An Investigation of Musculoskeletal Imbalances in the Thoracic and Cervical Regions, with Respect to an Improved Diagnostic Approach for Upper Crossed Syndrome

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Abstract

UCS is described as a muscle imbalance pattern located within the cervical and thoracic spine region. These imbalances have been shown to produce elevation and forward movement of the shoulders, winging of the scapula, and a forward extension of the head. These changes, in turn, lead to overstress of the cervical cranial junction and shoulders, which can cause neck and/or jaw pain, headaches, and shoulder problems.

The purpose of this study was to determine if quantifiable differences existed in active range of motion, muscle strength and muscle endurance capacity between a group of patients with Upper Crossed Syndrome (UCS) and an asymptomatic group.

A case-control experiment was completed. The case group consisted of 17 subjects with UCS, recruited through physical therapy and chiropractic clinics. The control group consisted of 17 healthy subjects, which were matched for age, gender and BMI on a group level. Isometric strength and endurance tests were completed. Neck range of motion was assessed about three axes.

Significant differences in strength generating ability (neck flexion/extension, shoulder internal/external rotation, shoulder abduction/adduction) and range of motion (neck bending, neck rotation) were evident between the two groups. Endurance measures though, were comparable between groups. The results show that it is possible to use objective measures to distinguish between people with UCS and healthy controls, and thus demonstrate the possibility to move from a subjective to a quantitative objective diagnostic approach.

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1.0 Introduction

1.1 Rationale

Upper Crossed Symptom (UCS), also referred to as proximal or shoulder girdle crossed syndrome was first introduced by Dr. Vladimir Janda (1987), a Czech neurologist and physiatrist. He has been recognized for his extensive clinical research on the pathogenesis and treatment of chronic musculoskeletal pain and is known for his concepts and theories related to muscle imbalance (Lardner, 2010). Janda's Upper Crossed Syndrome is characterized as a pattern of tight and reciprocal weak musculature throughout the thoracic and cervical spine area. With UCS, the upper trapezius, the levator scapula, the pectoralis major and pectoralis minor are categorized by patients and practitioners as "tight". In addition, a loss of muscle strength is typically found among the deep cervical flexors, the middle and lower trapezius and the rhomboid (Lardner, 2010).

The presence of this muscular imbalance can cause several postural changes which include: forward head posture, increased cervical lordosis and thoracic kyphosis, elevated and protracted shoulders, and rotation or abduction and winging of the scapulae (Figure 1b) (Page, et al., 2010). These postural deficiencies can create joint dysfunctions, particularly at the atlanto-occipital joint, C4-C5 segment, cervicothoracic joint, glenohumeral joint, and T4-T5 region. Some research suggests that postural deficiencies such as these can cause neck and/or jaw pain, headaches and shoulder problems (Szeto, et al., 2005).

With the growing number of computer users and widespread mechanization and automation (affecting virtually every sector of our lives), man spend more time in seated positions. Americans, according to a study in 2004, spend on average about 55% of their waking time, or about 7.7 hours per day, in sedentary behavior (Matthews et al., 2008). With this rapid development of modern technology, sitting has now become the most common posture in today's workplace (Lis, Black, Korn, & Nordin, 2007). This is further supported by additional research suggesting that three-quarters of all workers in industrialized countries have sedentary jobs that require sitting for long periods of time (Li & Haslegrave, 1999). Prolonged static postures and positions such as these are associated with certain metabolic, biomechanical, and orthopedic problems (Chaffin, Andersson, & Martin, 1999; Ford, Kohl, Mokdad, & Ajani, 2005). For example, Kang et al. (2012), found that computer workers exhibited a more anterior head position and an anteriorly projected center of gravity (COG) than a control group. This agrees with Janda (1983), who noted that muscular imbalance patterns, such as UCS, develop largely due to postural positioning in sedentary environments and repetitive work tasks (Lee, 2000). Since disorders resulting from sitting are a serious health problem and are predicted to rise in the future, an effective method for quantifying UCS is needed. Other occupational postures are also thought to be attributable to UCS. Dentists, surgeons and assembly line workers are often required to stand in awkward positions for prolonged periods of time and are thus also at risk of developing UCS.

The monetary effects that UCS and similar symptomology have on the economy are substantial. Buckle and Devereux (2002) estimated that 5.4 million working days are lost annually due to time off work because of work-related neck and upper limb musculoskeletal disorders in the UK. Therefore, approximately 1 month's work is lost annually for each individual case due to neck and upper limb musculoskeletal conditions in the UK, a part of which could be due to UCS. In the Netherlands, it was estimated that the direct cost of neck pain for 1996 was $160 million and the indirect cost was $527 million (Borghouts, Koes, Vondeling, & Bouter, 1999). When employees were asked to self-report work related musculoskeletal symptoms during a 12 month span, the body regions most commonly affected were head/neck (42%), low back (34%), upper back (28%), wrists/hands (20%) and shoulders (16%) (Janwantanakul, Pensri, Jiamjarasrangsri, & Sinsongsook, 2008). Buckle and Devereux (2002) found confirming evidence; according to their research, the average 12-month prevalence of worker self-reported symptoms in member countries of the EU was found to be highest for the neck region, at approximately 28%.

Cervical headaches, according to Janda (1994) are also associated with UCS. Cervicogenic headache is referred pain perceived in the head, thought to be caused by musculoskeletal tissues innervated by cervical nerves (Alix & Bates, 1999). It is characterized as unilateral head pain. Pain duration varies from hours to weeks and is usually moderate, spreading into the frontal-temporal and orbital regions (Pfaffenrath, Dandekar, & Pöllmann, 1987). There are many important facts regarding the enormity of headache sufferers today. Alix and Bates (1999) state that headaches are the cause of more than 18 million annual office visits in the United States, 156 million full-time work days lost yearly, and an estimated cost of $25 billion dollars in lost productivity. According to the same article, headaches are also found to be the most common reason to use over-the-counter analgesic medication (Moore, 2004). The impact of headaches on a patient's quality of life exceeds other chronic conditions such as osteoarthritis, hypertension, and diabetes (Osterhaus, Townsend, Gandek, & Ware, 1994). The prevalence of cervicogenic headache in the general population is estimated to be between 0.4% and 2.5%, but in pain management clinics, the prevalence is as high as 20% (Biondi, 2005; Haldeman & Dagenais, 2001). In addition, Blau and MacGregor (1994) supported Janda's preliminary research as they found indications of extracerebral involvement of the migraine process and an overlap between the trigeminal and cervical distribution.

It becomes obvious that symptoms related to UCS are manifold and often not directly linked to the disorder. The diagnosis of UCS therefore poses a variety of challenges to physicians. One reason for this difficulty is the long and symptomless onset of the disorder. Symptomatic patients generally seek help only after muscular imbalances have made significant changes to the mechanics of the upper body. Secondly, if a physician or chiropractor correctly diagnoses UCS, subjective judgment is the dominant feature in the current diagnostic methods employed. Discrepancies between physicians make an equivalent standard for characterizing UCS almost impossible. All of Janda's specially developed tests to diagnose UCS (i.e., Scapulohumeral rhythm test, Neck flexion Test, Push up test, breathing pattern assessments (Chaitow, 2008)), require a very deep understanding of underlying musculoskeletal processes and are characterized by a high dependency on the physician's judgment. In a case study by Moore (2004), a physician examined a 56 year old male with chronic headaches utilizing current diagnosis methods. He concluded that the patient "demonstrated positive orthopedic tests in the cervical region [which] included Jackson's compression, distraction, shoulder depression, and maximum compression bilaterally. In addition, Spurling's, Adson's, George's, Valsalva's, Soto-Hall, and Lhermitte's tests were negative" (Moore, 2004). In a review of even these examinations, Malaga et al. (2003) found that inter-examiner reliability and validity had high specificity but low sensitivity with only fair to good intra-examiner reliability. These results suggest that a reliable diagnostic approach is currently not available, which makes the detection of UCS erratic and insufficient. Due to these factors, less severe and early stages of the disorder might show very low detection rates. In addition, a worsening of the condition or an improvement due to rehab activities cannot be monitored to the degree needed, which is essential to assure the best possible care for patients.

Since symptoms of UCS are very hard to link to the disorder, the root of the problem, in many cases, remains unknown and thus untreated. This is not an uncommon problem as physician Karl Lewit noted, "He who treats the site of pain is often lost" (Page, et al., 2010). As a result, short term pain and symptom relief are very common treatment approaches. Center et al. (2009) found that one of the most commonly performed interventions in treating chronic neck pain in the United States are cervical epidural steroid injections. Instead of focusing on the underlying problem for non-specific neck pain, the rationale for corticosteroid instillation primarily is its anti-inflammatory affect and symptom relief (Huston, 2009). However, treatment approaches like these come with many downsides. Kaufman et al. (2002) found that in any given week, most US adults take at least 1 medication, and many take multiple agents. They further concluded that the substantial overlap of prescription medications raises concern about unintended interactions, some of which could have severe outcomes. A similar finding was observed by Jorason et al., (2000) who found a significant increase in medical use of morphine, fentanyl, oxycodone and hydromorphone from 1990-1996 (in the US). All these cases demonstrate the trend to treat symptoms- not causes. An improved systematic approach, to better detect the underlying problem of many UCS symptoms, is therefore desperately needed.

As mentioned earlier, injuries and symptoms related to UCS are a major burden on the economy due to lost work days, decrease productivity and worker compensation. To lessen this burden, a return-to-work or “work hardening” program could be implemented. These programs are based on the philosophy that many employees can safely perform productive work during the recovery process. Return-to-work options can involve transitional duties and or a gradual return to work, to slowly train the employee back into work fitness. By monitoring the process of the rehab measures, these return-to-work programs can have considerable financial repercussions for employers and insurers alike, not to mention their physical and emotional impact on the employee (Krause, Dasinger, & Neuhauser, 1998). Many studies show that these programs are effective and that a delay in return to work results in high compensation and treatment costs. Steenstra et al. (2006) showed that for lower back problems, an intervention group returned to work on average 30.0 days earlier than the usual care group. Scheer et al. (1995) were able to demonstrate that the number of lost work days per disability was cut in half when companies implemented modified work programs. Although few studies report cost data, those that do show savings in direct cost ranging from 8% (taking program cost into account) to 90% (not taking program cost into account). A reliable and accurate diagnostic tool is however crucial for the success of such programs. Without knowing the exact state of the patient's recovery process, an early resumption of a worker to the designed program could be detrimental to the recovery process. This would result in exactly the opposite of the intended return to work philosophy.

