

**The Influence of Idiopathic Chronic Neck Pain on Sternocleidomastoid and Upper Trapezius Muscle  
Activity and Elasticity**

by

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## **Dedication**

This dissertation is dedicated to my parents, sister, and husband. Thank you for everything you have done for me.

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## **Preface**

The chapters of this dissertation have been written as separate manuscripts for submission. There may be repetition between the chapters with regard to content. Chapter Two has been published in the *Journal of Electromyography and Kinesiology*. Chapter Three has published in the *Journal of Biomechanics*. Chapter Four is in preparation for submission.

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## **Abstract**

Approximately half of all adults will experience neck pain. Without early detection and proper treatment, neck pain will likely become chronic. Chronic neck pain is one of the primary causes of disability in the United States and results in great financial and economic burden. Additionally, idiopathic chronic neck pain is difficult to treat due to the unknown etiology underlying the condition. Idiopathic chronic neck pain is often associated with static working conditions, including seated computer work. The stationary nature of modern computer work contributes to a rising incidence of chronic neck pain, highlighting the need to determine the underlying adaptations associated with idiopathic chronic neck pain to improve the prevention and treatment of neck pain.

The purpose of this dissertation was to establish the neuromuscular and mechanical adaptations associated with idiopathic chronic neck pain during assessments of functional reaching and seated computer-work ergonomics. In Chapter 2, we used a combination of ultrasound shear wave elastography and electromyography to examine variations in activation and stiffness of the sternocleidomastoid across 3-dimensional isometric neck torques. In Chapter 3, we determined the influence of idiopathic chronic neck pain on the activation and stiffness of the upper trapezius and sternocleidomastoid during the maintenance of unilateral and bilateral functional reaching. Lastly, in Chapter 4, we determined the effect of chair recline and head and neck position on sternocleidomastoid and upper trapezius stiffness and activation during computer work in people with idiopathic chronic neck pain and healthy controls.

Results from this dissertation suggest that idiopathic chronic neck pain is associated with changes to both the neuromuscular control and mechanical properties of neck and shoulder musculature during both static reaching tasks and seated computer work. Our results indicate that shoulder position differences between healthy controls and people with idiopathic chronic neck pain may be driving stiffness adaptations in the sternocleidomastoid and upper trapezius muscle during reaching tasks. Our investigation into seated computer work found that head and neck posture has a greater effect than chair recline on upper trapezius stiffness and activation. The self-selected head and neck posture may indicate that individuals are able to determine which posture results in the lowest effort, and therefore activation, of their neck muscles.

Findings from this dissertation have broad and important clinical implications. We have established that shear wave velocity scales with muscle activation in muscles that have lines of action in three dimensions. Our novel findings suggest that the use of EMG alone in investigations into idiopathic chronic neck pain is not adequate to fully represent muscle function. The addition of ultrasound shear wave elastography in our studies provided more nuanced insight that would be missed using EMG alone. The findings of this dissertation could have new clinical utility for evaluating individuals with idiopathic chronic neck pain. We found these patients often displayed distinct changes in muscle stiffness that were not related to changes in muscle activity during similar reaching trials and reclined seated computer work. We also observed for the first time that there are clear sex differences in muscle stiffness and activity amongst key neck-shoulder muscles. These results highlight the importance of evaluating both muscle stiffness and activation changes before designing rehabilitation programs and motivates the need for further research to determine the feasibility of using ultrasound shear wave elastography for clinical examination of idiopathic chronic neck pain.

## **Chapter 1 - Introduction**

### **1.1 Overview**

Neck pain is a serious public health concern that will affect approximately half of all individuals at some point in their life [1, 2]. One-third of adults suffering from neck pain report difficulty performing activities of daily living due to their pain [3], which reduces their quality of life and impacts their ability to work. As a result, neck pain is now the fourth leading cause of disability in the United States [4]. The incidence of neck pain is expected to rise, which may be attributed to the increasingly computer-reliant and stationary nature of modern work [5]. Only approximately 25% of people with neck pain will seek treatment, and those with severe pain are more likely to visit medical professionals [6]. Unfortunately, due to the absence of proper treatment, most individuals with neck pain experience persistent symptoms or recurrence of neck pain within 5 years [1]. This leads to a substantial personal and economic burden [7], which underscores the need to reduce the occurrence and duration of neck pain.

Neck pain can be broadly categorized into subgroups describing the mechanism of injury, including pain arising from injury (e.g., sport or vehicle collision, whiplash disorder), herniated intervertebral disk, or infection. The fourth subgroup of neck pain is defined as idiopathic, with no underlying injury or known pathology. Idiopathic pain originates anywhere between the base of the skull and the seventh cervical vertebral process and/or surrounding a line connecting the seventh cervical vertebral process and the acromion process. Headaches can also accompany idiopathic neck pain [8]. Neck pain is also categorized by the duration of pain. Acute neck pain

lasts less than three months, while chronic neck pain lasts greater than three months. Unfortunately, the pathophysiology of idiopathic chronic neck pain is not well understood. It is therefore important to identify contributing factors to idiopathic chronic neck pain to improve the diagnosis and surveillance of these injuries.

### *1.1.1 Biomechanical and Neural Characteristics of Idiopathic Chronic Neck Pain*

Both psychosocial and physical factors play a role in the development of idiopathic chronic neck pain [9-11]. Neck pain is more prevalent in those with substantial stress [12], depression [12], low job satisfaction [13], and low level of education [7]. It is most frequently present in women between the ages of 45-59 years [2, 7, 14]. Idiopathic chronic neck pain is also associated with computer work and static postures, and is affected by time at work, break frequency, and repetition of movement [15-17]. Additionally, perceived muscular tension (those who report feeling “tense”) has a dose-response relationship to the occurrence of future neck-shoulder symptoms, even when adjusted for past pain [18]. Secondary gain, or the possible environmental gains resulting from pain complaints such as unemployment benefits or time off work, is also an important aspect of chronic pain that must be considered [19, 20]. Therefore, individual physical and psychosocial factors and the individual nature of perceived pain (as measured with instruments such as the Visual Analog Scale) add to the complexity of idiopathic chronic neck pain.

Painful stimuli are detected by nociceptive (e.g., pain-receptive) pathways of the central nervous system [21, 22]. When a threatening stimulus is detected, the central nervous system signals to withdraw from the stimulus and results in a sensation of pain in that area [21, 22]. In response to continuous or repeated painful stimuli in a given location, the threshold for pain detection by the nociceptive pathways diminishes [21, 23]. This leads to hypersensitivity of the



pain processing system within the central nervous system. People with altered central pain processing (i.e., hypersensitivity) are more likely to experience pain from normally non-pain-inducing stimuli [24]. This hypersensitivity is present in the original area of pain as well as the surrounding areas [23, 24]. In people with idiopathic chronic neck pain, evidence supports altered central pain processing. Compared to healthy controls, people with idiopathic chronic neck pain demonstrate lower pain thresholds in the neck and surrounding areas [25-29]. Some studies also demonstrate people with severe idiopathic chronic neck pain exhibit reduced pain thresholds in areas remote from the cervical area, such as the lower extremities [27, 28, 30]. This altered central pain processing may explain why individuals with idiopathic chronic neck pain experience greater pain or difficulty performing activities of daily living, such as computer work or tasks that involve reaching. Nociceptive stimuli that can result in the sensation of pain include mechanical (e.g., physical) or chemical irritation to the pain receptor nerve endings surrounding the spine [31]. Other research groups have hypothesized that mechanical irritation may be induced by inappropriate muscle tension during movement (i.e., abnormal activation), which can increase the tension loads transferred to the spine [31, 32]. Chemical irritation can be caused by the accumulation of calcium or lactic acid within a muscle [33]. Idiopathic chronic neck pain has been linked to adaptations that can cause mechanical and chemical irritation to the nociceptive pathways of the central nervous system [31, 33-36].

There are 26 layered pairs of muscles in the neck [37] that are recruited to produce movement of the head and generate torque about the cervical spine [38-40]. The muscles of the neck are integral to the maintenance of head and body posture [41], resisting unwanted perturbations [42], and contribute to head stability during tasks involving the use of the upper extremity [43]. There are three muscles linking the neck and shoulder complex: the upper

trapezius, levator scapulae, and rhomboid major. The upper trapezius is the most voluminous neck muscle, accounting for more than a quarter of all neck muscle volume, and assists with neck extension and shoulder elevation [44]. The levator scapulae assists with scapular elevation, and the rhomboid major assists with scapular stabilization and retraction. Additionally, the sternocleidomastoid, categorized as a neck muscle, originates on the mastoid process and inserts on the sternoclavicular joint [45], which provides an additional link between the upper extremity and the neck. The sternocleidomastoid assists with neck flexion, lateral bending, and axial rotation of the head. The sternocleidomastoid, a primary mover of the neck, and the upper trapezius, a primary mover of the shoulder, are considered superficial muscles (e.g., close to the skin surface). The musculature shared between the neck and shoulder complex (hereafter referred to as “neck-shoulder muscles”) suggests upper extremity function is innately linked to proper neck function. The actions, superficial location, and relatively large size of the sternocleidomastoid and upper trapezius make them optimal muscles to investigate in relation to neck function.

Idiopathic chronic neck pain is associated with alterations to the neuromuscular control of both the deep (e.g., scalenes, deep cervical flexors, and extensors) and superficial (e.g., sternocleidomastoid, splenius capitus, upper trapezius) neck and neck-shoulder muscles. These alterations differ for deep and superficial muscles, as well as whether the muscle is acting as the agonist (e.g., working in the same direction) or antagonist (e.g., working in the opposite direction) to a movement. Specifically, deep neck muscles exhibit lower activity levels during supine neck flexion in individuals with idiopathic chronic neck pain when compared to healthy controls [46]. We speculate that this reduction in muscle activity diminishes the control and protection of the cervical spine during supine neck flexion. The surrounding superficial muscles exhibit higher than normal activity levels during supine neck flexion and upper limb movement [34, 36, 41], possibly

compensating for the lower activation of the deep muscles [34]. The neuromuscular changes to painful neck-shoulder muscles are also dependent on the required actions. In the presence of pain, a muscle acting as an agonist or a synergist will often exhibit inhibited activity, while a muscle acting as an antagonist will exhibit enhanced activity [47, 48]. It may be possible that the described abnormal neuromuscular responses seen in people with idiopathic chronic neck pain may mechanically irritate the nociceptive pathways through altered muscle tension on the cervical spine or reduced coordination of movement.

It is common for idiopathic chronic neck pain to be accompanied by upper extremity pain and disability, specifically at the shoulder. These adaptations include decreased ability to control and maintain seated upper-thoracic posture [49], poor whole-body postural control during upper extremity perturbation [41], and altered neural control of the upper trapezius muscle during resting typing postures and repetitive upper limb movements [50, 51]. Those with idiopathic chronic neck pain exhibit altered activation patterns during activities involving the upper extremity, including many activities of daily living. Individuals with idiopathic chronic neck pain fatigue their upper trapezius muscle faster during repetitive upper limb movements [51]. Research also suggests the upper trapezius has a reduced ability to relax after the completion of an upper limb lifting task [35, 50] and decreased conduction velocity during a repetitive reaching task [51]. Slowed relaxation of a muscle after activation could be due to insufficient calcium uptake, resulting in taut bands in the muscle often referred to as trigger points [33]. This accumulation of calcium can result in the sensation of muscle pain [33], commonly reported in people with idiopathic chronic neck pain. The abnormal activations of the upper trapezius during activities involving the upper extremity indicate that upper trapezius function is inherently linked to movements involving the neck and shoulder. Movement strategies learned in the presence of pain will persist after the pain has

subsided [52], so rehabilitation may need to include assessments of neck-shoulder muscles during various activities of daily living.

### *1.1.2 Effects of Idiopathic Chronic Neck Pain on Muscle Elasticity*

Neuromuscular and kinematic adaptations at the neck and shoulder may also be accompanied by changes to muscle material properties, as increased muscle stiffness is often self-reported by people with neck pain. Muscle stiffness is defined as the force required to stretch muscle tissue by a unit distance. Stiffness is a mechanical property, meaning it is affected by specific geometric (e.g., cross-sectional area, pennation angle) and contractile (e.g., activation level) attributes of the tissue [53]. The elastic modulus (e.g., elasticity) of a tissue is essentially stiffness normalized by original tissue length and cross-sectional area and is defined as the slope of the stress-strain curve (force per unit area by the normalized change in length). Functionally, elasticity is the ability of a tissue to return to its original length after being deformed or stretched. Elasticity is a material property of skeletal muscle and is therefore independent of the geometric attributes of the tissue. The contractile properties of skeletal muscle will influence its elasticity, which increases with muscle activation [54] (i.e., the number of recruited motor units and the frequency in which they are stimulated). Altered muscle elasticity could inhibit the proper function of the muscle and could affect the movement about the joint [55, 56]. Addressing changes to muscle elasticity may require different therapeutic techniques than those used to treat changes in muscle activation. However, it is currently unclear how neck pain affects the elasticity of the neck-shoulder muscles. Identifying the effect of idiopathic chronic neck pain on neck-shoulder muscle elasticity can lead to more effective screening and rehabilitation interventions for these individuals.

During activities of daily living, the mechanical properties of the neck muscles play a crucial role in postural control. They provide stability to the head, neck, and shoulder during voluntary movement [5] and transmit load to the surrounding bones and connective tissues [32, 42]. There is an important difference in the mechanical properties among the muscles surrounding the cervical spine. Deep muscles closer to the spine are stiffer than the superficial muscles during relaxed prone lying and during isometric head lift [57], allowing them to provide constant support to the spine [58]. Alterations to the mechanical properties of the neck-shoulder muscles may manifest as morphological changes to muscle. For example, women with idiopathic chronic neck pain exhibit increased type I muscle fiber diameter in the upper trapezius [59] and reduced cross-sectional area of the upper trapezius and sternocleidomastoid [60]. These morphological changes likely impact the stiffness of these muscles. We speculate that maintaining healthy muscle stiffness is important to prevent pain and undue stress to the structures of the spine and to facilitate movement of the upper extremities during activities of daily living.

True measurements of *in vivo* tissue stiffness are not feasible for intact human muscles. Direct, *in vivo* measures of muscle stiffness are invasive and often require a decerebrate animal preparation [61]. Alternatively, mechanical *in vitro* testing of extracted tissues (using biopsies or cadaveric tissues) can be performed [62]. Both methods have limited ability to assess the mechanical properties of intact human muscles [63], particularly during volitional contractions. Ultrasound shear wave elastography is a reliable and non-invasive technology that uses acoustic radiation forces to produce small displacements in soft tissue, which results in the propagation of shear waves throughout the tissue. The propagation velocity of these shear waves is closely related to a tissue's shear elastic modulus, with shear waves traveling faster through stiffer tissues [64]. Ultrasound shear wave elastography has been used to explore the effects of neuromuscular

pathologies such as cerebral palsy [65, 66] and stroke [67]. Shear wave velocity scales linearly with muscle activation and passive stretch in muscles crossing hinge joints [68-71] and the sternocleidomastoid during two-dimensional (2-D) tasks [72]. Experimental muscle pain in the sternocleidomastoid leads to increased neural drive to that painful muscle in passive and active conditions [73], so an increase in muscle activation caused by neck pain would likely result in an increase in shear wave velocity. However, this has yet to be confirmed during the generation of 3-D torques in muscles with lines of action in three dimensions, like those of the neck.

Shear wave velocity can provide valuable insight into tissue stiffness changes independent of force production [74, 75]. Therefore, obtaining shear wave velocity alongside muscle activation data allows researchers to determine whether increased shear wave velocity is due to altered neural drive to the muscle or altered mechanical properties. Ultrasound shear wave elastography is also a beneficial tool for assessing the neck muscles because it can obtain measurements both from superficial and deep muscles of the neck. Deep muscles are inaccessible via surface electromyography (EMG). Ultrasound shear wave elastography has been successfully utilized to investigate the neck-shoulder muscles, specifically the sternocleidomastoid and the upper trapezius, both at rest and during planar isometric contractions [72, 76].

Increased neck muscle elasticity has been observed in people with neck pain under both relaxed conditions and during volitional contractions. Specifically, ultrasound shear wave elastography revealed greater shear wave velocity in the upper trapezius, levator scapulae, and sternocleidomastoid during relaxed supine and prone lying in people with idiopathic chronic neck pain when compared to healthy controls [55]. The increase in shear wave velocity during relaxed conditions indicates a change in the inherent quality of the tissue [55]. A similar quasi-static ultrasound elastography technique that utilizes manual compressions of the tissue has also been

used to provide *in vivo* measurements of muscle stiffness. During relaxed upright sitting, Ishikawa, et al. (2017) reported a lower strain ratio (indicating greater elasticity) of the upper trapezius in individuals with neck pain when compared to healthy controls [77]. This finding supports the hypothesis that adults with neck pain have greater upper trapezius stiffness. Furthermore, after a 30-minute computer task, these same individuals demonstrated a significantly lower strain ratio in the levator scapulae when compared to healthy controls [77]. These studies together suggest that adaptations to neck pain include increased elasticity both at rest and during volitional contraction for neck-shoulder muscles during seated typing tasks.

On the contrary, there is some evidence that individuals with neck pain may not exhibit differences in neck muscle elasticity. During several isometric neck and upper extremity tasks, Dieterich, et al. (2020) assessed the material properties of several cervical muscles in healthy controls and adults with chronic neck pain using ultrasound shear wave elastography. No differences were observed in shear elastic modulus between the neck pain group and healthy controls for any of the muscles measured [78]. However, these measurements were obtained from a portion of the upper trapezius primarily associated with postural control of the head and neck (e.g., lateral to the spine of C-4) and not control of the upper extremity. In comparison, the measurements acquired by Taş et al., (2018) and Ishikawa et al. (2017) that demonstrated differences in neck muscle elasticity were taken at the region of the upper trapezius that elevates the shoulder (e.g., lateral to the midpoint of the line from C-7 to acromion process) [55, 77]. Regions of the upper trapezius may be independently activated to perform specific tasks [79, 80]. For example, the portion of the upper trapezius with origins above the spine of C-6 does not contribute to scapular elevation [81]. Therefore, measurement of the upper trapezius should be taken at multiple sites to thoroughly assess the relationship between neck pain and muscle stiffness

of the shared neck-shoulder musculature. The existing literature is also limited to seated activities with minimal upper extremity range of motion. As many activities of daily living require a broader range of motion of the upper extremity [82], muscle elasticity should be investigated in the neck and shoulder muscles during more applicable activities of daily living.

### *1.1.3 Workplace Considerations*

The rising incidence of neck pain is commonly linked to the computer-reliant and stationary nature of modern work [5, 16, 83]. Although neck-shoulder muscular demand during computer work is typically less than 5% of maximum voluntary contraction [84, 85], sustained static work loads as low as 1% of maximum voluntary contraction can increase the risk of developing neck pain if those loads are sustained for long periods without breaks [86-88]. Poor sitting posture is associated with increased activation of various neck muscles such as the neck extensors [89, 90], decreased neck range of motion [91], and a change in cervical spine motion during head movement [92].

