UNIVERSITY OF ALBERTA

QUANTIFICATION OF ISOMETRIC CERVICAL STRENGTH AT DIFFERENT RANGES OF FLEXION AND EXTENSION

BY

LAXMI SURYANARAYANA ©

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Abstract

The purpose of this study was to quantify the isometric cervical strength at angles representing different percentages of total range of motion namely neutral, 25%, 50%and 75% in flexion and extension. The reliability of strength measuring device was tested prior to any measurements. The quantitative relationship between force and range of motion, force and direction of effort, and force and gender was also examined. The correlation between the forces (mean average and mean peak force) and the anthropometric measures (height, weight) was also examined.

Using a correlation study design, 39 volunteers in the age range of 18-30 years were recruited in two sessions, one for flexion and the other extension. The cervical isometric strength was determined at different angles of neck flexion and extension using a force measuring device whose reliability had already been established.

The testing device consisting of a sturdy, stable and strong telescopic upright and adjustable square metal tube was firmly bolted in the floor. Another rotating metal tube was pivoted, adjustably counterweighted and attached to the above upright at one end and an immovable object with a load cell in its path. A horizontal bar upholstered at the terminal end was slid on to the upright tube. The neck was positioned according to the desired degree of flexion and extension using a gravity goniometer and force was exerted on the horizontal resistance arm.

Cervical strength was found to be highest at the neutral position of the neck in flexion (19.76N females and 31.42N males) and extension (39.52 females and 45.10

males) and decreased with an increasing angular deviation of the neck. Significant differences in isometric neck muscle strength were found between some of different angles of neck flexion and extension, direction of effort, and also between genders ($p<0.01$).Furthermore, it was observed that the correlation coefficient between force produced and physical parameters of height and weight were not significant. No significant differences were observed in between the paired means recorded on two days establishing the reliability of testing ($p>0.005$).

Thus it can be concluded that the maximum force was exerted at the neutral position of the neck and was directionally dependent being less in flexion than extension. The results indicated reliability of the force measuring device. Males were stronger than females. The physical parameters did not play a significant role in the strength values.

Dedication

This work is dedicated to my dearest and loving parents(B.S.Suryanarayana and H.N. Satyavati) and my special twin brother(Girish Suryanarayana) for their constant support, encouragement, guidance and love they bestowed upon me during my thesis program. In spite of the long distance, it was always a joyous moment to hear their (parent's) voice of confidence and trust they showered upon me which taught me to persevere inspite of adversity. My twin brother has always remained my dearest friend, giving me the full freedom of disturbing him irrespective of the time of day and thus guiding me accordingly.

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Chapter 1

Introduction

1.1 Problem Statement

The growing incidence of neck pain is a cause of major concern in terms of financial impact, as well as health problems and loss of productivity (Barton et al., 1996). Functional disorders of the neck typically associated with pain and muscular fatigues have become a severe problem among the younger and middle aged groups in industrialized countries (Ylinen et al., 1994, Berg et al., 1994). Most of neck disorders are due to whiplash injuries, associated degenerative conditions, sports related trauma and occupational cervicobrachial disorders (Brattberg et al., 1989, Garces et al., 2002, Kumar et al., 2001, Berg et al., 1994, Leigh et al., 1989) causing pain and muscular weakness (Brattberg et al., 1989, Leigh et al., 1989). Neck muscles are postural muscles that stabilize the head during body movements (Ylinen et al., 1994). Weakness and atrophy of these muscles commonly seen in patients with increased frequency of neck pain (longer than six months) could be a predisposing factor in development of abnormal posture. For example, studies have observed that the weakness of the anterior cervical muscles seen in patients with chronic neck pain predisposes them to a forward head posture (Silverman et al., 1991, Krout et al., 1966). There is a relationship between chronic neck pain and muscular weakness, and studies have suggested a strong association that strength training reduces neck pain (Kumar et al., 2001, Highland et al., 1992, Berg et al., 1994, Martin et al., 1986, Ylinen et al., 2003).It has been postulated that in the presence of injury and pain, the force generating capacity is significantly compromised, and hence knowledge of normal force values could be useful for the basis of functional restoration and structuring treatment regimes (Kumar et al., 2001).

Few studies have examined normal values, using varying equipment and with questionable reliability (Kumar et al., 2001). Experiments performed by using hand-held dynamometers for evaluating isometric force production faced the limitation of measurement of the strength of the tester which varies with the strength of the experimenter (Wilkhom et al., 1991). In another study done on the isometric cervical strength using a strain gauge dynamometer there was a significant contribution from extrinsic muscles and other body parts due to the experiment protocol thus causing variability in interpretation of results(Kumar et al.,2001).

Other studies have restricted the measurement of the isometric cervical strength to specific degrees of range of motion (Garces et al., 2002, Chlu et al., 2002). For example, using a multicervical rehabilitation unit Chlu et al., 2002, quantified forces at 20° and 40° of flexion and extension. Similarly Garces et al., 2002 used a computerized dynamometer to measure the forces at three different degrees (0, 5, and 10) of cervical flexion and extension. The limitation of using fixed angular measurements is that range of motion varies among individuals, thus subjects muscles could be at different points in the length-tension relationship. Furthermore, strength measured at two or three particular degree is insufficient to estimate cervical strength at different range of motion. Hence it is essential to provide strength values through out the whole range of motion.

It has also been suggested that a variability of 12 to 20 degrees in active and passive range of motion exist at the cervical spine (Christensen et al.,1998).This variability across the subject could bias the forces quantified at each specific degree and constitute different proportion of the range of motion. This led us to consider percentage of range of motion as a meaningful statistic which will be comparable between subjects.

1.2 Significance of Study

The general purpose of this study was to provide a normal database of isometric cervical strength at different proportions of neck flexion and extension in young healthy volunteers. Most of the research cited in the literature investigates only specific degrees of neck flexion and extension. Lower strength values at an untested position in the range may often go undetected and hence, it is important to be concerned with the force values available through the total range of motion. To evaluate treatment outcome, it is relevant to have a normal database for comparing the normal force values with the clinical population.

Force values obtained from this study could be used in clinical practice to compare and set realistic goals for injured clients. By comparing a patient's values at different percentages of his or her available range, the therapist may be bale to focus the strengthening protocol at different points in the range of motion.

1.3 Objectives of the Study

- The first objective of this study was to examine the test re-test reliability of the strength measuring device.

  Hypothesis: The average test scores on two different days will not be significantly different.

- The second objective of this study was to quantify and examine isometric cervical strength (average and peak) in flexion and extension at neutral posture, 25%, 50% and 75% of flexion and extension.

  Hypothesis: Highest force (average and peak) will be exerted at the neutral position of the neck.

- The third objective of the study was to examine and quantify the relationship between force and range of motion (ROM)

  Hypothesis: A negative correlation will exist between the motions and force (one-tailed test).

- The fourth objective of this study was to determine the relationship between force and direction of effort, force and gender.

  Hypothesis: Force values will be higher in extension than flexion. Men will be stronger than women.

- The fifth objective of this study was to look at the association between the force values and physical parameters of height and weight.

Hypothesis: There will be no correlation between force values and the anthropometric measures.

1.4 Operational Definitions

1. Reliability

The degree of consistency with which an instrument or rater measures a variable (Domholdt et al., 2000).

2. Measurement Validity

It is the appropriateness, meaningfulness and usefulness of the specific inferences made from the test scores (Domholdt et al., 2000)

3. Isometric Force

Development of muscular tension with no change in muscle length is called as Isometric force (Hall et al., 1999).

1.5 Limitations

- The resultant force was calculated by using formula –

  Force measured = Force applied * distance measured/ distance applied. This could account for slight variation due to procedure errors. However the experimenter followed the protocols rigidly.

- Isolation of Cervical Muscles-

  Even though care was taken to minimize the contribution of extrinsic muscles from the different parts of the body, it was not possible to totally isolate the thoraxic contribution because of the anatomical and physiological configuration of the cervical region.

- Single inclinometer-

  The limitation of measurement of extraneous motion from upper thoraxic spine (Chen et al., 1999) could cause an increase in the range of motion measurement values.

- Gravity-

  Results were not corrected for the effect of gravity. The subjects in this current study were asked to exert isometric force with the head resting on resistance pad and hence the current authors believe that the effect of gravity was very small and insignificant.

1.6 Delimitations

The results of this study are delimited to isometric cervical strength measurements in the age range of 18-30 years and those listed in the inclusion criteria of methodology.

1.7 Abbreviations

ANOVA	Analysis of Variance
ROM	Range of Motion
FM	Force Measured
FA	Force Applied
Dm	Distance measured
Da	Distance applied
N	Newton
Lbs	Pounds
SCM	Sternocleidomastoid
Cm	Centimeters
Flex25%	Flexion at 25% of ROM
Flex50%	Flexion at 50% of ROM
Flex75%	Flexion at 75% of ROM
Flex Neutral	Flexion effort at Neutral position
Ext 25%	Extension at 25% of ROM
Ext 50%	Extension at 50% of ROM
Ext 75%	Extension at 75% of ROM
Ext Neutral	Extension effort at Neutral position

Chapter 2

Literature Review

2.1 Epidemiology of neck pain

Studies have reported an increased prevalence of neck pain especially in industrialized countries (Bovim et al., 1994, Brattberg et al., 1989). Not only has there been an increase in financial burden (Harder et al., 1998, Kumar et al., 2001) but the recovery period has extended beyond six months (Jordan et al., 1999). Headaches and neckaches affect two- thirds of the population, and cost millions of dollars from lost work time in industry (Legget et al., 1991). Bovim et al., 1994 in a Norwegian study reported a prevalence of 13% of chronic and persistent neck pain, whereas in Sweden it was reported as high as 26 %(Brattberg et al.,1989).

The Quebec Task Force on Whiplash Associated Disorders (WAD) (Spitzer et al., 1995) defines whiplash "as an acceleration-deceleration mechanism of energy transfer to the neck which may result from rear-end or side impact, predominately in motor vehicle accidents and from other mishaps. This energy transfer may result in bony or soft tissue injuries (whiplash injury), which may in turn lead to a wide variety of clinical manifestations" (whiplash associated disorders)(Kasch et al.,1994). The common clinical presentation of these injuries in patients are head, neck, and upper thoracic pain, along with stiffness, tenderness and reduced neck mobility(Dalla Alba et al.,2001, Eck et al.,2001). A cohort study done by the (WAD) Task Force found that about 3% of whiplash associate disorders had still not recovered after one year and that symptoms persisted for at least six months in more than 25% of whiplash cases (Harder et al., 1998). Also, there has been an increase in the financial burden by causing a rise in compensatory period from 72 days in 1987 to 108 days in 1989 (cited by Kumar et al., 2001)

The national survey of Quality of Employment (QES) conducted in USA, found that occupational disorders were maximally afflicted by pain in the age group of 50-64(Leigh et al., 1989). These are termed as an occupational cervicobrachial disorders involving craftsmen, operatives, laborers, service workers, clerks, and sales people, farmers and farm workers presenting with muscular pain, stiffness and numbness in neck and shoulders(Levoska et al.,1993,). Kilbom et al., 1988 had subjects working in automobile industry (assembling car motors) with lower muscular strength, prone for developing shoulder neck disorders (commonly termed as cervicobrachial disorders).As compared to occupational cervicobrachial disorders age group, whiplash injuries are more common in younger age group in the age range of 20-24 years(Suissa et al.,1995).

2.2 Interrelationship between strength training and neck pain

The main extensors of the neck are semispinalis capitis, semispinalis cervicus, multifidus and longissmus(Takebe et al.,1974) as cited by Conley et al.,1997, (Nolan et al.,1998) while the main flexors are longus capitis, rectus capitus anterior and longus capitus scalenus and sternocleidomastoid(Keith Bridwell).These muscles are postural muscles as they not only support the weight of the head but also bring about stabilization of the head during bodily movements(Ylinen et al.,1994). This stabilization may require a sustained muscular contraction. Weakness or fatigue of these muscles could be a predisposing factor for persistent head and neck pain

(Legget et al., 1991) in subjects suffering from chronic neck pain (Silverman et al., 1991). In a comparative study (Silverman et al.,1991) done on subjects suffering with mechanical neck pain (from last three months to 15 years) with those of healthy individuals, a profound decrease in neck strength was reported in this clinical group by approximately 50%. Thus this shows a decrease in neck muscle strength in patients suffering from neck pain.

Numerous studies have emphasized the importance of strengthening the neck muscles for reduction of pain. Highland et al., 1992 had patients with degenerative disc, herniated disc and cervical strain who underwent eight weeks of strength training regime. At the end of rehabilitation, along with an increase in the muscle strength (13 to15N) a reduction in the neck pain (from 9.0 to 2.9 approximately on a pain reduction scale) and increased mobility (10-12 degrees) was seen. Levoska and Kiukaanniemi1993 examined occupational cervicobrachial disorders in female office workers and found that the symptoms of neck and headache were reduced after active physiotherapy consisting of muscle training of neck and shoulder. Similarly, Ylinen et al., 1994 and Berg et al., 1994 reported that after exposing white and blue collar workers to a strength- training program of three and eight weeks respectively, an increase in muscular strength and reduction in pain(from 7 to 3 on a visual analogue scale) was observed. Ylinen et al., 1994 found an increase in the range of 34-49 N in comparison with the pre-treatment force values while Berg et al., 1994 found an increase of 35% of initial force values. The results of all the above studies using different clinical groups suggest that a strengthening protocol brings about a reduction in pain and an increase in neck mobility.

Unlike peripheral muscles groups no normal comparison is possible within a subjects. As the cervical muscles are axial components of the musculature, hence it is essential to provide a normal database with those of healthy individuals. Moreover this knowledge of normative data regarding neck strength is required for a comprehensive comparative clinical evaluation between patients suffering from chronic or recurrent neck pain and those of healthy individuals (Kumar et al., 2001, Chlu et al., 2002, Jordan et al., 1999). It helps in structuring intervening and monitoring rehabilitation program. Furthermore, it also enables us to understand the potential relationship of muscle function to pathology (Vasavada et al.,2001).Hence this measurement of muscle strength forms an important aspect of the rehabilitation program.

2.3 Experiments on quantification of cervical strength

Only a handful of studies have examined the force generating capacity of cervical musculature. Using different equipment, authors have quantified the isometric cervical strength in different ranges of motion (flexion and extension) in healthy individuals which has accounted for the wide variability of force values (Estandler et al., 1994). Commonly used equipment for assessing cervical strength includes the isokinetic dynamometer and the hand-held dynamometer (Deones et al., 1994). Isokinetic dynamometer are reliable devices for measuring muscle performance, but also have several disadvantages such as high equipment cost, large space requirements, time consuming testing sessions, and the need for trained personnel (Deones et al., 1994). Studies have been done using hand held dynamometers to assess cervical strength. For example, Silverman et al., 1994 used the hand held dynamometer (held against the forehead and superior to ear) to quantify the cervical muscle strength in flexion and rotations (left and right) using pain and control group. Even though this equipment is portable, easy to use, inexpensive, with minimal time requirement, unfortunately it provides poor reliability as strength measurement varies with strength of investigator (Jordan et al., 1999, Kumar et al., 2001, Garces et al., 2002, Deones et al., 1994).

A lack of standardized protocol has also contributed to the existence of variability of results. For example, Jordan et al ., 1999 used a strain gauge dynamometer with a built-in goniometer to measure the isometric cervical strength at 60, 45,30, 15 and 0 degrees of flexion, and at -15,0,15, 30, 45 and 60 degrees of extension. Subjects in their study had no stabilization of the torso and were asked to grip the two handles on the side while exerting force. The authors found no significant differences in flexion and extension strength with increased cervical angles. One could definitely expect a significant contribution of strength from extrinsic muscle and other body parts with such a protocol, thus causing a variation in the interpretation of results (Kumar et al., 2001).