UCS is also relevant in the realm of sports. Especially in overhead activities such as throwing, tennis, or volleyball are highly repetitive motions observed, which are thought to lead to muscular imbalances in the scapulothoracic region. These imbalances could make athletes more prone to overuse injuries and decrease their performance levels (Cools, Witvrouw, Mahieu, & Danneels, 2005). Cyclists and triathletes could also develop health problems associated with UCS, as they stay relatively static with the upper body for long periods of time. A study for example showed that the most common posture problems encountered by road racing cyclists are either the lower back or the neck and upper extremities (de Vey Mestdagh, 1998). An early detection of these imbalances and a systematic inclusion of rehab measures in the practice routine could result in improved mechanics, decreased injury risk and better performance.

In summary, disorders associated with UCS pose a serious health and safety problem and are predicted to rise in the future. Since current diagnostics rely heavily on subjective judgment, a uniform characterization and early detection is not possible. With a diagnostic methodology to quantify this disorder, we could identify the disorder in an early stage and apply remedies so that UCS could be prevented. By creating a customarily designed rehab regiment, we could quickly and effectively assist patients with more severe symptoms to counter or offset associated muscular imbalances. Additionally, such an approach could provide better understanding of the disorder and in turn these findings would facilitate improved return to work and recuperative approaches. Ultimately, the results of this study could enable impaired people to live a life without chronic pain, increase worker productivity and decrease the burden on the health care system.

1.2 Objectives

The primary objective was to find quantifiable measures which differ in Upper Crossed Syndrome patients and healthy controls. This was accomplished through the following objectives:

- Develop an experiment to extract relevant data from patients
- Identify preliminary data for future use in a model which can predict the current state of muscular imbalances in the cervical and thoracic spine area

1.3 Hypotheses

1. Patients who have UCS will show higher ratios of imbalance within muscle of the cervical and thoracic region

2. Patients who have UCS will show greater discrepancies “from normal” in measures of postural range of motion and isometric strength and endurance.

1.4 Implications

Symptoms of UCS become apparent after the disorder has made significant changes to the mechanics of the upper body. With an earlier detection, appropriate countermeasures can be prescribed so that UCS does not develop into a later stage. This could potentially eliminate a majority of symptoms discuss above. Early detection could be accomplished in form of a proactive screening approach, where people at increased risk (office worker, overhead athletes, etc.) can test for the presence of UCS.

Another potential of the research described is that it may equip physicians with a tool to individualize each patient’s rehab procedure. With the output of this research, new knowledge including where muscular imbalances are primarily located can be used to generate many innovative treatment options. Based on specific muscle patterns, it would be possible to target each patient’s problem with prioritized attention. With this efficient rehab approach, a faster and more effective treatment could be possible.

With the knowledge of the exact state of the disorder and possible rehab improvements, an effective return to work program could be implemented. As mentioned before these programs have been shown to reduce days away from work following injury or pain episodes. A crucial step in developing these programs however is a reliable and precise knowledge where the patient is in his/her healing process. The results of this research could support these future research efforts.

The realm of sports could also benefit from this research. An earlier detection of imbalances and a systematic inclusion of rehab measures in the practice routine could result in improved mechanics, decreased injury risk and better performances.

2.0 Literature review

In this chapter the scientific foundation of muscular imbalances as well as tight and weak muscles in connection with UCS are briefly introduced. A search for the etiology of certain pain syndromes and current concepts of diagnostics follows. Finally we discuss earlier research assessing muscular imbalances (Page, et al., 2010).

2.1 Muscular imbalances

2.1.1 Overview

Muscle balance can be defined as a relative equality of muscle length or strength between an agonist and an antagonist; this balance is necessary for normal movement and function. Muscle balance may also refer to the strength of collateral muscle groups. Muscle balance is necessary because of the reciprocal nature of human movement, which requires opposing muscle groups to be coordinated. Muscle imbalance occurs when length and strength of agonist and antagonist prevents normal function (Page, et al., 2010).

Muscles may become unbalanced as a result of adaptation or dysfunction. When muscle imbalance impairs function, it is considered to be pathological. Pathological imbalances may also be insidious; many people have these muscle imbalances without pain. Ultimately, however, pathological muscle imbalances lead to joint dysfunction and altered movement patterns, which in turn can lead to pain.

2.1.2 Etiology

In patients with chronic musculoskeletal pain, the source of the pain is rarely the actual root cause. Janda (1993) conceptualized musculoskeletal pathology as a chain reaction. Due to interactions of skeletal, muscular, and CNS, the dysfunction of any joint or muscle is reflected in the quality and function in others, not just locally, but globally (Page, et al., 2010). A vicious cycle of chronic pain involving the CNS and UCS seems plausible. Muscle imbalances often initiate the cycle.

2.1.3 Tight and weak muscles

Muscle tension (or tone) is the force with which a muscle resists being lengthened (Basmajian 1985). Muscle tension may also relate to a muscle's activation potential or excitability; thus testing muscle tension has two components; viscoelastic and contractile (Mense, Simons, & I Jon Russell, 2001). The viscoelastic component relates to the extensibility of structures, while the contractile component relates to neurological input, or drive. Janda (1987) found that muscle tightness is a key factor indicative of muscle imbalance. In general, muscles prone to tightness are one third stronger than muscles prone to inhabitation (Jull, Janda, 1987). Muscle tightness creates a cascade of events that lead to injury. Tightness of a muscle reflexively inhibits its antagonist, and can contribute toward muscle imbalance. This imbalance leads to joint dysfunction because of unbalances forces. Joint dysfunction crates poor movement patterns and compensations, leading to early fatigue. Finally overstress of activated muscles and poor stabilization lead to injury (Jull, Janda, 1987). Janda (1993) suggested that there are three important factors in muscle tightness: Muscle length, irritability threshold, and altered recruitment. Muscles that are tight usually are shorter than normal and display an altered length-tension relationship. Muscle tightness leads to a lowered activation threshold or lower irritability threshed, which means that the muscle is readily activated with movement (Janda, 1993). Movement typically follows a path of least resistance, and as such, tight and facilitated muscles often are the first to be recruited in movement patterns

2.2 Cervical spine

2.2.1 Anatomy of the cervical region

The cervical spine is possibly the most distinct region of the spine and one of the most complicated articular systems in the body, comprising 76 separate joints. Three of the more important joints for the purposes of the study are the the atlanto-occipital joint, the C4-C5 segment, and the cervicothoracic joint. The atlanto-occipital joint is the connection between the atlas (C1) and the occipital bone, a membrane bone at the back and lower part of the skull. The atlanto-occipital joint consists of a pair of condyloid joints and is a synovial joint. The C4-C5 segment is a zygapophysial or Z-joint. It is a synovial joint between the superior articular process of C5 and the inferior articular process of C4. The biomechanical function of a Z-joint is to guide and limit movement of the spinal motion segment. The cervicothoracic joint relating the disk between the seventh cervical vertebra and first thoracic vertebra is also a Z-joint (Cramer, 2013). The neck flexors and extensors co-activate to maintain alignment and smooth movement of the cervical spine and head.

Muscles in this area, which are characterized in UCS as tight, are the upper trapezius, levator scapula, and sternocleidomastoid. The upper trapezius has its origin at the occiput, the ligamentum nuchae and the C7 vertabrea. It inserts in the clavicle and scapula and its main functions are the elevation of the scapula and shoulders (“shrugging”), and capital/cervical extension. The levator scapula has its origin at C1-C4 and inserts at the scapula. It lies on the dorsolateral neck and descends deep to the sternocleidomastoid on the floor of the posterior triangle of the neck. Its main function includes elevation and adduction of the scapula, scapula rotation, lateral bending of cervical spine, and cervical extension. The sternocleidomastoid originates at the sternum and the clavicle and inserts on the temporal bone, the mastoid process, and the occiput. The two heads of origin gradually merge in the neck as the muscle rises upward laterally and posteriorly. The function of this muscle is to flex the cervical spine, bend it laterally, and rotate the head to the opposite side.

Weak muscles in this area also include the deep cervical flexors. The deep cervical flexors are comprised by the longus colli, the scalenus anterior, the scalenus medius, and the scalenus posterior. The longus colli has three heads, which originate at C3-C5, T1-T3, T1-T3 and they insert into the atlas, C5-C6 and C2-C4. Its main function is to rotate the cervical spine to the opposite side, and bend it laterally. The scalene family of muscles functions to flex the cervical spine, elevation the 1st and 2nd rib in inspiration, rotate the cervical spine to the opposite side, and bend the neck laterally to the same side. The scalenus anterior originates at C3-C6 and inserts at the 1st rib. The scalenus medius originates at C2-C7 and also inserts at the 1st rib and the scalenus posterior originates at C4-C6 and inserts at the 2nd rib.

2.2.2 Cerviogenic headache

Etiology

Studies conducted by the International Headache Society suggest that cerviogenic headaches account for approximately 15% to 20% of all recurrent benign headaches (Alix & Bates, 1999). The actual source of pain originates not in the head but in the cervical spine joint complex. Structures innervated by cervical nerves C1–C3 have been shown to be capable of producing cerviogenic headache pain (Bogduk, 1992; Hack, Koritzer, Robinson, Hallgren, & Greenman, 1995; Hildebrandt & Jansen, 1984). Musculoskeletal pathologic conditions that compromise the cervical spine and spinal nerves C1–C3 include hypomobility or fixation, tender muscle points, and reduced cervical range of motion (Vernon, Steiman, & Hagino, 1992). Possible sources of pain include the C2–C3 intervertebral disk annular fibers, muscles, joints, ligaments, and related dura mater of the upper cervical spine (Bogduk, 1992). On the basis of these findings, any pathophysiologic condition affecting the biomechanics of the cervical spine disrupts the balance between stability and mobility of cervical spine joint complex.

Diagnosis

Patients with cervicogenic headache will often have altered neck posture or restricted cervical range of motion (Hall & Robinson, 2004). Forward head posture in particular corresponds with lower strength and endurance of the deep neck flexors in cervical headache (G. Jull, Barrett, Magee, & Ho, 1999; Watson & Trott, 1993; Zito, Jull, & Story, 2006). Patients with recurrent headache exhibit imbalance in length and strength of the right and left SCM muscle (Cibulka, 2006). This head pain can be triggered or reproduced by active neck movement, or passive neck positioning especially in extension or extension with rotation toward the side of pain, or through application of digital pressure to the involved facet regions or over the ipsilateral greater occipital nerve. Muscular trigger points are usually found in the suboccipital, cervical, and shoulder musculature, and these trigger points can also refer pain to the head when manually or physically stimulated (Biondi, 2005). Diagnostic imaging such as radiography, magnetic resonance imaging (MRI), and computed tomography (CT) cannot confirm the diagnosis of cervicogenic headache but can lend support to its diagnosis (Fredriksen, Fougner, Tangerud, & Sjaastad, 1989; Pfaffenrath, et al., 1987). Vernon et al. (1992) reported that seventy-seven percent of all participants showed a substantial alteration of cervical lordosis. The findings consisted of reduced, total reduction, or actual reversal of the normal cervical spine curve. Nagasawa et al. (1993) compared cervical spine radiographic findings of patients with headaches to a control group of non-headache sufferers. It was found that the cervical spinal curvature index was less in headache patients than in the controls, with many patients having straight cervical curves.