During computer work, the position of the head and neck are significantly affected by the height and angle of the monitor relative to eye level [93, 94]. During seated desktop computer use, individuals shift their head posture forward by approximately 10% when compared to upright sitting [95]. This forward shift increases the gravitational demand of the head as the neck becomes more flexed, increasing the muscle activation requirements of the neck extensors, including the trapezius [96, 97]. There is a strong correlation between neck flexion angle and neck extensor activity, where increased neck flexion angle results in greater neck extensor activation [94]. As one transitions from a desktop computer to a laptop or tablet computer, neck flexion angle and the gravitational demand of the head will increase [96], requiring further support from neck extensor



muscles. The link between head and neck posture and the resulting neck-shoulder muscle activations highlights the importance of correct posture during sustained seated computer work. While poor neck posture increases the risk of idiopathic chronic neck pain, therapeutic intervention or workplace redesign can modify posture during computer work.

Ergonomics is an important area of practice that applies knowledge of how individuals interact with their environment to design and create working systems that optimize safety, efficiency, and comfort [98]. Poor ergonomic factors have been associated with neck pain in seated stationary workers [99]. Women may be at even greater risk of neck pain in the workplace [16, 90] since ergonomically-designed equipment is often too large for women's smaller body size. However, developments in ergonomically adjustable chairs, desks, and computer monitors, combined with proper ergonomic education for workers, have successfully reduced the development of neck and shoulder pain [13, 100, 101]. Much of the ergonomic literature has investigated the optimal monitor placement for reducing neck extensor activity [94, 102]. However, adjusting the recline of the chair (independent of other ergonomic variables) has never been thoroughly investigated and may be an important factor in future workplace designs for individuals with idiopathic chronic neck pain.

There is promising evidence that adjustments to chair recline can improve functional outcomes for individuals with idiopathic chronic neck pain. Increasing chair recline has been investigated regarding lower back pain and was found to reduce the activation of the lumbar muscles [103]. However, the effect of chair recline on neck muscles has yet to be investigated thoroughly. A previous study found that increasing chair recline angles decreased the activation of the cervical extensor spinae and upper trapezius muscles compared to upright sitting in healthy individuals without chronic neck pain [104]. However, the independent effect of chair recline on

neck muscle activation is unclear in these prior studies as the researchers also modified the monitor position [105] or keyboard position [104]. Prior studies also have not standardized chair recline angles and instead relied on self-selected recline angles [106]. An in-depth investigation into the effect of chair recline on neck-shoulder muscle function during computer work is needed to determine its potential benefit in reducing neck-shoulder muscle activity.

#### *1.1.4 Current Knowledge Gaps*

Several knowledge gaps exist regarding the relationship between idiopathic chronic neck pain, neck and upper extremity biomechanics, and workplace design. First, it is unclear if shear wave velocity scales linearly with muscle activation in muscles acting in three dimensions. The studies to date have largely assessed muscles around the neck during 1-dimension or 2-dimensional volitional torque production even though the muscles of the neck contribute to 3-dimensional volitional neck torques. Second, it is currently unknown if people with idiopathic chronic neck pain demonstrate differences in muscle elasticity in the neck-shoulder muscles during activities of daily living or functional reaching tasks compared to healthy controls. Lastly, there is a lack of knowledge regarding the effect of chair recline on neck-shoulder muscle activity and stiffness during office work for those with idiopathic chronic neck pain. Filling these knowledge gaps would provide valuable information to enhance diagnostic techniques, develop and evaluate neck pain treatments, and improve ergonomic recommendations for employees with existing idiopathic chronic neck pain.

## **1.2 Purpose, Specific Aims, and Hypotheses**

Current diagnostic and treatment options for idiopathic chronic neck pain lack the efficacy necessary to improve the quality of life for those suffering from idiopathic chronic neck pain. While neuromuscular control of neck muscles has been studied extensively in people with idiopathic chronic neck pain, it is less well understood how the stiffness of the neck-shoulder muscles is affected. There is a critical need to identify people at greater risk for developing idiopathic chronic neck pain and improve diagnostic options. Therefore, the purpose of this dissertation is to investigate the neuromuscular adaptations associated with idiopathic chronic neck pain during assessments of functional reaching and seated computer-work ergonomics

**Aim #1** of this dissertation will establish the relationship between muscle activity and elasticity of the sternocleidomastoid muscle in healthy individuals performing volitional 3-D isometric neck torques for 5-10 seconds. A positive linear relationship between shear wave velocity and muscle activation has been demonstrated in many muscles that cross hinge joints [68, 69], and in the sternocleidomastoid during 2-D tasks [72]. The 3-D moment arms of the sternocleidomastoid allow it to contribute to stiffness in 3-D. Therefore, evaluating the neck in three dimensions will allow a more accurate evaluation of the sternocleidomastoid's mechanical contributions to typical neck function. To achieve this aim, we use a novel combination of surface EMG and ultrasound shear wave elastography measures of the sternocleidomastoid to study the direction of greatest muscle activation and greatest muscle elasticity during the generation of volitional three-dimensional neck torques. We will test the following hypotheses in Aim #1:

*Hypothesis 1A:* We hypothesize that the sternocleidomastoid activation and elasticity preferred directions (neck torque direction with the greatest EMG amplitude and shear

wave velocity, respectively) will not be significantly different in healthy individuals during 3-D voluntary neck torques.

**Aim #2** of this dissertation will evaluate the effect of chronic neck pain on sternocleidomastoid and upper trapezius elasticity and muscle activity during functional reaching tasks. To achieve this aim, the same combination of EMG and ultrasound shear wave elastography will be used to compare the upper trapezius and sternocleidomastoid muscles in people with mild and moderate chronic neck pain to healthy controls while they complete bilateral and unilateral reaching tasks. Experimental pain in the sternocleidomastoid increases sternocleidomastoid activation [73]. Additionally, people with neck pain complain of the sensation of muscle stiffness, specifically of the upper trapezius. Our ability to combine EMG and ultrasound shear wave elastography measurements will allow us to conclude whether greater shear wave velocity results from augmented muscle activity or inherent changes to the muscle tissue. The Neck Disability Index (NDI), which is a self-reported level of disability caused by neck pain, will be used to identify participants for the chronic neck pain arm. The NDI includes questions about ten areas of daily living: pain intensity, personal care, lifting, reading, driving, headaches, concentration, work, recreation, and sleep. The final score provides insight into their level of impairment on a scale of 0-50, with 50 indicating the highest level of disability. Individuals who score as mild (NDI score 4-14) and moderate (NDI score 15-24) impairment due to neck pain will be included in the study. Healthy participants (NDI score 0-4) will be age, height, weight, and sex-matched to the chronic neck pain participants.

*Hypothesis 2A:* We hypothesize that individuals with chronic neck pain will demonstrate higher upper trapezius and sternocleidomastoid muscle elasticity during functional reaching tasks when compared to healthy controls.

**Aim #3** of this dissertation will investigate the influence of chair recline on the activation and elasticity of the upper trapezius in people with idiopathic chronic neck pain and healthy controls. Three chair recline positions ( $0^\circ$  (neutral),  $25^\circ$ , and  $45^\circ$ ) will be investigated while participants are seated at a desk with the head and neck in a self-selected posture, a controlled neutral posture, and a slightly flexed posture. Aim #3 will again use the combination of surface EMG and ultrasound shear wave elastography to investigate differences in neck and shoulder muscle activity and elasticity in people with idiopathic chronic neck pain and healthy age, height, and weight-matched controls.

*Hypothesis 3:* We hypothesize that the  $25^\circ$  and  $45^\circ$  chair recline positions and the neutral head and neck position will result in lower upper trapezius activity and elasticity during computer work in people with idiopathic chronic neck pain and healthy individuals when compared to upright sitting.

These aims will provide the following outcomes. Aim #1 will define the relationship between muscle activity of the sternocleidomastoid and ultrasound shear wave elastography estimates of muscle stiffness during three-dimensional voluntary neck torques. The outcomes of Aim #1 will determine if ultrasound shear wave elastography is an appropriate measurement technique for neck muscles and if shear wave velocity scales with muscle activation of the sternocleidomastoid during three-dimensional volitional torques in healthy controls. Aim #2 will

determine whether people with idiopathic chronic neck pain demonstrate differences in tissue stiffness of the neck-shoulder muscles during unilateral and bilateral reaching tasks. Because we are simultaneously collecting EMG and ultrasound shear wave elastography data, we will be able to conclude if these differences are due to changes in muscle activation or stiffness changes within the muscle tissue. Aim #3 will determine whether increasing chair recline is a sufficient ergonomic adjustment to reduce upper trapezius activation and elasticity for those with idiopathic chronic neck pain.

### **1.3 Significance**

This dissertation will be the first to robustly characterize the function of the neck-shoulder muscles in those with idiopathic chronic neck pain using ultrasound shear wave elastography. There are current gaps in the literature regarding the relationship between neck pain and neck and upper extremity function. First, the studies to date have largely used ultrasound shear wave elastography to assess muscles around the neck during 1-D or 2-D volitional torque production, even though the muscles of the neck contribute to 3-D volitional neck torques. Second, it is currently unknown if people with chronic neck pain demonstrate differences in muscle elasticity in the neck-shoulder muscles during activities of daily living or functional reaching tasks compared to healthy controls. Identifying the underlying functional changes to a muscle is important when choosing the treatment modality or modalities during physical rehabilitation. Lastly, chair recline has not been investigated thoroughly as an ergonomic adjustment to decrease discomfort and upper trapezius activation and elasticity during computer work for people with idiopathic chronic neck pain. Filling these knowledge gaps would provide valuable information to enhance diagnostic

techniques, develop and evaluate neck pain treatments, and improve ergonomic standards for employees with idiopathic chronic neck pain.

The contributions of this dissertation are expected to have broad translational importance to improvements in diagnostic and treatment options for those with idiopathic chronic neck pain, as well as prevention techniques for those working from home. Current investigations into the stiffness of neck-shoulder muscles for those with chronic neck pain are limited to stationary activities with very little shoulder range of motion. The findings from this dissertation will provide a more accurate representation of the properties and function of the neck-shoulder muscles during the production of three-dimensional neck torques and unilateral and bilateral reaching. Our findings will also apply to employees with idiopathic chronic neck pain who frequently work at a computer. Poor ergonomic setups and poor posture during long hours of stationary work increase the risk of developing idiopathic chronic neck pain. It is currently unknown if simple adjustments to chair recline are a successful adaptation to decrease discomfort for those with idiopathic chronic neck pain. The results of this dissertation will improve public health by providing suggestions regarding computer-work postures that will minimize the risk of developing idiopathic chronic neck pain and decrease the discomfort for those who already experience idiopathic chronic neck pain.

## **Chapter 2 The Relationship between Muscle Activation and Shear Elastic Modulus of the Sternocleidomastoid Muscle during 3-D Torque Production**

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### **2.1 Abstract**

The sternocleidomastoid (SCM) is a primary neck torque generator, but the relationship between its muscle activation and shear elastic modulus during 3-D torque production is unknown. This study examined variations in neural control and shear elastic modulus of the SCM across various 3-D isometric torques. Our primary hypothesis was that the SCM would display similar preferred directions where muscle activity and shear elastic modulus were maximal during voluntary 3-D isometric torque production. Surface electromyography (EMG) and ultrasound shear wave elastography (SWE) data were collected from the SCM in 20 participants performing 3-D isometric target-matching at two different torque amplitudes. We used spherical statistics to compare the preferred directions calculated from the SWE and EMG data at 40% and 80% torque level during 3-D isometric torque production. We demonstrated a small but significant difference between EMG and SWE preferred directions, with the SWE preferred direction oriented more



towards ipsilateral bending and less towards contralateral axial rotation than the preferred direction for the EMG data. We conclude that, although small differences exist, SCM stiffness is largely driven by activation during 3-D neck torques for healthy individuals.

*Keywords: muscle stiffness, muscle elasticity, electromyography, ultrasound shear wave elastography, cervical spine, neck biomechanics*

## 2.2. Introduction

The neck is a complex musculoskeletal system made up of 26 pairs of muscles [37]. The central nervous system (CNS) recruits these muscles to generate and maintain volitional torque production in flexion, lateral bending, and axial rotation about the cervical spine [38-40]. Most neck muscles have moment arms that allow them to contribute to torque production in multiple degrees of freedom (DOF) [107-109]. It is unknown how the CNS integrates neural, mechanical, and architectural properties to select specific muscle(s) to perform a given voluntary task [110, 111], as more muscles are available to be recruited than DOF in the cervical spine [39, 112].

The neuromuscular contributions of neck muscles can be characterized across a range of force or torque directions with electromyography (EMG). These methods assist in identifying the preferred direction of muscle activity, which represents the net force or torque direction where a given muscle maximizes its neural activity [107, 109, 110, 112]. Torque direction describes the net moment produced at the neck, which is the sum of all the individual torques from contributing muscles. The SCM exhibits consistent preferred directions of muscle activity during both 2-dimensional (2-D) isometric force or torque [107, 111, 113] and 3-dimensional (3-D) isometric torque production at various levels of volitional torque [112]. These preferred directions often do not coincide with the anatomical moment arms of the SCM [109, 112]. Therefore, the CNS likely considers more than muscle moment arms when preferentially tuning neck muscle activity.

The mechanical properties of neck muscles are also an important contributor to the maintenance of cervical spine position. For example, muscle stiffness is the first protective mechanism for the cervical spine in response to a postural perturbation, before reflexive or volitional feedback [53]. Ultrasound shear wave elastography (SWE) can estimate the in-vivo shear elastic modulus by measuring the propagation velocity of acoustic waves in the muscle [66,

71, 114, 115]. An increased shear wave velocity (SWV) is indicative of a greater shear elastic modulus and stiffer tissue [66, 71, 115]. Shear elastic modulus is highly related to the muscular activity [68, 116], but prior work is largely limited to studying volitional contractions along a single axis and focus on muscles crossing hinge joints like the biceps brachii.

The SCM contributes to the 3-D rotational torque production of the neck, and therefore the previously described linear relationship between muscle activity and muscle shear elastic modulus may not be valid. The SCM exhibits distinctly different spatial tuning of SWV and muscle activity in 2-D, with the SWE preferred direction more laterally oriented than the EMG preferred direction [111]. However, these findings may be an artifact of the lack of constraints on the axial rotation torque produced during these volitional contractions. The anatomical moment arms of the SCM muscle suggest torque coupling between the three rotational axes of the neck is likely as the muscle is activated [38] and could influence the spatial tuning of the SCM's shear elastic modulus during volitional contractions.

Therefore, the purpose of the current study was to investigate the relationship between muscle activation and shear elastic modulus of the SCM during voluntary 3-D isometric torque production in healthy individuals. Twenty healthy participants produced 26 spherically-distributed submaximal 3-D neck torques while ultrasound SWE and surface EMG were acquired bilaterally from the SCM. We hypothesized that the SCM would display similar preferred directions where muscle activity and shear elastic modulus were maximal during voluntary 3-D isometric torque production. We further hypothesized increasing volitional torque production would not influence the preferred directions for muscle activity and shear elastic modulus. Lastly, we hypothesized that the focus of the data, which describes the angular dispersion of the data about the preferred direction, would be similar for EMG and SWE data and both torque levels. This study provides

novel insight into the intricate relationship between muscle activation and shear elastic modulus in a muscle that has lines of action in 3-D, and validate the ability to assess the 3-D muscle shear elastic modulus with SWE to support the future investigations of cervical pathologies with this technology.

## **2.3 Materials and Methods**

### *2.3.1 Participants*

Twenty healthy participants (10 male, 10 female; mean (SE): age: 25.1 (0.76) years, height: 1.7 (0.03) m, weight: 70.1 (3.81) kg) were recruited to participate in the present study. All participants reported no chronic or acute neck or upper extremity pain on the day of testing. The protocol was approved by the Institutional Review Board (HUM00119195) at the University of Michigan, and all participants provided written informed consent before participation.

### *2.3.2 Experimental Design*

Data collection was completed in a single 2-hour session. A pre-amplified, parallel-bar surface EMG sensor (Delsys Bagnoli Surface EMG Sensor, Natick, MA, USA: contact material = 99.9% Ag, contact dimensions =  $10 \times 1$  mm, inter-electrode distance = 10 mm, CMRR (0–500 Hz) = 92 dB, Input Impedance  $>10^{15} \Omega//0.2$  pF) was placed on each participant. The skin over the area of interest was exfoliated and cleaned with an alcohol swab. Afterward, the electrode was placed over the muscle belly and parallel to the muscle fibers by one researcher. The EMG electrode was placed unilaterally on the belly of one SCM at the halfway point between the sternoclavicular joint and the mastoid process. The side of the neck where the EMG electrode was placed over the SCM (left or right SCM) was randomized for each participant.

Ultrasound images were obtained from the contralateral SCM at the halfway point between the sternoclavicular joint and the mastoid process. The SWE images were taken using a Supersonic

Imagine Explorer system (Aix-en-Provence, France) with a linear transducer (SL 15-4, Elements: 256, Optimization: Standard, Persistence: Medium, Smoothing: 5, Frame Rate: 12 Hz) from the belly of the SCM while the transducer was aligned parallel to the muscle fascicles, as confirmed on the B-mode image [66, 111, 117]. We systematically controlled for the location of the EMG electrode and ultrasound transducer to ensure data were collected from the same portion of the muscle, so to prevent any biases based on location. A single ultrasonographer collected all images across all participants.

Participants were seated in an instrumental halo equipped with a six-degrees-of-freedom load cell (Delta Transducer, ATI Industrial Automation, Apex, NC) (**Figure 1**). The load cell measured forces and torques about the flexion/extension, left/right lateral bending, and left/right axial rotation axes. Kinetic and EMG data were collected simultaneously at 2,000 Hz using a data acquisition unit (USB-6351, National Instruments, Austin, TX). The EMG lead was amplified with a gain of 1,000 or 10,000 to maximize signal-to-noise from the muscle without clipping. The height of the halo was adjusted to just above each participant's supraorbital ridge. Each participant was asked to sit with their head and neck in a neutral posture, and their torso was secured against the back of the chair with two seatbelts crisscrossing the chest and a third seatbelt secured around the waist. To ensure participants could produce the desired torques, their head was secured using seven adjustable pads lining the halo. Digitization of anatomical landmarks (including the spinous process of C7, the right and left tragi of the ear, and the sternal notch) were acquired relative to the load cell using a stylus (OptoTrak Certus, Northern Digital Inc., measurement error = 0.1 mm). These anatomical landmarks were then used to determine the orthogonal axes of rotation about which cervical spine torques were calculated using previously reported methods [112], including the flexion/extension and lateral bending axes about T1 vertebral body and axial rotation axis about

the dens of C2. These axes of rotation were used in the calculation of neck torque in the following methods.

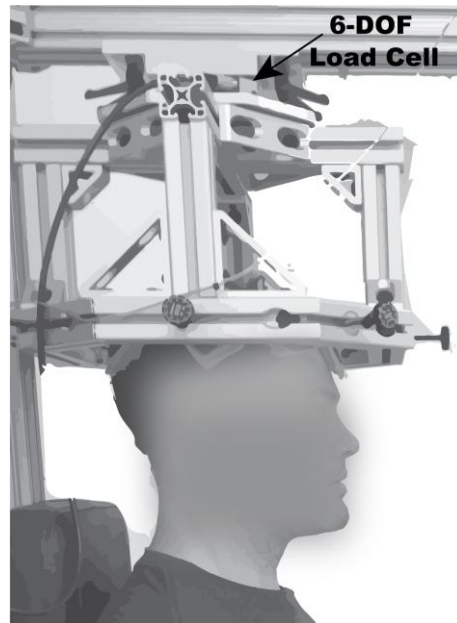


Figure 2.1 The experimental setup secured each participant's head with a metal halo attached to a six-degrees-of-freedom load cell. Each participant was seated in a neutral position with hips and knees at 90° and their torso was secured to the chair back with seatbelts to ensure the recorded torques were only produced by the neck.