In other studies, investigators have limited themselves to assessing isometric cervical strength at specific degrees of neck flexion and extension (Garces et al., 2002, Chlu et al., 2002). Even though the main objective in one of these studies was to provide a normal database, the investigators chose to quantify the isometric cervical strength only at neutral, 5 and 10 degrees of flexion and extension (Garces et al., 2002). This is insufficient to be termed as "normal database" as the total cervical range of motion is 0-120 degrees and thus there is a paucity of values at other ranges of motion.

One could also expect a normal variation of 12-20 degrees in active range of motion in between subjects (Christensen et al., 1998). For example, a specific degree may not correspond to the same angular deviation in each subject due to the variability of the total range of motion across different subjects.

2.4 Range of Motion Measurement Device

The cervical spine is the most mobile region of the spine (Takeshima et al., 2002) and because of the few available landmarks and depth of the soft tissue overlying the bony segments, offers a challenge to researchers in the analysis and accurate assessment of cervical inter-segmental motion (Ordway et al., 1999, Tucci et al., 1986). Numerous methods have been proposed for measuring the cervical range of motion using different kinds of equipment leading to a considerable variability in the normal values for active and passive range of motions (Lantz et al., 1999, Ordway et al., 1997, Mayer et al., 1997, Tucci et al., 1986, Khulman et al., 1993). There are two methods used to measure cervical range of motion: invasive and noninvasive. Examples of some the noninvasive technologies are a protractor, bubble goniometer, universal goniometer, pendulum goniometer, visual assessment, electrogoniometer, tape measurement, and flexible rule and inclinometer (single and dual) (Lantz et al.,1999, Khulman et al.,1993). The inclinometer (dual) is considered as a clinical standard methodology for assessing spinal range of motion as stated by the American Medical Association (AMA) (American Medical Association: Guides to Evaluation of permanent impairment Chicago: American Medical Association 1993)(Mannion et al.,2000).

Invasive methods include radiography, cineroentogonography, computed tomography, and three dimensional movements in cadaveric specimens (Lantz et al., 1999, Ordway et al., 1997). Even though these invasive technologies provide precise measurements, they are expensive and time consuming and are impractical for clinical use (Ordway et al., 1997).

This study used a gravity goniometer (inclinometer) to measure cervical motion. This gravity goniometer is also called a "gravity reference inclinometer". It consists of a metallic gravity pointer encased within a flat protractor-like scale that moves freely about an axis to measure the cervical range of motion in a sagittal plane (flexion and extension)(Youdas et al.,1991). When directly vertical, the pointer is aligned with the force of gravity and rests at 0 degrees on the protractor scales. This pointer registers the amount of motion in degrees when the gravity goniometer is moved (Khulman et al., 1993). It is a simple, inexpensive, reliable, and highly accurate method to measure cervical range of motion. It is secured to subject's head by a Velcro strap eliminating the possibility of palpation error in locating anatomical landmarks (Khulman et al., 1993). Recently, another type of gravity goniometer called the Cervical Range of Motion (CROM) has been introduced in the market by Performance Attainment Associates which is capable of measuring the cervical range of motion for flexion, extension, lateral flexion and rotation using separate inclinometers (Ordway et al., 1999, Tousignant et al., 2000). Reliability studies (Tucci et al., 1986, Youdas et al., 1991) have reported the gravity goniometer as a reliable tool for measuring the cervical range of motion. Tucci and coworkers (1986) observed a significant intraclass correlation coefficient (ICC) of >0.911 ($p<0.01$) for intra-observer and inter-observer reliability when comparing the gravity goniometer with universal goniometer. In another study done by Youdas and associates (1991) using a visual estimation and universal goniometer, similar intra class correlation coefficients were seen (ICC>0.80).

Clinical Validity of an instrument requires accuracy and precision, typically established by evaluating the agreement of an instrument with a gold standard technique (Chen et al., 1999) termed 'criterion related validity'. Usually for the spinal range of motion measurements the radiographic method is considered as a valid reference method (Chlen et al., 1999, Tousignant 2000).Ordway and associates1997 a good correlation was found between gravity referenced cervical range of measurement and gravity referenced radiographs when comparing the outcomes of three methods, a cervical range of motion device, a 3-Space system and lateral radiographs. Another comparative study done by Tousignant et al., 2000 between CROM and radiographs, found a similar high correlation (0.97).

2.5 Summary

From the literature review, it was clear that neck pain has become a significant problem in industrialized countries. Studies have shown the relationship between reduction of neck pain and strengthening of neck muscles. By providing a normative data of isometric neck strength, it would enable the health professionals to have a comparative clinical evaluation with those of the injured clients. Even though some studies have reported measurement of isometric strength, there is variability in the data due to lack of standardized equipment and protocols. Some of the other studies have focused on measurement of isometric strength at only a few angles of neck motion. Restriction at few degrees can often be misleading in the interpretation of force values at other degrees of neck in a clinical population. For example, a patient may be able to exert force at neutral position of the neck but because of any type of neck pathology would be unable to do so at other ranges. Hence it is equally important to assess the strength values at different ranges of neck. As variability of active neck range of motion across healthy volunteers exists, our study was interested in looking at the relative ranges of motion rather than specific degrees. As far as the current author knows, there has been no report on isometric strength measured at relative percentages of range of motion.

Chapter 3
Materials and Methods

3.1 Study Design

This was an experimental study. Thirty nine healthy participants were randomly recruited in the study and isometric neck muscle strength was measured twice under two sessions- one for flexion and the other extension. This design met the needs of the study objectives within the limits set by subject selection.

The main outcome of this study was to measure the isometric cervical strength in two directions, flexion and extension using the force measuring device at four different positions of the neck namely neutral, 25%, 50% and 75% of the total range of motion in a particular direction. The relationship of measured force with other variables such as gender, direction of effort and physical parameters (height and weight) was also assessed.

3.1.1 Subject Recruitment

Thirty nine volunteers (19 males and 20 females); 18-30 years of age were recruited by notices posted at the University of Alberta (Appendix B). Some of studies which have examined the isometric cervical strength had representatives of all the age groups from each decade (Chlu et al., 2002, Jordan et al., 1999 and Garces et al., 2002) mainly from 20-80 years. Chlu et al., 2002 and Garces et al., 2002 in their study had 34 and 42 subjects representing the age group of 19-40 years. However Jordan et al., 1999 had only 10 subjects representing this age group.

In an epidemiological study done by Whiplash Associated Disorder, the highest incidence of whiplash injuries was reported in the younger age group of 20-24 years (Suissa et al., 1995). Hence the current study chose this age group. Demographic details of both genders are provided in Table 4.1.

Participants were enrolled in this study if they met all the following inclusion criteria:

- 18-30 years of age.
- No history of any musculoskeletal problems or neck injury.
- No sore neck for any reason over the last 12 months.
- No pretraining of neck muscles.
- Ability to understand spoken and written English.
- Provision of written consent.

All eligible subjects were provided with the information letter describing objectives and procedures of the study (Appendix A). Subjects who volunteered were asked to come for two sessions (flexion and extension). During the two-month period between January 2003 and March 2003, a total of forty-one subjects volunteered. The subjects signed an informed consent and were provided with the purpose and protocol of experiment.

3.1.2 Sample size

The main objective of this study was to provide a normal database of isometric cervical strength values for young healthy individuals in the age range of 18 to 30 years. Fisher and Bell1993 with observed a correlation coefficient of r=0.4 (CI 95%= 0.84 to 0.99) for a sample size of 40 subjects. After a sample size calculation a sample of 40 subjects was targeted for this study(Appendix B).

3.1.3 Setup

The setup consisted of an adjustable chair, sliding platform, and floor mounted strength measuring device (Figure 3.1). The chair was made up of a molded plastic seat mounted on a sturdy iron platform with four telescopic metal legs fixed to a base plate. Between the base plate and the iron platform, a screw jack was mounted with a lever to raise or lower the seat according to the height of the C7/T1 disc measured from the floor. The back rest and the seat pan were fitted with a Velcro four-point restraint system for the subject's trunk stabilization. Two bolts were placed at opposite ends and tightened for a rigid fixation of the chair.

3.1.4 Force Measuring Device

The testing device used for this study was that of Kumar et al., 2001· It consisted of a vertical telescopic 15 cm wide rectangular metal tube welded to a thick iron plate rigidly bolted to the floor. The 12 cm wide inner tube could be raised or lowered and securely locked in its place. On top of the inner tube, a block bearing was mounted to which another hollow metal square tube was attached to allow it to rotate freely. Perpendicular to this tubing was attached an adjustable arm with an upholstered sliding pad at the farther end for head contact and force exertion. At the lower end of the tubing, a counter weight was attached with an adjustable length rod to compensate for the variable positioning of the horizontal resistance arm. Fourteen centimeters below the pivot point, a horizontal metal rod was built at right angles to the tubing arm. A cable was attached to a pulley with an intervening load cell (I-250) secured to floor. All adjustable parts of this apparatus were labeled in centimeters so that identical measures could be reproduced at different measuring sessions (Figure 3.1).

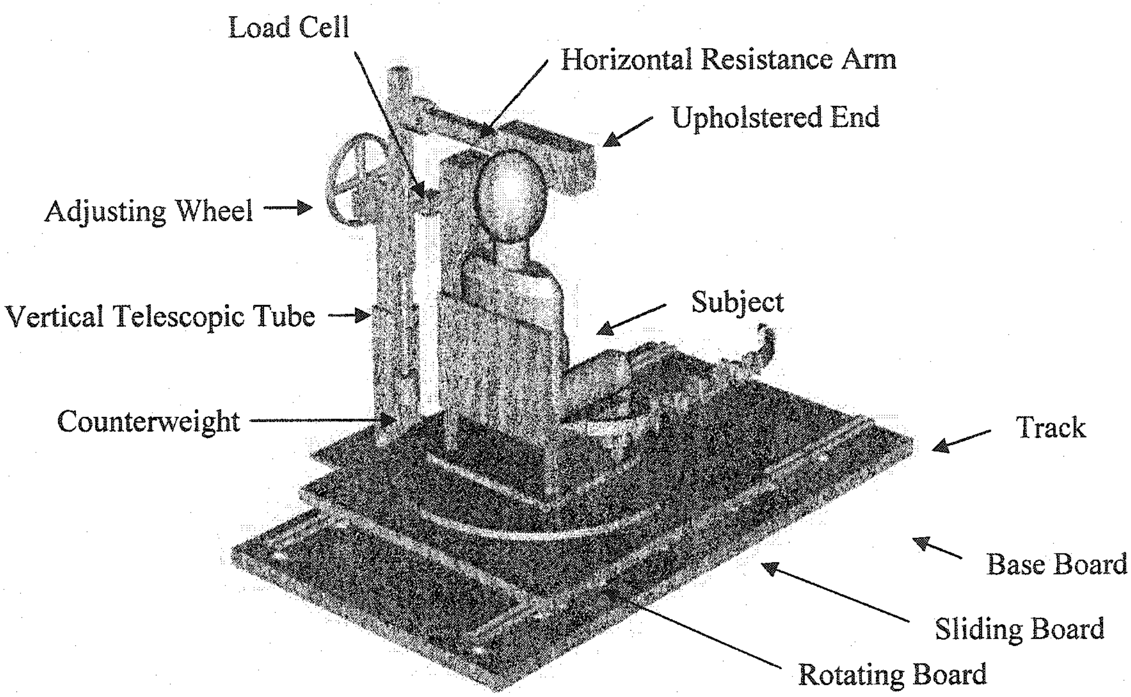


Figure 3.1: Force Measuring Device by Kumar et al., 2001

3.1.5 Data recording setup

Our data recording setup consisted of an I-250 load cell and accompanying force monitor for signal conditioning and display. The output of the force monitor was fed to a 486 computer through a metrabyte DAS 20 A to D board with a frequency of 1 Khz (kiloHertz). To account for the sensitivity of the load cell to record the voltage, force measuring equipment was calibrated before the start of our experiment. Standard weights between 10 and 50 lbs were applied to achieve reliable results for calibration and a high correlation coefficient of 0.998 was observed between volts and the pounds. Similarly, the angles were calibrated at ten degrees increments starting from 0 to 60 degrees and had a similar relationship with the correlation coefficient being 0.997.

3.1.6 Procedure

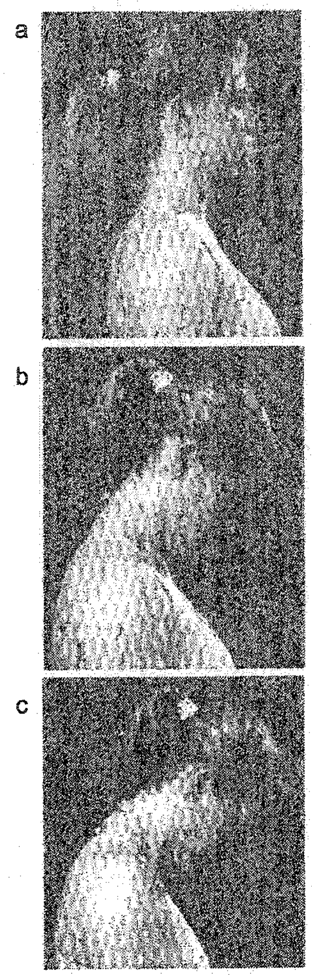
The subjects were informed about the objectives and procedures of the experiment. After signing the informed consent form, their height and weight was measured and recorded. Their age was also noted. The subjects were then seated in an erect and upright posture, arms by the side and feet flat on the floor with the lumbar spine resting against the back of molded plastic chair. This was followed by the stabilization of the torso with a four point Velcro restraint system in order to prevent excess motion from thoracic and lumbar spine. The subjects were informed that in order to meet the objectives of the test, it was essential for them to exert a maximal effort except in cases where there was a sudden onset of any symptoms or pain, at which time they should stop the experiment immediately and inform the investigator. At the beginning of each test, they were reminded of this requirement.

3.1.7 Range of Motion Measurement

The gravity goniometer was placed at the side (temporal) of the head with a refastenable strap as shown in the picture3.1. Subjects were asked to assume their neutral position of the neck for assessing the range of motion. The gravity goniometer was adjusted in such a way that the pointer rested at zero degrees and thus was in accordance with the subject's neutral position of the neck. They were then asked to perform flexion or extension and the deviation of the pointer of gravity goniometer from the starting position (zero degrees) till the end range of motion was noted. For cervical flexion, subjects were instructed to make an effort to tuck the chin in, and then roll the head further to chest (Cram et al.,1999) (picture1) while for extension, they were asked to face the ceiling(Ordway et al.,1997).Based on the total range, the percentage was calculated accordingly. For example, if a subject's range of motion in extension was 70 degrees, then 25%, 50% and 75% was 17.5, 35, 52.5 degrees respectively. Prior to assessing the range of motion, subjects were given a few warm up exercises (flexion and extension) for 3-4 times.

This study defined neutral position as subject's head facing directly forward and the gravity pointer resting at 0 degrees on the protractor scale. It was cited by Khulman et al., 1993 in his study that the neutral position of the head ranges between 10 degrees of flexion and 9 degrees of extension with the subjects in upright position, looking directly forward and with the plane of the lower surface of the upper teeth as the horizontal reference. However, this study was aimed at finding the force values in the relative percentages of range of motion for each individual depending upon their recorded degrees. Hence the current authors believe that this wouldn't have accounted for much of the variability.

This study used a single inclinometer which faced the limitation of measurement at the lower cervical spine as compared to dual inclinometer and thus did not measure the physiological motion at the thoraxic region with end range of cervical motion (Khulman et al., 1993). However strict protocol was followed to minimize the movement from the upper thoraxic spine. Further possible errors faced with this goniometer are inaccuracies in reading the goniometer and perceptions of end range of motion (Khulman et al., 1993). In order to eliminate or minimize the above mentioned errors, a single experimenter was involved through out the procedure. Subject's effort was taken into consideration by explaining to them the details of the whole procedure.