2.2.3 Neck pain

Etiology

Neck pain occurs frequently in western societies (Andersson, 1997). The pain may arise from any of the structures in the neck. These include the intervertebral discs, ligaments, muscles, facet joints, dura and nerve roots (Bogduk, 1988). There are a large number of potential causes of neck pain. These vary from tumours, trauma (e.g. fractures, whiplash), infection, inflammatory disorders (e.g. rheumatoid arthritis) and congenital disorders. In most cases, however, no systemic disease can be detected as underlying cause of the complaints. This group consists of patients with mainly mechanical disorders including degenerative changes and could be labelled as non-specific neck pain (Bogduk, 1984). The origin and exact pathophysiologic mechanisms of this group often remain obscure and the origin of neck pain is thought to be multifactorial. Excessive physical strain may cause microtrauma in connective tissues, and psychosocial stress may lead to increased muscular tension (Sjogaard, Lundberg, & Kadefors, 2000). Degenerative changes in cervical vertebrae and disks are common and increase with advanced age in asymptomatic people. Thus, examination using radiographs or magnetic resonance imaging does not elucidate the origin of pain in most cases (Gore, 2001). The deep neck flexors play a major role in chronic neck pain. They have been implicated in chronic neck pain and whiplash, just as the TrA has been implicated for chronic low back pain. Falla et al. (2004) found that the deep neck flexors in particular have reduced EMG activity in patients with neck pain. Barton et al. (1996) have shown that the deep neck flexors are weak and have delayed onset in patients with chronic neck pain. Patients with chronic neck pain also exhibit problems maintaining cervical lordosis.

2.3 Thoracic spine:

2.3.1 Anatomy of the thoracic region and shoulder

The thoracic region contains the most vertebrae (12) of any of the movable regions of the spine. The normal thoracic curve is a rather prominent kyphosis, which extends from T2 to T12 (Masharawi et al., 2008). The thoracic spine is also closely connected to the thoracic cage, which includes the sternum, ribs and cartilage. Due to thoracic region's relationship with the ribs, it has relatively little movement.

The scapulothoracis joint is anatomically and biomechanically involved in shoulder function and movement of the arm. To obtain a correct three-dimensional movement of the shoulder girdle and upper arm, the scapula rotates upwards, tilts to the back and rotates externally, the clavicle elevates and retracts and the humerus elevates and rotates externally. The scapulothoracic joint is formed by the posterior thoracic cage and the anterior scapula. The acromioclavicular joint, or AC joint, is at the top of the shoulder. It is the junction between the acromion of the scapula and the clavicle. The sternoclavicular joint is the connection of the end of the clavicle, the upper and lateral part of sternum and the cartilage of the first rib. The glenohumeral joint or shoulder joint is a multiaxial synovial ball and socket joint and involves articulation between the scapula and the head of the humerus. Due to the very limited interface of the humerus and scapula, it is the most mobile joint of the human body.

Muscles in this region that are characterized as tight include the pectoralis minor and the pectoralis major (Page, et al., 2010). The pectoralis minor originates at third to fifth rib and inserts at the scapula. It lies on the upper thorax directly under the pectoralis major and its function includes scapular protraction, and elevation of the ribs in forces inspirations. The pectoralis major originates at the clavicle, the sternum, and the second to sixth rib. This large, fan shaped muscle, covers the anterior and superior surfaces of the thorax and inserts at the humerus. Its functions include adduction of the shoulder, internal rotation of shoulder, elevation of thorax in force inspiration, internal rotation of shoulder, flexion of shoulder horizontal.

Weak muscles in the thoracic region are the middle and lower trapezius, the rhomboid minor and rhomboid major, and the serratus anterior and the posterior deltoid. The middle fibers of the trapezius arise from the spinous process of the seventh cervical and the spinous processes of the first, second, and third thoracic vertebrae. They are inserted into the medial margin of the acromion, and into the superior lip of the posterior border of the spine of the scapula. The lower fibers of the trapezius arise from the spinous processes of the remaining thoracic vertebrae (T4-T12). From this origin they proceed upward and laterally to converge near the scapula where they insert. The main function of the middle and lower fibers of the trapezius are scapula adduction, depression and upward rotation of the scapula. The rhomboid major originates at T2-T5 and inserts at the scapula. The rhomboid minor originates at C7-T1 and also inserts at the scapula. The main function of the rhomboids is to adduct, rotate downward and elevate the scapula. The serratus anterior originates at the first to eighth rib and inserts at the scapula. Its main functions include scapula abduction, upward rotation of scapula, and it prevents winging by drawing the medial border of scapula anteriorly close to the thoracic wall. The posterior deltoid originates at the scapula and inserts at the humerus and its main functions are to extend and externally rotate the shoulder.

2.3.2 Shoulder impingement

Etiology

The subacromial space lies directly inferior to the acromion, coracoid process, acromioclavicular joint, and coracoacromial ligament. Lubricated by the subacromial bursa, the subacromial space in health is narrow, and the anatomical structures surrounding it are responsible for maintaining static and dynamic shoulder stability. The space between the acromion and the superior aspect of the humeral head is called the impingement interval, and abduction of the arm narrows the space further. Any pathological condition that further narrows this space increases the incidence of impingement (Waldman, 2014). Although subacromial impingement syndrome can occur as a result of acute trauma, the usual clinical presentation is more insidious, without a clear-cut history of trauma to the affected shoulder. Muscular imbalances can cause a superior migration of the humeral head, which also narrows the subacromial space (Brossmann et al., 1996; Hallström & Kärrholm, 2006). The pathomechanics of impingement may involve one or both of the shoulder force couples: the deltoid and rotator cuff or the scapular rotators. Alterations in deltoid and rotator cuff coactivation and rotator cuff imbalances are evident in patients with impingement (Burnham, May, Nelson, Steadward, & Reid, 1993; Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1990). Untreated, subacromial impingement syndrome can lead to progressive tendinopathy of the rotator cuff and gradually increasing shoulder instability and functional disability.

Diagnosis

Subacromial impingement syndrome is a clinical diagnosis supported by a combination of clinical history, physical examination, radiography, and MRI. MRI of the shoulder provides the best information regarding any pathological process of the shoulder. Other diagnostics include the use of EMG. Compared with uninjured, athletes with impingement have significantly more EMG activity in the upper trapezius and significantly less EMG activity in the lower trapezius (Cools, Declercq, Cambier, Mahieu, & Witvrouw, 2007). Athletes with impingement also demonstrate trapezius muscle imbalance on both the injured and uninjured shoulders, showing upper-to-lower ratios of 1.56 to 2.19, which are significantly higher than ratios observed in uninjured controls (Page, et al., 2010). Muscle tightness has also been implicated. A tight pectoralis minor limits upward rotation, external rotation and posterior tilt and reduces the subacromial space (Borstad & Ludewig, 2005).

2.3.3 Thoracic outlet syndrome

Thoracic outlet syndrome (TOS) is characterized by compression of the neurovascular structures between the neck and the shoulders. Symptoms include parasthesia, numbness, and pain in the upper extremity. It was suggested that muscle tightness and imbalance play a role in TOS (Page, et al., 2010). Poor posture and repetitive overhead work may contribute to TOS (S. E. Mackinnon & Novak, 1994). Abnormal posture and compensated work patterns cause an imbalance in the upper back, neck and shoulder, contributing to increase mechanical pressure around the nerves (S. Mackinnon, Patterson, & Novak, 1996). Hajek and colleges (1978) described the postural deviations resulting from muscle imbalance in TOS. Tightness of the SCM leads to forward head position, tightness of the upper trapezius and levator scapula, pactoralis minor and major cause elevation and protraction of the shoulder girdle and scapula. Novak et al.

(1995) reported improvement in 60% of patients with TOS at 1 year following a program. Exercises included stretching and strengthening exercises.

2.4 History of muscular imbalance testing

Strength ratios have been historically used to quantify muscle imbalances between agonists and antagonists, and in investigations of musculoskeletal injury. Tyler and colleagues (2001) found that groin muscle strain occurring among hockey players was more prevalent in athletes with a ratio of hip abduction and adduction strength that was less than 80%. Baumhauer and coworkers (1995) reported that athletes with a high ratio of eversion strength to inversion strength, as well as athletes with low ratio of dorsi flexor strength to planar flexor strength, were more likely to experience inversion ankle sprains. McGill (2007) developed an evidence-based approach to developing a core training program for the trunk. According to McGill's core exercise strategy, the first step must be to improve endurance capacity, especially any muscular imbalances. Reports have indicated that individuals with poor endurance capacity of the trunk as well as muscular imbalances have an increased risk of back pain (Biering-Sorensen, 1984; McGill, 2007). Other research supports the idea that McGill's findings of the core can be used for cervical and thoracic muscle imbalances. Dvir et al. (2008) and Raney et al. (2009) concluded that patients suffering from neck-related disorders present a significant reduction in cervical strength compared to normal subjects. A normal flexion-to-extension strength ratio is estimated to be 60% (Garces, Medina, Milutinovic, Garavote, & Guerado, 2002). Watson et al. (1993) and Zito et al. (2006) found that headache groups were significantly different from non-headache groups in respect to forward head posture, less isometric strength, and less endurance of the upper cervical flexors. Jull et al. (2007) found similar results. Tests for range of motion, cervical flexor and extensor strength and cross-sectional area of selected extensor muscles at C2 showed significant differences between a headache and a control groups. In similar fashion, Fernández-de-las-Peñas et al. (2006) were able to show that forward head posture and cervical headaches are positively related to decreased cervical mobility. Muscular imbalances in the shoulder complex were tested by Bak et al. (1997). In an experiment with swimmers, they found that both concentric and eccentric internal rotational torque was reduced in painful shoulders. This resulted in significantly greater concentric and eccentric external-to-internal rotational strength ratios of the painful shoulder.

However, other researchers have found that neither neck muscle strength nor passive mobility of cervical spine have predictive value for later occurrences of neck pain in pain-free working-age women (Hamberg-van Reenen, Ariens, Blatter, van Mechelen, & Bongers, 2007; Salo, Ylinen, Kautiainen, Hakkinen, & Hakkinen, 2012). Thus, screening healthy subjects for weaker neck muscle strength or decreased mobility of the cervical spine may not be recommended for preventive purposes, and further research is thus warranted.

3.0 Methods

This chapter describes how the objectives of the study were achieved and the statistical procedures that were used for obtaining the results. Details about the participants, instrumentation, experimental design and data analysis are discussed below.

