Investigating the Effects of Subclinical Neck Pain, Cervical Treatment, and Neck Muscle Fatigue on Wrist Joint Position Sense

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Abstract

The purpose of this work was to evaluate the effects of neck pain, cervical treatment, and neck muscle fatigue on joint position sense of the wrist. 12 healthy participants and 12 participants with chronic subclinical neck pain were recruited. Participants took part in two sessions, separated by 48 hours. On the first day, participants preformed two wrist proprioception sessions using a haptic robotic device separated by an isometric cervical extensor fatigue protocol. On the second day participants performed an additional two proprioception sessions, this time separated either by a neck treatment (pain group) or 20 minutes of rest (control group). Each session consisted of 12 trials; 6 in wrist flexion and 6 in wrist extension. Matching error, error bias and variability were measured for each trial. Kinematic data for each trial was recorded from the robotic device and analyzed. Results showed significantly higher error scores for the pain group when compared to the control group at baseline (p=<0.05). Joint position error scores increased significantly in the control group after the fatigue protocol (p= <0.05). Error scores for the pain group decreased significantly after a single treatment session (p= <0.05). This study confirms that altered afferent input from the neck (due to pain and/or fatigue) can influence wrist joint position sense (JPS). Furthermore, the results suggest that a single treatment can improve wrist JPS accuracy.

Keywords: proprioception, biomechanics, upper extremity, joint position sense, cervical extensor muscle, fatigue, upper limb
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List of Abbreviations

AAJ – Atlanto-axial joint
AAR – Active angle-reproduction test
CATC – Certified athletic therapist
CEM – Cervical extensor muscle
CNS – Central nervous system
DIC – Dorsal intercarpal ligament
dSLIL – Dorsal scapholunate interosseous ligament
DoF – Degree of freedom
EB – Error bias
ECRB – Extensor carpi radialis brevis
ECRL – Extensor carpi radialis longus
ECU – Extensor carpi ulnaris
ED – Extensor digitorum
FCR – Flexor carpi radialis
FCU – Flexor carpi ulnaris
FDS – Flexor digitorum superficialis
GTO – Golgi tendon organ
HRA – Head repositioning accuracy
HRE – Head repositioning errors
IIT – Italian Institute of Technology
JPS – Joint position sense
ME – Matching error
NDI – Neck disability index
pLTqIL – Palmar lunotriquetral interosseous ligament
ROM – Range of motion
SLIL – Scapholunate interosseous ligament
STQ – Scaphotriquetral ligament
STD – Standard deviation
TqC – Triquetrocapitate ligament
TqH – Triquetrohamate ligament
UT – Upper Trapezius
V – Variability
WAD – Whiplash associated disorder
WSIB – Workplace Safety and Insurance board
1.0 Introduction

1.1 Background

Neck and upper limb disorders are two of the most common musculoskeletal conditions. It is reported that two thirds of the population will experience neck pain in their lives (Abichandani & Parkar, 2015). According to the Workplace Safety and Insurance board (WSIB), almost half of all lost time claims registered with WSIB are related to musculoskeletal disorders (WSIB, 2018). Occupational injuries place a huge burden on the Ontario healthcare system, with the combined direct and indirect costs estimated to be $19 billion from 1996-2006 (Musculoskeletal Disorders and Ergonomics, n.d).

Chronic mechanical neck pain is defined as pain in the anatomical region of the neck where there is no specific pathological cause (Abichandani & Parkar, 2015). It can include neck pain that is present with or without pain in the upper limb and it is prevalent in 60-70% of the general population. Typical symptoms of neck pain can include limited range of motion, cervicogenic headaches, or radiculopathy. Chronic mechanical neck pain can result from arthritis of the cervical facet joints, degenerative disc disease in the cervical spine, postural dysfunction, or it may be of insidious onset. It has been demonstrated that patients with neck pain present with significant forward head posture (translation) when compared to healthy controls (Yip, Chiu, & Poon, 2008). Johnson suggested that prolonged forward head posture may increase loading to the non-contractile structures and place abnormal stress on the posterior cervical structures, which may lead to pain (Johnson, 1998). Furthermore, work by Szeto and colleagues revealed that symptomatic neck pain subjects with high discomfort levels had significantly
increased activity in the right upper trapezius (UT) during typing tasks when compared to healthy controls (Szeto, Straker, & O’Sullivan, 2005). This pattern of muscle activation is maladaptive, as the UT is not well designed to function as a postural stabilizer of the cervical spine. These results suggest that altered muscle recruitment patterns may be related to musculoskeletal symptoms. Neck pain has also been shown to lead to muscle imbalances, joint instability, and altered upper limb proprioception (Paulus & Brumagne, 2008; Szeto et al., 2005; Yip et al., 2008).