Participants were asked to perform maximal voluntary contractions (MVC) in the flexion, extension, right and left lateral bending, and right and left axial rotation directions for ~3 seconds each at the beginning of the testing session. Two trials of MVCs were completed, separated by a 90-second rest period. The subsequent target-matching protocol was scaled to each participant's highest axial rotation MVC, which was calculated as the highest average value recorded over 200ms.

Participants were provided with visual feedback of their real-time torque production and their prescribed torque target. Participants controlled a cursor on a screen by changing the magnitude and direction of the 3-D torques generated within the instrumented halo. The location of the target on the screen displayed current torques produced along the flexion/extension axis as an upward/downward movement of a cursor and current torques produced along the left/right

lateral bending axis as leftward/rightward movement of the cursor. The cursor had a visible dial within it that rotated as torques were produced along the axial rotation axis. Increasing axial rotation torque was required as the deviation of the dial increased away from the 12 o'clock position to the right or left. The directions of the targets within a block were uniformly distributed about a sphere, requiring participants to produce 1-D, 2-D, and 3-D torques at a given torque magnitude (either 40% or 80% of the participant's maximal axial rotation MVC). Participants were instructed to move the cursor to match the prescribed submaximal torque and hold that torque for at least 2 seconds. Before data collection, all participants completed a practice block of 26 targets scaled to 40% of axial rotation MVC to ensure familiarity with the task.

Following the practice block, participants completed four randomized blocks of ramp-and-hold (RH) isometric target-matching. Two blocks of 26 targets were performed at 40% MVC and 80% MVC. Participants generated the prescribed 3-D cervical spine torque until an SWE image was taken by pressing a footswitch (Savant Elite2, Kinesis Corporation, Bothell, WA). This foot switch allowed the ultrasonographer to simultaneously capture the SWE image and trigger the data acquisition unit to record the resultant torque and EMG data.

#### 2.3.4 Data Analysis

For each trial, EMG data were detrended, band-pass filtered between 30-400 Hz, rectified, and low-pass filtered at 7 Hz [112]. The data were then averaged over over a 200ms window, ranging from 100 ms before to 100 ms after the footswitch was pressed to collect the SWE image.

EMG data from each trial was normalized to the highest recorded activation value using Equation

1.

$$EMG_{norm} = \frac{(EMG_{trial} - EMG_{base})}{(EMG_{max} - EMG_{base})} \quad (\text{Eq. 1})$$

The maximum ( $EMG_{max}$ ) and minimum ( $EMG_{base}$ ) activation values were computed across all trials.

The SWE images were analyzed in MATLAB (2011a, MathWorks, Inc., Natick, MA) to calculate SWV using established algorithms [111, 117]. The region of interest was systematically selected within the MATLAB program by a single researcher to ensure only SWV data corresponding to the muscle belly was analyzed. An algorithm provided by the manufacturer produced a quality map to evaluate the quality of the pixels within each image (quality factor ranged from 0-1). Only the pixels with a quality factor greater than 0.7 were used to calculate the mean SWV for each image.

The preferred direction and focus of both EMG and SWE data were then calculated using spherical statistics [118]. The preferred direction of a muscle describes the torque direction where the muscle has the highest respective value (EMG or SWV), while the focus describes the level of spread the data exhibits about the preferred direction. For EMG data, the preferred direction of each muscle was found by calculating the resultant vector (i.e. vector sum) for all EMG magnitudes across the 26 target locations. For SWE data, the preferred direction was found by calculating the resultant vector of all mean SWV magnitudes across the 26 targets. Each participant's average EMG and SWE preferred direction for a given torque target were computed using the vector average from two repetitions. All vectors were converted to a unit vector for statistical analysis by dividing each vector component by the vector magnitude. Focus ( $r$ ) was calculated by dividing the magnitude of the resultant vector by the sum of EMG and SWV magnitudes, respectively, across all targets [112, 118]. Angular deviation, the angular translation of focus, was calculated as  $\sqrt{1 - r}$  [112]. Lastly, the average EMG and SWV focus for each torque amplitude was calculated for each participant.



### 2.3.5 Statistical Analysis

The calculated EMG and SWE mean preferred directions in Cartesian coordinates (x,y,z) for all participants were mirrored to the right side to allow for direct within-subject comparisons of ipsilateral/contralateral bending and ipsilateral/contralateral axial rotation. The SWE and EMG data from all participants were fit to a Kent distribution (with  $\kappa > 2.6$  considered a significant Kent distribution) [119-121]. The Kent distribution allows for a 95<sup>th</sup> percentile confidence interval ellipse to be fit about the mean preferred direction for the data for a given experimental condition.

To test our first hypothesis, we performed within-subject pairwise comparisons of the SCM's preferred direction for the EMG and SWV data. Separate comparisons were made for volitional contractions at the 40% and 80% MVC torque level. To test our second hypothesis, we performed a pairwise comparison of the SCM's preferred direction as volitional torque was increased from 40% to 80% MVC. Separate comparisons were performed for the EMG and SWV data. For all pairwise comparisons, the preferred directions were considered significantly different if the mean preferred direction of one condition was not included in the 95<sup>th</sup> percentile confidence ellipse for the other condition. Finally, the preferred direction for each condition was converted to spherical coordinates (azimuth and elevation) to allow for comparisons with prior studies.

To test our final hypothesis, the focus for the SCM between the SWE and EMG collections at both 40% and 80% MVC was assessed using a two-way repeated-measures ANOVA (SPSS 24, IBM, Chicago, IL), where data type (SWE, EMG) and torque amplitude (40% MVC, 80% MVC) were within-subjects fixed factors. Finally, intra-rater reliability was also evaluated for the SWV values calculated from the SWE images using the intraclass correlation coefficient (ICC). Significance was set at  $p < 0.05$  for all analyses.

## 2.4 Results

On average, the participants were strongest in extension (mean (SE): 36.8(3.6) Nm) and were similarly strong in flexion (mean (SE): 27.5(3.6) Nm) and right and left lateral bending (mean (SE): 24.7(3.2) Nm and 25.9(3.4) Nm, respectively). Participants were weakest when producing right and left axial rotation (mean (SE): 7.5(0.9) Nm and 7.6(0.8) Nm, respectively). The maximal isometric strength of the entire participant group as well as stratified by sex is displayed in **Table 1**. The SWE images acquired during the experiment exhibited excellent intra-rater reliability across all targets and torque amplitudes, with a mean ICC value of 0.92 (95% CI: 0.91-0.93).

Table 2.1 The mean (SE) maximal voluntary torque production (reported in Nm) for the participant group and stratified by sex. Abbreviations for torque direction: flexion (FLEX), extension (EXT), right lateral bending (RLB), left lateral bending (LLB), right axial rotation (RAR), and left axial rotation (LAR). Data is reported as the mean and standard error (SE) of the mean.

<b>Torque Direction</b>	<b>Group (N=20)</b>	<b>Male (N=10)</b>	<b>Female (N=10)</b>
FLEX	27.5 (3.6)	37.5 (5.7)	17.6 (1.1)
EXT	36.8 (3.6)	47.4 (5.1)	26.3 (2.1)
RLB	24.7 (3.2)	32.6 (5.0)	16.8 (2.1)
LLB	25.9 (3.4)	34.4 (5.5)	17.5 (1.9)
RAR	7.5 (0.9)	9.5 (1.4)	5.5 (0.4)
LAR	7.6 (0.8)	9.9 (1.3)	5.3 (0.5)

The SCM's preferred direction for both muscle activity and SWV was primarily oriented towards a combination of flexion, ipsilateral lateral bending, and contralateral axial rotation. Intensity plots for a representative participant demonstrate the location of the preferred direction and focus of the data for both SWE and EMG in 3-D (**Figure 2A-B**), as well as the associated tuning curves illustrating both the preferred direction and angular range of the SCM for both SWE (**Figure 2C, E**) and EMG (**Figure 2D, F**). The tuning curves display the representative participant's azimuth angle on the flexion/lateral bending plane (**Figure 2C, D**) and elevation

angle on the axial rotation/flexion plane (**Figure 2E, F**). The mean preferred directions are reported as azimuth and elevation angles for all participants in **Table 2**.

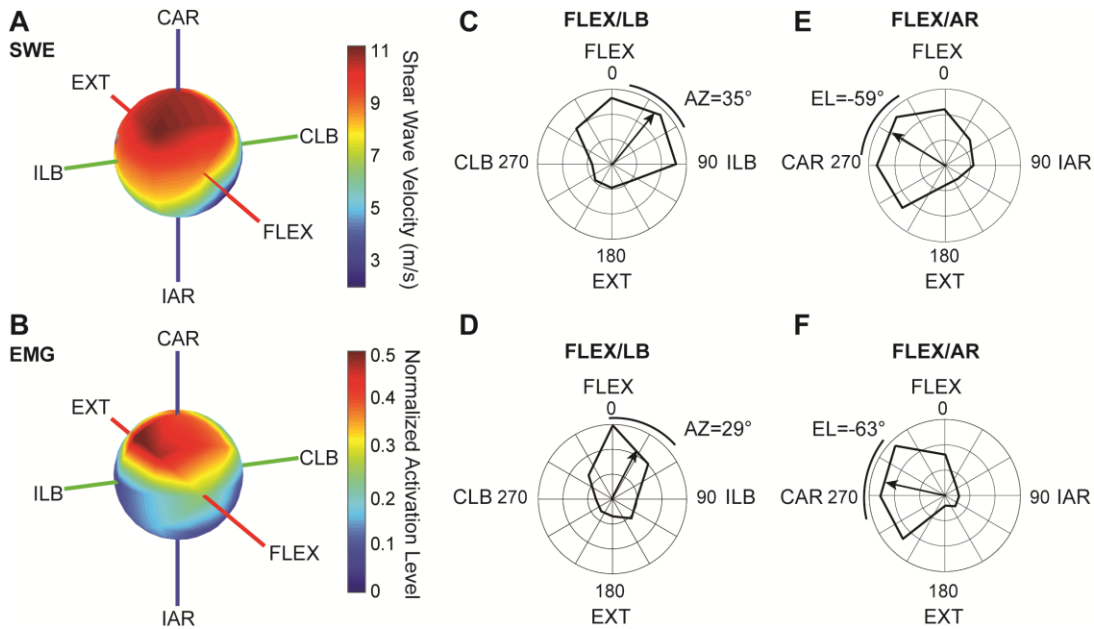


Figure 2.2 Representative intensity spheres and tuning curves exhibiting how SWE (top row) and EMG (bottom row) vary for the SCM across the 26 uniformly distributed submaximal 3-D cervical spine torques (scaled to 80% of the maximal torque produced during axial rotation). Color bars beside the intensity spheres in A and B reflect the range of data collected from the representative individual. For the tuning curves, the C and D plots are the flexion/extension and ipsilateral/contralateral bending plane (FLEX/LB) and the E and F plots are the flexion/extension and ipsilateral/contralateral axial rotation plane (FLEX/AR). The tuning curve (solid line) represents how EMG activity or SWV change across each torque direction. The preferred direction calculated across all torque directions is denoted by the arrow. An angular bracket outside the circular region indicates one angular deviation for this participant. The azimuth (AZ) and elevation (EL) angles for the participant’s preferred direction vector for SWE (C) or EMG (E), respectively. Abbreviations denote torque directions (flexion (FLEX), extension (EXT), contralateral bending (CLB), ipsilateral bending (ILB), contralateral axial rotation (CAR), and ipsilateral axial rotation (IAR))) and type of data collected (SWE = shear wave elastography and EMG = electromyography).

The preferred directions for both muscle activity and shear wave velocity acquired from all participants were unimodal and were fit well with a Kent distribution ( $\kappa > 36.5$  for all experimental conditions). The preferred directions for all participants and the corresponding 95% confidence interval ellipses are displayed in **Figure 3**. The major and minor axes of these ellipses are provided in **Table 2**. There was a significant difference between the EMG and SWE preferred directions at both 40% and 80% torque level. This is visually indicated in **Figure 3A** as the mean

preferred direction for the EMG data was not bound within the 95<sup>th</sup> confidence interval ellipse for the preferred direction of the SWE data. Therefore, we reject our primary hypothesis that preferred directions would be similar between data types during 3D isometric torques. Increasing the volitional torque from 40% to 80% MVC did not significantly change the preferred direction for either the EMG or SWE data (e.g. the mean preferred direction for the 80% MVC condition was within the 95<sup>th</sup> confidence for the 40% MVC condition) (**Figure 3B**). Therefore, we accept our secondary hypothesis that increasing volitional torque production would not influence the preferred directions for muscle activity and shear elastic modulus.

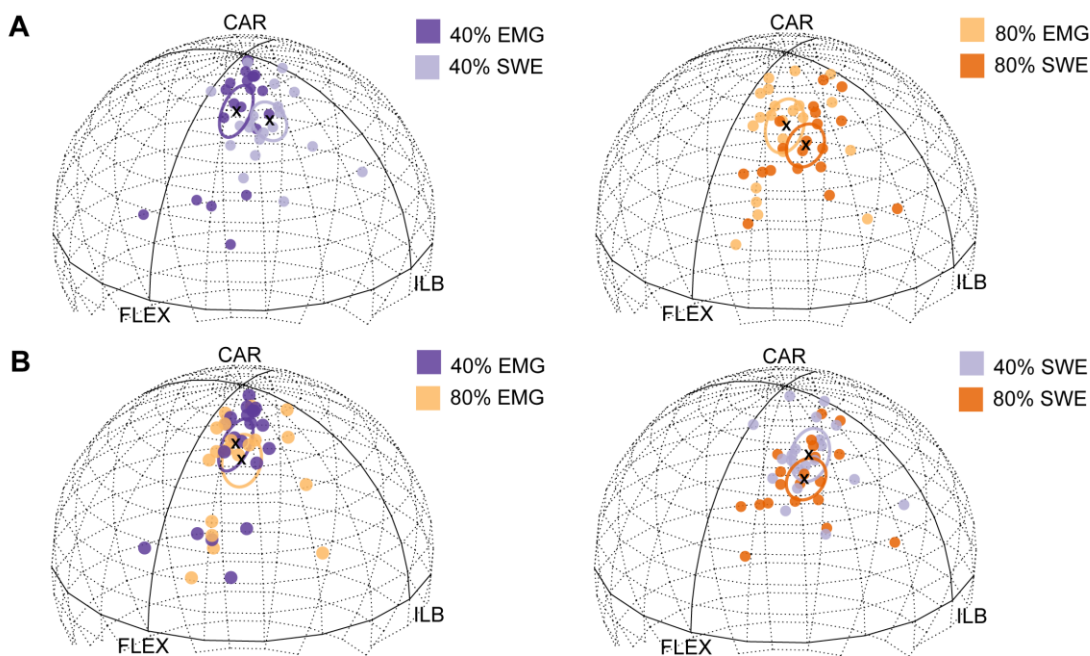


Figure 2.3 Pairwise comparisons of the preferred directions for each participant's EMG and SWE data are shown. Four groups were compared, including EMG data at 40% (dark purple) and 80% (light orange) MVC, as well as SWE data at 40% (light purple) and 80% (dark orange). All groups demonstrated a preferred direction in a combination of flexion, ipsilateral lateral bending, and contralateral axial rotation. For each group, 95% confidence interval ellipses about the mean direction were constructed. The four spheres correspond to the four pairwise comparisons completed, with A) investigating the effect of data type on the preferred direction and B) investigating the effect of torque level on the preferred direction. The black X's represent the mean preferred direction for each group, and the ellipse surrounding the mean preferred direction is the 95% confidence interval ellipse for the corresponding data.

Table 2.2 The mean preferred direction (reported as the azimuth and elevation of the 3-D vector), focus, and the major and minor axes for the ellipse representing the 95% confidence interval about the mean preferred direction for a given experimental condition. The experimental conditions included two data types (EMG and SWE) and two volitional torques (40% and 80% MVC). Forward flexion is 0°, right lateral bending is 90°, extension is 180°, and left lateral bending is 270°. Focus values are mean ± standard error (S.E). Abbreviations are for the type of data collected: electromyography (EMG) and ultrasound shear-wave elastography (SWE), as well as the calculated 95% confidence interval (CI) axes values.

Data Type	% MVC	Mean Azimuth	Mean Elevation	Focus	95%CI Major	95%CI Minor
EMG	40	24.9°	-62.9°	0.18 ± 0.02	10.47	4.25
	80	29°	-57.4°	0.22 ± 0.02	9.67	5.93
SWE	40	44.1°	-58.4°	0.17 ± 0.01	7.05	5.41
	80	38.5°	-50.5°	0.18 ± 0.01	7.42	5.42

The spatial focus of the SCM’s muscle activity and SWV were significantly influenced by torque amplitude ( $F_{1,19}=5.0$ ,  $p=0.038$ ), with a higher focus associated with trials scaled to 80% MVC (**Figure 4, Table 2**). However, the spatial focus did not differ between the EMG and SWE data ( $F_{1,19}=1.7$ ,  $p=0.21$ ), nor was there an interaction effect of data type by torque level ( $F_{1,1}=3.4$ ,  $p=0.079$ ). Therefore, we reject, in part, our hypothesis that focus would be similar for EMG and SWE data and between both torque levels.

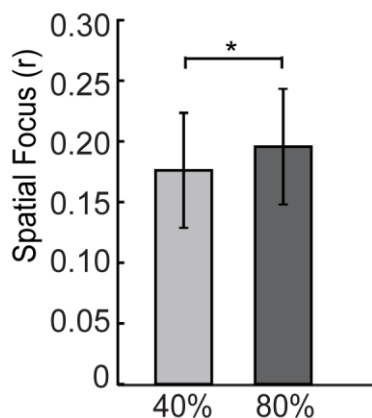


Figure 2.4 Mean spatial focus is plotted for the SCM for both torque levels (40% and 80% axial rotation MVC). The SCM muscle exhibited a significantly higher focus during the 80% MVC torque amplitude than the 40% MVC amplitude. This main effect of torque amplitude is denoted by an asterisk (\*). Black bars denote standard error (S.E) of the mean.

## 2.4 Discussion and Summary

The purpose of this study was to investigate the relationship between the muscle activations and shear elastic modulus of the SCM muscles during 3-D isometric torque production. We hypothesized that the SCM would display similar preferred directions where muscle activity and shear elastic modulus were maximal during voluntary 3-D isometric torque production at both 40% and 80% torque level due to the previously established linear relationship between muscular activity and tissue elasticity in muscles acting in 2-D [68, 116]. The SCM exhibited preferred directions in a 3-D combination of flexion, ipsilateral bending, and contralateral axial rotation for both EMG and SWE collections, which are consistent with results from previous studies [111, 112]. During 3-D torque production, the shear elastic modulus of the SCM has a preferred direction that is more laterally oriented with a reduced axial rotation component when compared to muscular activity at both the 40% and 80% torque level. Additionally, increasing the torque production level increased the focus of the SCM muscle activity and shear elastic modulus. The current study establishes the feasibility of assessing the relationship between muscular activity and shear elastic modulus in the SCM during 3-D torque production and provides normative values for expanding these methodologies to assess common cervical pathologies including chronic neck pain.