3.1 Overview

The primary goal was to relate muscular imbalances proposed by the Upper Crossed Syndrome to quantitative measures. To do this we measured range of motion (ROM), strength and endurance in applicable anatomical regions. The experiment was a cross-sectional study with a case and control group.

3.2 Participants

3.2.1. Sample size

A power calculation was performed. Values from cervical flexion/extension ratios were used from an earlier study by Cagnie et al. (2007):

$$\mu_1 = 1.6,\ \mu_2 = 1.35,\ \sigma = 0.3,\ \alpha = 0.05, power = 0.8.$$

For a one sided test, the result implies that each group should have 18 subjects.

3.2.2 Recruitment

One group, showing signs of UCS, was recruited through local physiotherapist and chiropractor clinics in southwest Virginia. Inclusion criteria for this group were: presence of postural deficiencies such as forward head posture, increased cervical lordosis and thoracic kyphosis, elevated and protracted shoulders, and rotation or abduction and winging of the scapulae, and constant or frequently occurring neck- and shoulder pain for more than 6 months. Exclusion criteria were severe disorders of the cervical spine, such as disk prolapse, spinal stenosis, postoperative conditions in the neck and shoulder areas, history of severe trauma, instability, spasmodic torticollis, frequent migraine, peripheral nerve entrapment, fibromyalgia, shoulder diseases (tendonitis, bursitis, capsulitis), inflammatory rheumatic diseases, severe psychiatric illness and other diseases that prevent physical loading or other non-musculoskeletal sources of pain, prior surgery involving the cervical or thoracic spine and pregnancy.

The researchers attempted, once the case group was identified, to recruit a control group that was balanced on a group level for confounding effects such as gender, age and BMI. In addition, to be included, healthy subjects should not have had neck- or shoulder pain for at least 1 year before testing, any other disease that prevented physical loading, or any prior surgery involving the cervical or thoracic spine.

3.2.3 Metrics

For the experiment, 17 participants in each group (15 female, 2 male in both) were recruited. The distribution of age and anthropometric measures were similar between the case and control group (Table 1).

Table 1 – Anthropometric data of study participants

	Case	Control
	Mean (SD)	Mean (SD)
Age	40.11 (16.15)	37.17 (14.92)
Mass (kg)	68.38 (14.06)	63.97 (6.86)
Height (m)	1.68 (0.08)	1.66 (0.08)
BMI	24.09 (4.79)	23.14 (3.31)

3.3 Instrumentation

3.3.1 Biodex System 3

A Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY) was used for the study. The Biodex system uses a dynamometer containing strain gauges and potentiometers to measure torque, position and velocity output from almost any joint. Torque can be measured through concentric, eccentric, and isometric resistance at dynamometer speeds ranging from 0°/s up to 500°/s. In the current study, isometric strength and endurance as well as ROM were be quantified via the Biodex with a sampling rate of 100 Hz (Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2004).

3.3.2 MTx sensors

The MTx is an inertial and magnetic measurement unit and comprises 3D gyroscopes, 3D accelerometers and 3D magnetometers (38x 53x21 mm, 30 g) (Roetenberg, Luinge, & Slycke, 2009). This sensor was used for cervical ROM assessment. The sampling rate for this study was 100 Hz.

3.4 Experimental design

The experiment was a case-control study. The researcher did not manipulate the study environment, but simply measured characteristics relevant to UCS. This design approach allowed comparison of two groups at a single point in time. This method enables researchers to compare many different variables simultaneously. However, extrapolation and cause-and-effect relationships cannot be assessed.

3.4.1 Dependent variables

There were a total of 38 dependent variables. Neck strength and endurance measurements included flexion/extension and side bending. Neck ROM included flexion/extension, side bending and rotation (Ylinen, Salo, Nykänen, Kautiainen, & Häkkinen, 2004; Youdas et al., 1992). The shoulder joint strength and endurance measurements included abduction/adduction, and internal/external rotation for both arms (Barnes, Van Steyn, & Fischer, 2001). For the thoracic region, measures included shoulder protraction/retraction (push/pull) strength and endurance for the dominant and non-dominant side. A summary of all dependent variables are listed in Table 2. Postures and specifications of all tests are summarized in sections 3.5.2 – 3.5.7.

Table 2 - Dependent variables investigated in the present study

Number	Region	Name	Side	Type	Unit
1	Neck	Flexion	-	ROM	Degrees
2		Extension	-		
3		Bending	R		
4		Bending	L		
5		Rotation	R		
6		Rotation	L		
7		Flexion	-	Strength	Nm
8		Extension	-		
9		Bending	R		
10		Bending	L		
11		Flexion	-	Endurance	Seconds
12		Extension	-		
13		Bending	R		
14		Bending	L		
15	Shoulder	Abduction	dominant	Strength	Nm
16		Adduction			
17		Internal Rotation			
18		External Rotation			
19		Abduction		Endurance	Seconds
20		Adduction			
21		Internal Rotation			
22		External Rotation			
23		Abduction	non- dominant	Strength	Nm
24		Adduction			
25		Internal Rotation			
26		External Rotation			
27		Abduction		Endurance	Seconds
28		Adduction			
29		Internal Rotation			
30		External Rotation			
31	Scapula	Push	dominant	Strength	Nm
32		Pull			
33		Push		Endurance	Seconds
34		Pull			
35		Push	non-dominant	Strength	Nm
36		Pull			
37		Push		Endurance	Seconds
38		Pull			

3.4.2 Randomization

Since consecutive strength and endurance measures in the shoulder and neck area lead to an accumulation of fatigue, randomization and sufficient rest between the tests were necessary. Randomization was realized by creating three levels of the tests. The first level included the joints in question (neck, shoulder, and scapula). A 3x3 Latin square was used to counterbalance within this level. The second level determined which exercise was performed. For the neck and scapula, a 2x2 table was used, for the shoulder a 4x4 Latin square. The third level randomized between sides or agonist/antagonists. Here, a 2x2 table was used again. ROM, isometric strength and endurance of a certain test were treated as a block and thus not changed in order.

3.5 Procedure

3.5.1 General

All variables mentioned above, were collected in one experimental session.
For cervical ROM, data collection was accomplished with the MTx sensor. The sensor was securely fastened on the top of the head of the subject. The subject was asked to move through the active range of motion for cervical flexion/extension, cervical side bending right/left and cervical rotation right/left. All angles were measured with respect to the starting position. This starting position, in which the subject was asked to sit as straight as possible and look straight ahead, was used to zero all axes of rotation.

Strength was assessed isometrically. Each test was performed with two submaximal warm-up and three maximum trials. Between each maximum trial was a rest period of 20 sec given. Subjects were verbally encouraged to exert maximal effort. The peak trial value was recorded to represent a maximum voluntary contraction (MVC) (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004). For all tests, the subject was asked to hold on to the fixture and completely relax. In this position, we zeroed the force output to account for gravity.

In the isometric endurance test, the subject was required to generate 40% of the previously found MVC for as long as possible. 40 % MVC resulted in endurance times of around 1.5 minutes during pilot testing and was thus chosen. The subjects were given a visual display of their performance. The display had upper and lower bounds in addition to the 40% MVC midline (Figure 1). The specifications for these bounds were ±10% of the MVC value added to the 40%

MVC midline (Mehta & Agnew, 2012). The subject was asked to keep the torque output within these bounds. When the torque output crossed the lower bound for a short period of time, verbal encouragement was given. If the torque output crossed a second time, the trial was terminated. There was one submaximal warm-up trial to familiarize the subject with the test and one max trial. We used the same coefficient as in the strength test to account for gravity.

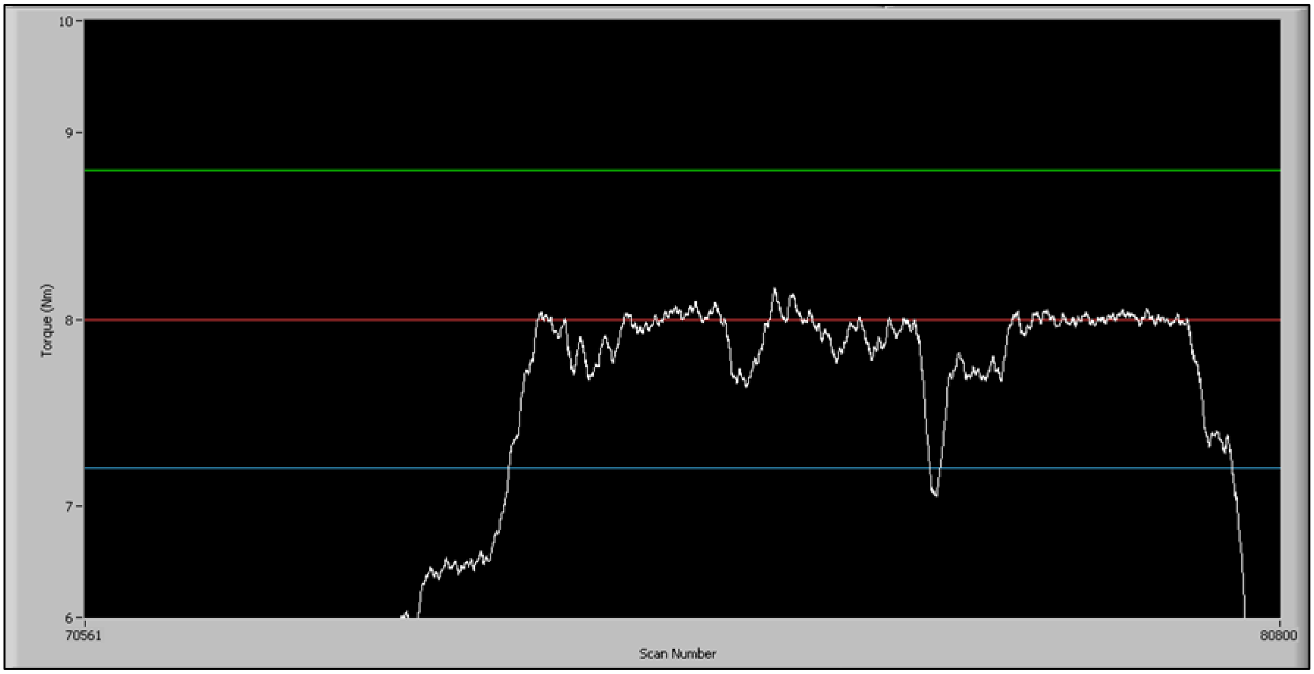

Figure 1 - Data collection interface for endurance test

3.5.2 Cervical flexion

During cervical flexion, the subject was positioned supine on the inclined Biodex system. A belt was used at shoulder height to prevent any additive strength effect from trunk musculature during the testing procedure. In the supine position, subjects were asked to cross their arms to prevent craniocaudal movements of the thorax. The axis of rotation of the dynamometer was aligned with the C7 spinous process and the fixture was fixed at 20° above horizontal. The subject was asked to push directly forward against the padded strain gauge fixture. The lower end of the padded fixture was aligned with the nasal bridge (Figure 2a).