Picture3. 1: a) Neutral posture b) End range of motion for cervical flexion from upper cervical spine

c) End range of motion for cervical flexion from the lower cervical spine.

(As taken from Cram and Kneebone 1999 [15])

3.1.8 Force Measurement

Depending upon the random sequence generated by the computer (flexion or extension and the percentage of the range of motion-25, 50, or 75) the horizontal resistance arm was positioned to correspond with a particular percentage of degree of flexion and extension. The horizontal upholstered bar was slid onto the vertical portion of the resistance arm and adjusted to the appropriate height for the subjects to ensure the placement of this arm in the frontal plane. The subject's forehead or occiput was placed in direct contact with resistance pad for exerting force (represented "force applied ") which in turn was connected to the vertical telescopic tube attached to the load cell via a pulley (Figure 3.2 and Picture3.2).

The distance between the resistance pad and centre of pulley was referred to as "effort moment arm" which varied with each subject, whereas "pulley moment arm" was fixed and represented the length between the centre of pulley and string. The measured force was recorded from the load cell. The torque along the pulley was equal to force applied * effort moment arm = force measured * pulley moment arm (the radius of the pulley which is fixed).

Therefore, FA= FM* pulley moment arm/ effort moment arm.

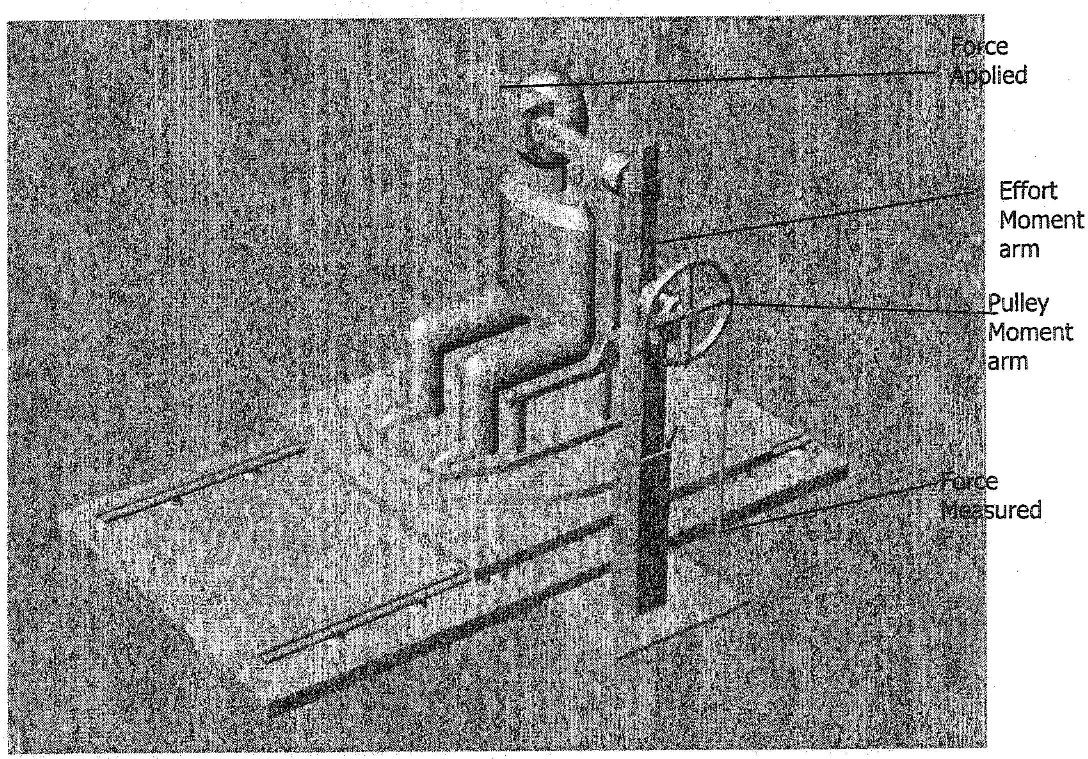


Figure3. 2: Schematic Representation of calculation of force.

Picture 3.2(a) and (b):A subject exerting force in flexion and extension with a gravity goniometer around the forehead.

3.1.9 Data collection

After the placement of the subject's forehead or the occiput against the resistance pad, the subjects were asked to push against the resistance arm as hard as they could, with gradual building of the force over the first two seconds and then maintenance of force for another 3 seconds. After 5 seconds of recording, the computer signaled the end of the recording period and the subjects relaxed. A trial of three measurements was taken at each position. The cervical strength was measured for flexion in one session and extension in another session. Two different sessions were considered in order to avoid the fatigability of the cervical muscles which could bias the forces exerted by the subjects. All the even number subjects were allotted flexion effort in the first session where as the odd number subjects were allotted extension effort in the first session. The sequences of the condition for the direction of movement were randomized (Table 3.1). The subjects were allotted a minimum of 2 minutes rest between the trials. Prior to the start of the trial, the subjects were told to exert their maximum effort, concentrating on using their neck only, and to raise their feet from the footrest minimizing leverage from lower extremities. The torso stabilization was constantly observed and the torso restraint was tightened if any torso movement was seen during testing. However, no verbal encouragement was issued to the subjects while they were exerting force.

Table 3.1: Random sequence generated

Name of the subject	*Condition*	*Distance applied*	*Distance measured*
	Flex N		
	Flex 50%		
	Flex 25%		
	Flex 75%		
	Ext 75%		
	Ext 25%		
	Ext 50%		
	Ext N		

3.2 Data Analysis

The collected voltage data were converted to Newtons. The mean average and mean peak strength were obtained from these sets. Mean average force represented average force over a period of time (5 seconds) while the peak force was the maximum force exerted by the subject during the period of 5 seconds. Mean average force and peak force was collected for each trial. Forces mentioned in the results and discussion chapter represents the sample (19 males and 20 females) mean average force and mean peak force.

In the reliability experiment, the subjects (6 females and 4 males) were called on two different days with a gap of one week.

Thirty-nine subjects enrolled in the study were included in the final analysis. SPSS for Windows (Statistical Packages for Social Sciences, Inc., Chicago IL) was used for the statistical analysis. Descriptive statistics (mean and standard deviation) were used to quantify the isometric cervical strength while correlation analysis was performed to examine the relationship between range of motion and force and physical parameters and force. ANOVA test was used for quantifying the relationships between direction of effort, gender, and range of motion on isometric strength. A student paired t-test was used to perform reliability analysis.

The strength values were calculated in units of force (N) rather than torque. As Torque= Magnitude of applied force (f) *distance (d) that force lies from axis of segmental rotation and hence for calculation of "d", an approximation of center of rotation had to be done. In order to avoid the determination of "d" and thus further variability in results, the force values were measured in Newton.

3.3 Ethical Consideration

This study received approval from Ethics Research Health Board, University of Alberta in August 2002(Appendix C). Each participant read the information letter which described the purpose of the study and guaranteed confidentiality and freedom to withdraw at any time and signed consent form.

Chapter 4

Results

This study quantified the isometric cervical strength at different conditions in flexion and extension and examined its relationship with the range of motion and physical parameters (height and weight) in young healthy volunteers in the age range of 18-30 years. It also looked at the influence of gender and direction of effort on strength values.

4.1 Physical Parameters

The participants in this study had a mean age of approximately 22 years, while the weight was ± 57.3Kg for females and ±71 kg for males. The average height of female and male subjects was 163 cms and 177 cms respectively (Table 4-1).

Table 4-1: Descriptive statistics of the physical parameters (weight, height and age)

Gender	Variables	Mean	Std Deviation (S.D)	Maximum	Minimum
Females (n=20)	Weight (Kgs)	57.30	11.40	97.50	45.40
	Height (cms)	163.0	6.0	173	150
	Age (years)	22.56	3.91	29	18
Males (n=19)	Weight (Kgs)	71.0	12.0	103.0	56.0
	Height (cms)	177.0	8.0	190.0	165.0
	Age (years)	22.26	3.68	30.0	18.0

4.2 Quantification of Force

The force values were measured in pounds (lbs) and converted into Newtons (N) for each subject. The raw force data are reported in Appendix D, Table D.1

Table 4.2:- Mean Average isometric strength of cervical flexors and extensors (SD Within parenthesis) in Newtons

Gender	*Condition*	*Mean*	*95%CI*
Females	Ext Neutral	39.52(25.09)	33.21 - 45.84
	Ext 25%	27.61(16.66)	23.42 - 31.80
	Ext 50%	20.37(12.35)	17.26 - 23.48
	Ext 75%	15.36(11.29)	12.52 - 18.21
	Flex Neutral	19.76(10.16)	17.14 - 22.39
	Flex 25%	15.15(7.74)	13.26 - 17.15
	Flex 50%	12.73(5.96)	11.19 - 14.27
	Flex 75%	5.73(4.33)	4.61 - 6.85
Males	Ext Neutral	45.10(24.33)	38.52 - 51.68
	Ext 25%	40.92(23.07)	34.80 - 47.04
	Ext 50%	34.44(21.26)	28.80 - 40.08
	Ext 75%	27.30(20.38)	21.89 - 32.71
	Flex Neutral	31.42(9.96)	28.85 - 33.99
	Flex 25%	23.07(8.99)	20.75 - 25.40
	Flex 50%	19.02(10.82)	16.20 - 21.84
	Flex 75%	12.40(10.61)	9.66 - 15.14

Table 4.2, provides force summary for both genders. The mean average force value for men and women was 45.10 N and 39.52 N respectively in the extension neutral position of the neck. The above means are estimates of the population parameter; which is expected to fall with in the CI of 95% as shown in the Table 4.2.A preset alpha level of 0.05 was set for the hypothesis testing.

Figures 4.1(a) and (b) and 4.2 (a) and (b) represents the bar graph showing mean average and mean peak forces with their SD in females and males respectively. The graph was plotted by taking the average or peak of the forces with standard deviation and representing it against each condition. From the graphs it was clear that the highest forces (mean average and mean peak) in males and females were registered at the neutral position of the neck. A considerable variability in force values was observed at the neutral position of the neck in flexion and extension.

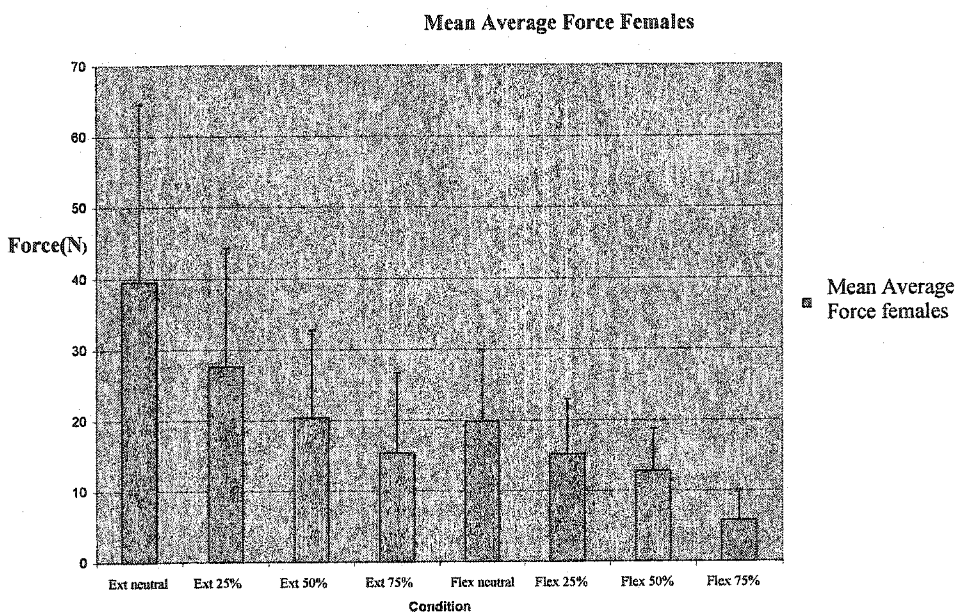


Figure 4.1(a): Mean average forces in females with standard deviation.

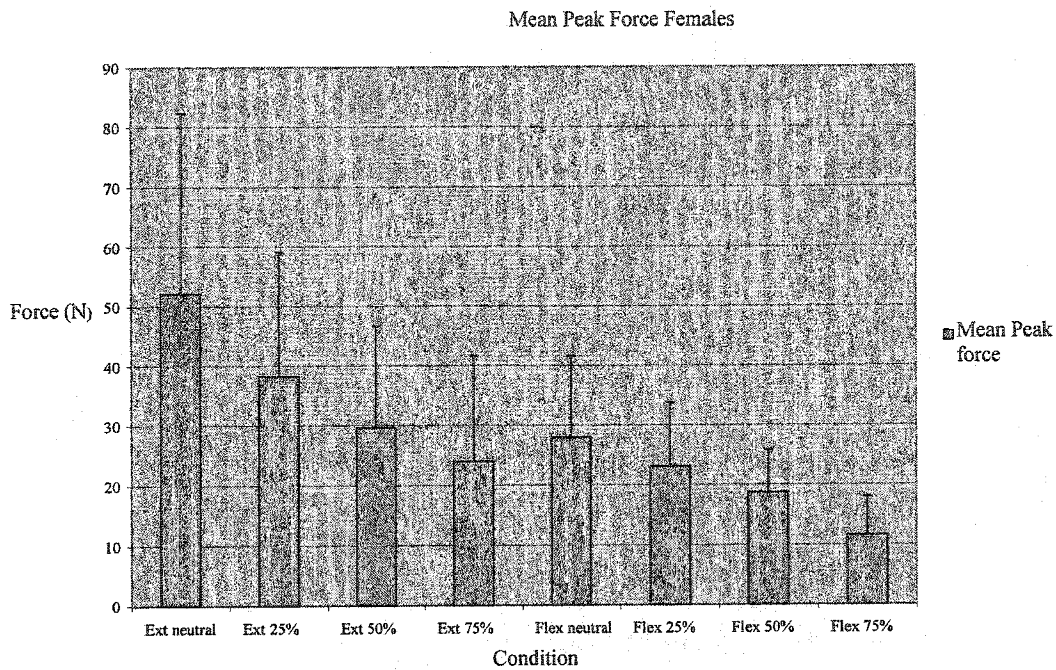


Figure 4.1(b): Mean peak forces in females with standard deviation.