The significant difference in the preferred directions of the SCM's muscle activity and shear wave velocities were largely driven by the SWE data being oriented more towards ipsilateral bending and less towards contralateral axial rotation than the EMG data. On average, the azimuth angle of the preferred direction vector for the SWE data was  $14^\circ$  closer to lateral bending than the corresponding azimuth angle for the EMG data. The elevation angles were  $5.7^\circ$  less for the SWE data than the EMG data. The difference in azimuth angle is consistent with our group's previous work in 2-D, which demonstrated a mean  $13.7^\circ$  difference between EMG and SWE even when not

controlling for axial rotation torque production [111]. Previously reported 3-D azimuth angle values for the SCM calculated from EMG data differ slightly from our results, with some oriented closer to forward flexion [112], and others more laterally oriented [109]. Our elevation angles calculated from EMG and SWE are lower than those reported by Vasavada, Peterson [112] with a difference of  $6.7^\circ$  and differed drastically from Fice, Siegmund [109] with their elevation angle  $37^\circ$  lower than the present study. The deviation from the latter study may be due to differences in experimental design. We scaled all components of each target to the participants' axial rotation MVC and therefore likely required greater muscular demand during axial rotation torque production than Fice, Siegmund [109]. Given that we scaled our targets equally for both EMG and SWE, this increased axial rotation demand would not have altered our findings in relation to our hypotheses.

This study demonstrated statistically significant differences between the preferred directions for muscular activity and shear elastic modulus for the SCM during 3-D isometric contractions. A closer inspection of our data in **Figure 3** seems to indicate that these differences are small and therefore may not be a clinically meaningful difference in healthy individuals. Our results largely demonstrate that the shear elastic modulus of the SCM is predominantly driven by muscle activation during 3-D volitional neck torque production. The more ipsilateral bending and less contralateral axial rotation orientation of the preferred direction vector for the SWE findings may be indicative of the anatomical properties (including moment arms, fascicle length, and pennation angles) influencing the shear modulus of the tissue. This anatomical information may be leveraged in a way that allows greater shortening of the muscle without greater muscle activation [122], which could independently influence the shear elastic modulus [123]. To our knowledge, the complicated relationship between anatomical properties, muscle elasticity, and

level of muscle activation has only been investigated in the lower leg muscles. Also, these findings in the lateral direction largely confirm our prior work and suggest that unconstrained axial rotation torque production is not responsible for our prior findings. While shear wave velocity of the SCM muscle scales largely with muscle activation in healthy individuals, further work is needed to determine if these relationships hold in participants with cervical pathologies.

Our findings could have clinical utility for monitoring muscle activity and force production in other neck muscles with SWE that cannot be monitored with surface EMG. While surface EMG is feasible with a superficial neck muscle like the SCM, surface electrodes cannot collect quality electromyographic data from the deep muscles of the neck [124]. Indwelling intramuscular electrodes can be used to monitor muscle activity in deep muscles of the neck [125], but these methods are invasive and inherently risky, particularly at the neck [126]. An alternative method of recording activity of the deep cervical flexors involves the invasive procedure of inserting an EMG electrode through the nose and suctioning it to the back of the oropharynx [46]. SWE provides a valuable tool for collecting muscular activity data from deep muscles of the neck while being safe, non-invasive, and pain-free for the participant. Especially for populations experiencing painful cervical pathology, SWE may be a preferred method to quantify deep muscular activation when investigating the effect of pathology on neck function.

There were limitations to this study. Cervical torque production during dynamic movements is more clinically relevant than the isometric assessments performed here. However, it takes 3-5 seconds to obtain a satisfactory SWE image, limiting our collection to isometric conditions. Our analytical methods are also sensitive to the number of targets included in the study. Although 26 targets provided a complete 3-D representation of EMG and SWE activity, the inclusion of more targets would create a more specific preferred direction for each muscle and



further insight into muscle behavior. We also adopted an approach where we scaled our targets to the MVCs produced during axial rotation, the weakest direction for the neck. It is likely that the increased the axial rotation component of the targets resulted in in higher elevation angles at the preferred direction. However, the targets were scaled the same for both EMG and SWE, so it is unlikely that this affected our hypothesis testing. The method we used to scale our targets differs from some similar studies, limiting our ability to directly compare our findings. Our findings on torque production about the cervical spine are limited to the SCM, as it was the only muscle evaluated here with SWE. Future work should be expanded to assess the feasibility of SWE as a tool to monitor neck pathologies typified by changes to tissue stiffness.

## **2.5 Conclusions**

During 3-D torque production at the neck, SCM shear elastic modulus as measured by ultrasound SWE is largely driven by muscle activation in healthy individuals. While the preferred direction of the SCM calculated by both EMG and SWE was statistically different, the absolute difference in preferred directions were small and therefore it is unlikely this difference is clinically meaningful. These results support the future use of SWE for evaluating the SCM of healthy individuals and individuals with cervical pathologies. SWE also provides as non-invasive method for evaluating neural activity in the deep muscles of the neck. Future work should attempt to characterize distinctive neural control of muscle activations and shear elastic modulus in varying types of cervical pathologies and assess the feasibility of monitoring these changes using SWE.

## **2.6 Acknowledgments**

We thank Katherine B. Wei for her expertise and contributions to the data analysis. This study was funded in part by the University of Michigan Rogel Cancer Center CCubed program. This is placeholder text that is formatted correctly, but should be replaced by the contents of your dissertation.

### **Chapter 3 The Influence of Idiopathic Chronic Neck Pain on Upper Trapezius and Sternocleidomastoid Muscle Activity and Elasticity during Functional Reaching: A Cross-Sectional Study**

The following chapter was published in the *Journal of Biomechanics* in August 2022, and all images contained in this chapter are copyrighted by Elsevier. Please refer to the following publication when referencing this work: Wolff, W. L., Heinemann, C.M., & Lipps, D. B. (2022). The influence of idiopathic chronic neck pain on upper trapezius and sternocleidomastoid muscle activity and elasticity during functional reaching: A cross-sectional study. *Journal of Biomechanics*, 141, 111223. doi.org/10.1016/j.jbiomech.2022.111223.

#### **3.1 Abstract**

It remains unclear whether idiopathic chronic neck pain is associated with changes in muscle stiffness alongside alterations in neuromuscular control. Therefore, the purpose of this study was to determine the influence of idiopathic chronic neck pain on the muscle stiffness and muscle activity of the upper trapezius and sternocleidomastoid muscles during the maintenance of unilateral and bilateral functional reaching tasks. Surface electromyography (EMG) and ultrasound shear wave elastography were collected from the sternocleidomastoid and upper trapezius muscles in 18 individuals with idiopathic chronic neck pain and 18 matched healthy controls. Participants completed three functional reaching tasks; 1) unilateral forward reach, 2) bilateral forward reach, and 3) unilateral upward reach, and held at the top of each reaching movement for data to be collected bilaterally. A univariate ANOVA was utilized for each outcome measure (mean EMG

amplitude and shear wave velocity) and each reaching task. Individuals with idiopathic chronic neck pain exhibited significantly lower upper trapezius activation during bilateral reaches without corresponding changes to stiffness during similar trials. Similarly, this cohort exhibited decreased sternocleidomastoid stiffness during forward reaching, without corresponding activation changes. Lastly, women demonstrated consistently higher sternocleidomastoid activation and stiffness when compared to men. These findings indicate individuals with idiopathic chronic neck pain may adapt their movement strategies, possibly for pain avoidance. The demonstrated changes in muscle stiffness independent of changes in muscle activity highlight the importance of evaluating both muscle stiffness and activation in individuals with idiopathic chronic neck pain prior to designing rehabilitation programs.

*Keywords: neck pain, sternocleidomastoid, upper trapezius, ultrasound shear wave elastography, electromyography, muscle stiffness*

### 3.2 Introduction

Neck pain is the fourth leading cause of disability in the United States [4], resulting in personal and economic burdens for the individuals affected [7]. Approximately 67% of all individuals will be affected by neck pain during their life [1, 2]. One-third of adults with neck pain report difficulty performing activities of daily living due to their pain [3], which affects their ability to care for themselves and reduces their quality of life. Idiopathic neck pain (e.g., pain with no underlying injury or known pathology) becomes chronic when the pain has lasted over three months. Unfortunately, most individuals with idiopathic chronic neck pain experience persistent symptoms or recurrence of pain within five years [1]. Therefore, there is a need to further investigate the pathophysiology of idiopathic chronic neck pain.

People with idiopathic chronic neck pain often self-report the sensation of muscle stiffness [77]. Enhanced muscle stiffness may be due to adaptations in the neuromuscular control of the neck-shoulder muscles and changes to the muscles' material properties [127]. Increased neck muscle stiffness could inhibit the proper function of the muscle [55] and result in pain due to increased loading onto the cervical spine [33]. Ultrasound shear wave elastography is a reliable and non-invasive technology that can estimate muscle's *in vivo* shear elastic modulus by measuring the propagation velocity of shear waves throughout the tissue [66, 71, 114]. Shear wave elastography can evaluate neck muscle function [72, 128]. When combined with surface electromyography (EMG) recordings of muscle activity, changes in tissue stiffness can be explained by altered neural drive or changes to the tissue's underlying material properties [74, 75].

It is unclear how idiopathic chronic neck pain affects the stiffness of neck-shoulder muscles [55, 77, 78]. Identifying a link between chronic neck pain and muscle stiffness is particularly important for females, who have a higher idiopathic chronic neck pain prevalence than males [2]

and demonstrate higher passive muscle stiffness in other muscles, like the biceps brachii [129]. This necessitates further research on the sex disparities in neck muscle mechanics for those with idiopathic chronic neck pain. Individuals with neck pain exhibit increased neck muscle stiffness. Specifically, shear wave elastography revealed greater SWV in the upper trapezius (UT), levator scapulae, and SCM during relaxed supine and prone lying in people with idiopathic chronic neck pain than healthy controls [55]. The increase in SWV during relaxed conditions indicates a change in the tissue material properties [55] or increased muscle tone when relaxed. Contrarily, there were no observed differences between these groups in neck extensor muscle stiffness during several isometric neck and upper extremity tasks [78]. The lack of consensus on idiopathic chronic neck pain's effect on muscle stiffness maybe due to a lack of investigation of functionally relevant tasks. Many upper extremity activities of daily living require a broad range of motion [82], which necessitates investigating neck-shoulder muscle stiffness during more applicable activities of daily living such as reaching tasks.

Therefore, the purpose of the current study was to determine the influence of idiopathic chronic neck pain on the muscle stiffness and muscle activity of the UT and SCM muscles during the maintenance of unilateral and bilateral functional reaching tasks. We hypothesized that the SCM and UT would exhibit significantly greater muscle activity and stiffness for all three reaching tasks for individuals with idiopathic chronic neck pain when compared to healthy controls. Our secondary hypothesis was that females would exhibit increased stiffness and muscle activity in the UT and SCM compared to males. The findings of this study provide novel insight into the neuromuscular and material changes to the SCM and UT during functional reaching for individuals with idiopathic chronic neck pain.

### **3.3 Methods**

### *3.3.1 Setting*

This cross-sectional study sought to determine neuromuscular differences between adults with idiopathic chronic neck pain and healthy controls. Data collection was completed in a single 2-hour session. Recruitment and data collection took place between September 2020 and August 2021, with a brief pause in data collections from December 2020 – February 2021 due to research restrictions in response to the COVID-19 pandemic.

### *3.3.2 Participants*

We recruited 18 individuals with mild-to-moderate idiopathic chronic neck pain (7 male, 11 female) and eighteen sex, age, stature, and body mass-matched healthy controls (7 male, 11 female). All participants were right-hand dominant except for three healthy controls. Inclusion criteria for the idiopathic chronic neck pain group were adults with neck pain lasting greater than three months and a Neck Disability Index (NDI) score of 5-24 (out of 50). Exclusion criteria included any musculoskeletal diagnosis of or injury to the head, neck, or shoulder, or current participation in physical rehabilitation programs for the neck or shoulder. For the healthy control group, inclusion criteria were adults without the existence of neck or shoulder pain, and exclusion criteria for the healthy control group included an NDI score above 4. The protocol was approved by the Institutional Review Board (HUM00169762) at the University of Michigan, and all participants provided written informed consent.

We powered our study based on a prior study that demonstrated a 25% increase in muscle elasticity (effect size  $f = 0.45$ ) in individuals with idiopathic chronic neck pain compared to healthy controls [55]. A total sample size of 32 was required to detect a between-subjects difference in muscle elasticity with an ANOVA model based on this effect size, an alpha level of 0.05, 80% power, 0.7 correlation between repeated measures [130], and eight measurements.

### 3.3.3 *Experimental Design*

The study examined how mean SWV and normalized EMG from the SCM and UT muscles were modified by participant group (healthy and idiopathic chronic neck pain) and reaching task (unilateral or bilateral, and forward reach or upward reach). We further examined how the side of image collection (right or left) and, for the unilateral reaches, reaching arm (right or left) modified our outcome measures. SWV data were collected with an ultrasound shear wave elastography machine (Supersonic Imagine Aixplorer system, Aix-en-Provence, France), and surface EMG data were collected using Delsys Quattro EMG sensors (Natick, MA, USA). All participants underwent identical data collection sessions.

Functional clinical assessments were collected at the beginning of the session. Grip strength was measured with a handheld dynamometer. Active neck range of motion in six directions (flexion, extension, right and left lateral bending, left and right axial rotation) was obtained using a plastic goniometer. One researcher collected the range of motion measurements for all participants.

Surface EMG electrodes were placed unilaterally on the UT and SCM for each participant. The skin over the areas of interest were prepped with an exfoliating gel and subsequently cleaned with an alcohol wipe. The specific muscle locations of interest were first marked with hypoallergenic tape to ensure consistent electrode and ultrasound transducer placement. The electrodes were then placed parallel to the muscle fiber and over the UT and SCM muscle belly by a single researcher. The SCM electrode was placed just distal to the midpoint between the mastoid process and sternoclavicular joint. The UT electrode was placed 2 cm distal to the midpoint between the C-7 spinous process and the acromion process.



It is not feasible to simultaneously collect surface EMG and shear wave elastography from the same exact location on the muscle belly. Therefore, the testing procedures had to be repeated with EMG and ultrasound measures being collected on contralateral sides of the neck (**Figure 1**). The side of the initial electrode placement (right or left neck) was randomized for each participant to minimize the effect of learning adaptations. This resulted in muscle activity and muscle stiffness data be recording for both the UT and SCM muscles from both sides of the neck. The study team ensured the reaches were performed the same way as participants repeated the procedures.

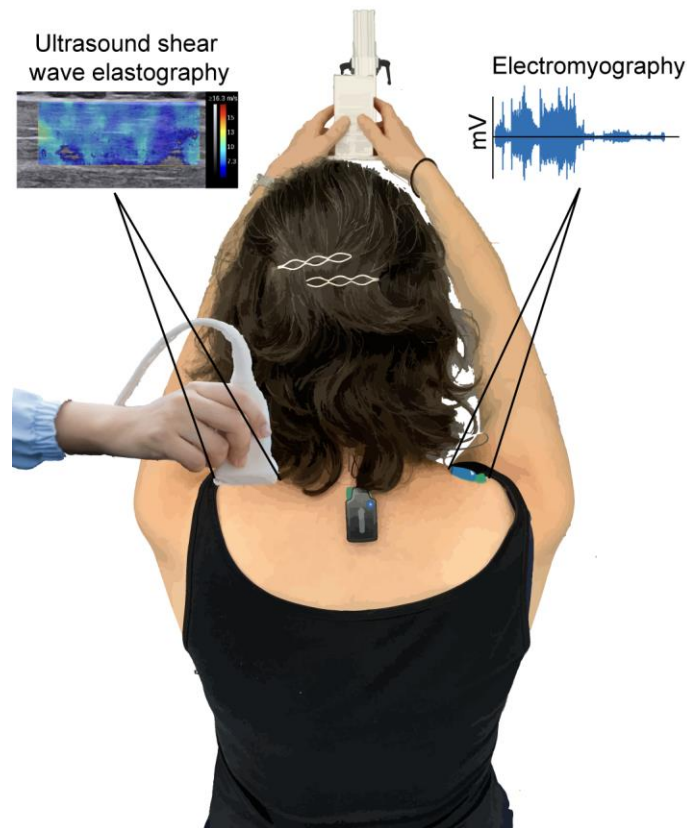


Figure 3.1 Experimental setup of the functional reaching tasks. We collected electromyography (EMG) data from one side of the participant and ultrasound shear wave elastography (SWE) data from the contralateral side. After all reaching tasks were completed, the EMG and SWE were switched to the opposite side and the experimental protocol was repeated. Setup for the upper trapezius is shown here, but data were also collected simultaneously from the sternocleidomastoid (not shown) following the same experimental setup.

Ultrasound images were obtained from the contralateral SCM and UT in the same locations described above for the EMG electrode placement. The shear wave elastography images were taken with a linear transducer (SL 15-4, Elements: 256, Optimization: Standard, Persistence: Medium, Smoothing: 5, Frame Rate: 12 Hz) from the belly of the SCM or UT. The transducer was aligned parallel to the fascicles of the muscle of interest using the displayed B-mode image [67, 72, 117]. The location of the EMG electrode and ultrasound transducer was kept consistent to prevent any biases based on transducer location. A single ultrasonographer collected all images across all participants.

Before completing any reaching tasks, resting ultrasound shear wave elastography images were collected. Two images were taken of the UT bilaterally while the participant was lying prone with their face resting in a hollow headrest and arms resting along their side. Two images were taken of the SCM bilaterally while the participant was lying supine with their head resting at the same level as their body and their arms resting along their sides. The participants then performed maximum voluntary contractions (MVCs) against manual resistance. The MVCs completed were neck flexion, extension, left and right lateral bending, and maximal shoulder shrug from a neutral seated position. Each maximal contraction was sustained for ~2 seconds. Two trials of MVCs were completed, with a 90-second rest period between the two trials.

The participants completed three functional reaching tasks: 1) a unilateral forward reach to a head-high shelf, 2) a bilateral forward reach to a head-high shelf, and 3) a unilateral upward reach to a lightbulb that was positioned 4-inches above head-height. The participants were instructed to stand an arm-length away from the reaching target [82] while ensuring this distance did not include rotation of the torso or exaggerated protraction of the scapula. A small object (5cm x 10cm x 5cm) was placed on the shelf for the unilateral and bilateral forward reaches, and a

lightbulb was hanging in the target position for the unilateral upward reach. The instructions dictated to the participants asked them to reach toward the object in a natural motion but not to pick up the object or rest their hand on the object or shelf. They were then instructed to pause at the top of their reaching movement and hold for up to 5 seconds as the shear wave elastography image was taken of one muscle (either UT or SCM), and EMG data was collected simultaneously. Participants were then asked to return to the resting position for ~5 seconds. Special care was taken to ensure participants did not rest the arm on the shelf. Each task was completed four times to allow for two successful images to be taken from both the UT and SCM. The unilateral tasks were completed using each arm. A footswitch (Savant Elite2, Kinesis Corporation, Bothell, WA) was utilized to capture each shear wave elastography image, which simultaneously triggered a Delsys Trigno Analog Adapter (Delsys, Natick, MA) to record EMG data.

Potential sources of bias were reduced by randomizing the order of reaching tasks and the order that the muscles were imaged within each task. Additionally, the side of first image collection was randomized for each individual. Rigorous standards for sensor and probe placement ensured consistent placement between participants and between trials. Finally, a single ultrasonographer collected all images.