3.5.3 Cervical extension

During cervical extension, the subject was in the same position as in the cervical flexion test, except the fixture was placed at the back of the head of the subject. The lower end of the fixture was aligned with the lower end of the occipital bone. The fixture was adjusted to 20° below horizontal. The subject was then asked to push directly backward against the padded strain gauge fixture (Figure 2b).

3.5.4 Cervical bending

During cervical bending, the subject was asked to lay on their right or left side, with the axis of rotation aligned with the C7 spinous process. The fixture was placed above the head for both neck bending moment right and left. The subject was asked to push directly up against the padded strain gauge fixture. The lower end of the padded fixture was place at right below the ear. The subject was asked to cross hands in front of the chest to eliminate additional force contribution. Belts at the waist and shoulders were also used to fix the subject in place (Figure 2c).

3.5.5 Shoulder internal/external

The shoulder internal/external rotation test was performed with arms in 90° abduction and 0° forward flexion. The drum of the dynamometer was tilted 10° from the vertical. Subjects were asked to grasp a handgrip and maintain the forearm and wrist in neutral pronation/supination (MacDermid, Ramos, Drosdowech, Faber, & Patterson, 2004). These tests were performed using both the dominant and non-dominant arm (Figure 2d).

3.5.6 Shoulder abduction/adduction

During shoulder abduction/adduction, the subjects sat upright, with the arm 90 degree abducted. The center of rotation was aligned with the shoulder. Belts were used to fix the subject at the waist and at both shoulders. Subjects were asked to grasp a handgrip and maintain the forearm and wrist in neutral pronation/supination. The subject was asked to push towards the ceiling for abduction, and pull towards the ground for adduction. These tests were performed by both the dominant and non-dominant arm (Figure 2e).

3.5.7 Scapula push/pull

For the scapula protraction/retraction test, the subject was positioned supine on the inclined Biodex system. A belt was used at shoulder height to prevent any additive strength effect from trunk musculature during the testing procedure. The subject was asked to abduct the shoulder 90 degrees and bend the arm at the elbow 90 degrees. The subject was then asked to push up against the handle and/or pull down on the handle. These tests were performed by both the dominant and non-dominant arm (Figure 2f).

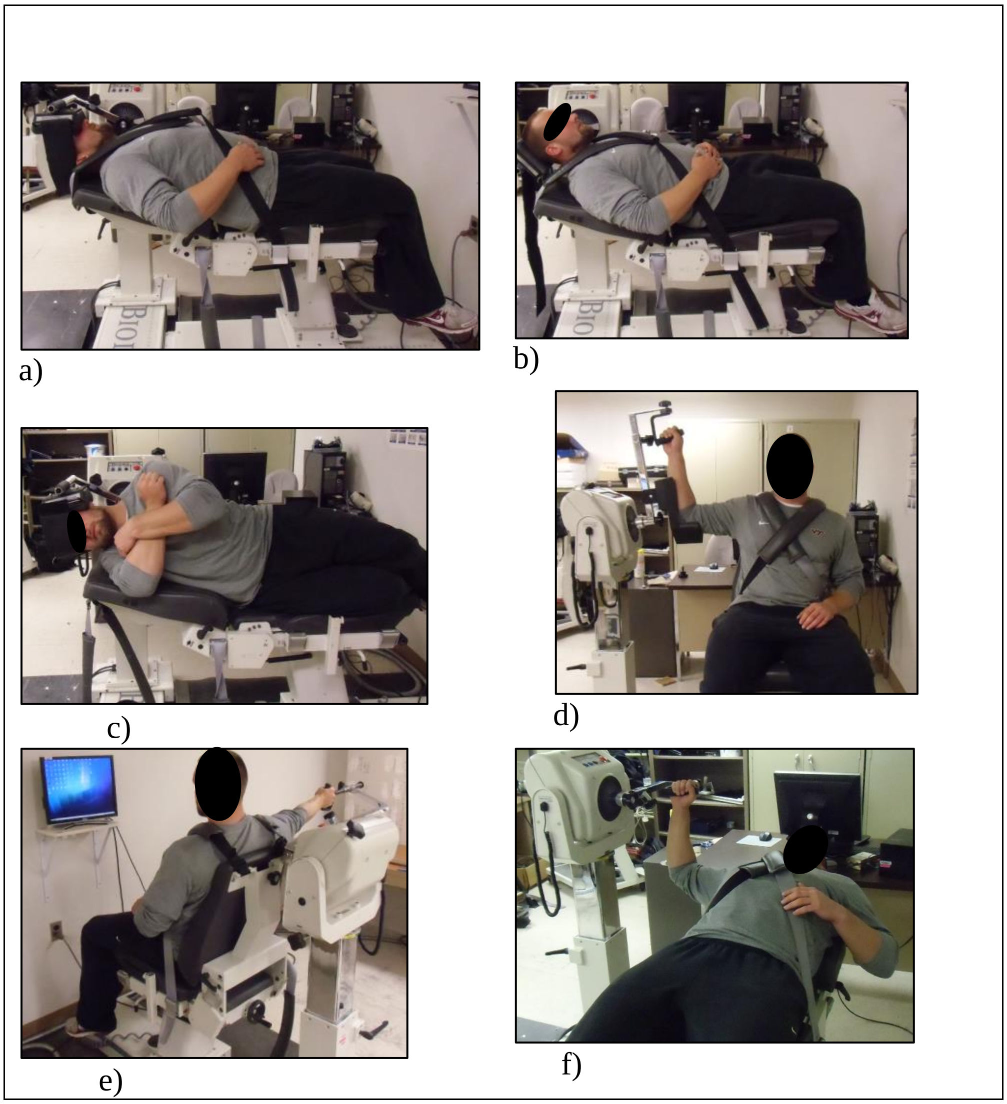

Figure 2 – a) Cervical Flexion Test b) Cervical Extension Test c) Cervical Bending Test d) Shoulder Rotation Test e) Shoulder Abduction/Adduction Test f) Scapula Protraction/Retraction Test

3.6 Statistics

Unpaired t-tests between all measurements in the case and control group were performed. Absolute strength was normalized by body weight. Correlation analysis and data reduction techniques (i.e., exploratory factor analysis) were also employed. Factor analysis was used to reduce and cluster like tests, and to thus attempt to minimize the final protocol or test battery for future use. Additionally all flexion/extension, bending and abduction/adduction pairs were grouped and ratios calculated. For all ratios, unpaired t-tests were performed as well. An a priori level of significance ($\alpha = 0.05$) was chosen for all statistical analyses.

4.0 Results

The results have been divided into three main categories: strength, endurance, and range of motion.

4.1 Strength

When analyzing each test individually (dominant (d) and non-dominant (n) side separate), a significant difference in strength for neck flexion and neck extension between the two groups was observed. External shoulder rotation for the dominant side also approached significance. Summary results for all strength measures are presented in Table 3.

Table 3 - Normalized strength (Nm/kg) for each individual test

Normalized Strength (Nm/kg)	**Case**	**Control**	**p-value**
	Mean (SD)	Mean (SD)	
Neck flexion	0.189 (0.051)	0.265 (0.014)	**0.0008***
Neck extension	0.214 (0.068)	0.338 (0.025)	**0.0018***
Neck bending (n)	0.282 (0.121)	0.336 (0.188)	0.344
Neck bending (d)	0.283 (0.136)	0.326 (0.171)	0.438
Push (n)	0.659 (0.156)	0.701 (0.151)	0.441
Pull (n)	0.508 (0.150)	0.484 (0.129)	0.627
Push (d)	0.651 (0.152)	0.691 (0.184)	0.497
Pull (d)	0.498 (0.154)	0.508 (0.165)	0.854
Internal (n)	0.245 (0.084)	0.264 (0.104)	0.556
External (n)	0.183 (0.067)	0.228 (0.093)	0.118
Internal (d)	0.283 (0.116)	0.293 (0.134)	0.802
External (d)	0.195 (0.080)	0.101 (0.024)	**0.074**
Abduction (n)	0.642 (0.104)	0.618 (0.029)	0.542
Adduction (n)	0.597 (0.038)	0.654 (0.038)	0.302
Abduction (d)	0.670 (0.167)	0.671 (0.183)	0.999
Adduction (d)	0.650 (0.194)	0.750 (0.185)	0.136

When analyzing individual strength ratios, we discovered a significant difference in the internal/external shoulder rotation ratio for the dominant side. It should also be noted that the internal/external shoulder rotation ratio for the non-dominant side approached significance as well. Summary results of all strength ratio tests and corresponding statistical outputs are presented in Table 4.

Table 4 - Strength ratios for individual tests

Ratio	**Case**	**Control**	**p-value**
	Mean (SD)	Mean (SD)	
Neck Flexion/Extension	0.934 (0.306)	1.019 (0.793)	0.694
Neck bend (n)/ bend (d)	1.049 (0.274)	1.045 (0.282)	0.966
Push/pull (n)	1.345 (0.300)	1.495 (0.364)	0.20
Push/pull (d)	1.374 (0.372)	1.441 (0.438)	0.631
Int/ext (n)	1.405 (0.362)	1.193 (0.331)	**0.084**
Int/ext (d)	1.497 (0.282)	1.159 (0.240)	**0.0007***
Ab/add (n)	1.120 (0.225)	1.005 (0.390)	0.30
Ab/add (d)	1.073 (0.253)	0.928 (0.304)	0.142

To increase statistical power, we combined the same tests for the dominant and non-dominant side (e.g. push left and push right, internal rotation left and internal rotation right, etc.), and neck strength between sides was combined (left and right). The combination yielded a significant difference in external shoulder rotation strength and shoulder adduction strength as described in Table 5.

Table 5 - Normalized strength generating ability (Nm/kg) for combined tests

Normalized Strength (Nm/kg)	**Case**	**Control**	**p-value**
	Mean (SD)	Mean (SD)	
Neck bending (comb.)	0.283 (0.127)	0.331 (0.177)	0.214
Push (comb.)	0.655 (0.152)	0.696 (0.166)	0.298
Pull (comb.)	0.503 (0.149)	0.496 (0.146)	0.852
Internal (comb.)	0.264 (0.102)	0.279 (0.119)	0.575
External (comb.)	0.189 (0.073)	0.241 (0.097)	**0.016***
Abduction (comb.)	0.656 (0.137)	0.644 (0.155)	0.738
Adduction (comb.)	0.624 (0.179)	0.716 (0.157)	**0.03***

Combining tests also resulted in a significant internal/external shoulder rotation ratio (p = 0.0004) and a significant shoulder abduction/adduction ratio (p = 0.0041) between the case and control group (Table 6).