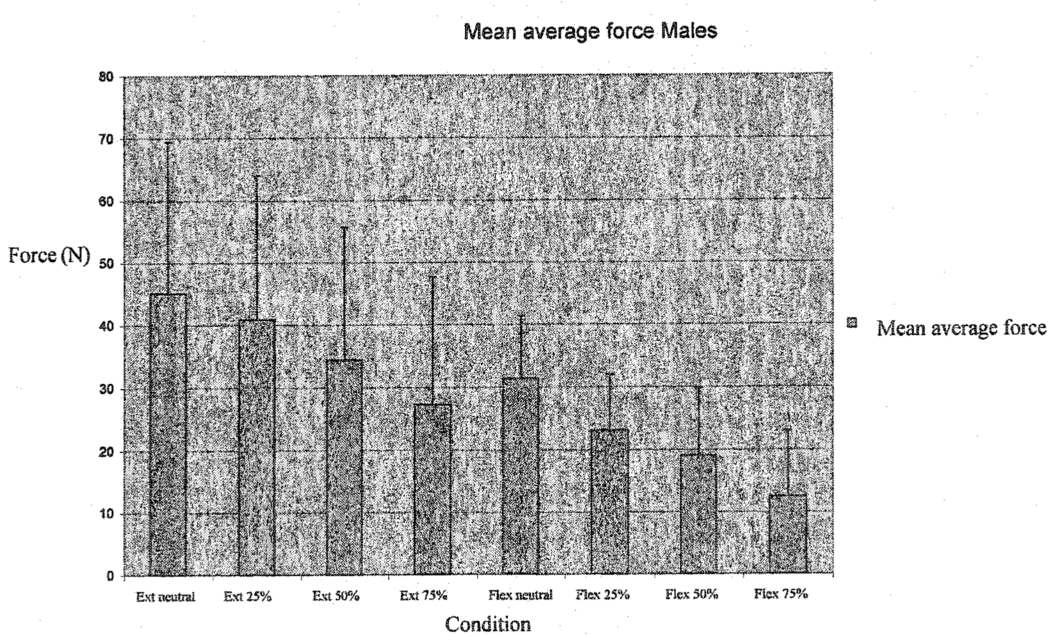


Figure 4.2(a): Mean average forces in males with standard deviation

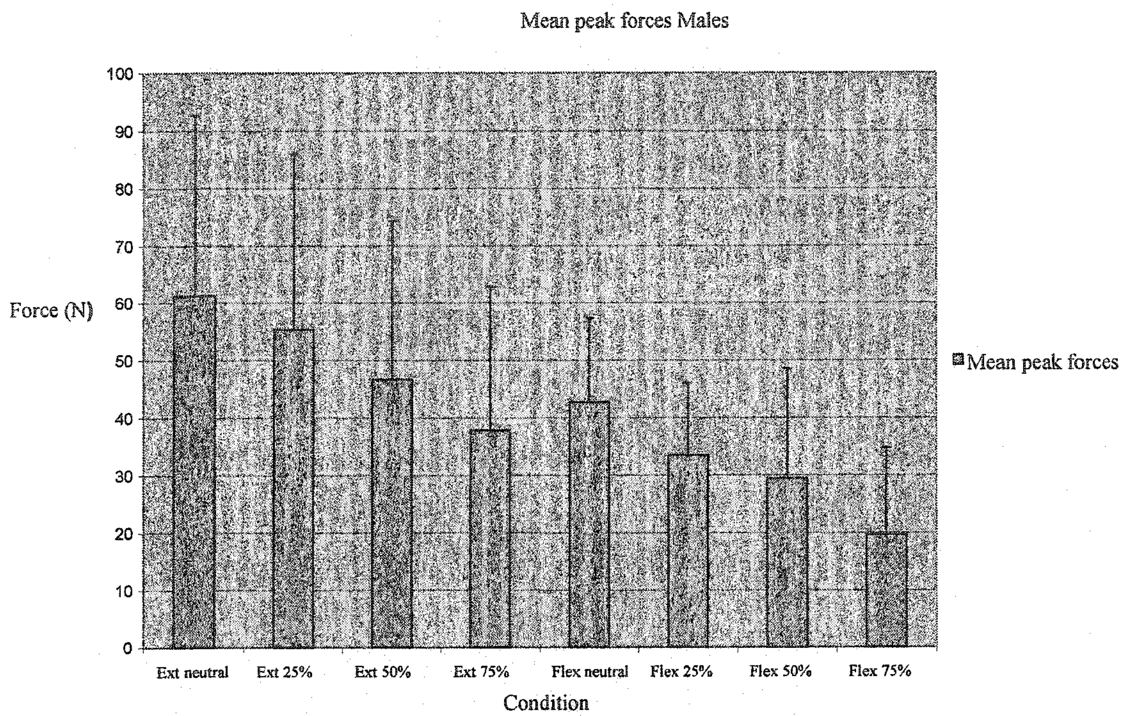


Figure 4.2(b): Mean peak forces in males with standard deviation

Table 4.3:- Represents the account of percentages strength from the neutral in genders

Condition	*% strength from Neutral(females)*	*Neutral baseline (100%)*	*% strength from Neutral(males)*
Flex 25%	76%	100%	71%
Flex 50%	64%	100%	60%
Flex 75%	28%	100%	39%
Ext 25%	69%	100%	86%
Ext 50%	51%	100%	73%
Ext 75%	38%	100%	59%

If flexion and extension neutral in both genders were presented separately for reference values then flexion 25%, 50%, 75% produced 76%, 64% and 28% of force in females and 71%, 60% and 39% in males. In extension 25%, 50% and 75% of neck motion produced 69%, 51% and 38% in females and 86%, 73% and 59% in males respectively (Table 4.3). This percentage strength from the neutral position was calculated by dividing the force value of the respective condition with the force value of the neutral position of a particular direction. For example, percentage from the baseline (neutral position) = force at flex 25%/ force at flex neutral.

Figures 4.3 and 4.4 give a graphical representation of strength values in different conditions from the neutral position as the baseline reference. This bar graph was plotted by plotting the percentages with respect to 100. It can be inferred from these graphs values that females in general tend to exert greater force at 25% (13 degrees) and 50%(25degrees) of neck flexion than their male counterparts. Thus an approximate prediction of force values at different angles of neck could be estimated with the known values at normal position of neck.

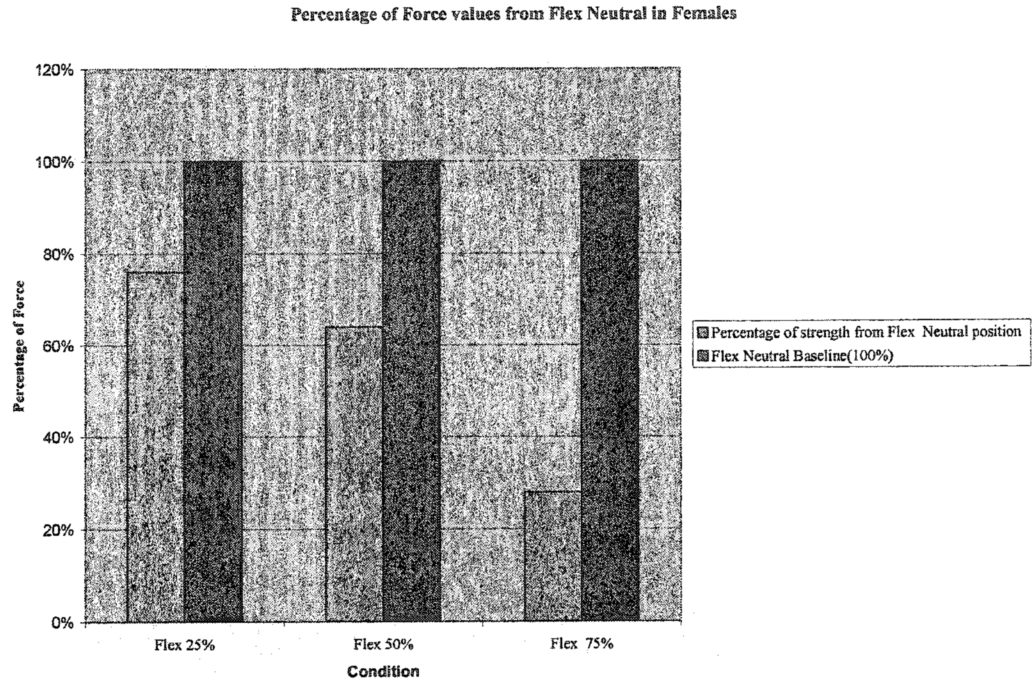


Figure 4.3 (a): Represents percentage of Force values in females from Flexion Neutral

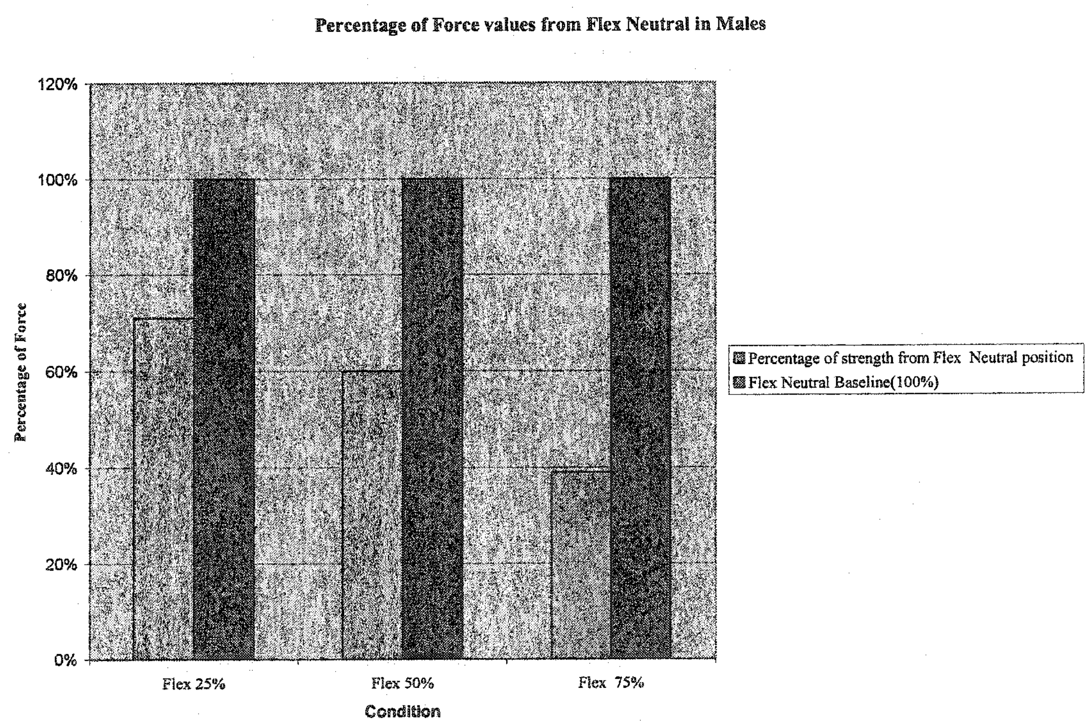


Figure 4.3 (b):- Represents percentage of Force values in males from Flexion Neutral

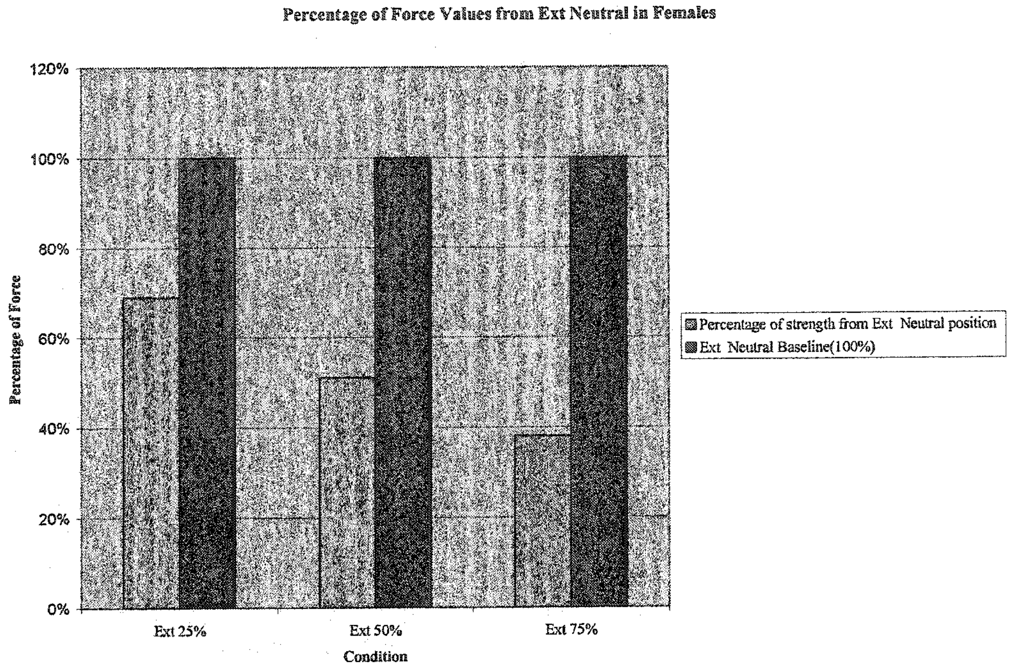


Figure 4.4 (a): Represents percentage of Force values in females from Ext Neutral

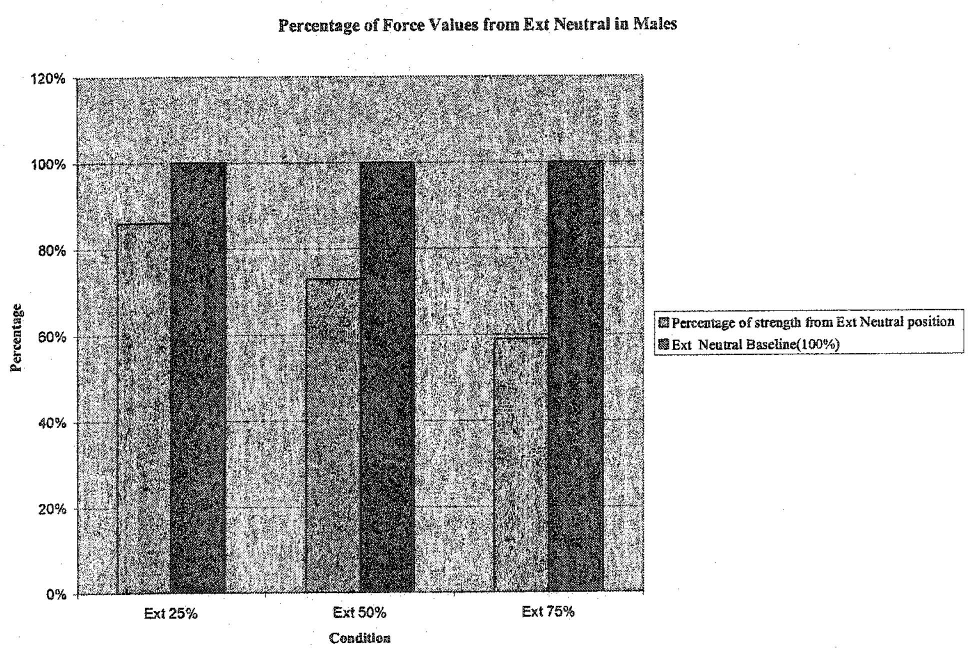


Figure 4.4 (b): Represents percentage of Force values in males from Ext Neutral

4.3 Range of Motion and Force

Range of motion was measured using a gravity goniometer. The raw table representing the descriptive statistics (mean and standard deviation) of range of motion is provided in table 3 (Appendix D). Thus in males and females, extension of 25%, 50% and 75% represented a range of motion approximately 17°, 34°, 52° degrees, while flexion was 13°, 25° and 38° degrees respectively.

Table 4.4: Correlations between Mean average force and Range of motion in flexion and extension

Gender	Force	Range of Motion
Females	Flexion	-0.56**
	Extension	-0.47**
Males	Flexion	-0.60**
	Extension	-0.28**

**** Correlation coefficient significant at 0.01 levels (1-tailed)**

Table 4.4 shows relationship between the mean average force and range of motion in flexion and extension in males and females. There was an inverse relationship between these two variables which implied a decrease in strength values with increase range of motion.

Further illustration of this negative correlation is demonstrated by line graphs in both the genders in Figures 4.5 and 4.6.