### *3.3.4 Statistical Analysis*

The primary outcome measures for this study were the mean SWV and normalized EMG (%MVC) of the SCM and UT muscles. For each task, EMG data was detrended, band-pass filtered with a 3<sup>rd</sup> order Butterworth filter between 30-500 Hz, and rectified. The average EMG amplitude was then calculated over a 200 ms window surrounding each EMG collection, ranging from 100 ms before to 100 ms after the ultrasound image was obtained. EMG data from each collection point

was normalized as a percentage of MVC collected for the corresponding muscle. Shear wave elastography images were analyzed using established algorithms in MATLAB [72, 117]. A single researcher systematically selected the region of interest within the MATLAB program to ensure only the SWV data from the muscle belly was analyzed, excluding the surrounding tissues.

We examined our primary hypotheses that the mean SWV and EMG amplitude for the SCM and UT would be significantly greater for all three reaching tasks for individuals with idiopathic chronic neck pain when compared to healthy controls using a univariate ANOVA for each outcome measure and each reaching task. We ran separate models for each outcome measure and reaching task to improve the interpretability of our results. Participant group (idiopathic chronic neck pain vs. healthy) was our primary variable, and treated as a fixed factor in the ANOVA model. The model adjusted for relevant experimental within-subjects factors, including the muscle side examined (left, right), and the reaching arm (ipsilateral vs. contralateral to examined muscle). We examined our secondary hypothesis that females would exhibit increased stiffness and muscle activity in the UT and SCM when compared to males by including sex (male, female) as a fixed factor in the ANOVA models as well. Significance was set at  $\alpha=0.05$  *a priori*.

### 3.4 Results

Participant demographics and grip strength are displayed in Table 1. There were no significant differences between the idiopathic chronic neck pain and healthy groups in age, stature, body mass, head or neck circumference, or grip strength (all  $P>0.35$ ) (**Table 1**). On average, the participants with idiopathic chronic neck pain had reduced range of motion in extension ( $P=0.003$ ) and left lateral bending ( $P=0.029$ ), but no significant differences in flexion, right lateral bending, or right or left axial rotation (all  $P>0.05$ ) (**Table 2**).

Table 3.1 Mean demographic data for the chronic neck pain and healthy participants. Values are mean  $\pm$  standard error (S.E). Abbreviations are for chronic neck pain (CNP), Neck Disability Index (NDI), circumference (CIR), left (L.), and right (R.). There were no significant differences between group demographics.

			<b>Age</b>	<b>Stature</b>	<b>Body</b>	<b>HeadCIR</b>	<b>NeckCIR</b>	<b>R.Grip</b>	<b>L.Grip</b>
<b>Group</b>	<b>NDI</b>	<b>Sex</b>	<b>(years)</b>	<b>(m)</b>	<b>Mass (kg)</b>	<b>(cm)</b>	<b>(cm)</b>	<b>(kg)</b>	<b>(kg)</b>
<b>CNP</b>	15.3	11 F	34.4	1.7	69.4 (2.7)	55.3 (0.6)	34.5 (0.8)	42.0	39.7
	(1.3)	7 M	(2.5)	(0.02)				(3.1)	(3.0)
<b>Healthy</b>	<1	11 F	32.2	1.7	71.9 (3.3)	55.3 (0.6)	33.7 (0.9)	45.3	43.9
	(0.1)	7 M	(3.0)	(0.03)				(3.0)	(4.1)

Table 3.2 Mean volitional range of motion data for the chronic neck pain and healthy participants. Values are mean  $\pm$  standard error (S.E). Abbreviations are for chronic neck pain (CNP), flexion (FLEX), extension (EXT), right lateral bending (RLB), left lateral bending (LLB), right axial rotation (RAR), and left axial rotation (LAR). Significant group differences are denoted with an asterisk (\*).

<b>Group</b>	<b>FLEX (°)</b>	<b>EXT (°)</b>	<b>RLB (°)</b>	<b>LLB (°)</b>	<b>RAR (°)</b>	<b>LAR (°)</b>
<b>CNP</b>	43.8 (2.1)	44.2 (2.0)*	35.9 (2.2)	29.4 (1.6)*	63.8 (2.3)	66.7 (2.3)
<b>Healthy</b>	46.9 (2.4)	53.9 (2.3)*	34.8 (1.6)	34.3 (1.5)*	69.3 (1.8)	70.7 (1.4)

Individuals with idiopathic chronic neck pain exhibited significantly lower UT EMG amplitudes during bilateral reaches, but there were no changes to the elastic properties of the UT during similar trials. There was a significant main effect of group on UT EMG amplitude for the bilateral forward reach ( $F_{1,5}=8.71$ ,  $P=0.004$ ), with the idiopathic chronic neck pain group exhibiting lower UT EMG amplitude when compared to healthy controls (**Figure 2A**). However, the significant reductions in EMG amplitude did not correspond with changes in the elastic properties of the UT during the bilateral forward reach ( $F_{1,5}=0.028$ ,  $P=0.87$ ) (**Figure 2A**). Unilateral reaching produced was no significant main effect of group on either UT EMG amplitudes or SWV (all  $F_{1,7}<1.854$ ,  $P>0.175$ ). Lastly, there was no main effect of group on UT passive SWV data ( $F_{1,3}=0.103$ ,  $p=0.75$ ).

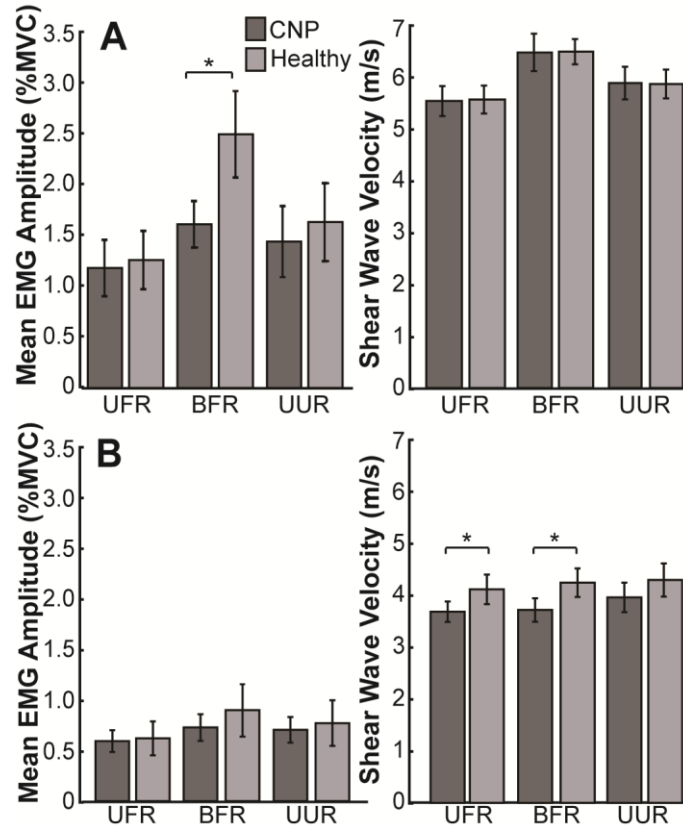


Figure 3.2 Mean EMG amplitude and SWV are plotted for the UT (Figure 2A) and the SCM (Figure 2B) for all three functional reaching tasks. The UT muscle in the chronic neck pain group exhibited significantly lower EMG amplitude for the bilateral forward reach when compared to healthy controls. The SCM muscle in the chronic neck pain group exhibited significantly lower SWV for both the unilateral and bilateral forward reaches when compared to healthy controls. These main effects of group are denoted by an asterisk (\*). Black bars denote the standard error (S.E.) of the mean. Abbreviations include idiopathic chronic neck pain (CNP), electromyography (EMG), unilateral forward reach (UFR), bilateral forward reach (BFR), and unilateral upward reach (UUR).

There were no differences in SCM EMG amplitude between individuals with idiopathic chronic neck pain and controls during unilateral or bilateral reaching (all  $F_{1,5} < 0.31$ ,  $P > 0.577$ ). However, individuals with idiopathic chronic neck pain exhibited lower SCM SWV during forward reaching, as there was a significant main effect of group during the unilateral ( $F_{1,7} = 5.3$ ,  $P = 0.023$ ) and bilateral forward reaches ( $F_{1,5} = 4.5$ ,  $P = 0.038$ ) (**Figure 2B**). There was no main effect of group on SCM SWV during the unilateral upward reach ( $F_{1,7} = 3.6$ ,  $P = 0.059$ ). Lastly, there was no main effect of group on SCM passive SWV data ( $F_{1,3} = 0.249$ ,  $P = 0.62$ ).

Women often exhibited higher SWV and EMG amplitudes of the SCM than men during most functional reaching tasks. There was a main effect of sex on SCM SWV during both the bilateral forward and the unilateral upward reaches (both  $F_{1,7}>4.5$ ,  $P<0.038$ ), and on SCM EMG amplitudes during all three reaches (all  $F_{1,7}>13.78$ ,  $P<0.000$ ) (**Figure 3**). However, there was no main effect of sex on SCM SWV during the passive condition ( $F_{1,7}=0.097$ ,  $P=0.76$ ). Women exhibited lower UT SWVs at rest than men ( $F_{1,7}=6.9$ ,  $P=0.011$ ). However, there were no sex differences for UT SWV or EMG amplitudes during any functional reaching task (all  $F_{1,7}<0.955$ ,  $P>0.41$ ) (**Figure 3**).

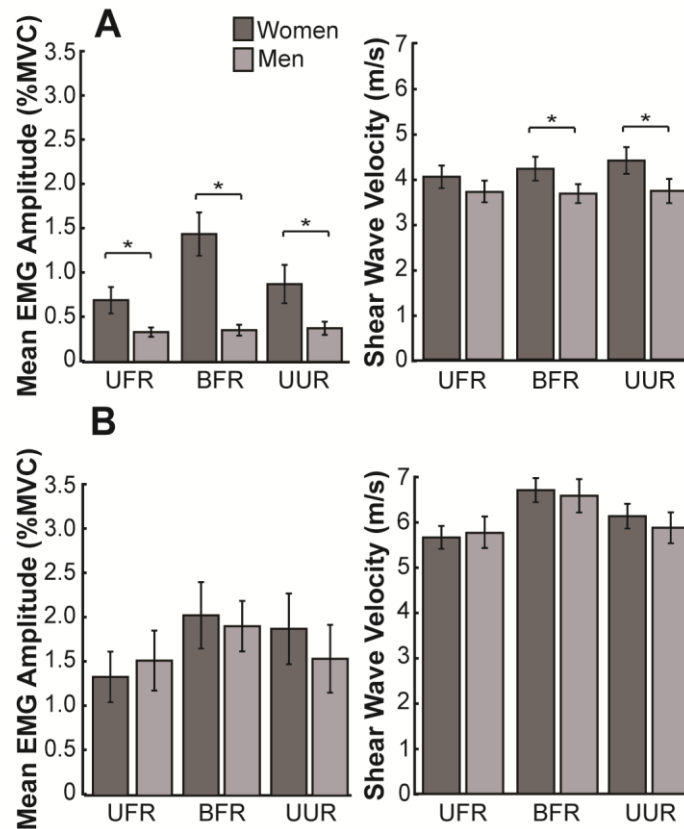


Figure 3.3 Mean EMG amplitude and SWV are plotted for the SCM (Figure 3A) and UT (Figure 3B) for all three functional reaching tasks. Women exhibited significantly higher SCM EMG amplitude for all three reaching tasks and higher SWV during the bilateral forward and unilateral upward reach when compared to men. This main effect of sex is denoted by an asterisk (\*). Black bars denote the standard error (S.E.) of the mean. Abbreviations include idiopathic chronic neck pain (CNP), electromyography (EMG), unilateral forward reach (UFR), bilateral forward reach (BFR), unilateral upward reach (UUR), and maximum voluntary contraction (MVC).

### 3.5 Discussion

This study aimed to determine the influence of idiopathic chronic neck pain on the stiffness and muscle activity of the UT and SCM muscles during functional reaching. We hypothesized that the mean SWV and EMG amplitude for the SCM and UT would be significantly greater for all three reaching tasks for individuals with idiopathic chronic neck pain when compared to healthy controls. Based on our findings, we reject this hypothesis. Instead, we demonstrated that the stiffness of the SCM is lower in individuals with idiopathic chronic neck pain during forward reaches with no changes in muscle activity during similar trials. We found the opposite occurred for the UT muscle. The UT exhibited lower muscle activity during bilateral forward reaches with no related changes in muscle stiffness during similar trials.

We further hypothesized that females would exhibit greater stiffness and muscle activity in the UT and SCM compared to males. We partially accept this hypothesis, as only the SCM demonstrated higher stiffness and activation in women compared to men. Overall, this study demonstrates distinct differences in the activation and stiffness of the UT and SCM muscles during functional reaching for individuals with idiopathic chronic neck pain. These methods provide a framework to improve the diagnosis and evaluation of idiopathic chronic neck pain and provide new evidence for individualized rehabilitation programs to improve outcomes in individuals with idiopathic chronic neck pain.

A novel finding from our study was that SCM SWV was significantly lower in people with idiopathic chronic neck pain during forward reaches without a difference in muscle activation during similar trials. There were no baseline group differences in the SWV of either the SCM or UT muscles at rest. Therefore, we believe that the observed difference in stiffness during volitional movement could be due to reduced neck range of motion during forward reaches [131]. Lower



SWV may indicate participants avoid extending their neck during functional reaching when possible (i.e., not looking up at the object they are reaching for). Neck extension will stretch the SCM muscles, leading to increases in SWV both during voluntary contraction and during passive stretching of the muscle [70]. Therefore, reducing neck extension during a head-high forward reach could lower muscle stiffness without increased muscle activity. Future research should include motion capture alongside EMG and ultrasound shear wave elastography in order to determine whether observed differences in SCM activation and stiffness are due to reduced range of motion.

We observed individuals with idiopathic chronic neck pain displayed less active neck range of motion in extension. Reductions in neck extension during reaching are common for individuals with idiopathic chronic neck pain, including a reduced change in neck angle during overhead reaching in people with chronic neck pain when compared to healthy controls (mean difference of  $-10.36^\circ$ ) [132]. However, we can not eliminate the possibility that this reduced mobility could be an attempt to avoid painful head positions, as pain avoidance affects movement strategies [133, 134]. Future work should investigate the underlying cause of lower stiffness to properly design rehabilitation programs for those with idiopathic chronic neck pain.

Individuals with idiopathic chronic neck pain also demonstrated significantly lower UT activation during the bilateral forward reach without subsequent differences in muscle stiffness. These findings support altered movement strategies during reaching. Indeed, individuals with idiopathic chronic neck pain exhibit altered movements during a repetitive reaching task compared to healthy controls [135]. This clinical population also exhibits altered cervical movement strategies during volitional neck maximal range of motion [136]. Additionally, people with idiopathic chronic neck pain have lower activation of the ipsilateral UT during functional upper limb tasks [34], which is likely attributable to pain avoidance. We posit this lower UT activation

in idiopathic chronic neck pain participants caused them to adopt a more protracted shoulder position during the bilateral head-high reach, thereby lengthening the UT. This stretching of the UT will increase the SWV recorded from muscle without corresponding muscle activity [70].

We demonstrated that women exhibit higher SCM muscle activity and stiffness during functional reaching than men. Our findings support prior findings of higher passive muscle stiffness in women compared to men [129] and higher normalized arm muscle activation during a non-fatiguing repetitive upper extremity task when compared to healthy men [137]. Women and men utilize different movement strategies during repetitive upper extremity task, with women exhibiting reduced arm and shoulder muscle activation variability [137, 138]. These findings highlight the importance of identifying sex-related differences in idiopathic chronic neck pain adaptations, as these may impact rehabilitation program design for women. As women experience neck pain at a higher rate than males [2], future work is warranted to explore if the observed sex differences are related to the development of idiopathic chronic neck pain in women.

There were limitations to this study. The SWV and EMG data obtained reflects muscle stiffness and activation during the maintenance of a functional reach, and not the dynamic reaching movement. Ultrasound images were acquired as participants maintained a posture for 3-5 seconds, as our scanner cannot assess SWV during dynamic movements. Additionally, the study lacked motion capture to evaluate participants' standing posture or movement patterns. The lack of kinematic data limits our ability to examine altered movement strategies by individuals with idiopathic chronic neck pain. Future work should consider including motion capture alongside ultrasound shear wave elastography and EMG to more comprehensively examine the influence of idiopathic chronic neck pain on muscle function. Lastly, our study took place during the COVID-

19 pandemic, but we did not collect information on whether or not our participants were affected prior to data collection.

Our findings could have new clinical utility for evaluating individuals with idiopathic chronic neck pain, who displayed distinct changes in muscle stiffness that were not related to changes in muscle activity during similar trials (and vice versa). We also observed for the first time that there are clear sex differences in muscle stiffness and activity amongst key neck-shoulder muscles. These results highlight the importance of evaluating both muscle stiffness and activation changes before designing rehabilitation programs. As treatments for idiopathic chronic neck pain can target either muscle activation (i.e., motor retraining or muscle strengthening) or improving muscle stiffness (i.e., massage or relaxation), specific programs should be designed for the individual following an in-depth evaluation of the underlying muscle function. The clinical use of ultrasound shear wave elastography would allow for practitioners to identify specific muscle(s) for targeted treatment, as well as monitoring progress throughout a course of rehabilitation. Future work should investigate the utility of ultrasound shear wave elastography and surface EMG to screen patients for idiopathic chronic neck pain and monitor their progress in rehabilitation programs.

### **3.5 Acknowledgements**

This work was supported by the University of Michigan School of Kinesiology and the University of Michigan Rackham Graduate Research Grant. We thank Athena Michelle Prine for her assistance with data collection and study design.

## **Chapter 4 The Influence of Chair Recline on Upper Trapezius Activity and Elasticity during Seated Computer Work**

### **4.1 Abstract**

Idiopathic chronic neck pain has been linked to prolonged static or repetitive working conditions, including seated computer work. Increasing chair recline during seated computer work may reduce the load placed on the upper trapezius, a common location of pain for those with idiopathic chronic neck pain. Therefore, the purpose of this study was to determine the effect of increasing chair recline on upper trapezius stiffness and muscle activity during computer work in people with idiopathic chronic neck pain and healthy controls. Surface electromyography (EMG) and ultrasound shear wave elastography were collected from three subdivisions of the upper trapezius muscles in 15 individuals with idiopathic chronic neck pain and 15 matched healthy controls. Participants sat in a standardized computer-work setup while chair recline (0°, 25°, 45°) and head and neck posture (self-selected, neutral, and flexed) were systematically adjusted. Repeated-measures ANOVAs were completed for each muscle and data type. Across all participants, the 45° recline resulted in a lower stiffness of the upper trapezius subdivision closest to the spine of the scapula compared to the other recline levels. For individuals with idiopathic chronic neck pain, however, the 45° recline also resulted in a higher stiffness in the cranial subdivision of the upper trapezius. There was no effect of recline on upper trapezius activation. For all three subdivisions of the upper trapezius, muscle activation was significantly lower in the neutral head and neck posture compared to the flexed head and neck posture. Our results suggest that a neutral head and neck position may unfavorably affect upper trapezius stiffness and activation. This may mean that

a self-selected neck position may be best for an ergonomic setup and that the commonly suggested neutral position may not be a beneficial prompt when positioning someone during seated computer work.

*Keywords: neck pain, upper trapezius, ultrasound shear wave elastography, electromyography, muscle stiffness*

## 4.2 Introduction

More than half of all individuals will experience neck pain at some point in their life [1]. Neck pain is currently the fourth leading cause of disability in the United States, resulting in substantial economic and personal burden for those affected [139]. Idiopathic neck pain (e.g., no underlying injury or known pathology) is considered chronic when the pain has lasted three months or longer. Idiopathic chronic neck pain has been linked to prolonged static or repetitive working conditions, including seated computer work [5, 18]. Identifying modifiable factors within a standard computer-work setup that lessen the muscle activity of neck-shoulder muscles could reduce the risk of developing idiopathic chronic neck pain.