Table 6 - Strength ratios for combined tests

Ratio	Case	Control	p-value
	Mean (SD)	Mean (SD)	
Push/pull (comb.)	1.359 (0.333)	1.468 (0.397)	0.226
Internal/external (comb.)	1.451 (0.052)	1.176 (0.285)	**0.0004***
Abduction/adduction (comb.)	1.096 (0.237)	0.923 (0.239)	**0.004***

All significant strength measurements can be seen in Figure 5, all significant strength ratios are presented in Figure 6.

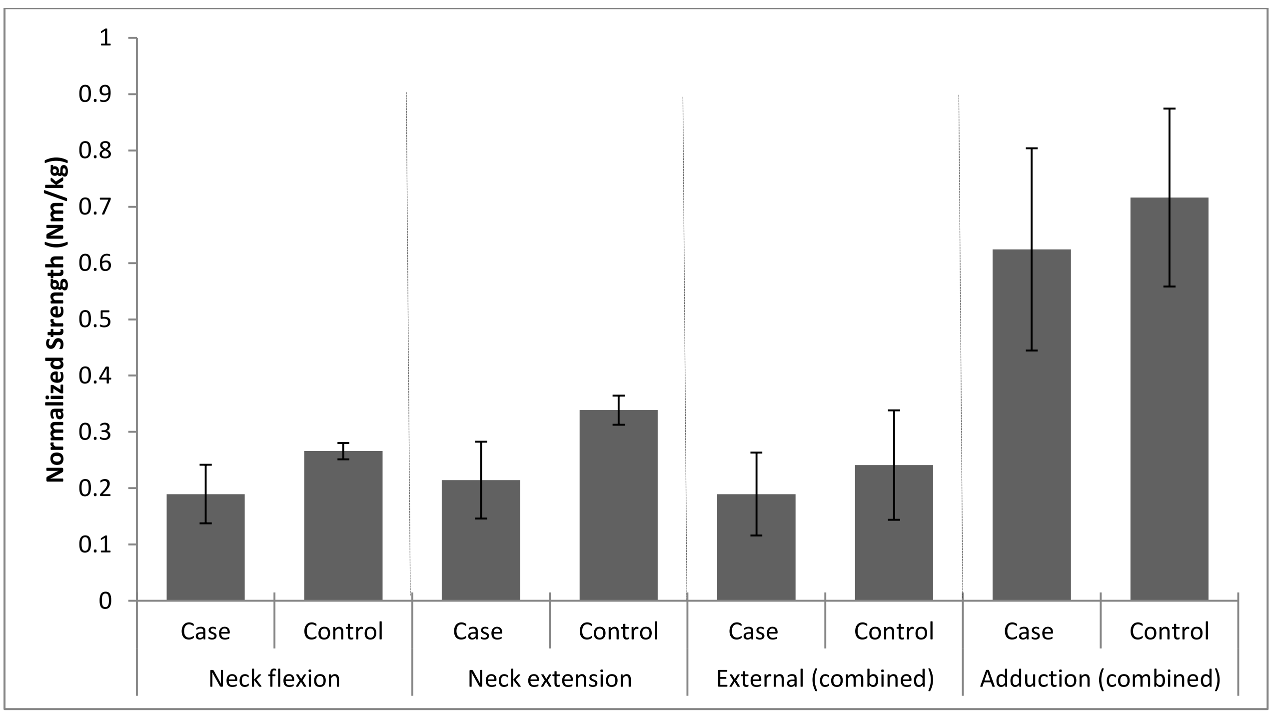

Figure 3 - Significant strength measures for individual and combined tests. In each condition, the case group differed significantly from the control group (p<0.05). Error bars represent standard deviation.

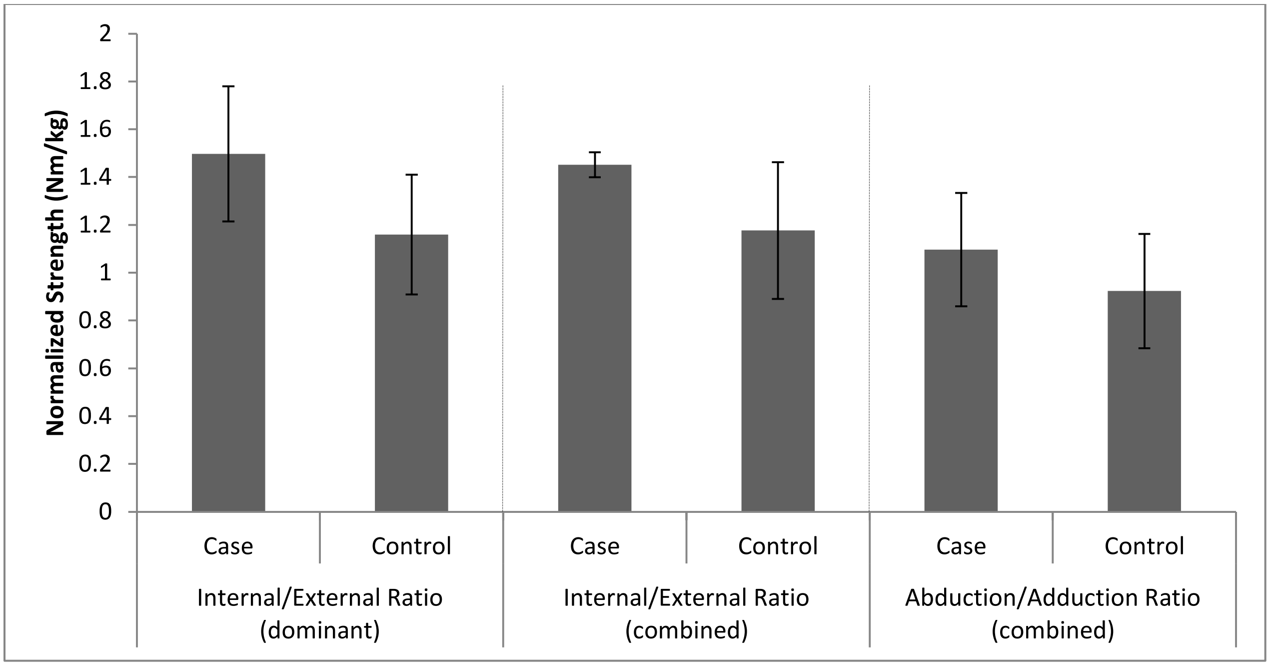

Figure 4 – Significant strength ratios for individual and combined tests. In each condition, the case group differed significantly from the control group ($p<0.05$). Error bars represent standard deviation.

4.2 Endurance

First we looked at individual effects, then at individual ratios. After that, we combined dominant and non-dominant sided tests. There were no significant differences in the endurance capacity for individual effects (Table 7) or individual ratios between the two groups (Table 8).

Table 7 - Endurance times for individual tests

Endurance Time (sec)	**Case**	**Control**	**p-value**
	Mean (SD)	Mean (SD)	
Neck flexion	54.98 (45.63)	48.76 (70.29)	0.77
Neck extension	132.69 (59.38)	127.64 (88.78)	0.85
Neck bending (n)	76.07 (70.11)	61.24 (53.89)	0.50
Neck bending (d)	63.15 (41.98)	56.59 (52.72)	0.70
Push (n)	95.93 (38.22)	81.50 (43.02)	0.31
Pull (n)	158.60(99.69)	176.61 (146.46)	0.68
Push (d)	86.08 (33.20)	91.24 (54.90)	0.74
Pull (d)	147.48 (99.80)	153.09 (107.61)	0.88
Internal (n)	80.90 (42.23)	64.86 (63.23)	0.40
External (n)	79.27 (23.60)	61.02 (41.84)	0.14
Internal (d)	64.31 (38.61)	61.52 (54.97)	0.87
External (d)	77.99(37.99)	73.18 (14.35)	0.78
Abduction (n)	70.87 (36.01)	64.91 (53.04)	0.71
Adduction (n)	88.94 (55.24)	88.09 (80.31)	0.97
Abduction (d)	72.43 (35.99)	64.56 (44.86)	0.58
Adduction (d)	76.13 (38.42)	115.10 (134.49)	0.27

Table 8 - Endurance ratios for individual tests

Ratio	**Case**	**Control**	**p-value**
	Mean (SD)	Mean (SD)	
Neck Flexion/Extension	0.442 (0.297)	0.391 (0.339)	0.66
Neck bend (n)/ bend (d)	1.277 (0.726)	0.147 (1.176)	0.59
Push/pull (n)	0.919 (1.105)	0.890 (1.348)	0.94
Push/pull (d)	0.746 (0.377)	0.946 (1.273)	0.54
Int/ext (n)	1.040 (0.467)	1.068 (0.531)	0.88
Int/ext (d)	1.158 (1.546)	0.922 (0.464)	0.55
Ab/add (n)	0.929 (0.555)	0.908 (0.481)	0.91
Ab/add (d)	1.061 (0.593)	0.847 (0.379)	0.22

Increasing statistical power by combining dominant and non-dominant sides still yielded no significant difference between the two groups.

4.3 Range of motion

The results for the neck range of motion tests are summarized in Table 9. Two individual effects showed significant differences between the case and control group. These effects were neck bending to the non-dominant side, and neck bending to the dominant side. Neck rotation to the non-dominant side and neck rotation to the dominant side approached significance.

Table 9 - Neck ROM individual tests

ROM (degrees)	**Case**	**Control**	**p-value**
	Mean (SD)	Mean (SD)	
Neck Flexion	61.69 (14.45)	63.28 (14.07)	0.75
Neck Extension	72.76 (18.58)	75.30 (18.14)	0.69
Neck bending (n)	45.61 (10.74)	54.82 (9.94)	**0.014***
Neck bending (d)	43.11 (7.72)	51.30 (10.59)	**0.015***
Neck rotation (n)	75.70 (13.55)	84.71 (13.86)	**0.064**
Neck rotation (d)	70.17 (15.54)	78.23 (11.30)	**0.094**

When combining both sides for neck bending and both sides for neck rotation, neck bending and neck rotation showed significant differences. The combined ROM results can be seen in Table 10.

Table 10 - Neck ROM combined tests

ROM (degrees)	**Case**	**Control**	**p-value**
	Mean (SD)	Mean (SD)	
Neck bend (comb.)	44.36 (9.30)	53.06 (10.27)	**0.0005***
Neck rot (comb.)	72.94 (14.63)	81.47 (12.88)	**0.013***

All significant ROM tests are shown in Figure 7.