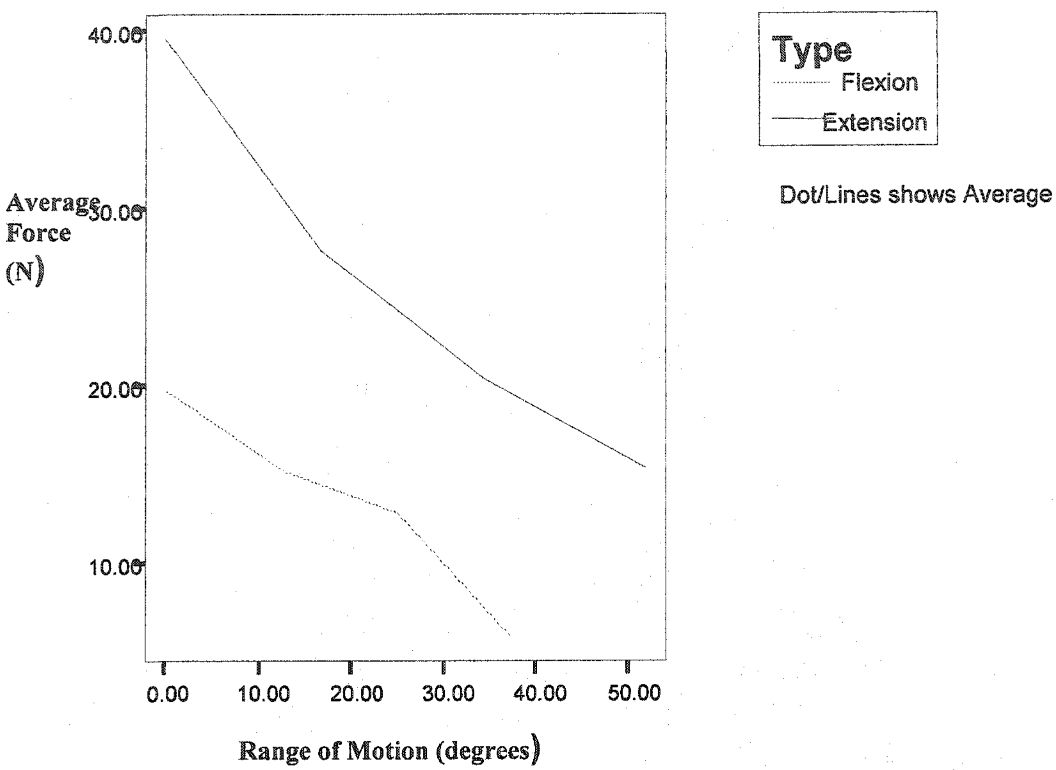


Figure 4.5(a): Mean average force exerted by females at different degrees of neck in flexion and extension.

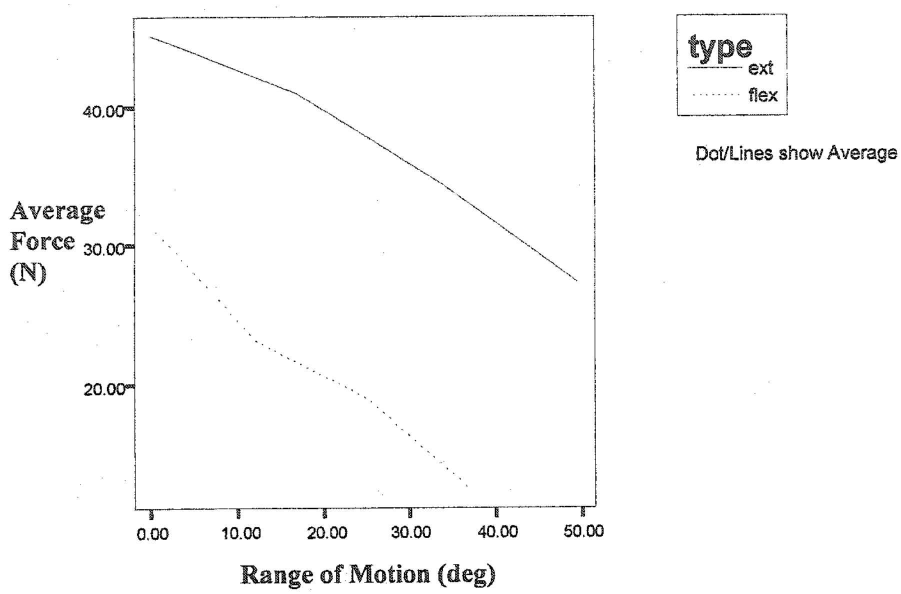


Figure 4.5(b): Mean average Force exerted by males at different degrees of neck in flexion and extension.

Figure 4.5 (a) and (b) shows the line graphs in females and males plotted against average force and range of motion. The graph illustrates change of force values with respect to the range of motion. There was a gradual decline of force with increasing range of motion for both genders. However an upward rise in slope was observed in these graphs at 25° of neck flexion, with a droop towards the end. The above two graphs could be related with the post hoc analysis as shown in Table 4.6 and 4.7.The mean average difference in Table(I-J) shows that men had lesser difference in average of strength values in extension as compared to women. This has accounted for difference in the curve in genders. For example, in men the graph showed an increase in 50% of extension from extension neutral. This was due to the difference in between the average from ext 25% to 50% which was only about 3.69N as compared to women which had about 7.81 N.

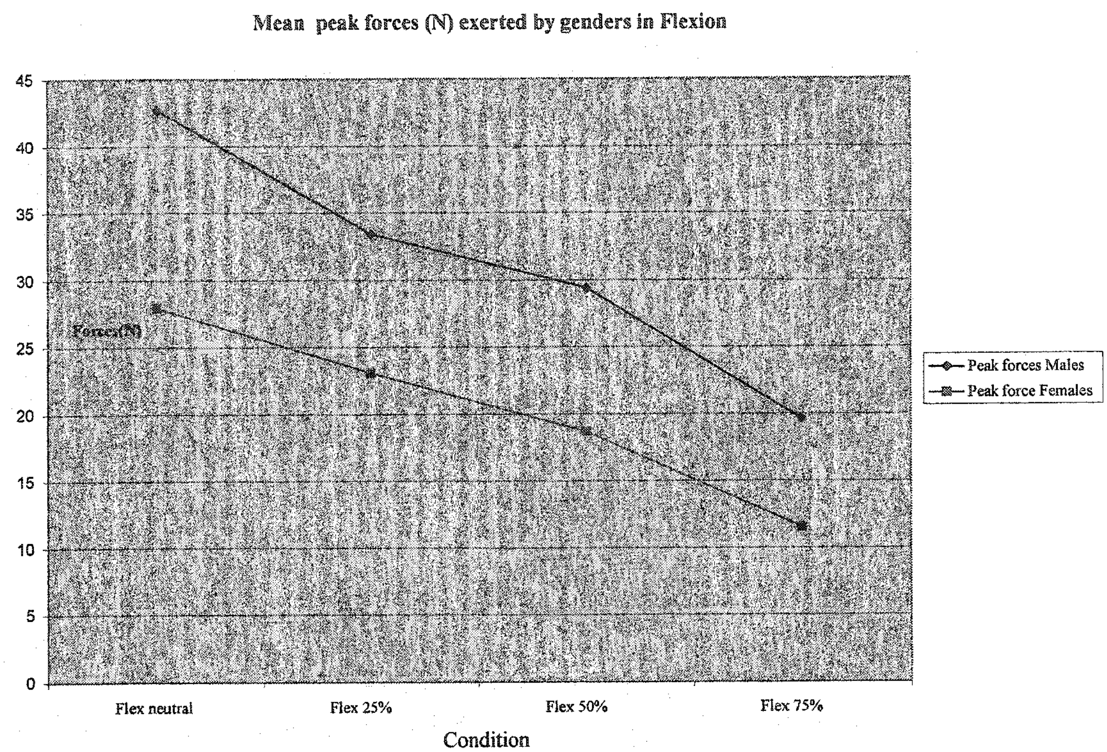


Figure 4.6(a): Mean peak forces exerted by males and females in Flexion

Figure 4.6(a) and (b) illustrates the peak force plotted against the different condition of neck in flexion and extension. Females showed a gradual trend of the decrease of force values while the males had a slight increase in the peak force at flexion 50% with a droop towards the end.

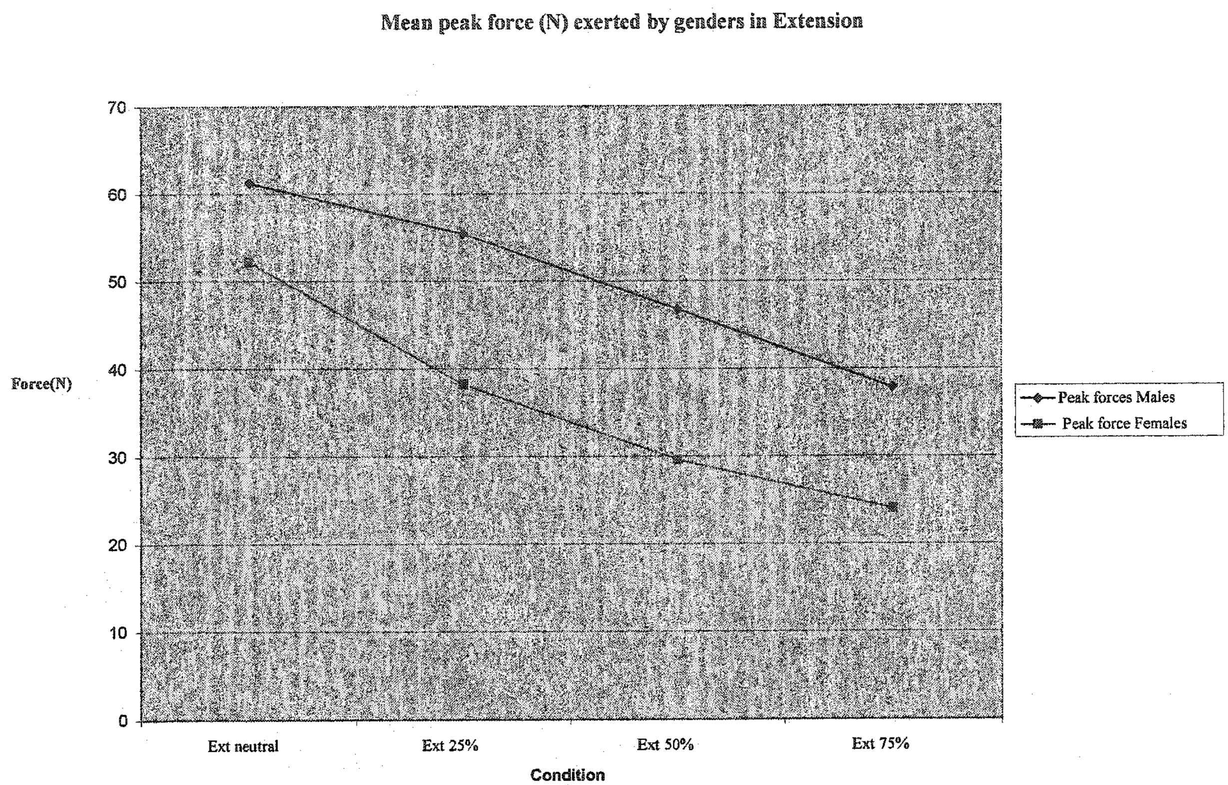


Figure 4.6(b): Mean peak forces exerted by males and females in Extension

Table 4.5: A 2-way ANOVA of Mean average Force in the flexion and extension.

Direction of effort		*df*	*F*	*Sig.*	*Standard error of estimate*
Flexion	Range of Motion	3	826.33	0.001	1.34
		236			
Extension	Range of Motion	3	1711.38	0.001	3.06
		248			

Table 4.5 shows a difference in force values at different angles in flexion and extension ($p<0.01$). This difference was further quantified with a post hoc analysis using 1-way ANOVA as shown in the Table 4.6 and 4.7 in males and females.

Table 4.6: A 1-way ANOVA quantifying the relationship between mean average force and extension condition.

		Females	*Males*	*Females*	*Males*
(I) Condition	(J) Condition	Mean average difference(I-J)	Mean average difference(I-J)	Sig.	Sig.
Ext neutral	Ext 25%	11.96	4.40	<0.00	NS
	Ext 50%	19.77	7.69	<0.00	NS
	Ext 75%	23.25	19.36	<0.00	<0.00
Ext 25%	Ext neutral	-11.96	-4.40	<0.00	NS
	Ext 50%	7.81	3.29	NS	NS
	Ext 75%	11.39	14.96	<0.00	0.01
Ext 50%	Ext neutral	-19.77	-7.69	<0.00	NS
	Ext 25%	-7.81	-3.29	NS	NS
	Ext 75%	3.58	11.67	NS	NS
Ext 75%	Ext neutral	-23.35	-19.36	<0.00	<0.00
	Ext 25%	-11.39	-14.96	<0.00	0.01
	Ext 50%	-3.58	-11.67	NS	NS

(NS- Not significant)

Table 4.6 refers to the quantified relationship between mean average force and extension condition. The detailed post hoc analysis is presented in Appendix D .In between extension conditions, females had a greater mean average difference as compared to males (refer to Table D.4). This accounted for significant difference between some of the conditions; as shown in the above table however men did not demonstrate greater mean average differences between each condition.

Table 4.7: A 1-way ANOVA quantifying the relationship between mean average force and flexion condition.

		Females	*Males*	*Females*	*Males*
(I) Condition	(J) Condition	Mean average difference(I-J)	Mean average difference(I-J)	Sig.	Sig.
Flex Neutral	Flex 25%	4.73	8.59	NS	NS
	Flex 50%	7.41	12.1	NS	0.08
	Flex 75%	12.54	17.65	0.001	0.001
Flex 25%	Flex neutral	-4.73	-8.59	NS	NS
	Flex 50%	2.68	3.51	NS	NS
	Flex 75%	7.81	9.06	NS	NS
Flex 50%	Flex neutral	-7.41	-12.10	NS	0.08
	Flex 25%	-2.68	-3.51	NS	NS
	Flex 75%	5.13	5.55	NS	NS
Flex 75%	Flex neutral	-12.54	-17.65	0.001	0.001
	Flex 25%	-7.81	-9.06	NS	NS
	Flex 50%	-5.13	-5.55	NS	NS

(NS- Not significant)

Both genders demonstrated almost the same relationship with in each flexion condition. This shows that there was not much difference (5-7N) in the average force as the range of motion increased. One could also conclude that there is not a significant change in the force muscles production with increase in the range of motion.

4.4 Relationship between Direction of effort and Force, Gender and Force.

4.4.1 Direction of effort and force (mean and peak).

Table 4.8: Flexion/Extension ratio within genders

Flexion/Extension	Gender	Mean average force (% of extension increase over flexion)	Mean peak force (% of extension increase over flexion)
Neutral	Females	1:2.0 (50%)	1:1.65 (47%)
	Males	1:1.43 (31%)	1:1.43 (31%)
25%	Females	1:1.82 (46%)	1:1.65 (40%)
	Males	1:1.77 (44%)	1:1.65 (40%)
50%	Females	1:1.60 (38%)	1:1.58 (38%)
	Males	1:1.81 (45%)	1:1.57 (38%)
75%	Females	1:2.68 (67%)	1:2.08 (52%)
	Males	1:2.20 (55%)	1:1.92(49%)

Table 4.8 represents flexion-extension ratio with in males and females. This ratio was calculated by dividing the extension force from flexion (ratio of flexion /extension). Flexion-extension percent ranged from 31-67% for mean average and mean peak forces in both sexes (Table 4.8). A trend for gender difference in the ratio of flexion and extension was observed from values in the above table. Women exhibited a greater flexion-extension ratio than men (Women-1:1.2, men –1:1.1.80).

In each condition, extension exhibited greater strength values than flexion. Thus there is an increase in force values with the change in anterior to posterior direction. Men showed an approximate average extension (calculated by summing all the extension increase and dividing it by 4) increase over flexion by 56% while women had the extension increase by 49.75%

4.4.2 Relationship between gender and force (average and peak).

Men showed on an average a greater mean average and mean peak strength values as compared to women by approximately 50%. The percent of increase ranged between 13-54% (Table 4.9 and Figure 4.7 and 4.8). The highest percentage of increase of men over women was seen at flexion 75%.