Ergonomics standards for seated computer work in the United States include positioning a monitor 15-20° below the horizontal eye level at a viewing distance of 0.5-1 meters and adjusting a chair to place the thighs approximately horizontal to the floor and with the lower legs vertically oriented [140]. However, this posture is potentially problematic as it often leads to a flexed head and neck posture, which likely increases neck torque. The gravitational moment produced by the head's mass and the resultant net muscle moment are the primary contributors to torque about the neck. Greater head and neck flexion with seated computer work will increase the gravitational moment about the 7<sup>th</sup> cervical vertebra (C-7) [96, 141, 142]. In response to this increased gravitational moment, increased activation of the upper trapezius (UT) and cervical extensor spinae is required to support the head [34, 106]. Updated ergonomic standards for seated computer work may need to consider reducing the head and neck flexion posture commonly adopted with current guidelines.

Much of the literature investigating the effect of computer work ergonomics on neck-shoulder muscle function focuses on the position and height of the computer monitor. Idiopathic

neck pain can be reduced by raising the monitor's height to a high enough position to reduce neck flexion and muscle activation of the cervical extensor spinae and UT. For example, a higher monitor position reduced cervical extensor spinae and UT activation compared to lower screen positions during seated computer work [94]. Additionally, participants tend to assume a slightly reclined trunk position when the monitor is high (120 cm above the desktop) [94]. While prior work has not directly investigated reclined postures during seated computer work, it is speculated that a reclined position may benefit those with idiopathic chronic neck pain. Increasing the chair recline could decrease the gravitational moment of the head about C-7, lowering the required muscle activation of the neck extensors. Therefore, further work is warranted to establish the effect of chair recline on neck-shoulder muscle biomechanics and the presence of idiopathic chronic neck pain.

Upper trapezius stiffness and discomfort are common complaints from those with idiopathic chronic neck pain [143]. There is not currently a consensus in the literature on whether subjective muscle stiffness is associated with increased stiffness when measured objectively. Therefore, it is essential to fully characterize the effect of computer work on UT stiffness in those with idiopathic chronic neck pain. Neuromuscular assessments of neck-shoulder muscle alterations during working postures typically rely on electromyography (EMG) measures of muscle activity. A limitation of solely using EMG is its inability to gather data on both muscle activity and changes in inherent muscle stiffness. Using ultrasound shear wave elastography alongside EMG allows researchers to assess changes in muscle elasticity and is the most clinically relevant proxy for measuring muscle stiffness. Ultrasound shear wave elastography is a non-invasive method for quantifying muscle stiffness in vivo and can be used in combination with EMG to better understand the effects of chronic neck pain on muscle function. Identifying the

underlying changes to SCM and UT activity and stiffness during seated computer work may aid the development of specific rehabilitation recommendations or ergonomic setup guidance for those with idiopathic chronic neck pain.

Therefore, this study aimed to determine the effect of increasing chair recline on UT stiffness and muscle activity during computer work in people with idiopathic chronic neck pain and healthy controls. The sternocleidomastoid (SCM) was also investigated to determine whether chair recline results in greater SCM stiffness or activation while potentially offloading the UT. Participants were evaluated in three recline positions (e.g., 0° (upright), 25° recline, and 45° recline), with subsequent positioning of the head and neck in three controlled postures (self-selected posture, neutral, and flexed posture). Within each recline and head/neck posture, EMG and ultrasound shear wave elastography data were collected from the three subdivisions of the UT and the SCM. We hypothesized that the increased chair recline positions of 25° and 45° and a neutral or self-selected neck and head posture would significantly decrease the UT activation and stiffness. Additionally, we hypothesize that people with idiopathic chronic neck pain will exhibit increased UT stiffness and activation in all postures compared to healthy individuals.

### **4.3 Materials and Methods**

#### *4.3.1 Participants*

We recruited 15 individuals with mild-to-moderate idiopathic chronic neck pain (5 male, 10 female, Neck Disability Index scores ranging 5-24 (out of 50)) and 15 sex, age, height, and weight-matched healthy controls (Neck Disability Index scores ranging 0-4). The protocol was approved by the Institutional Review Board (HUM00204942) at the University of Michigan, and all participants provided written informed consent.



We powered our study based on a prior study that demonstrated a 25% increase in muscle stiffness (effect size  $f = 0.45$ ) in individuals with idiopathic chronic neck pain compared to healthy controls [55]. A total sample size of 30 was required to detect a repeated-measures ANOVA between-groups difference in muscle stiffness with an alpha level of 0.05, 80% power, 0.7 correlation between repeated measures [130], and 36 measurements.

#### *4.3.2 Experimental Design*

All participants completed one 2-hour data collection. Demographic data were collected, including head and neck circumference, grip strength using a hand-held dynamometer, and neck range of motion using a plastic goniometer. The participant verbally reported hand dominance. Surface EMG (Delsys, Trigno, Quattro, Natick, MA) were collected from three portions of the upper trapezius to understand the distribution of activation: UT1) 1 cm lateral to the spinous process of C-4, UT2) 2 cm lateral to the midpoint between the C7 and acromion process, and UT3) midway between point B and the spine of the scapula (**Figure 1A**) [144, 145]. Additionally, EMG data were collected from the bilateral SCM muscles to ensure that the experimental postures did not increase the loads or activity of neck flexor muscles while the UT muscle is potentially offloaded. The SCM electrode was placed on the belly of the SCM 2 cm below the midpoint. The skin over the areas of interest was prepped with an exfoliating gel and subsequently cleaned with an alcohol wipe. The specific muscle locations of interest were first marked with hypoallergenic tape to ensure consistent electrode and ultrasound transducer placement between experimental conditions. The electrodes were then placed parallel to the muscle fiber and over the muscle belly by a single researcher. The placement of EMG electrodes over the muscle subdivisions of interest made it difficult to acquire simultaneous ultrasound measures from the same location. Therefore,

we collected EMG and ultrasound shear wave elastography data from contralateral sides simultaneously, then repeated the experimental protocol to ensure we collected all data (EMG and ultrasound shear wave elastography) from both sides of the participant.

Before starting the recline trials, resting ultrasound shear wave elastography (Hologic Supersonic Imagine MACH 30 system, Aix-en-Provence, France) images were obtained from the SCM and three subdivisions of the UT during prone and supine lying on a massage table to obtain passive stiffness data. The shear wave elastography images were taken with a linear transducer (Supersonic Imagine, SLH20-6) from the belly of the muscle of interest. Then, after applying the surface EMG electrodes but before completing any computer tasks, the participants underwent two baseline resting trials. The participants were asked to lay prone on the massage table and relax as much as possible. They were then instructed to take a deep breath, then release and fully relax. Three seconds of EMG data were collected following this exhale. Participants then performed seated maximum voluntary contractions (MVCs) against manual resistance. The MVCs completed were in neck flexion, extension, left and right lateral bending, and shoulder shrug. Two trials of MVCs were completed with a 90-second rest period between the two trials.

A 12-camera motion capture system (Motion Analysis, Santa Rosa, CA) was used to collect position data during all experimental protocols. Established head and neck marker placements were used to calculate the neck angle as well as the head angle [146]. Markers were placed on the spinous process of C-7 and bilaterally on the tragus of the ear and lateral portion of the eye. Neck angle was defined as the angle between the C-7 and tragus markers relative to vertical. Head angle was defined as the angle between the tragus and lateral portion of the eye markers relative to the horizontal.

The remainder of the experimental protocol utilized a standard office desk setup. A height-adjustable desk and chair, cordless mouse and keyboard, and laptop were used (**Figure 1B**). Three chair recline positions were investigated; upright ( $0^\circ$  recline),  $25^\circ$  recline, and  $45^\circ$  recline. These recline positions were completed while the head and neck were in one of three positions: 1) self-selected by the participant, 2) neutral head and neck guided by the researcher [147], and 3)  $5\text{-}10^\circ$  neck flexion guided by the researcher (**Table 1**). A neck flexion of only  $5\text{-}10^\circ$  from the self-selected posture was chosen to ensure that individuals do not exceed the maximum physiological flexion limit while in a more reclined posture [148]. The participants remained in each position for approximately 2.5 minutes, allowing for one minute of adaptation before data collection began. All positions were completed while the participants were looking at a 14" laptop monitor with their hands resting on a standard keyboard lying flat on the desk. Participants were instructed to maintain focus on a photo on the laptop screensaver throughout each trial. The desk height, distance from eye to monitor or laptop screen, monitor height, and distance to the keyboard were individually adjusted to be consistent for all tasks. The monitor was positioned  $15^\circ$  below eye level with a viewing distance of approximately 0.5 meters. The height of the desk was adjusted so that the top of the desk was slightly above elbow height while seated, and the keyboard was positioned so that the participant could sit in a typing position comfortably while upper arms were supported by added padding to the backrest of the chair.

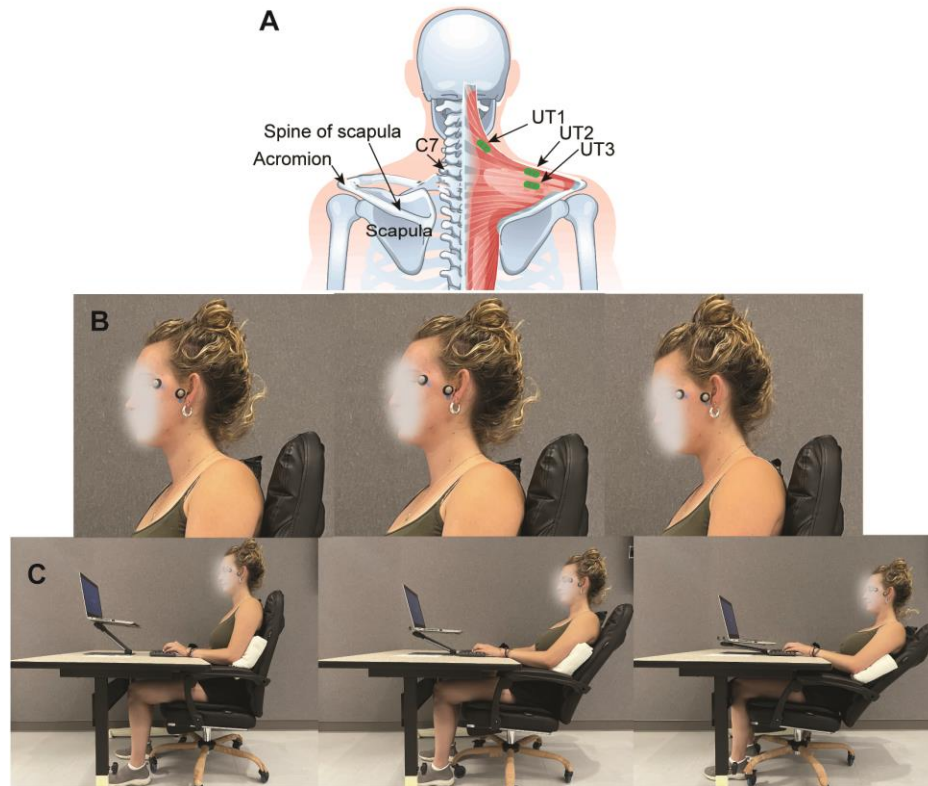


Figure 4.1 Electrode placement (A) and experimental setup of the seated computer-work task (B and C) are shown. We collected electromyography (EMG) data from three subdivisions of the UT (A). Electrode locations for the upper trapezius are shown here, but data were also collected simultaneously from the sternocleidomastoid (not shown). Three head and neck positions were investigated (B); shown in the order of self-selected, neutral, and flexed. The three recline angles (shown in C) investigated were 0° (upright), 25°, and 45°. Ergonomic standards were used to position the participant so that the laptop monitor height, desk height, distance from the eye to the laptop screen, and distance to the keyboard were individually adjusted to be consistent for all tasks. Figure A modified from © VectorMine – Shutterstock.com.

Table 4.1 A list of the 9 positions that were investigated, including all combinations of chair recline angle and head/neck position. Desk height, distance from the eye to the laptop screen, monitor height, and distance to the keyboard were kept consistent for all positions. The order of positions was randomized, but self-selected head/neck posture was always completed first.

Chair Recline	Head/Neck Position
0°	Self-selected
0°	Neutral
0°	Flexed
25°	Self-selected
25°	Neutral
25°	Flexed
45°	Self-selected
45°	Neutral
45°	Flexed

The order of these postures was randomized for each participant, but self-selected head and neck posture was completed first within each chair recline. Self-selected was completed first to eliminate any bias produced by the other guided head and neck postures. Once all nine positions were completed, the EMG electrodes were switched to the other side of the participant, and the procedure was repeated on the contralateral side. A Visual Analog Scale (VAS) for pain was obtained at the beginning of the data collection, at the midpoint, and end of the data collection to ensure that the procedure was not causing participants excessive discomfort.

#### 4.3.3 Analysis

For each trial, EMG data were detrended, band-pass filtered with a 3<sup>rd</sup> order Butterworth filter between 30-500 Hz, and rectified. The root mean square (RMS) was quantified over time, and the average EMG amplitude of each trial was calculated, excluding the first and last ten seconds of the collection. EMG RMS data from each trial were normalized as a percentage of MVC RMS collected for the corresponding muscle using Equation 1 [149].

$$EMG\ RMS_{norm} = \frac{(EMG\ RMS_{trial} - EMG\ RMS_{base})}{(EMG\ RMS_{max} - EMG\ RMS_{base})} \quad (\text{Eq. 1})$$

The maximum ( $EMG\ RMS_{max}$ ) and minimum ( $EMG\ RMS_{base}$ ) activation values were computed across all trials.

Ultrasound shear wave elastography images were analyzed using established algorithms in MATLAB [72, 117]. Within the MATLAB program, the region of interest was systematically selected by a researcher to ensure only shear wave velocity data from the muscle belly was analyzed. A quality map of each image was created to evaluate the pixel quality within each image (quality factor ranged from 0-1). Only the pixels with a quality factor greater than 0.5 were included in the mean shear wave velocity calculation for each image.

Our primary outcome measures were mean shear wave velocity and normalized EMG RMS amplitude obtained from the SCM and 3 locations of the UT during each recline trial. We tested our primary hypothesis that chair reclines of 25° and 45° would significantly decrease the UT activation in people with idiopathic chronic neck pain and healthy controls using separate repeated-measures ANOVAs for each muscle and data type. Between-subjects factors included group (chronic neck pain, control), and within-subjects fixed factors included chair recline (0°, 25°, 45°), head and neck posture (self-selected, flexed, neutral), and side of collected data (dominant, non-dominant). Two-way interactions between group (chronic neck pain, control), chair recline (0°, 25°, 45°), and head and neck posture (self-selected, flexed, neutral) were also assessed. Group differences in demographics and head and neck angles were evaluated using two-sided independent t-tests and univariate ANOVAs, respectively. Significance was set at  $p < 0.05$  for all statistical tests, and post-hoc Bonferroni tests were used when appropriate. The Greenhouse-Geisser corrected values were used for any sphericity assumption violations.

#### 4.4 Results

Participant demographics, grip strength, and neck range of motion are displayed in Table 2. There were no significant differences between the idiopathic chronic neck pain and healthy groups in age, height, weight, head or neck circumference, or grip strength (all  $p < 0.13$ ) (**Table 2**). On average, the participants with idiopathic chronic neck pain had reduced range of motion in neck extension ( $p = 0.04$ ), but no significant differences were observed in flexion, right or left lateral bending, or right or left axial rotation (all  $p > 0.17$ ) (**Table 2**). During the experimental protocol, individuals with idiopathic chronic neck pain self-selected a neck posture that was significantly more flexed than the healthy controls ( $F_{1,1} = 16.971$ ,  $p < 0.001$ ), but there was no main effect of group on head angle ( $F_{1,1} = 3.23$ ,  $p = 0.073$ ), (**Table 3**).

Table 4.2 Mean demographic data for the chronic neck pain and healthy participants. Values are mean  $\pm$  standard error (S.E). Abbreviations are for idiopathic chronic neck pain (iCNP), Neck Disability Index (NDI), circumference (CIR), left (L.), right (R.), flexion (FLEX), extension (EXT), right lateral bending (RLB), left lateral bending (LLB), right axial rotation (RAR), and left axial rotation (LAR). Significant group differences are denoted with an asterisk (\*).

Group	iCNP	Healthy
<b>NDI</b>	12.6 (0.9)	<1 (0.2)
<b>Sex</b>	10 F, 5 M	10 F, 5 M
<b>Age (years)</b>	38 (4.7)	40 (4.7)
<b>Height (m)</b>	1.7 (0.03)	1.7 (0.03)
<b>Body mass (kg)</b>	66.7 (2.7)	74.5 (4.6)
<b>HeadCIR (cm)</b>	55.0 (0.5)	55.3 (0.5)
<b>NeckCIR (cm)</b>	33.1 (0.8)	33.7 (0.9)
<b>R.Grip (kg)</b>	35.7 (3.1)	43.3 (3.7)
<b>L.Grip (kg)</b>	35.7 (3.1)	40.4 (3.6)
<b>FLEX (°)</b>	53.3 (1.9)	49.6 (2.1)
<b>EXT (°) *</b>	49.0 (1.8)	54.5 (1.9)
<b>RLB (°)</b>	28.9 (1.9)	31.9 (1.8)
<b>LLB (°)</b>	30.3 (2.3)	30.1 (2.0)
<b>RAR (°)</b>	61.3 (2.8)	66.1 (1.9)
<b>LAR (°)</b>	68.5 (2.9)	66.3 (2.8)

Table 4.3 Mean neck and head angle in each posture for the chronic neck pain and healthy participants. Values are mean  $\pm$  standard error (S.E). Abbreviations are for idiopathic chronic neck pain (iCNP). There was a significant effect of group on neck angles, with the iCNP group self-selecting more flexed neck angles.

Recline	Position	Neck Angle		Head Angle	
		Healthy	iCNP	Healthy	iCNP
0°	Self-Selected	46.1° (1.1)	48.6° (1.0)	23.1° (1.1)	22.8° (1.5)
	Neutral	43.0° (0.8)	46.1° (1.1)	24.9° (1.3)	26.1° (1.4)
	Flexed	51.5° (1.1)	53.6° (1.5)	16.9° (1.4)	17.7° (1.3)
25°	Self-Selected	41.1° (0.6)	44.3° (1.1)	22.7° (1.2)	25.0° (1.1)
	Neutral	37.9° (0.6)	40.9° (1.2)	26.4° (1.1)	29.1° (1.4)
	Flexed	46.0° (0.8)	49.8° (1.4)	18.6° (1.0)	19.4° (1.2)
45°	Self-Selected	36.9° (0.7)	38.4° (1.0)	25.3° (1.3)	29.1° (1.4)
	Neutral	34.1° (0.8)	36.5° (0.9)	28.6° (1.5)	31.1° (1.5)
	Flexed	41.0° (1.0)	46.0° (1.2)	20.4° (1.2)	22.0° (1.3)

Individuals with idiopathic chronic neck pain exhibited greater stiffness in the cranial regions of the UT (e.g., UT1) when compared to healthy individuals (**Figure 2**,  $F_{1,28}=5.187$ ,

p=0.031). However, this greater UT1 stiffness was not caused by enhanced muscle activity, as no significant group differences in muscle activity were observed ( $F_{1,28}=0.023$ ,  $p=0.881$ ). A significant group by recline interaction ( $F_{2,27}=4.158$ ,  $p=0.024$ ) revealed that individuals with idiopathic chronic neck pain exhibited lower UT1 stiffness in the 45° recline when compared to both the 0° recline ( $p=0.035$ ) and 25° recline ( $p=0.004$ ) (**Figure 2**). There was also a significant main effect of side on UT1 stiffness ( $F_{1,28}=8.414$ ,  $p=0.007$ ), with the dominant side exhibiting a greater stiffness than the non-dominant side. While no group differences in UT1 muscle activation were observed, there was a main effect of head and neck position on UT1 muscle activation ( $F_{2,27}=7.164$ ,  $p=0.002$ ), with the flexed head and neck posture resulting in higher muscle activation than the neutral neck position ( $p=0.003$ ) (**Figure 3A**).