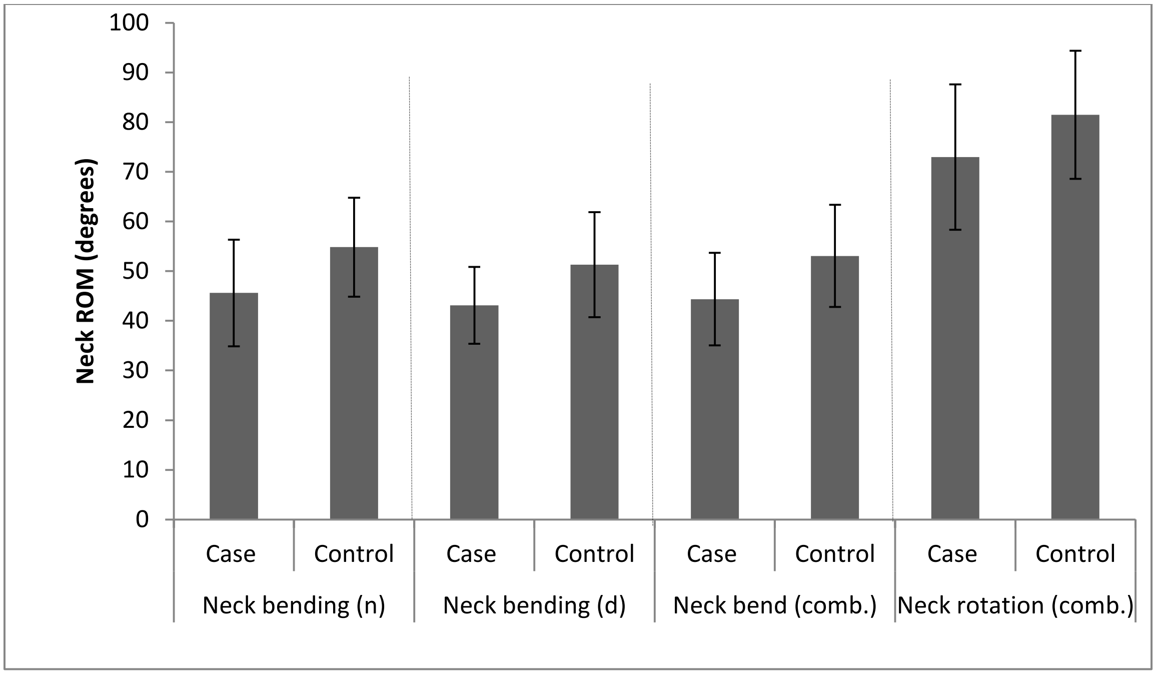

Figure 5- Significant Neck ROM measures for individual and combined tests. In each condition, the case group differed significantly from the control group ($p<0.05$). Error bars represent standard deviation.

Correlations between the combined strength values for the dominant and non-dominant sides and individual range of motion tests can be seen in Table 11. As no significant trends or findings were found amongst all tests of endurance, these were excluded from further analysis and data reduction.

Table 11 - Correlation matrix of combined strength values for the dominant and non-dominant sides and individual range of motion tests

	Neck flexion ROM	Neck extension ROM	Neck bend (n) ROM	Neck bend (d) ROM	Neck rot (n) ROM	Neck rot (d) ROM	Neck flexion strength	Neck extension strength	N bend strength	Push strength	Pull strength	Internal rot strength	External rot strength	Abduction strength	Adduction strength
	1.000														
N.ext ROM	-0.122	1.000													
N.bend(n) ROM	0.070	0.126	1.000												
N.bend(d) ROM	-0.185	0.110	-0.116	1.000											
N.rot(n) ROM	-0.084	0.145	0.089	0.217	1.000										
N.rot(d) ROM	0.395	-0.291	0.31	-0.162	-0.114	1.000									
N.flex strength	0.001	0.028	-0.37	0.242	0.113	-0.072	1.000								
N.ext strength	0.078	0.187	-0.441	0.312	0.118	-0.311	0.529	1.000							
N.bend strength	-0.283	0.017	-0.145	0.323	0.19	-0.018	0.519	0.537	1.000						
Push strength	-0.257	0.094	-0.179	0.119	0.282	-0.073	0.041	0.146	0.322	1.000					
Pull strength	-0.227	0.202	-0.076	0.273	0.030	-0.052	-0.028	-0.001	0.117	0.634	1.000				
Int.rot strength	-0.227	0.037	-0.285	0.249	0.250	-0.093	0.363	0.365	0.603	0.388	0.265	1.000			
Ext.rot strength	-0.147	0.02	-0.345	0.325	0.264	-0.071	0.462	0.414	0.659	0.333	0.129	0.829	1.000		
Ab. strength	0.011	0.203	-0.018	0.195	0.138	0.04	0.001	0.171	0.431	0.575	0.495	0.528	0.387	1.000	
Add.strength	-0.063	0.02	-0.096	0.502	0.133	-0.087	0.204	0.364	0.423	0.341	0.329	0.541	0.493	0.651	1.000

Due to the strong correlations observed, especially in strength tests, an exploratory factor analysis was performed in an attempt to group likewise tests and/or identify meaningful performance factors that contrasted group performance. For this analysis, principle components were extracted based on varimax rotation, with suppressed absolute loading values of less than 0.40. The results of the analysis suggested that the performance variables can be clustered into 4 independent factors, which can be seen in Table 12 and Table 13. A discussion of the different factors and the factor analysis follows in section 5.4

Table 12 Factor analysis result with variance explained by each factor

	Variance	Percent	Cum Percent
Factor 1	3.5893	23.929	23.929
Factor 2	2.8296	18.864	42.793
Factor 3	1.6588	11.059	53.851
Factor 4	1.3765	9.176	63.0288

Table 13 Rotated factor loading with absolute loading value of 0.4

	Factor 1	Factor 2	Factor 3	Factor 4
External rotation strength	0.784023			
Neck flexion strength	0.77167			
Neck extension strength	0.762302			
Neck bend strength	0.743191			
internal rotation strength	0.674861	0.499689		
adduction strength	0.483998	0.556668		
push strength		0.802119		
pull strength		0.798349		
abduction strength		0.798211		
Neck rot (d) ROM			0.838202	
Neck flexion ROM			0.644695	
Neck extension ROM				0.631676
Neck rot (n) ROM				0.624103
Neck bend (n) ROM	-0.50172		0.431769	0.557151
Neck bend (d) ROM				

5.0 Discussion

The purpose of this study was to find quantifiable differences in active range of motion, muscle strength and muscle endurance capacity between a group of patients with Upper Crossed Syndrome and an asymptomatic group. The results of the study suggest that there are measurable differences. This is supported by differences in neck flexion and extension strength, shoulder external rotation and shoulder adduction strength. In addition, neck range of motion, particularly for neck bending and neck rotation showed significant differences between the two groups. These findings suggest that quantifiable objective differences are present and can possibly be used to improve current diagnostic approaches of UCS.

5.1 Strength

5.1.1 Neck strength

In contrast to the hypothesis that there will be a difference in the neck flexion/extension strength ratio, we found that both neck flexion and neck extension strength were significantly reduced. Due to the similar reduction in both measures, we therefore believe that the ratio for neck flexion/extension may not be a meaningful metric. Consequently, focus should be given to the overall strength reduction in neck flexion and extension. This result is consistent with findings from Ylinen et al. (2004) who observed significant reductions in isometric strength in neck flexion and extension in patients with chronic neck pain compared to a control group.

Muscles involved in neck flexion, which are also described by Janda (1996) as weak muscles and thus are in accordance with this research, are the deep cervical flexors. The deep cervical flexors are comprised by the Longus Colli, the Scalenus Anterior, the Scalenus Medius, and the Scalenus Posterior. Muscles involved in neck extension are the Splenius Capitus Cervicis, Semispinalis Capitus, Semispinalis Cervicis, Spinalis Capitus, Longissimus Cervicis, the Upper Trapezius and the Levator Scapulea. These muscles are either not mentioned by Janda or in the case of the Upper Trapezius and the Levator Scapulae characterized as overactive. This leads to a variety of possible interpretations. One is that our findings simply contradict Janda's theory. Another possibility is that due to the isometric nature of our test, we worked at an angle where these overactive muscles do not play a major role. Another explanation is, that due to pain that subjects in the case group experience in the neck, they experience discomfort during the test or are hesitant (due to past experience) and therefore exhibit a reduce strength capacity. This phenomenon was observed in a study by Ylinen et al. (2004) and could also apply here. Another possibility is that our test apparatus and methods lacked precision. In another study, Cagnie et al. (2007) were able to show a significant flexion/extension ratio with a p-value of 0.001 when comparing neck pain patients with a control group. Especially the low standard deviation (3.6 for flexion and 5.8 for extension) of their tests has to be noted. This low deviation could mean a more reliable test and could explain their findings in comparison to our methods.

Strength values and ratios for neck bending showed no significant difference between the two groups. Even after combining neck bending to the non-dominant and the dominant side, there was no difference detectable. The muscles which are involved in neck lateral bending are the Sternocleido Mastoid (SCM), the Upper Trapezius, the Scalenes, and the Levator Scapulae. All these muscles are characterized by Janda as overactive and tight. This could lead to the hypothesis that tight muscles in the case group are at the same strength level as a healthy muscle in the control group. This could be the subject of a different investigation.

5.1.2 Shoulder internal/external rotation strength

Strength tests for shoulder internal and external rotation proved to be one of the most conclusive tests of our study. While internal shoulder rotation for the dominant and non-dominant side showed no differences, external rotation yielded a significant difference on the dominant side. This resulted in a significant internal/external shoulder rotation ratio for the dominant side. When combining both sides, external rotation and the internal/external ratio showed significant differences. These results show the tendency of UCS patients to exhibit rotator cuff imbalances. Internal rotation muscles seem to be comparable in their strength generating ability to the control group. External rotator muscles however show significant strength reduction between the two groups. With this imbalance, postural deficiencies such as a rounding of the shoulders can be explained. This imbalance could also cause an alteration of the humeral head position. As described in the shoulder impingement pathology, a forward mitigation of the humeral head can cause a further reduction of the subacromial space and could thus lead to a variety of shoulder injuries and pain symptoms. The findings of these tests are consistent with a variety of other studies which looked at shoulder pain and shoulder impingement syndrome (Baltaci, 2004; Wang, 2000).

It is interesting to note that the dominant side showed a tendency for greater imbalances. This could be explained by the increased usage of the dominant side in everyday life. This fact could be valuable for diagnostic and rehabilitation regiments and further research is warranted.