Table 4.9: Flexion and Extension ratio between genders

Condition	*Mean average force* *(% of increase of males over females)*	*Mean peak force*
Flexion Neutral	1:1.59 (38%)	1:1.52(35%)
Flexion 25%	1:1.52 (35%)	1:1.44 (32%)
Flexion 50%	1:1.49 (34%)	1:1.57(37%)
Flexion 75%	1:2.16 (54%)	1:1.70(42%)
Extension Neutral	1:1.14 (13%)	1:1.73(15%)
Extension 25%	1:1.48 (33%)	1:1.44(31%)
Extension 50%	1:1.69 (41%)	1:1.57(37%)
Extension 75%	1:1.77 (44%)	1:1.57(37%)

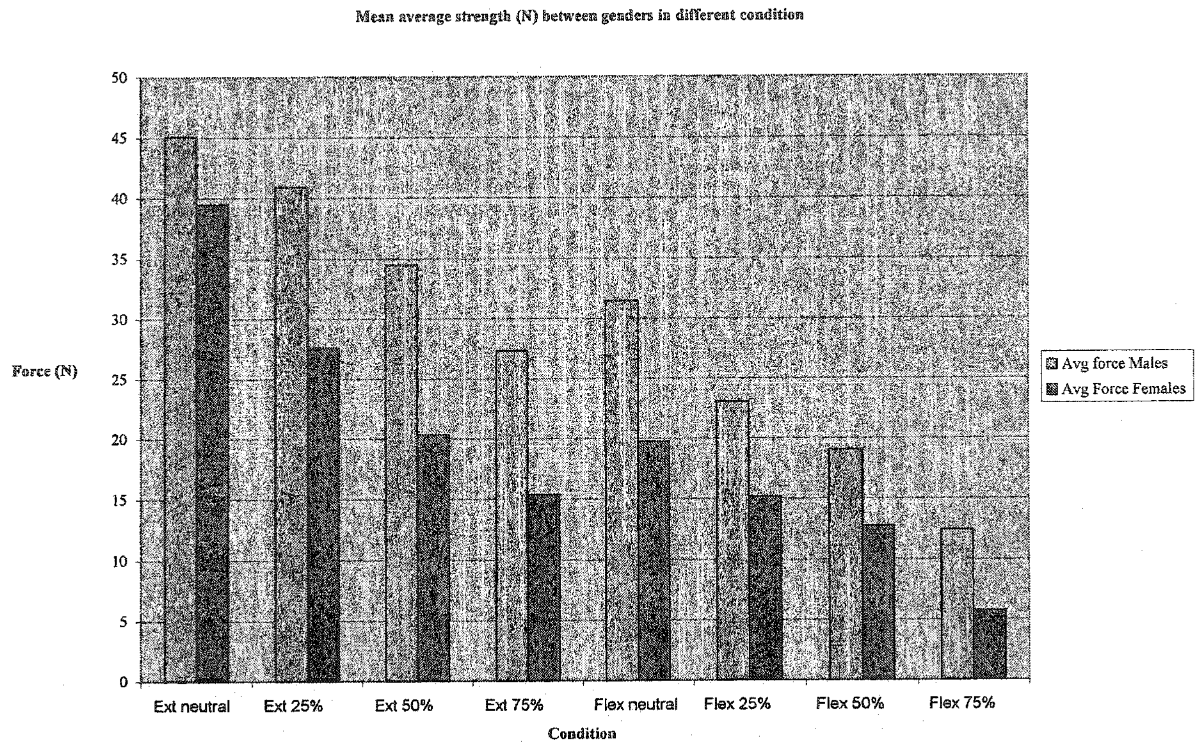


Figure 4.7:- Comparison of mean average force values in between genders at different conditions of neck.

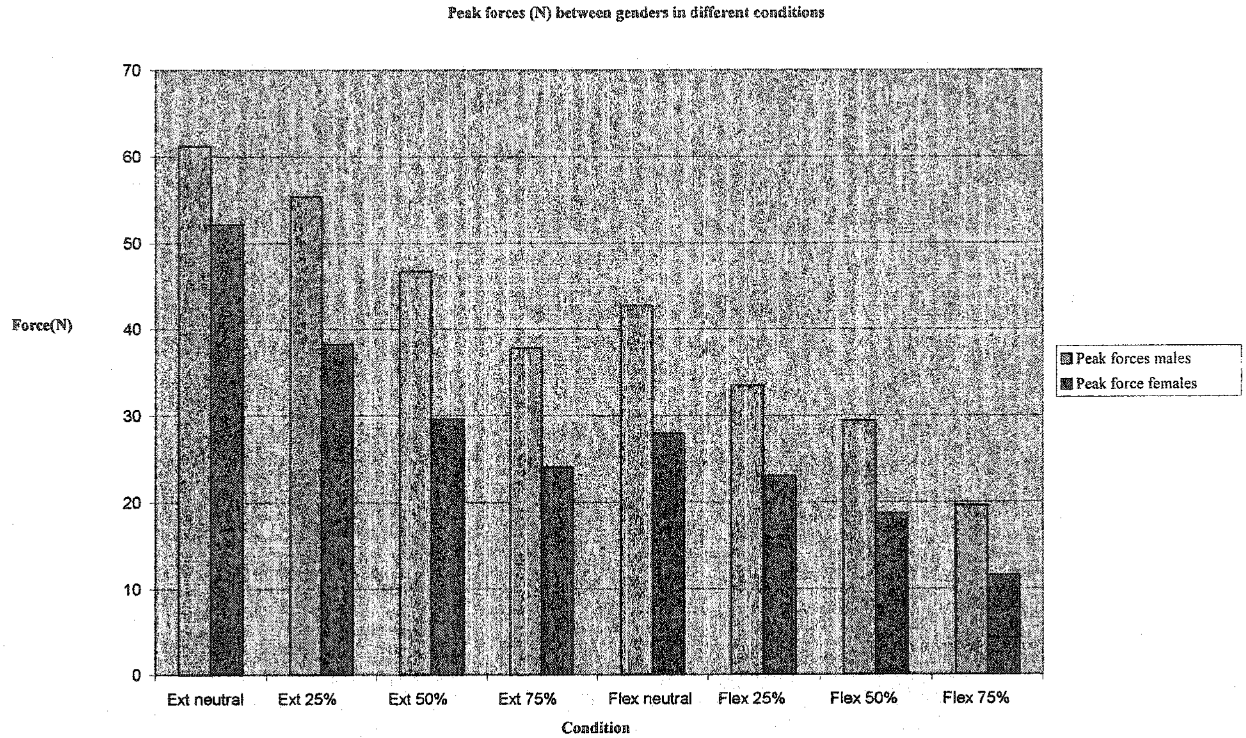


Figure 4.8:- Comparison of mean peak force values in between genders at different conditions of neck.

A two- way ANOVA was used to determine the relationship between genders and direction of effort on force values (Table 4.10).There was a significant effect of gender and force and its direction ($p<0.001$).However no significant interaction was seen between gender and direction This means that women and men have similar strength producing characteristics when subjected to a given direction of effort.

Table 4.10: ANOVA summary for direction and gender

Source	df	F-value	P-value
Gender	1	71.4	0.001
Direction	1	155.883	0.001
Gender*direction	1	1.26	NS

(NS -Not Significant)

4.5 Force and Physical measures

Bivariate correlation was used to quantify the relationship between the physical measures (height and weight) and force (average and peak) (Table Number 4.11).The correlation yielded a low value demonstrating no significant relationship between these variables. (Table 4.11)

Table 4.11: Pearson correlation coefficient(r) Physical parameters and Force (Average and Peak)

Females(n=21)	Coefficient correlation	Height	Weight
Average Force	r	-0.042	0.009
Peak Force (N)	r	-0.011	-0.048

Males (n=20)	Coefficient correlation	Height	Weight
Average Force	r	-0.018	0.030
Peak Force (N)	r	0.000	-0.006

4.6 Reliability analysis

The mean average strength values were collected on two different sessions for 10 subjects (4males and 6 females) with a gap of one week. The descriptive of mean average forces are shown in Table 4.12. The results were subjected to one sample student paired t-test which showed no statistical difference between the force values on those two days.

Table 4.11: Comparison of forces on two different days (d1 and d2)

Extension

Mean average force (Day1-Day2)	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
-1.54	27.03	3.52	-0.44	58.00	0.66

Flexion

Mean average force (Day1-Day2)	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
.0040	6.69	.87	.005	58.00	0.996

Table 4.12: Descriptive of the Mean average forces on two different days in Extension and Flexion.

Extension

Condition		*Mean*	*Std Deviation*	*Maximum*	*Minimum*
Ext reliab 25%	Mean average force d1	39.57	7.58	52.89	26.40
	Mean average force d2	45.42	15.46	83.29	23.20
Ext reliab 50%	Mean average force d1	28.90	18.35	68.95	3.37
	Mean average force d2	32.02	20.30	74.73	3.85
Ext reliab 75%	Mean average force d1	29.66	13.72	50.89	11.30
	Mean average force d2	23.07	16.38	48.89	2.71
Ext reliab neutral	Mean average force d1	75.84	14.78	98.70	52.36
	Mean average force d2	74.92	12.55	97.11	57.65

Flexion

Condition		*Mean*	*Std Deviation*	*Maximum*	*Minimum*
Flex reliab 25%	Mean average force d 1	14.30	3.80	23.09	9.06
	Mean average force d 2	12.66	3.25	18.64	8.56
Flex reliab 50%	Mean average force d 1	14.00	9.23	35.91	2.14
	Mean average force d 2	13.09	9.15	29.61	3.32
Flex reliab 75%	Mean average force d 1	13.01	6.20	24.29	3.88
	Mean average force d 2	16.83	7.40	30.73	10.11
Flex reliab neutral	Mean average force d 1	35.53	16.80	65.75	17.67
	Mean average force d 2	34.14	19.39	73.54	10.76

Chapter 5

Discussion

The purpose of this study was to measure isometric cervical strength at different ranges of flexion and extension. Additional objectives were to find the relationship between range of motion, physical parameters (height and weight) with the isometric cervical strength and test-retest reliability of the strength measuring device.

This study found a decrease in force with increased range of motion in both flexion and extension. Males exhibited higher strength values than females. The extensor muscle group exhibited 50% higher strength values than flexors. Anthropometric measures had a no correlation with force values thus emphasizing that these physical characteristics do not play a significant role in determining force values.

5.1 Comparison of Isometric strength across different studies

This study found the highest force recorded at the neutral position of the neck in flexion and extension (Table 4.2). The graphical charts and showed a considerable variability in the strength values across the subjects (Figures 4.1 and 4.2). The variance was more in females at the neutral positions in extension and flexion, while males showed variability across all the conditions (Appendix D.2.1). However at extension and flexion 75%, the variability in males was less as compared to other conditions of the neck. This variability could be due to the use of cervical muscles across people in a different manner for their day to day activities.

Some of the authors have quantified the cervical strength of flexors and extensors (Garces et al., 2002, Chlu et al., 2002, Jordan et al., 1999, Kumar et al., 2001) while others have restricted themselves to flexion or extension (Barton et al., 1996 Silverman et al., 1991). The current study quantified the mean average flexion force as 19.76(N) for females and 31.42(N) for males. The mean average extension force recorded was 39.52(N) in females and 45.10(N) in males. Table 5.1 provides a brief summary of the force values as reported by different authors. The data reported in this study for flexors and extensors are lower than those of others (Garces et al., 2002, Jordan et al., 1999, Chlu et al.,2002, Kumar et al.,2001)

Table 5.1: Summary of the Force (N) values in flexion and extension as reported by different authors.

Name of the authors	*Equipment used and position*	*Number of subjects in the age range of 18-40 years.*	*Measured angles in Flexion (F) and Extension(E)*	*Forces recorded*	*Comments*
Jordan et al.,1999	Strain guage dynamometer	10	0,15, 30, 45, 60(F),(E),-15(E)	30degrees 133N(E), 91N(F). All the force in other angles were within 1-2 SD.	Subjects were pretrained. No proper stabilization of subject's torso and were asked to grip handles while exerting force.
Kumar et al., 2001	Reliable force measuring device	40	Neutral (F),(E)	57-30(F),79-56(E)	Measured only at neutral position.
Garces et al.,2002	Computerised dynamometer	42	Neutral, 5,10 (F)(E)	Refer to the table number 5.2	Restricted the measurement only at 3 angles.
Chlu et al.,2002	Multicervical rehabilitation unit	34	20,40 (F)(E)	20 degrees in Males (F)90.61(N) (E) 96.17 40 degrees in females (F)68.64 (E)74.08.	No detailed mention about methodology.

This wide variation in the force values across different studies in literature could also possibly be due to equipment used, positioning of subjects, training effect or ethnic differences (Chlu et al., 2002) .Using the same force measuring device, Kumar et al., 2001 reported a bit higher recording of forces, flexion 57(N) for males and 30(N) for females and extension 79(N) for females and 96.17(N) for males. Their study tested the cervical strength of young adults in the sagittal, coronal and intermediate planes in neutral position of the neck. Even though the experimental design, procedures and protocols of this study, were in accordance with their methodology (mentioned in chapter 3), the current author believe that this difference could be due to the difference of objectives of study. Their study was interested in strength values in different planes in the neutral position, while the current study was looking at the isometric strength at different ranges of flexion and extension. The sequence of the position in this study was randomized and a trial of three measurements was taken for each condition. Hence the results reported here are the averages of forces over three trials as compared to their study which looked at only one trial. The current authors also believe that variation among subjects could have accounted for this force difference.

With regards to ethnic differences, it was reported that the grip strength of Vietnamese is about one third as compared to Americans in Chapanis study (cited by Chuang et al., 1997).Similarly Chuang and associates1997 in their study of evaluation of isometric neck- shoulder muscle strength in Chinese population, found the strength values relatively smaller to those obtained from western countries. Current authors believe that as their study had similar ethnic population hence, physical parameters did not play an important role in determining the forces.

Jordan et al., 1999 reported 59-91.1N for flexors and 78.14-133N for extensors using a strain gauge device. The participants in Jordan's study (1999) were subjected to a pre-training protocol (resistance training) and lack of proper stabilization (Kumar et al., 2001, Vasavada et al., 1998). The pre-training protocol in their study consisted of light resistance training of 5-6Kgs in flexion and extension with six to seven repetitions in each direction before the start of the experiment. The author himself suggested that adequate practice before recording of the measurement could have lead to the higher force values in their study. Further more it has been documented in different studies that resistance training appears to have a better recruitment of motor neural units (Conley et al., 1997, Tsuyama et al., 2001) which could probably have lead to this increased force values. There was no stabilization of the subjects by any restraint system such as shoulder harness and moreover subjects were asked to grip side handholds while exerting force. This could have widely accounted for the contribution of extrinsic muscles and other body parts for the force exerted, thus leading to higher force values (Kumar et al., 2001)

Garces et al., 2002 used a computerized dynamometer (Table 5.2) to measure isometric cervical strength. The higher force values in their study as compared to rest of the other studies could only be accounted to the subject's variation. Current authors did not find any relevant reasoning for this greater force values and thus believe it be more related to the difference in equipments and measurement of force.

