information letter about the study being conducted by Dr. Potvin, Ebram Ibrahim, and Michele Webb at McMaster University. I have had the opportunity to ask questions about my involvement in this study, and to receive any additional details I wanted to know about the study. I understand that I may withdraw from the study at any time, if I choose to do so, and I agree to participate in this study. I have been given a copy of this form.

______________________________ ______________________________

Name of Participant Signature