5.1.3 Shoulder abduction/adduction strength

The shoulder abduction/adductions test showed only significant results after combining both sides. The large interpersonal differences in strength generation could be the reason for the need of an increased statistical power. The combined test showed that shoulder adduction was significantly weaker in the case group than in the control group. This in turn then also yielded a significant abduction/adduction ratio for combined sides. To explain this, we have to look at the muscles involved in shoulder abduction and adduction. The main muscle involved in shoulder abduction is the deltoid. At neutral wrist position we tested abduction and adduction in, the anterior part of the deltoid is especially demanded. For shoulder adduction, Infraspinatus, Teres Minor, Subscapularis, Lattisimus Dorsi and the Rhomboids play key roles. Although Janda only characterized the Rhomboids as weak, we see the trend that posterior rotator cuff muscles and muscles responsible for holding the shoulder and scapula back and down show weaknesses. This shows again a muscular imbalance pattern from anterior to posterior and could be a possible reason for postural deficiencies such as winging of the scapula and an upward mitigation of the shoulder.

5.1.4. Push/pull strength

The push and pull tests were the most inconclusive assessments in this experiment. The study could not detect significant differences between the two groups when looking at individual sides and ratios, or when combining sides and ratios. This result was not expected, because the hypothesis was that the larger the muscle group, the easier it would be to detect muscular imbalances. However, the experimental setup and inherent inability to isolate the muscles in question could account for the inconclusive results. Especially in the pulling test, participants had different strategies to pull and thus recruited different muscles. In particular, the contribution of the bicep muscle played a critical role in the researcher’s opinion. Although the explanation on how to perform the test was precise and consistent and all possible straps from the Biodex system were used to fix the subject, it is quite possible that muscle recruitment strategies varied between subjects. The researchers believe that this was the biggest issue with the push and pull examinations. Due to this inconsistency, another test to assess muscle strength in the thoracic spine is needed, especially to determine the strength capacity of scapula muscles. One possibility could be the experimental setup of Cools et al. (2002). In their experiment, they used a closed chain attachment with the Biodex System 3.Their protocol consisted of 5 isokinetic concentric contractions at a linear velocity of 12.2 cm/sec and 10 repetitions at a velocity of 36.6~cm/sec. The shoulder girdle protraction and retraction movements were performed with the arm horizontal in the scapular plane, which is 30° anterior of the frontal plane. Results show an excellent reproducibility for isokinetic peak torque at both velocities, and should be applied and investigated in future research.

5.2 Endurance

All endurance results for this study were inconclusive. Although it is difficult to compare exact strength and endurance ratios between studies due to methodological differences, a total absence of significant endurance differences was not expected. Previous studies found significant differences between case and control groups and we expected similar results. For chronic neck pain for example, Peolsson et al. (2007) showed a decreased endurance capacity for neck flexion between a case and control group. One major difference however between this study and our investigation was the amount of weight which had to be held till exhaustion. Whereas Peolsson's study used the weight of the head for flexion (subject was instructed to raise their head just above the examination table until exhaustion) and a 2kg or 4kg weight for females and males respectively for neck extension, (the subject was in a prone position and raised the head just above the examination table), our study used precise fractions of the MVC. When using a more or less absolute resistance for the endurance test, individual strength generating capacity has to be considered. For some patients the weight of their head or the 4kg weight might equal to 40% of their max, for some people to 60%. The difference in endurance times due to the different MVC values can be significant. This difference in methodology could be a reason for the differences in the endurance tests results.

Another possible issue with our endurance tests could lie in the nature of isometric endurance testing. This method might not be the optimal way to assess fatigability. A study by Ellenbecker et al. (1999) assessed shoulder internal and external rotation muscular fatigue ratios. In their study, a muscular fatigue protocol consisting of 20 maximal effort concentric contractions of internal rotation and external rotation was used to measure muscular fatigue at 300°/s. A relative fatigue ratio was calculated by dividing the work in the last 10 repetitions by the work in the first 10 repetitions. Higher fatigue ratios indicate improved muscular fatigue resistance. With this approach, Ellenbecker et al. were able to show significant differences between the fatigue ratios for internal and external shoulder rotation.

5.3 Range of motion

Originally the study protocol consisted of an additional range of motion test for shoulder internal and external rotation. However after a majority of the first 10 subjects experienced pain/discomfort during the test, we stopped performing the examination and eliminated it from the protocol. This only left cervical range of motion tests to be investigated. The results found in this study are very similar to previous studies (Ylinen, 2004). We were able to observe significant reduction in cervical bending to both sides and significant differences in neck rotation (after we combined sides) between the two groups. This reduction can be explained by the muscle tightness and tension in the Sternocleido Mastoid (SCM), the Upper Trapezius, the Scalenes, and the Levator Scapulae. All these muscles are characterized as tight by Janda (1996) and play a major role in cervical bending.

5.4 Factor analysis

The results of the factor analysis can be interpreted as the following; Factor 1 is comprised of strength measurements (external rotation, neck flexion, neck extension, neck bending, internal rotation, adduction), which showed the tendency to be significantly different between the groups. Factor 2 includes the strength measurements which show the tendency to be not significant (internal rotation, push, pull, abduction, adduction) and factor 3 and 4 are mainly comprised of neck range of motion tests. This technique could be very powerful when a larger sample would be recruited in a later study. The results of this analysis should function more as a proof of concept to group and analyze significant measures to reduce the testing protocol.

5.5 Limitations

5.5.1 Participants

Although the researchers tried to recruit an equal number of male and female participants, a majority of the test subjects were female (15 females and 2 males in each group). A possible explanation could be the higher prevalence of chronic neck pain in females. Earlier research (Bovim, 1994) suggests that females suffer more often from chronic neck pain. This could be a reason why more females see a physician for their pain symptoms and thus were more likely to be recruited, due to our advertisement in local physical therapy and chiropractor clinics.

5.5.2 Strength tests

The researcher suggests that in future studies, all max (MVC) tests should be averaged across multiple trials. In this study, three maximal trials were performed and the max performance was recorded and used. To decrease variability an average across multiple strength tests would be recommended.

During the study, it became obvious that for some participants, the single sided tests led to an off balance position. This means that some participants for example, pushed so hard during the push/pull tests that they rotated from their original position. This changed the angle at which they worked and possibly altered muscle recruitment, and mechanical leverage against the fixture. Although Biodex belts were used, this was an issue especially for strong participants. A possible solution would be to have a handle on both sides to push simultaneously. With this approach, no torque could be generated that would cause the patient to twist. This could lead to a higher repeatability of the test.

5.5.3 Endurance tests

As mentioned before, the inconclusiveness of the endurance tests was not expected. This gives rise to the question if an isometric endurance test should be replaced by another method. One possibility was described in section 6.2.

Another guideline for future research could be that all endurance tests should work in the same direction against or with gravity. In this study, although the weight of arm or neck was used to calibrate to zero, it seemed that endurance tests, which worked against gravitation had a shorter endurance time. Since all participants went through the same protocol it did not change the results of the study. However in our opinion (granted feasibility) all endurance tests should work in the same direction, to further reduce experimental error and allow for a better calculation of endurance ratios.

5.5.4. Range of motion tests

For the neck range of motion, the researchers experienced that it was hard to fix patients completely. Some participants had additional movement from other parts of the body, mainly the shoulder and upper thoracic spine area. This limited the precision of the results between subjects. Another problem was to be consistent with the calibration of the starting point of the test (zero angle in all 3 dimensions). The instructions were consistent throughout all participants, namely that the subject had to sit as straight as possible and look straight ahead. However this method is very subjective and could be improved in future research.

For shoulder internal external rotation we experienced too late that the method we planned on doing was not feasible. We used the Biodex on an isotonic setting with minimal resistance (1lb). When we used minimal resistance the fixture with the arm accelerated too much, which led to pain/discomfort when the fixture was decelerated by the patients arm at the endpoints of their ROM. When a higher resistance was used, the subject was not able to accurately and smoothly move the fixture against the resistance in the end range. Patients often displayed “jerky” movements at the end range which resulted in significant deviations (15+ degrees). To avoid injury, we decided to eliminate the test from the protocol. However, shoulder internal and external rotation range of motion is an important metric, which should be analyzed in future research of UCS patients.

Another range of motion or position test which could be enormously important for UCS research would be to measure the winging of the scapula. A study done by Karduna et al. (2001) tracked kinematic scapula data by using a magnetic tracking device. Their findings showed promising results in accurately measuring scapula kinematics. Due to the weak nature of scapula muscles and the associated changes in scapula kinematics, tests like these could be very valuable to quantify UCS consistently in patients.

5.6 Future directions

This research showed that there are quantifiable differences between a group of people who have UCS and an asymptomatic group. The next steps in this research will be to increase the number participants in a future study. Also a male base or a study which controls for gender has be conducted to find if male UCS patients show the same tendencies as female patients. Although most of our tests showed differences, the researcher's opinion is that certain test can or have to be optimized to extract better information. This is especially true with the push and pull tests utilized and the protocol used for the endurance tests.

Following, a database of healthy subjects by gender, age and BMI, etc. should be established, to compare possible UCS subjects against their healthy matched control group. If this research will be used as a diagnostic tool, a logistic regression model could be developed and tested to determine if such an evaluative approach such as this is valid. The results of this study are a proof of principle of the feasibility of such a tool and serve as a pillar for future model development.

In conversations with participants we saw the interest of people about the state of their muscular balances. Many people asked why they do not have such a technology at the gym to see if they are training correctly and if they are in balance. A screening tool could be developed which shows interested people even without UCS, how and if they show muscular imbalances.

6.0 Conclusions

The current study of 34 subjects measured strength, endurance and range of motion capacity in a group of people with UCS and an asymptomatic group. The results showed that there were significant differences in strength generating ability and range of motion capacity between the two groups. Endurance measures yielded no significant difference. The findings partially proved our hypothesis that people suffering from UCS show higher ratios of imbalance within associated muscle pairs and regions. Higher ratios of imbalance could be observed in shoulder internal/external rotation and shoulder abduction/adduction. Our findings for neck strength however suggest that a strength ratio might not be appropriate due to the strength reduction in neck flexion as well as in neck extension. For this, absolute strength or strength normalized by body weight seems to be a more conclusive measure. Our study also showed that neck range of motion is significantly different between the two groups, which suggest that muscle length and tightness also play a vital role in UCS.

The findings of the study agree in many aspects with the original characteristics Janda described when he first introduced this syndrome. The study was able to partially prove that muscles which are characterized as weak or overactive by the Upper Crossed Syndrome, result in lower and higher strength generation respectively, and have an impact in neck range of motion.

To the author’s knowledge, this is the first study which examined if there are quantifiable differences in patients with UCS when compared to a control group. To bring UCS to more public attention, future research has to be performed and exact quantitative measures for a diagnostic approach have to be developed. This research showed that it is possible to used objective measures to distinguish between people with UCS and healthy people and thus demonstrates the possibility to move from subjective to quantitative objective diagnostics.

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