Table 5.2: Force values (N) as reported by Garces et al., 2002

Gender	*Extension degrees*	*Force(N)*	*Flexion degrees*	*Force(N)*
Males	0	139.88	0	118.36
	5	141.2	5	119.97
	10	140.41	10	119.16
Females	0	84.73	0	72.36
	5	93.89	5	79
	10	96.18	10	80.37

Different positions such as prone, supine and standing have been used in the literature for the assessment of neck force (Queisser et al., 1994, Vernon et al., 1992, Ylinen et al., 2003).These positions are uncomfortable for the participants and furthermore the standing position could also involves major participation of the extrinsic muscles such as feet, arms and trunks (Garces et al., 2002, Silverman et al., 1991, Jacobs et al., 1995) due to the difficulty in proper stabilization. The sitting position is not only a functional testing position for both directions, but also is comfortable and offers a representation of the positions in which we typically use our cervical muscles.

5.2 Strength measuring device and its reliability

For an accurate measurement of cervical muscle strength, it is important to isolate this particular segment from other trunk muscles. The shoulder harness used in our study minimized the effect of other extrinsic and specific muscles, segments from different parts of body such as feet, arms and trunks. Moreover in our protocol, subjects had no arm support from the experimental set up and were specifically asked to lift their legs off the foot rest during exertion so as to further minimize the use of leverage from the lower extremities. By adopting a gravity neutral method, the vertical telescopic device was placed parallel to the gravity vector "g" which corresponded to the neutral position of the gravity goniometer placed on the subject's head. This was referred to as the starting position.

This device had also been previously used by Kumar and his associates (Kumar et al.,2001, 2002., 2002) in different research pertaining to isometric cervical strength, such as quantification and electromyographic spectral of superficial cervical muscles in different planes of exertion(sagittal, coronal and oblique). They found a high reliability of this device with intra class correlation coefficient ranging from 0.89-0.95.The equipment, in our study was modified to measure strength at different angular motion of neck, the detailed exposition already covered under methodology (Chapter 3). Further more this equipment is cheap, requires very little operator training, measures the cervical strength in different planes, and occupies a lesser space. The current authors re-tested the reliability of this device on a sample of ten subjects on two different days. The student paired t-test showed no significant changes in results on those two days, confirming the reliability of this device (Table

4.11). This test was used only as supplement for the reliability as this instrument has already been found to have a high ICC values and hence no other reliable test was considered here.

5.3 Range of Motion and Isometric strength

The total range of motion observed in this study was 52° for flexion and 68° for extension (Appendix D Table D.3) by using Gravity Goniometer (Myrin goniometer). A wide variation of measurement of cervical motion for young healthy volunteers in the age group 18-40 years exists in the literature. These are due to different equipment used to assess cervical spine mobility (Queisser et al., 1994, Martin et al., 1986, Lantz et al., 1999, Ordway et al., 1997, 1999, Khulman et al., 1993). Khulman et al., 1993 and Tucci et al., 1986 recorded the flexion range of motion to be 69-72° and extension range of motion to be 64-70° with a gravity goniometer. Using a Cervical range of motion device (Ordway et al.,1997) and MRI,(Giulaino V) a lower flexion range of 48-65 degrees and extension range of 50-72 degrees was observed. In another study done by Lantz et al., 1999 flexion with an electrogoniometer was reported to be 60° and extension to be 56°. Thus a wide discrepancy concerning the range of motion at the cervical region can be seen in the literature. The flexion values reported in this study as compared to Khulman et al., 1993 and Tucci et al., 1986 were quite low. This could be due to the instruction given to the subject for performing cervical flexion. The subjects were instructed to perform chin tuck initially followed by rolling of the head further to the chest. This instruction was specifically given in order to have the combination of upper and lower cervical flexion (Cram et al., 1999). The values reported are thus similar to the guidelines laid down by the American Medical Association (Cram et al., 1999) (Chapter 3 Picture 3.1).

Even though in the literature a variation of 12-20 degrees of cervical range of motion was cited (Christensen et al., 1998) the current author did not find any significant differences in the range of motion between each volunteer. Hence it can be postulated that the percentage of range of motion approximates the same degrees in each subjects. Furthermore, females had a greater degree of the range of motion as compared to males, but it was not statistically significant (Appendix D-table D.3).

While this study generated different strength values at different angular motions of the neck, the maximum strength values (mean average and mean peak) were observed at the neutral position of the neck. An inverse relationship was found between the force production and increasingly deviated position within the range of motion of neck which implied a decrease in the force output with increased motion at the neck in both the directions (Table 4.4).

Researchers have found the highest isometric cervical strength at neutral position of flexion and extension (Garces et al., 2002, Legget et al., 1991, Berg et al., 1994). However, Jordan et al., 1999 and Chlu et al., 2002 recorded the highest strength (average) values at 30° of flexion and extension, while Garces et al., (2002) reported at 10°. Although, the peak torque was observed at neutral position in Garces's 2002 study, the standard deviation fell within the range of 1-2 N in these studies, thus finding almost similar force values at all positions of the neck.

There was a significant difference in muscle strength between some of the conditions in men and women *($p<0.01$)* (Table 4.5).A further post hoc analysis which quantified the significance at different condition is shown in Table 4.6 and 4.7. In females, extension neutral showed a significant difference with ext 25%, 50% and 75%. On the other hand men demonstrated the significant difference of mean force in extension neutral with only extension 75%. The average differences in females from the extension neutral to extension 75% position were higher as compared to males. This difference was approximately in the range of 11-22 N in females, while in men the range of difference was approximately 4-11N. Females and males had similar results with respect to significance in flexion trials. Flexion neutral had significant relationship with only flexion 75% in men and women, but also showed the difference with flexion 50% in men. Only one study has reported a significant difference at each range of motion. For example Chlu et al., 2002 quantified the strength at flexion neutral, 20 degrees flexion and 20 degrees extension. They found significant differences of force between each angles of flexion and extension ($p<0.01$). However the author failed to give a detailed experimental procedure in terms of the neck's positioning, posture assumed, and randomization. Furthermore, there was no mention of the strength values at the neutral position of the neck. Studies done by Jordan et al., 1999 (0, 15,30,45,60 degrees of flexion and extension) and Garces et al., 2002 (0, 5,10degrees of flexion and extension) found the mean difference of approximately 1 N in different neck angles they tested. Both these authors did not find any significant differences in strength values at different degrees of neck motion. Hence the current study believes that the lesser strength values and the average difference between each conditions of the neck could be based on the physiological aspects of the muscle contraction.

A graph plotted between forces and range of motion for flexion showed a downward slope with an apparent increase at 50% flexion (Figures 4.5(a) and (b) Figure 4.6(a) and (b)). This increase in neck flexion at 25-30 degrees perhaps could be attributed to the potential rise of sternocleidomastoids, thus elevating the total moment generating capacity (Vasavada et al., 1998). On the contrary a similar graph plotted for extension showed a constant downward slope.

5.4 Direction of effort and isometric strength

The flexion–extension ratio for males was 1:1.69 for mean average and mean peak forces, while females recorded 1:1.5 and 1.53 for mean average and mean peak respectively (Table 4.8). In each condition, extension dominated over flexion by 50%.This ratio ranged in the literature from 0.4 to 0.8(Jordan et al.,1999,Garces et al.,2002, Kumar et al.,2001, Valkeinen et al.,2002, Vasavada et al.,1998, Chlu et al.,2002).The ratio reported in the current study (0.5-0.7) corresponds well with the above-mentioned findings. The mean increase of extension strength over flexion by 50% reflects the postural role of extensor musculature and obvious muscle mass difference between posterior and anterior muscles of the cervical spine (Jordan et al., 1999, Vasavada et al., 1998, Chlu et al., 2002). This association between the extensors and flexors of the cervical spine was even found to be similar to the range of lumbar spine (cited by Jordan et al., 1999).

Numerous factors could contribute to this difference in force generation in a particular direction such as cross sectional area, neural activation or posture (Benhamou et al., 1989, Tsuyama et al., 2001, Vasavada et al., 1998). Different authors have suggested a relationship between cross sectional area of the muscle and force production of the post cervical region. Neck extensor muscles such as semispinalis, splenius, trapezius and multifidus had a significant correlation between muscle strength and cross sectional area (r=0.832) (Benhamou et al.,1989, Conley et al.,1997, Fukunaga et al.,1970, Maughan et al.,1983). Thus the increased extensor strength appears to relate to the physiological characteristics of the muscle. This is also influenced by the motor unit recruitment, firing rate behavior, and muscle fiber composition (Benhamou et al., 1989). These firing units are distinctly different in larger and smaller muscles. The larger motor units contain the large diameter fast twitch fibers and are recruited at a higher force level. The anterior muscles are very sparse and small as compared to the dense posterior muscles. They contain slow twitch fibers which brings about production of the force at a slower rate thus leading to decreased force values (Tsuyama et al., 2001).

A larger difference between the flexion and extension ratio in women indicates that they are proportionately stronger in extension or weaker in flexion as compared to men. This observation was also reported in Kumar's (2001) study. However these findings need to be supplemented with further physiological differences in gender of the cervical muscles.

5.5 Gender and Isometric Strength

With regards to gender and isometric strength, men demonstrated greater force values than women by 50% (Table 4.9). The highest increase was seen at flexion 75% (35 degrees of neck flexion), where men had an increase over women by 54%. On the other hand, extension neutral had the least increase of males over females by approximately 13% (Figures 4.7 and 4.8). Most of the studies pertaining to isometric cervical strength have shown an increase in male force values over the female force values by about 25-50%(Jordan et al.,1999, Garces et al.,2002, Kumar et al.,2001, Chlu et al.,2002). Researchers have even reported a higher increase of male's strength values over females up to 70% (Chlu et al., 2002). In an EMG study of the cervical neck muscles, a significant relationship was demonstrated between gender and the muscle ($p<0.001$)(Kumar et al.,2002). All the above mentioned studies thus conclude a difference of force production between males and females This difference in strength values between men and women could arise due to the difference in the morphometric quantities (physiologic cross sectional area, fascicle length and tendon length) or neural activation (Valkeinen et al.,2002, Vasavada et al.,1998).

In a study done on force production characteristics (Valkeinen et al., 2002) of the cervical muscles it was observed, that the maximum neck flexion and extension force of women was 50% and 61% respectively as compared to men. Similarly in the current study, men showed the least increase over women only at flexion 75%. Current authors did not find any literature providing scientific rationale for this gender difference but believe that a number of factors may contribute to these force production characteristics such as the divergent use of the cervical muscles, neurophysiological factors such as motor neuron recruitments, number of slow and the fast twitch fibers and muscle morphometry.

5.5.1 Gender, direction and isometric strength

Our study showed that the cervical strength is directionally dependent, increasing from anterior to the posterior direction. Moreover, males showed greater strength values as compared to females. Furthermore, both males and females exhibit similar force characteristics in a particular direction. Thus, while gender and direction both independently influence the isometric strength, they are not dependent on each other ($p>0.001$) (Table 4.10).Added to this finding, similar observation was reported in the EMG study of cervical muscles (Kumar et al., 2002).

5.6 Physical Parameters and Isometric Strength

The results of our study demonstrated no correlation between the anthropometric measures (height, weight) and force (Table 4.10). The findings of the current study were consistent with the findings of Chlu et al.,2002 and Vasavada et al.,1998 .However a few studies have related a moderate to high correlation between these variables and the force(Jordan et al.,1999, Garces et al.,2002, Kumar et al.,2001). For example, in athletes, muscular strength and body weight has been shown to have a high positive correlation ($r=0.80$)(Jordan et al.,1999, Garces et al.,2002, Jacobs et al.,1995) which is considerably decreased in normal population(Jordan et al.,1999, Emwemeka et al.,1986). In a study done by (Gomez et al., 1991) as cited by Estandler et al., 1994) on isokinetic trunk muscles strength in healthy subjects, a strong correlation was seen between body weight, and the torque output. On the contrary, it was found that anthropometric measures were poor predictors of torque output (Estandler et al.,1994).Garces et al.,2002 reported a high association between these physical parameters and force variables, whereas Kumar et al.,2001found the significance only with weight and Jordan et al.,1999with height on the isometric cervical strength.

5.7 Suggestions for Future Research

The proposed study could form a basis for defining the normal values. This study uses younger subjects in sitting position, with measurement of strength in flexion and extension. Further appropriate research could involve older subjects and in different positions such as lying and testing in rotation and lateral flexion. Electromyographic study could be implemented for finding the force output of these superficial muscles at different angular movement of the neck.

Clinical population with decreased force output of cervical muscles could be compared with normal healthy population at different range of motion, leading to the specificity of rehabilitation of neck injuries. This could also further add up to knowledge of use of role of superficial and deep cervical muscles.

Chapter 6

Conclusions

Five major conclusions were reached based on the results of this research project

1. The maximum force (mean average and mean peak) was exerted in neutral position of neck in flexion and extension.
2. A negative relationship exists between the deviation of neck position with respect to neutral and force which implies a decrease in force values with increased deviation. There was a significant difference in muscle strength at different angular positions of the neck in flexion and extension in males and females.
3. A greater strength was exhibited in the direction of extension as compared to the flexion. When compared to the direction of effort, force values are higher in extension than flexion.
4. Men demonstrated greater force values than women. Both genders exhibit similar force characteristics when subjected to a similar direction of neck angle deviation.
5. Physical measurements had no correlations with mean average and mean peak forces concluding that these variables do not play a significant role in influencing the production of force.

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UNIVERSITY OF ALBERTA

INFORMATION LETTER

Thank you for your interest in volunteering for the experiment entitled:
Quantification of Isometric Cervical Strength at different Ranges of Flexion and Extension

Principal Investigator: Laxmi Suryanarayana, Master's student, Department of Physical Therapy, University of Alberta. Phone

Co-Investigator: Shrawan Kumar, Ph.D., University of Alberta, Phone:
Sandra Curwin, Ph.D., University of Alberta, Phone:
Prasad N. G., Ph.D., University of Alberta, Phone: (

Should you have any questions or concerns, and wish to contact a person not involved in the experiment, an Additional Contact, please call:
Dr. Paul Hagl -9674

Purpose of the study

- The purpose of this study is to determine strength of your neck muscles in different position of head (from fully tucking the chin to elevating it). We are studying to know how much force one can exert in these positions. We are carrying out this study because people with neck injuries usually have weak neck muscles. As a result the strength is decreased subsequently. The values obtained from our study could be used as a relevance value for the force values of the neck injuries. Having both the strength values, the clinician can then develop a regime for them.
- The results will also be used for future research in this area.

Brief description of details

- Before starting, we will ask that you read this letter and sign a consent form. You will then be asked several inclusion/exclusion questions. If you qualify for the study based upon the results of the questions, we will begin the experiment

- Before the start of the experiment, assessment of your range of motion of neck would be done. Depending upon the randomized position (given by the computer), you neck will be positioned in a particular position.

- The resistance arm of the strength-measuring device would be placed in direct contact with your head. You would be asked to push as hard as your can for the first two-second followed by maintainence of three seconds. This would be repeated three times.

- The strength measurement will take place in eight different position of your neck right

Appendix B

Sample size calculation

Calculation of range of r (correlation)

From Literature, we took r=0.4 at 0.05 level.

Now,

$Zr \sim N (1/2 \ln [(1+0.5/1-0.5), 1/ (20-3)]$

Where 20 is the sample size (20 males and 20 females) and 0.5 is predefined

(Fisher and Bell-1993)

Solving this gives,

Zr= (0.5943, 0.05493)

Zr= 1/2 ln(1+r/ 1-r)where r=0.4

= 0.416

The corresponding standard normal deviate is

$Z= 0.416-0.5493/\sqrt{0.0588}$

= -0.0322

which does not exceed the critical value at 0.05 level

For a 95% confidence interval, with these data, the interval is

$(0.416 - 1.96\sqrt{1/17}, 0.416+ 1.96\sqrt{1/ 17}) = -0.059, 0.891.$

Calculating the value of r from calculator by putting both the values of Za range of correlation from 0.84 to 0.997 can be estimated.