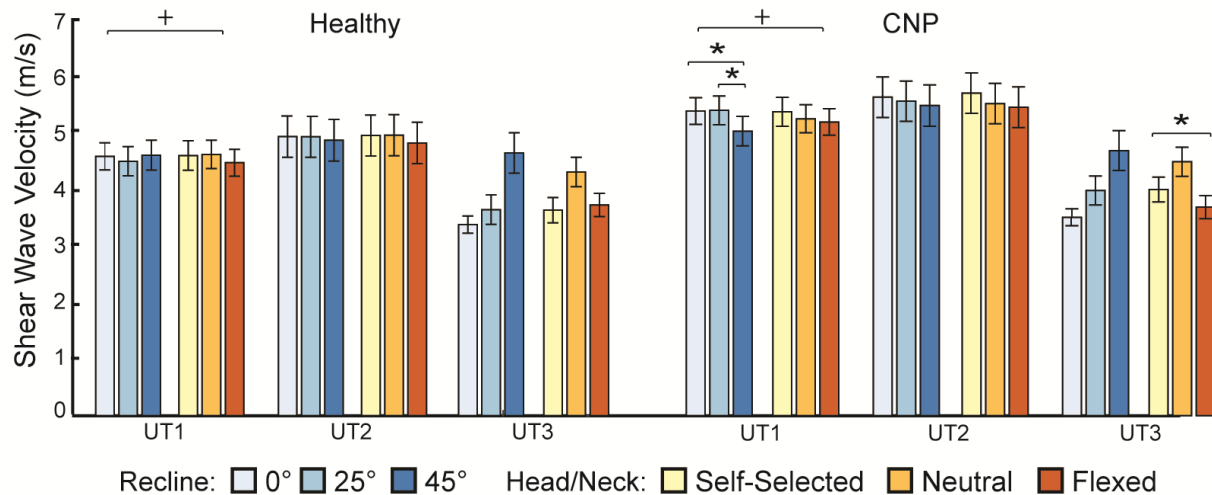


Figure 4.2 Mean SWV is plotted for the three subdivisions of the UT for all chair recline levels and head and neck positions for the healthy group (left) and idiopathic chronic neck pain group (CNP) (right). Interaction effects are denoted by an asterisk (\*) and significant group differences are denoted by a plus (+). There was a significant group by recline interaction for the CNP group, with the 45° recline resulting in lower UT1 stiffness. There was also a significant group by head and neck posture interaction, with the CNP group demonstrating greater UT3 stiffness in self-selected when compared to the flexed posture. Black bars denote the standard error (S.E.) of the mean. Abbreviations include maximum voluntary velocity (MVC).



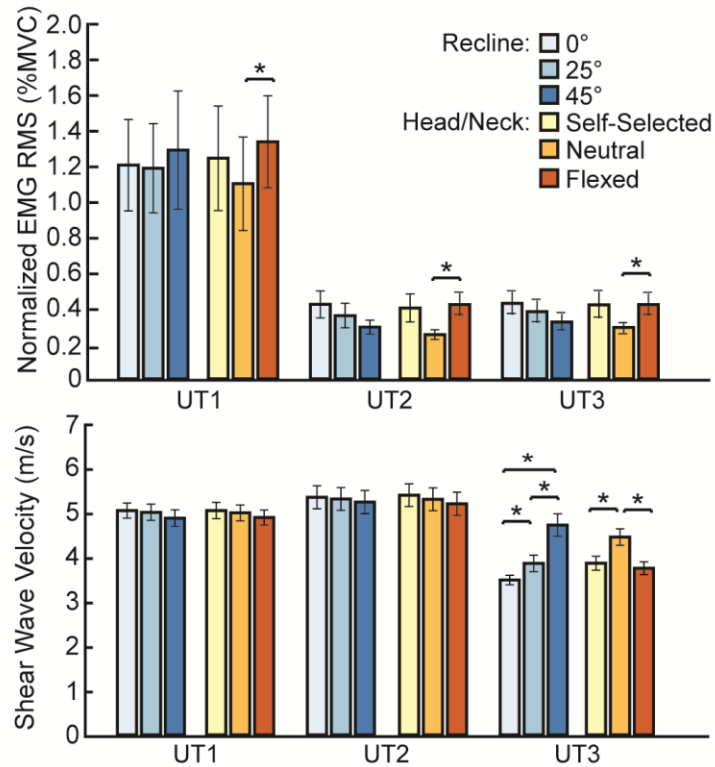


Figure 4.3 Mean EMG (top) and SWV (bottom) are plotted for the three subdivisions of the UT for all participants over the three chair recline levels and head and neck positions. There was a main effect of head and neck posture on UT1, UT2, and UT3 activation, with the flexed posture resulting in higher activation when compared to the neutral position. As the incline increased, UT3 activation increased. Additionally, a neutral head and neck posture resulted in greater UT3 stiffness when compared to the self-selected and flexed. There were also several main effects of both recline and head and neck posture on UT3 stiffness. Main effects are denoted by an asterisk (\*), and black bars denote the standard error (S.E.) of the mean. Abbreviations include maximum voluntary velocity (MVC).

The region of the UT just distal to the halfway point between C7 and the acromion process (e.g., UT2) was relatively insensitive to changes in chair recline and did not differ between healthy individuals and adults with idiopathic chronic neck pain. There was no significant difference in UT2 stiffness or activation between healthy individuals and adults with idiopathic chronic neck pain (both  $F_{1,28} < 2.072$ ,  $p > 0.161$ ). There was a main effect of side on UT2 stiffness, with the dominant side exhibiting greater stiffness than the non-dominant side ( $F_{1,28} = 4.4732$ ,  $p = 0.038$ ). There was also a main effect of head and neck position on UT2 activation ( $F_{2,27} = 5.227$ ,  $p = 0.013$ ), with the neutral head and neck position resulting in lower UT2 activation when compared to the

flexed position ( $p=0.004$ ) (**Figure 3A**). There were no other main effects or interactions in UT2 activation or stiffness (all  $F<2.271$ ,  $p>0.075$ )

There were several demonstrated alterations in the stiffness and activation of the most caudally examined UT subdivision, UT3, in response to recline and head and neck posture, but no differences were observed between the healthy and idiopathic chronic neck pain group. There was a main effect of recline on UT3 stiffness ( $F_{2,27}=22.820$ ,  $p<0.001$ ). Multiple comparisons indicated that the  $45^\circ$  recline resulted in greater UT3 stiffness when compared to the  $25^\circ$  recline ( $p<0.001$ ) and  $0^\circ$  recline ( $p<0.001$ ) (**Figure 3B**). There was also a main effect of head and neck position on UT3 stiffness ( $F_{2,27}=44.556$ ,  $p<0.001$ ), where the neutral head and neck position resulted in significantly higher UT3 stiffness when compared to both the self-selected and flexed positions (both  $p<0.001$ ) (**Figure 3B**). While there was no main effect of group ( $F_{1,28}=0.525$ ,  $p=0.475$ ), a significant group by head and neck position interaction ( $F_{2,27}=3.28$ ,  $p=0.046$ ) revealed that people with idiopathic chronic neck pain displayed higher UT3 stiffness in the self-selected posture when compared to the flexed position ( $p=0.007$ ) (**Figure 2**). There was also a main effect of head and neck posture on UT3 activation ( $F_{2,27}=4.206$ ,  $p=0.035$ ) (**Figure 3A**). Interestingly, the neutral head and neck posture resulted in lower UT3 activity when compared to the flexed head and neck posture ( $p=0.026$ ). There were no other main effects, interactions, or group differences for UT3 stiffness or activation (all  $p>0.071$ ,  $F<2.224$ ).

Adjustments in chair recline and head and neck position affected the muscle activation and stiffness of the SCM muscle, and individuals with idiopathic chronic neck pain demonstrated greater SCM stiffness than healthy controls ( $F_{1,28}=4.483$ ,  $p=0.041$ ). There was a main effect of recline on SCM stiffness ( $F=4.610$ ,  $p=0.024$ ), with the  $25^\circ$  recline eliciting a greater stiffness when compared to the  $0^\circ$  recline ( $p=0.037$ ) (**Figure 4**). There was also a main effect of head and neck

posture on SCM stiffness ( $F_{2,27}=12.305$ ,  $p<0.001$ ), with the flexed position resulting in greater SCM stiffness than the neutral position ( $p<0.001$ ) (**Figure 4**). For individuals with chronic neck pain, a group by head and neck posture interaction ( $F_{2,27}=6.464$ ,  $p=0.002$ ) revealed that the self-selected head and neck position resulted in a lower SCM stiffness when compared to both the neutral and flexed posture ( $p<0.001$ ). SCM activation was affected by both recline and head and neck posture. There was a main effect of recline ( $F_{2,27}=8.266$ ,  $p=0.006$ ), the 45° recline eliciting a greater SCM activation than both the 25° recline ( $p=0.009$ ) and 0° recline ( $p=0.022$ ). A main effect of head neck position ( $F_{2,27}=10.818$ ,  $p<0.001$ ) revealed that the neutral position resulted in greater SCM activation than both the self-selected ( $p=0.007$ ) and flexed posture ( $p=0.002$ ) (**Figure 4**). No group main effect and no significant interactions (all  $F_{2,27}<3.128$ ,  $p>0.057$ ) were present in SCM activation.

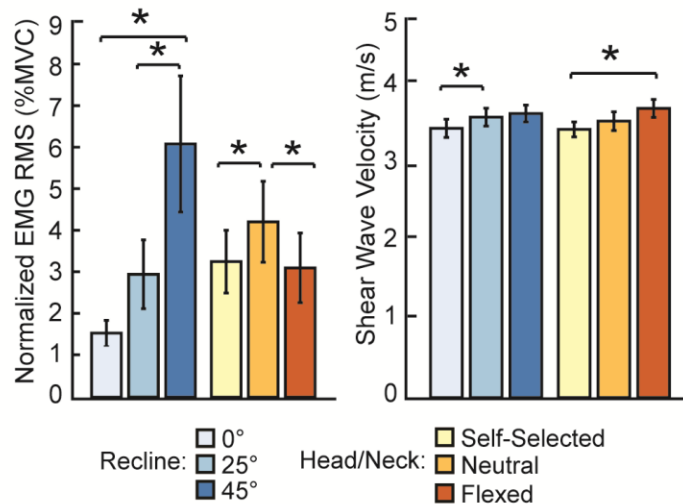


Figure 4.4 Mean SWV (right) and EMG (left) are plotted for the sternocleidomastoid (SCM) for all participants over the three chair recline levels and head and neck positions. There was a main effect of recline level on SCM activation, with SCM activation increasing with greater recline. There was also a main effect of head and neck posture on SCM activation, with the neutral head and neck posture resulting in greater stiffness than the other positions. Additionally, there were main effects of recline and head and neck posture on SCM stiffness, with the 0° recline resulting in lower stiffness than the 25° recline, and the flexed head and neck posture resulting in greater SCM stiffness than the self-selected. Main effects are denoted by an asterisk (\*), and black bars denote the standard error (S.E.) of the mean. Abbreviations include maximum voluntary velocity (MVC).

#### 4.5 Discussion

This study aimed to determine the influence of chair recline on the stiffness and muscle activity of three subdivisions of the UT during seated computer work in individuals with and without chronic neck pain. We hypothesized that a chair recline of 25° and 45° would significantly decrease the UT activation and stiffness by decreasing the gravitational moment of the head and that the stiffness and activation would be higher in individuals with idiopathic chronic neck pain when compared to healthy controls. Based on our findings, we partially accept this hypothesis. Individuals with idiopathic chronic neck pain exhibited higher stiffness in one subdivision of the UT, in the cranial subdivision lateral to C-4. For individuals with idiopathic chronic neck pain, a 45° chair recline did decrease the stiffness of the UT in the cranial subdivision when compared to the 0° and 25° recline. However, across all participants, the 45° recline resulted in a higher stiffness of the UT closest to the spine of the scapula (e.g., most caudal region) compared to the other recline levels. Therefore, the 45° recline decreased the stiffness of one subdivision of the UT but increased the stiffness in another subdivision for those with idiopathic chronic neck pain. We did not see any impact of recline on UT activation, contrary to our hypothesis.

We also hypothesized that a neutral or self-selected head and neck posture would decrease UT activation and stiffness compared to a flexed head and neck posture. Again, we only partially accept this hypothesis. The stiffness and activation of the UT subdivisions responded uniquely to changes in head and neck posture. For all three subdivisions of the UT, muscle activation was significantly lower in the neutral posture compared to the flexed head and neck posture, as hypothesized based on previous findings [89]. However, the lower activations in the neutral posture did not correspond to lower stiffness for the most caudal region of the UT; UT3. The neutral head and neck posture resulted in greater UT3 stiffness when compared to the self-selected and flexed postures. This was a novel finding, as muscle stiffness is often correlated with muscle

activation [68-70]. Because we collected both ultrasound shear wave elastography and EMG data, we can exclude higher activation as the cause of greater stiffness for the UT3. One possible explanation is altered scapular movement, including a combination of protraction or depression resulting in UT3 being stretched, which would increase stiffness [70]. However, it was outside this study's scope to account for the independent motion of the scapula relative to the thorax. Future work must account for scapular motion when evaluating shared neck-shoulder musculature such as the UT.

Our systematic approach allowed us to establish the independent effects of chair recline on the stiffness of the individual fiber regions of the UT. We found that increasing chair recline elicited a significant increase in the stiffness of the most caudal subdivision while not significantly impacting the stiffness of the other two subdivisions. Although it is unclear what is driving this increase in stiffness, we believe there are two potential sources. Postural changes elicited by increasing recline could lead to increased scapular protraction and or/internal rotation (i.e., rounded shoulder), which would lengthen the caudal region of the UT and produce greater stiffness. We attempted to minimize shoulder musculature demands by positioning the keyboard at a consistent distance from the participant's body and providing posterior support to the upper arms to reduce shoulder musculature demands. Since we did not fully constrain the shoulder, it is feasible that participants altered their shoulder position between recline levels. Future work should control the position of the shoulders by instructing participants to keep their shoulders on the back of the chair and by quantifying how much participants roll their shoulders forward with increasing recline. Another mechanism that could allow independent changes in muscle stiffness could be the activation of muscle spindles as a response to muscle stretch. A hypothesis by Johansson and Sojka (1991) suggests that reflexive muscle spindle activation in response to muscle stretch (e.g.,

postural changes) increases muscle stiffness in the absence of muscle activation [127]. This increased stiffness could cause a positive feedback loop, where metabolite production within the muscle could exacerbate the problem and lead to more activated spindles. This phenomenon is difficult to measure *in-vivo*. However, future work could utilize a combination of motion capture, EMG, and ultrasound shear wave elastography to rule out postural differences as a potential cause of increased stiffness.

The suggested muscle activation level to reduce neck pain risk during static or prolonged work without breaks is below 1% MVC [86, 87, 150]. The subdivision of the UT lateral to C-4 was the only subdivision of the UT that we observed activation values above the 1% threshold, suggesting that this subdivision may contribute to the development of chronic neck pain. Our results observed independent control of UT subdivisions in agreement with existing literature [80, 144]. The UT responds to experimentally-induced pain by shifting muscle activity (as recorded with surface EMG) from one subdivision of the muscle to another [151]. Specifically, the UT experiences greater reductions in EMG amplitude in the cranial region than the caudal region [151]. This demonstrates an overall inhibition of the UT in response to experimental muscle pain and a shift in EMG amplitude towards the caudal fibers. Additionally, based on our observations of UT stiffness changes without corresponding changes in activation, we believe that ergonomic recommendations should include muscle length considerations.

Across both experimental groups, the dominant side exhibited greater stiffness of the cranial subdivision and the subdivision midway between C-7 and the acromion compared to the non-dominant side. There was no corresponding difference between the dominant and non-dominant sides for the activation of these subdivisions. Our participant pool was overwhelmingly right-hand dominant (97%). Although the participants did not use the computer mouse during any

of our trials, we posit that their prior normal use of a computer mouse on the dominant side may lead to adaptations in posture during seated-computer work. Previous studies have found comparable activation between right and left UT activation during right-handed mouse use [152]. Therefore, our lack of activation difference between sides supports the notion that posture could lead to greater stiffness on the dominant side.

There were limitations to this study. Participants were only seated in each position for approximately 2.5 minutes. Therefore, this study does not represent how these variables and outcome measures behave across a full day of work. The shortened protocol allowed us to minimize fatigue and be respectful of our participants' time and support future work looking at longer stretches of work. Additionally, each posture was repeated twice to obtain EMG and shear wave velocity from the dominant and non-dominant sides. We also did not have the participants perform any computer work or work simulation during data collection. We chose this to limit the physiological response to stress and any movement that might interfere with our imaging. The UT is a large superficial muscle. Therefore, EMG crosstalk between the UT and underlying muscles is a possibility that cannot be overlooked. A standardized approach of placing these EMG sensors should minimize the effect of EMG crosstalk. Lastly, our participants were all within the healthy body mass index (BMI) category. Our results may not translate to individuals with greater BMI scores as a high BMI has been associated with an increased risk of developing chronic neck pain [153].

In conclusion, this study sought to determine how chair recline impacts UT activation and stiffness for individuals with and without idiopathic chronic neck pain during seated computer work. We found our results to be highly variable. Overall, head and neck posture seemed to have a greater impact on UT activation and stiffness than the chair recline alone. Our results found that

a neutral and flexed head and neck position may unfavorably affect UT stiffness and activation. This suggests a self-selected neck position may be best for an ergonomic setup. The greater comfort experienced in the self-selected head and neck posture may indicate that individuals can determine which posture results in the lowest effort, and therefore activation, of their neck muscles. This also suggests that the commonly suggested neutral position may not be a beneficial prompt when positioning someone during seated computer work. In fact, the neutral posture resulted in greater stiffness in the UT subdivision nearest the spine of the scapula compared to the self-selected posture.



## **Chapter 5 General Discussion and Conclusions**

This dissertation addresses several important knowledge gaps regarding head-neck muscle function and the relationships among idiopathic chronic neck pain, neck and upper extremity biomechanics, and workplace design. First, this dissertation establishes the relationship between sternocleidomastoid activity and elasticity during the generation of volitional 3-D neck torques in healthy individuals. Using the knowledge gained from the first aim, we were able to confidently apply the same methodology to investigate the independent contributions of stiffness and activation to shear wave velocity during more functional movements in people with idiopathic chronic neck pain. Repetitive or sustained activities, including reaching and seated computer work, are often associated with the existence of idiopathic chronic neck pain, although the exact neck and shoulder muscular adaptations during these activities are not well understood. This dissertation demonstrated the effect of idiopathic chronic neck pain on the upper trapezius and sternocleidomastoid muscle stiffness and activation during functional reaching tasks. Lastly, this dissertation establishes the efficacy of chair recline in modulating neck-shoulder muscle activity and stiffness during office work in those with and without idiopathic chronic neck pain. Filling these knowledge gaps provides valuable information to enhance diagnostic techniques, develop and evaluate neck pain treatments, and improve ergonomic recommendations for employees with and without idiopathic chronic neck pain.

## **5.1. Demonstrating the relationship between muscle stiffness and muscle activation in muscles acting in three dimensions**

Muscle stiffness is a common complaint for individuals with idiopathic chronic neck pain [143]. Ultrasound shear wave elastography is used to evaluate musculoskeletal health and function. This technique quantifies muscle stiffness in healthy individuals and people with various clinical conditions. Muscle stiffness scales linearly with muscle activation in bi-articular muscles that cross a single hinge joint [68, 69]. Prior to this dissertation, it remained unknown whether this relationship applied to muscles with lines of action acting in three dimensions, such as many muscles that move the neck and shoulder. Neck-shoulder muscles, including the sternocleidomastoid, have insertions that allow them to contribute to the generation of neck torques in three degrees of freedom [107-109]. We obtained stiffness via ultrasound shear wave elastography and activity via EMG from the sternocleidomastoid during the performance of three-dimensional neck torques. We used these data to calculate the preferred directions of both data types, in which direction the muscle was most stiff and active. We found that sternocleidomastoid stiffness largely scales with voluntary neck torque production in three dimensions. While small-but-significant differences between the preferred directions of the shear wave velocity and EMG data were found, the locations of these preferred directions within the sphere of 3-dimensional torques were very similar. Therefore, we concluded that the two outcome measures scale together in healthy individuals. These findings have several implications for investigating muscle stiffness and activation in those with neck conditions: 1) ultrasound shear wave elastography can be used in healthy individuals to investigate muscle function when EMG is not feasible, 2) the combination of ultrasound shear wave elastography and EMG can parse out the individual contributions of activation and inherent tissue properties to investigate muscle stiffness in those with chronic neck

pain, and 3) the preferred direction of sternocleidomastoid stiffness differs from the line of action suggested based on the muscle moment arm.

The muscles of the neck possess moment arms that allow them to contribute to torque generation in multiple lines of action [108]. Chapter 2 utilized shear wave elastography to provide normative values for the lines of action (i.e. preferred directions) of the sternocleidomastoid in healthy individuals. These preferred directions represent healthy sternocleidomastoid lines of action during the production of isometric three-dimensional isometric torques. Normative values may be beneficial for investigating neck pathologies where abnormal muscle activation is of interest. Additionally, we provided the specificity of the sternocleidomastoid (i.e., the focus), which provides insight into co-contraction behavior in healthy individuals. Individuals with idiopathic chronic neck pain exhibit increased co-contraction of the sternocleidomastoid [110]. Therefore, quantifying the focus of the sternocleidomastoid across varying torque directions can provide insights into the underlying neuromuscular adaptations contributing to idiopathic chronic neck pain. These normative values for the SCM preferred direction and specificity can be applied to other clinical pathologies, including the effects of chemoradiation for head and neck cancer on neck function and the donor site morbidity associated with reconstructive surgery of the head and neck.

## **5.2. Informing rehabilitation and treatment design for individuals with idiopathic chronic neck pain**

Idiopathic neck pain (i.e. neck pain with no known cause) is the most common type of neck pain [154]. Only approximately 25% of people with all types of neck pain will seek treatment [6], and those who do are often referred to physical therapy treatment [155]. Because the etiology of

idiopathic chronic neck pain is not well understood, clinicians often experience difficulty successfully treating this condition [156]. Exercise training can provide temporary improvement for those with idiopathic chronic neck pain. When designing a treatment plan, clinicians can choose multiple forms of rehabilitation [156]. Methods of rehabilitation include physical exercise (i.e., strengthening the muscles of the neck), motor retraining (i.e., using biofeedback to reprogram the muscle activations), massage (i.e., managing trigger points and relaxing muscles), and stretching (i.e., lengthening the muscle). These different methods individually target specific functions of the neck and shoulder muscles: strength, activation level or timing, or resting muscle length. However, pre-treatment evaluations are not in-depth or objective enough to determine the underlying mechanisms contributing to pain or dysfunction. Moreover, recurrence of idiopathic chronic neck pain is high [1, 157], suggesting that the long term efficacy of treatment is lacking.

Results from this dissertation highlight the importance of a full evaluation of neck and shoulder muscle function during various tasks to better inform the design of rehabilitation programs. Specifically, we determined the influence of idiopathic chronic neck pain on the stiffness and activity of the upper trapezius and sternocleidomastoid muscles during the maintenance of unilateral and bilateral functional reaching tasks in Chapter 3. We found that individuals with idiopathic chronic neck pain exhibited significantly lower upper trapezius activation during bilateral reaches without corresponding changes to stiffness during similar trials. Similarly, this cohort exhibited decreased sternocleidomastoid stiffness during forward-reaching without corresponding activation changes. These findings show stiffness and activation dysfunction happen independently of each other in neck-shoulder muscles in individuals with idiopathic chronic neck pain. While the bulk of literature investigating muscle activity and stiffness using ultrasound shear wave elastography found stiffness was dependent on muscle activity [70,

158], these studies have overwhelmingly been performed in healthy populations and have not investigated neck-shoulder muscles like this dissertations.

The results of this dissertation found that head and neck posture had a unique effect on upper trapezius muscle activation and stiffness. Additionally, in Chapter 4, we investigated the effect of chair recline and head and neck posture on the stiffness and activation of subdivisions of the upper trapezius during seated computer work for those with idiopathic chronic neck pain and healthy controls. For all three subdivisions of the upper trapezius, muscle activation was significantly lower in the neutral posture compared to the flexed head and neck posture. However, despite lower activation, the neutral head and neck posture resulted in greater stiffness of the caudal region of the upper trapezius closest to the spine of the scapula compared to the self-selected and flexed postures. These findings highlight novel information regarding muscle behavior that would be overlooked without ultrasound shear wave elastography, emphasizing the utility of this technology for performing a thorough evaluation of neck function before treatment plan development.

Ultrasound shear wave elastography is a tool that could provide objective, repeatable metrics for evaluating and monitoring neck muscle health and function. Results from Chapters 2-4 show that ultrasound shear wave elastography is feasible to use on the small muscles of the neck and shoulder. Additionally, ultrasound shear wave elastography is a relatively portable (e.g., can be moved from room to room) device that can supply immediate results when used in a clinic. Chapter 3 identified differences between healthy individuals and people with idiopathic chronic neck pain in upper trapezius muscle stiffness during bilateral reaches and sternocleidomastoid stiffness during unilateral reaches. Chapter 4 identified differences in shear wave velocity in upper trapezius subdivisions between healthy individuals and people with idiopathic chronic neck pain

during seated computer work. These findings indicate that ultrasound shear wave elastography could provide a tool for the early identification of individuals in need of intervention. However, future work is still needed to explore its efficacy for screening chronic neck pain patients before a change in clinical practice can occur. In comparison, EMG is time-consuming and is not often used in rehabilitation or clinical settings. Surface EMG can only provide quality data on the neck's superficial muscles, excluding over 50% of all neck muscles. Ultrasound imaging is ubiquitous in clinical settings, and shear wave elastography is currently available as a simple add-on to many clinical scanners. Unlike surface EMG, ultrasound shear wave elastography can examine deep muscles, which can be particularly valuable at the neck due to the multiple layers of muscles. Finally, many clinicians and sonographers are already trained in using ultrasound. This training can easily transfer to ultrasound shear wave elastography due to the similarities in methods, if future research clearly defines the appropriate use of ultrasound shear wave elastography in the clinic.

### **5.3. Informing ergonomic recommendations for individuals with and without idiopathic chronic neck pain**

Idiopathic chronic neck pain is common in those sitting for long periods for static work such as seated computer work [15, 16, 99]. Ergonomic recommendations have been developed for seated computer work to limit musculoskeletal injuries or the development of pain [100, 101]. The standard recommendations in the United States, among other countries, include sitting in an upright office chair (no recline or very slight recline), with a computer monitor 0.5-1 meter away from the eyes (e.g., viewing distance) positioned 15-20° below the horizontal eye level, and a chair adjusted to position thighs approximately horizontal to the floor so that the lower legs can be

positioned perpendicular to the floor [140]. However, this sitting position is often associated with a flexed head and neck. During standard seated desktop computer use, individuals shift their head posture forward by approximately 10% compared to upright sitting [95]. This forward shift increases the gravitational demand of the head as the neck becomes more flexed, increasing the muscle activation requirements of the neck extensors [96, 97]. There is a strong correlation between neck flexion angle and neck extensor activity, where increased neck flexion angle results in greater contributions from neck extensors, primarily the upper trapezius [94]. Increased neck flexion leads to a greater moment of the weight of the head about the center of rotation, C-7, which requires a greater amount of upper trapezius activity to hold the weight of the head. Chapter 4 examined the effect of chair recline and head and neck position on upper trapezius stiffness and activation. The results of this dissertation indicate that a neutral neck position, independent of recline level, reduces the required contributions of the three subdivisions of the upper trapezius. However, a neutral head and neck posture had the opposite outcome on the stiffness of one subdivision of the upper trapezius (e.g., the subdivision closest to the spine of the scapula). This suggests that ergonomic recommendations for seated computer work must consider shoulder position in addition to head and neck posture.

Idiopathic chronic neck pain is associated with sustained activation of the neck extensor muscles. Muscle activity below 5% maximum voluntary contraction during sustained work reduces the risk of developing neck pain [84, 85]. However, further research has suggested that sustained activations as low as 1% maximum voluntary contraction can still increase the risk of developing idiopathic chronic neck pain if sustained for a full 8-hour workday without breaks [86-88]. The results of this dissertation suggest that the subdivision of the upper trapezius lateral to C-4 had the largest activation requirement during seated computer work compared to the other two

subdivisions. This subdivision demonstrated an activation above the 1% maximum voluntary threshold during all seated conditions, while the others were well below that threshold. This suggests that this subdivision of the upper trapezius should be the focus of reducing muscle activation during seated computer work.

Several studies have suggested that reclining the back of an office chair can reduce the required activation of the extensors by lowering the gravitational moment of the head and neck. However, we are unaware of prior studies that specifically investigated chair recline independent of other factors in seated computer work. We isolated the effect of chair recline in Chapter 4 by tightly controlling all other variables, including monitor height, viewing distance, and arm support, during seated computer work. Although the activation of the upper trapezius subdivisions did not significantly change with increasing recline, there was a clear downward trend in activation with increasing recline for the caudal subdivision and the subdivision midway between the C-7 and acromion. Our findings suggest that recline can reduce the activation of upper trapezius subdivisions. However, stiffness of the most caudal subdivision of the upper trapezius significantly increased with increasing recline. Seated positions with rounded shoulders can cause protraction and internal rotation of the scapula. Based on the insertions of the upper trapezius, this may lengthen the upper trapezius's caudal region, increasing its stiffness independent of voluntary activation. The novel findings of this dissertation suggest that muscle length considerations should be included in the ergonomic development process, as a lengthened muscle may cause an increase in muscle stiffness and the sensation of pain.

#### **5.4. Informing future research on idiopathic chronic neck pain and the collections sites for upper trapezius**



The upper trapezius muscle is a large superficial muscle of the neck and shoulder. It originates along the spine from the external protuberance of the occipital bone to the lower thoracic vertebrae (typically assumed to end at C-7) and runs laterally to its insertion point on the acromion and spine of the scapula, and the lateral third of the clavicle [45]. The upper trapezius is primarily a postural muscle [45], assisting with scapular movement and stabilization. The upper trapezius also contributes to neck extension, lateral flexion, and shoulder elevation. Adequate upper trapezius function is critical to normal neck and shoulder function.

There are subdivisions of the UT that have been suggested to have independent activation and control [80, 144]. Previous research has established that the activation of these subdivisions can be independently tuned by the central nervous system during various levels of activation [80, 144], following experimental pain [151], and based on the duration of contraction [159-161]. For example, a study on men and women found that in response to experimental pain, the activation pattern of the upper trapezius shifted more caudally in men but not in women [79]. Consequently, women are significantly more likely to develop chronic neck pain when compared to men [2, 7]. The distribution of UT activation within the subdivisions should be investigated as a contributing factor. In Chapter 4, we collected ultrasound shear wave elastography and EMG data from three subdivisions up the upper trapezius during seated computer work with the chair reclined at 0°, 25°, and 45°. We also investigated the impact of head and neck posture on upper trapezius stiffness and activation by completing trials with a self-selected, neutral, and flexed position of the head and neck. Our study revealed that the subdivisions of the upper trapezius are individually affected by changes in posture elicited by recline and/or head and neck position. Much of the existing literature investigating the etiology or presentation of idiopathic chronic neck pain collects only electromyography data from a single collection site on the upper trapezius. Our findings suggest

this approach cannot fully detect adaptations of this muscle in response either postural changes or the presence of idiopathic chronic neck pain. Additionally, this finding can inform the clinical management of idiopathic chronic neck pain, as it may be beneficial to independently assess the subdivisions of the upper trapezius when monitoring improvement or function.

### **5.5 Limitations**

There were limitations to the chapters in this dissertation. Cervical torque production during dynamic movements is more clinically relevant than the isometric assessments performed in Chapters 2 and 3. However, ultrasound shear wave elastography is extremely sensitive to movement artifacts and takes 3-5 seconds to be satisfactorily performed, which prevented us from evaluating muscle stiffness during motion. Although our findings only apply to isometric conditions, tasks such as sustained reaching and prolonged computer work are largely isometric.

Our lack of shoulder and upper extremity kinematic data limits our ability to examine altered movement strategies by individuals with idiopathic chronic neck pain. The conclusions in this dissertation often cited upper extremity movement patterns or position differences as an underlying cause of upper trapezius stiffness changes. However, we cannot support these conclusions without upper extremity kinematic data. Future work should consider including motion capture alongside ultrasound shear wave elastography and EMG to more comprehensively examine the influence of idiopathic chronic neck pain on neck-shoulder muscle function.

The results of this dissertation are limited to the muscles we investigated. There are 26 pairs of muscles in the neck, most with moment arms that allow them to contribute to producing torque in multiple directions. We chose to focus on the larger, more superficial muscles of the head and neck given the sheer number of muscles, small size of many neck muscles, and limited ability to acquire surface EMG from the deep neck muscles. While this reduces the broad application of

our results to all neck muscles, this dissertation provides valuable information about the sternocleidomastoid and upper trapezius, which are often associated with idiopathic chronic neck pain. Additionally, the sternocleidomastoid and upper trapezius together comprise approximately 50% of all neck muscle volume and are two of the greatest torque-generators acting at the neck [44].

In our investigation of chair recline during seated computer work, participants only sat in each position for approximately 2.5 minutes. This amount of time does not represent a full day of work for the typical adult. We acknowledge that this may limit the ability to extend our results to an entire workday. However, we were primarily interested in the direct result of the posture change due to increasing chair recline. We believe that our results reflect the muscular adaptations in response to reclining the chair during seated computer work but do not reflect the chronic response of these muscles to prolonged work in our included recline angles.

An overall limitation of our primary research methods (e.g., the combination of electromyography and ultrasound shear wave elastography) is the lack of applicability in the clinic. Although we have shown that ultrasound shear wave elastography is a valuable tool that can be used in practice, shear wave elastography could be combined with EMG to differentiate the contributions of activation to increased shear wave velocity. We acknowledge that many clinics do not perform EMG during neck evaluations, which will reduce the level of insight gained into muscle function. Ultrasound shear wave elastography provides insights into the stiffness of individual muscles, but it will be difficult to determine whether the contributions to changes in stiffness include activation, stretch, or both. In fact, previous work has shown that increasing passive muscle length has a greater impact on muscle shear wave velocity than activation in the gastrocnemius [70]. The possible muscle length changes associated with slight changes in posture

during our investigations could have confounded the results of this dissertation. However, we believe that adding ultrasound evaluations to traditional methods of testing muscle stiffness can aid physical therapists and other clinicians in their diagnosis and treatment processes. Clinicians use various subjective measures for strength, muscle stiffness and length, and movement analysis when evaluating their patients. Combining standard clinical methods with objective, repeatable ultrasound shear wave elastography measurements could strengthen their ability to diagnose and monitor patient health. However, future research is needed to define the clinical uses and limitations to ultrasound shear wave elastography prior to its implementation in the clinic.

### **5.6 Recommendations for future research**

1) In Chapter 2, we determined that muscle stiffness largely scales with muscle activation in the muscles of the neck with lines of action in three dimensions. It would be useful to have normative data on stiffness (in terms of the preferred direction and focus) for more neck and shoulder muscles from healthy individuals. There is substantial activation data for muscles of the neck, but stiffness data is not as abundant for healthy controls and does not currently exist in the literature for those with idiopathic chronic neck pain. Obtaining and publishing normative stiffness data for other neck muscles, including the upper trapezius and scalene muscles, and individuals with idiopathic chronic neck pain could be beneficial for future studies investigating neck muscle dysfunction.

2) The results from Chapters 3 and 4 indicate that upper trapezius and sternocleidomastoid muscle stiffness differs between healthy individuals and people with idiopathic chronic neck pain. Additionally, these stiffness differences were not associated with correlated activation changes. We cannot soundly conclude here the exact underlying mechanisms that create increased muscular

stiffness in individuals with idiopathic chronic neck pain. We posit that our observed differences could be due to movement pattern differences or shoulder and scapula postural differences resulting in muscle length changes. Future research should explore whether postural differences at the glenohumeral joint or scapula drive greater dysfunction in individuals with chronic neck pain utilizing a combination of EMG, ultrasound shear wave elastography, and motion capture.

3) Results from Chapter 4 suggest that the standard ergonomic recommendations for seated computer work, which include upright sitting and a neutral head and neck posture, may not be beneficial for reducing neck-shoulder muscle stiffness. Specifically, we found that the subdivision of the upper trapezius closest to the spine of the scapula had a higher stiffness in the neutral posture when compared to the self-selected and flexed head and neck posture. Future work should consider investigating the effect of shoulder position during seated computer work on the length and stiffness of the upper trapezius by including conditions related to scapular position (i.e., protracted, self-selected, and retracted) alongside the conditions included in the current dissertation.

4) A promising clinical use of ultrasound shear wave elastography is to monitor patient progress throughout a rehabilitation program for idiopathic chronic neck pain. However, before ultrasound shear wave elastography can be used in the clinic, the efficacy of this technology in measuring change in muscle length (e.g., passive and active) and muscle activity need to be clarified. As current treatment programs for chronic neck pain include combinations of muscle stretching, strengthening, and massage, it would be beneficial to evaluate magnitude changes in shear wave velocity in response to increasing and decreasing muscle length and activation in a controlled study. Also, it would be helpful to test the efficacy of ultrasound shear wave elastography as a tool

for patient evaluation during a treatment program by comparing objective shear wave velocity outcomes to the results of traditional evaluations of muscle function.

5) Following Chapter 4, future work should implement longitudinal workplace interventions to investigate how increasing chair recline impacts individuals with idiopathic chronic neck pain during seated computer work. Longitudinal evaluations of the effects of chair recline during seated computer work should include objective measures of shear wave velocity of the upper trapezius, subjective discomfort measures, and other related measures. These investigations would help to inform updated ergonomic recommendations for those with idiopathic chronic neck pain

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