Health Research Ethics Board

UNIVERSITY OF ALBERTA HEALTH SCIENCES FACULTIES,
CAPITAL HEALTH AUTHORITY, AND CARITAS HEALTH GROUP

HEALTH RESEARCH ETHICS APPROVAL

Date:	August 2002
Name of Applicant:	Ms. Laxmi Suryanarayana
Organization:	University of Alberta
Department:	Physical Therapy
Project Title:	Quantification of Isometric Cervical Strength at Different Ranges of Flexion and Extension

The Health Research Ethics Board (HREB) has reviewed the protocol for this project and found it to be acceptable within the limitations of human experimentation. The HREB has also reviewed and approved the subject information letter and consent form.

The deliberations of the HREB included all elements described in Section 50 of the *Health Information Act*, and found the study to be in compliance with all the applicable requirements of the Act.

The approval for the study as presented is valid for one year. It may be extended following completion of the yearly report form. Any proposed changes to the study must be submitted to the Health Research Ethics Board for approval. Written notification must be sent to the HREB when the project is complete or terminated.

:s Board (B: Health Research)

File number: B-060702-REM

University of Alberta

Capital Health

CARITAS HEALTH GROUP

Appendix D

Table D.1: Females (n=21) Descriptive Statistics of Force in Newton (N) and Pounds (lbs)

Condition		*Mean*	*Std Deviation*	*Maximum*	*Minimum*
Ext 25%	Average force(lbs)	6.35	3.54	15.68	1.70
	Average force(N)	28.46	15.86	70.24	7.63
	Peak force(lbs)	8.89	4.32	21.34	2.66
	Peak force(N)	39.83	19.36	95.60	11.91
Ext 50%	Average force(lbs)	4.61	2.73	10.88	1.01
	Average force(N)	20.65	12.25	48.73	4.51
	Peak force(lbs)	6.70	3.79	16.19	1.84
	Peak force(N)	30.00	17.00	72.51	8.25
Ext 75%	Average force(lbs)	3.81	2.23	9.13	1.02
	Average force(N)	17.07	9.98	40.90	4.55
	Peak force(lbs)	5.77	3.04	14.36	1.91
	Peak force(N)	25.83	13.63	64.31	8.57
Ext neutral	Average force(lbs)	9.02	5.52	21.98	3.06
	Average force(N)	40.41	24.74	98.47	13.71
	Peak force(lbs)	11.92	6.62	28.78	4.13
	Peak force(N)	53.40	29.67	128.93	18.48
Flex 25%	Average force(lbs)	3.47	1.65	8.84	1.28
	Average force(N)	15.56	7.41	39.58	5.72
	Peak force(lbs)	5.23	2.34	11.67	1.77
	Peak force(N)	23.42	10.47	52.29	7.94
Flex 50%	Average force(lbs)	2.87	1.32	6.01	1.22
	Average force(N)	12.88	5.93	26.92	5.47
	Peak force(lbs)	4.25	1.55	7.77	2.36
	Peak force(N)	19.04	6.97	34.83	10.59
Flex 75%	Average force(lbs)	1.73	0.74	4.63	1.00
	Average force(N)	7.74	3.31	20.76	4.48
	Peak force(lbs)	3.12	1.23	6.78	1.77
	Peak force(N)	13.99	5.49	30.37	7.94
Flex neutral	Average force(lbs)	4.53	2.16	10.37	1.29
	Average force(N)	20.28	9.66	46.44	5.77
	Peak force(lbs)	6.36	2.96	13.82	2.13
	Peak force(N)	28.49	13.25	61.93	9.54

Table D.2: Males (n=19) Descriptive Statistics of Force in Newton (N) and Pounds (lbs)

Condition		*Mean*	*Std Deviation*	*Maximum*	*Minimum*
Ext 25%	Average force(lbs)	9.62	5.26	19.17	1.10
	Average force(N)	43.08	23.56	85.87	4.92
	Peak force(lbs)	12.95	7.07	28.71	1.99
	Peak force(N)	58.03	31.66	128.63	8.93
Ext 50%	Average force(lbs)	8.88	6.77	36.02	1.00
	Average force(N)	39.79	30.34	161.37	4.48
	Peak force(lbs)	12.07	9.09	46.76	1.99
	Peak force(N)	54.09	40.73	209.48	8.93
Ext 75%	Average force(lbs)	6.28	4.43	19.06	1.02
	Average force(N)	28.12	19.84	85.40	4.57
	Peak force(lbs)	8.63	5.48	22.93	2.18
	Peak force(N)	38.67	24.53	102.72	9.74
Ext neutral	Average force(lbs)	10.60	4.99	25.18	3.46
	Average force(N)	47.49	22.37	112.81	15.48
	Peak force(lbs)	14.44	6.44	32.06	4.53
	Peak force(N)	64.70	28.83	143.63	20.28
Flex 25%	Average force(lbs)	5.14	1.92	9.80	1.83
	Average force(N)	23.04	8.59	43.90	8.20
	Peak force(lbs)	7.47	2.71	14.25	3.12
	Peak force(N)	33.46	12.12	63.86	13.98
Flex 50%	Average force(lbs)	4.36	2.31	13.48	1.56
	Average force(N)	19.53	10.35	60.41	6.98
	Peak force(lbs)	6.56	3.87	20.30	2.48
	Peak force(N)	29.40	17.34	90.95	11.09
Flex 75%	Average force(lbs)	3.12	2.13	11.68	1.01
	Average force(N)	13.98	9.56	52.33	4.53
	Peak force(lbs)	5.20	3.25	20.19	1.20
	Peak force(N)	23.31	14.57	90.44	5.36
Flex neutral	Average force(lbs)	7.06	2.24	13.76	1.86
	Average force(N)	31.63	10.02	61.62	8.32
	Peak force(lbs)	9.59	3.31	17.94	2.94
	Peak force(N)	42.98	14.84	80.39	13.16

Table D.2.1: Variance of mean forces across genders

Gender	Condition	Variance
Female	Ext 25%	251.59
	Ext 50%	150.02
	Ext 75%	99.61
	Ext neutral	612.05
	Flex 25%	54.85
	Flex 50%	35.22
	Flex 75%	10.96
	Flex neutral	93.25
Males	Ext 25%	554.85
	Ext 50%	920.73
	Ext 75%	393.50
	Ext neutral	500.50
	Flex 25%	73.71
	Flex 50%	107.20
	Flex 75%	91.38
	Flex neutral	100.46

Table D.3: Descriptive Statistics of Range of Motion in degrees

Gender	Condition	Mean	Std Deviation	Maximum	Minimum
Females (n=21)	Ext 25%	17	4	21	0
	Ext 50%	34	5	43	18
	Ext 75%	52	6	64	35
	Ext Neutral	0	0	0	0
	Flex 25%	13	2	18	10
	Flex 50%	25	5	35	20
	Flex 75%	38	7	53	30
	Flex Neutral	0	0	0	0
Males (n=20)	Ext 25%	17	3	21	10
	Ext 50%	34	6	43	20
	Ext 75%	49	10	64	30
	Ext Neutral	0	0	0	0
	Flex 25%	12	2	18	10
	Flex 50%	25	4	35	20
	Flex 75%	37	7	53	30
	Flex Neutral	0	0	0	0

Table D.4: Post hoc analysis quantifying the relationship of force production between different conditions of the neck in females.

(I) Condition	*(J) Condition*	*Mean average difference (I-J)*	*Std. Error*	*Sig.*	*Lower Bound (95%CI)*	*Upper Bound (95%CI)*
Ext neutral	Ext 25%	11.96	2.30	0.00	3.30	20.61
	Ext 50%	19.77	2.30	0.00	11.11	28.42
	Ext 75%	23.35	2.30	0.00	14.69	32.00
	Flex neutral	20.13	2.33	0.00	11.36	28.89
	Flex 25%	24.86	2.33	0.00	16.09	33.62
	Flex 50%	27.54	2.33	0.00	18.77	36.30
	Flex 75%	32.67	2.33	0.00	23.91	41.44
Ext 25%	Ext neutral	-11.96	2.30	0.00	-20.61	-3.30
	Ext 50%	7.81	2.30	NS	-0.85	16.47
	Ext 75%	11.39	2.30	0.00	2.73	20.05
	Flex neutral	8.17	2.33	NS	-0.59	16.94
	Flex 25%	12.90	2.33	0.00	4.14	21.67
	Flex 50%	15.58	2.33	0.00	6.82	24.35
	Flex 75%	20.72	2.33	0.00	11.95	29.48
Ext 50%	Ext neutral	-19.77	2.30	0.00	-28.42	-11.11
	Ext 25%	-7.81	2.30	NS	-16.47	0.85
	Ext 75%	3.58	2.30	NS	-5.08	12.24
	Flex neutral	0.36	2.33	NS	-8.40	9.13
	Flex 25%	5.09	2.33	NS	-3.67	13.86
	Flex 50%	7.77	2.33	NS	-0.99	16.54
	Flex 75%	12.91	2.33	0.00	4.14	21.67
Ext 75%	Ext neutral	-23.35	2.30	0.00	-32.00	-14.69
	Ext 25%	-11.39	2.30	0.00	-20.05	-2.73
	Ext 50%	-3.58	2.30	NS	-12.24	5.08
	Flex neutral	-3.22	2.33	NS	-11.98	5.55
	Flex 25%	1.51	2.33	NS	-7.25	10.28
	Flex 50%	4.19	2.33	NS	-4.58	12.96
	Flex 75%	9.32	2.33	0.03	0.56	18.09
Flex 25%	Flex neutral	-4.73	2.35	NS	-13.60	4.14

	Flex 50%	2.68	2.35	NS	-6.19	11.55
	Flex 75%	7.81	2.35	NS	-1.06	16.69
	Ext neutral	-24.86	2.33	0.00	-33.62	-16.09
	Ext 25%	-12.90	2.33	0.00	-21.67	-4.14
	Ext 50%	-5.09	2.33	NS	-13.86	3.67
	Ext 75%	-1.51	2.33	NS	-10.28	7.25
Flex 50%	Flex neutral	-7.41	2.35	NS	-16.28	1.46
	Flex 25%	-2.68	2.35	NS	-11.55	6.19
	Flex 75%	5.13	2.35	NS	-3.74	14.01
	Ext neutral	-27.54	2.33	0.00	-36.30	-18.77
	Ext 25%	-15.58	2.33	0.00	-24.35	-6.82
	Ext 50%	-7.77	2.33	NS	-16.54	0.99
	Ext 75%	-4.19	2.33	NS	-12.96	4.58
Flex 75%	Flex neutral	-12.54	2.35	0.00	-21.41	-3.67
	Flex 25%	-7.81	2.35	NS	-16.69	1.06
	Flex 50%	-5.13	2.35	NS	-14.01	3.74
	Ext neutral	-32.67	2.33	0.00	-41.44	-23.91
	Ext 25%	-20.72	2.33	0.00	-29.48	-11.95
	Ext 50%	-12.91	2.33	0.00	-21.67	-4.14
	Ext 75%	-9.32	2.33	0.03	-18.09	-0.56
Flex neutral	Ext neutral	-20.13	2.33	0.00	-28.89	-11.36
	Ext 25%	-8.17	2.33	NS	-16.94	0.59
	Ext 50%	-0.36	2.33	NS	-9.13	8.40
	Ext 75%	3.22	2.33	NS	-5.55	11.98
	Flex 25%	4.73	2.35	NS	-4.14	13.60
	Flex 50%	7.41	2.35	NS	-1.46	16.28
	Flex 75%	12.54	2.35	0.00	3.67	21.41

Table D.5: Post hoc analysis quantifying the relationship of force production between different conditions of the neck in males.

(I) Condition	(J) Condition	Mean average Difference (I-J)	Std. Error	Sig.	Lower Bound (95%CI)	Upper Bound (95%CI)
Ext neutral	Ext 25%	4.40	3.43	NS	-8.52	17.33
	Ext 50%	7.69	3.43	NS	-5.23	20.61
	Ext 75%	19.36	3.47	0.00	6.28	32.45
	Flex neutral	15.86	3.43	0.00	2.94	28.78
	Flex 25%	24.45	3.40	0.00	11.63	37.27
	Flex 50%	27.96	3.44	0.00	14.98	40.93
	Flex 75%	33.51	3.43	0.00	20.58	46.43
Ext 25%	Ext neutral	-4.40	3.43	NS	-17.33	8.52
	Ext 50%	3.29	3.37	NS	-9.41	15.98
	Ext 75%	14.96	3.41	0.01	2.10	27.82
	Flex neutral	11.45	3.37	NS	-1.24	24.15
	Flex 25%	20.05	3.34	0.00	7.45	32.64
	Flex 50%	23.55	3.38	0.00	10.80	36.30
	Flex 75%	29.10	3.37	0.00	16.40	41.80
Ext 50%	Ext neutral	-7.69	3.43	NS	-20.61	5.23
	Ext 25%	-3.29	3.37	NS	-15.98	9.41
	Ext 75%	11.67	3.41	NS	-1.19	24.54
	Flex neutral	8.17	3.37	NS	-4.53	20.86
	Flex 25%	16.76	3.34	0.00	4.16	29.35
	Flex 50%	20.27	3.38	0.00	7.52	33.02
	Flex 75%	25.81	3.37	0.00	13.12	38.51
Ext 75%	Ext neutral	-19.36	3.47	0.00	-32.45	-6.28
	Ext 25%	-14.96	3.41	0.01	-27.82	-2.10
	Ext 50%	-11.67	3.41	NS	-24.54	1.19
	Flex neutral	-3.51	3.41	NS	-16.37	9.35
	Flex 25%	5.09	3.39	NS	-7.68	17.85
	Flex 50%	8.59	3.43	NS	-4.32	21.51
	Flex 75%	14.14	3.41	0.02	1.28	27.00
Flex neutral	Ext neutral	-15.86	3.43	0.00	-28.78	-2.94
	Ext 25%	-11.45	3.37	NS	-24.15	1.24
	Ext 50%	-8.17	3.37	NS	-20.86	4.53
	Ext 75%	3.51	3.41	NS	-9.35	16.37
	Flex 25%	8.59	3.34	NS	-4	21.19
	Flex 50%	12.1	3.38	0.08	-0.65	24.85
	Flex 75%	17.65	3.37	0.00	4.95	30.35
Flex 25%	Ext neutral	-24.45	3.40	0.00	-37.27	-11.63

	Ext 25%	-20.05	3.34	0.00	-32.64	-7.45
	Ext 50%	-16.76	3.34	0.00	-29.35	-4.16
	Ext 75%	-5.09	3.39	NS	-17.85	7.68
	Flex neutral	-8.59	3.34	NS	-21.19	4.00
	Flex 50%	3.51	3.36	NS	-9.14	16.16
	Flex 75%	9.06	3.34	NS	-3.54	21.65
Flex 50%	Ext neutral	-27.96	3.44	0.00	-40.93	-14.98
	Ext 25%	-23.55	3.38	0.00	-36.30	-10.80
	Ext 50%	-20.27	3.38	0.00	-33.02	-7.52
	Ext 75%	-8.59	3.43	NS	-21.51	4.32
	Flex neutral	-12.10	3.38	0.08	-24.85	0.65
	Flex 25%	-3.51	3.36	NS	-16.16	9.14
	Flex 75%	5.55	3.38	NS	-7.20	18.30
Flex 75%	Ext neutral	-33.51	3.43	0.00	-46.43	-20.58
	Ext 25%	-29.10	3.37	0.00	-41.80	-16.40
	Ext 50%	-25.81	3.37	0.00	-38.51	-13.12
	Ext 75%	-14.14	3.41	0.02	-27.00	-1.28
	Flex neutral	-17.65	3.37	0.00	-30.35	-4.95
	Flex 25%	-9.06	3.34	NS	-21.65	3.54
	Flex 50%	-5.55	3.38	NS	-18.30	7.20