To optimally perform many occupational tasks, not only is upper limb strength and endurance required, but upper limb proprioception as well. The sensory stream responsible for both spatial awareness and unconscious perception of body movements is termed proprioception (Marini, Ferrantino, & Zenzeri, 2018). In order for a joint to maintain proprioceptive function, there are both anatomical and physiological criteria that need to be met. Sensory end organs (mechanoreceptors) that are reactive to joint pressure, motion, and velocity must be present in the joint capsule, muscles, and/or ligaments (Hagert, 2010). Impulses from mechanoreceptors are transmitted to the CNS, relaying information about joint position and joint movement, resulting in afferent proprioception feedback. Muscle spindles and golgi tendon organs are two important mechanoreceptors that contribute to proprioception. Intact limb proprioception is essential for many aspects of motor control such as interlimb coordination, the formation of muscle synergies, and for correcting and updating movement strategies (Marini et al., 2017).

Fatigue describes the gradual decrease in the maximal force generation capacity of a muscle. Fatigue can occur as a result of intensive repetitive maximal contractions, or
by repeating submaximal contractions over a longer period of time (Enoka & Duchateau, 2008). Muscle fatigue can alter afferent feedback from muscles (Zabihhosseinian, Holmes, & Murphy, 2015), and the sense of position can be disturbed (Allen & Prosko, 2006). Many researchers have investigated the effects of muscle fatigue on proprioception (Allen & Prosko, 2006; Brockett, Warren, Gregory, Morgan, & Prosko, 1997; Fortier, Basset, Billaut, Behm, & Teasdale, 2010; Gandevia, Allen, Butler, & Taylor, 1996; Myers, Guskiewicz, Schneider, & Prentice, 1999; Vuillerme, Pinsault, & Vaillant, 2005; Zabihhosseinian et al., 2015). It has been suggested that fatigue disturbs the sense of movement which is produced by muscle spindles, and the position-matching task is subsequently affected (Letafatkar, Alizadeh, & Kordi, 2009).

A large body of previous work examines the effect of fatigue and neck pain on proprioception of the impacted body segment (i.e. neck). For example, in 1991, Revel and colleagues investigated the effects of neck pain on cervicocephalic kinesthetic sensibility (Revel, Andre-Deshays, & Minguet, 1991). Sandlund and colleagues looked further down the chain, and investigated whether patients suffering from Whiplash Associated Disorders (WAD’s) demonstrated alterations in shoulder proprioception (Sandlund, Djupsjöbacka, Ryhed, Hamberg, & Björklund, 2006). Additionally, Myers examined the effects of muscle fatigue on shoulder proprioception (Myers et al., 1999). Brockett and colleagues investigated the effects of both concentric and eccentric elbow exercises on forearm position sense (Brockett et al., 1997). More recently, Zabihhosseinian and colleagues were among the first to look at the effect of neck fatigue further down the kinematic chain and investigate the effects of cervical extensor muscle
(CEM) fatigue on elbow joint position sense. Their results demonstrated that neck muscle fatigue decreases upper limb proprioception (Zabihhosseinian et al., 2015).

Neck muscles are rich in sensory receptors and as such are known to play a very important role in sensory input to the central nervous system (CNS) (Zabihhosseinian et al., 2015). It has been shown that the CNS uses the position of the head and neck to interpret the position of the upper limb (Knox & Hodges, 2005). As such, any altered input from neck muscles may affect the sensory inputs to the CNS and therefore affect upper limb proprioception. Many authors have examined the effects of neck pain on cervical kinesthetic sensibility (Feipel, Salvia, Klein, & Rooze, n.d.; Heikkilä & Wenngren, 1998; Lee, Wang, Yao, & Wang, 2008). More recently, researchers have shown interest in the influence that neck pain might have on structures further down the kinematic chain. Sandlund and colleagues investigated whether patients suffering from WAD’s demonstrate alterations in shoulder proprioception and found reduced shoulder position sense in the WAD patients when compared with their control group (Sandlund et al., 2006). Abichandani and Parkar measured repositioning error in the shoulder, elbow and wrist joints in women with chronic mechanical neck pain. Their results showed a statistically significant difference in wrist and shoulder proprioception when compared to the healthy control group (Abichandani & Parkar, 2015).

1.2 Research Gap

To date, most research related to the effects of pain and fatigue on upper limb proprioception has focused primarily on the joint affected. This is not always applicable
to everyday demands. Our bodies require multiple joints and muscles to work together in order to complete complex tasks. Damage anywhere along a muscular chain can potentially impact the ability of that entire chain to function adequately. Investigations have shown that alterations at the neck (due to chronic pain) can lead to decreased proprioception at the elbow and shoulder joints (Myers et al., 1999; Zabihhosseinian et al., 2015). Despite the growing amount of research focusing on neck pain and neck fatigue, little to no research exists on the effects that neck pain or fatigue may have on wrist proprioception. The hand and wrist provide the last degree of freedom for adjustments or corrections in reaching movements along the kinematic chain. Thus, if wrist proprioception is affected by altered sensory processes due to neck pain, this can have significant consequences for upper extremity task performance for work, leisure and sport. Additionally, little research exists that examines the effect of cervical treatment on wrist proprioception in subjects with subclinical neck pain. Due to the demands of most occupational tasks, investigation into the effects of neck pain and fatigue on wrist proprioception is necessary.

1.3 Research Questions

1. Does chronic subclinical neck pain affect proprioception at the wrist?

2. Does cervical extensor neck muscle fatigue affect wrist proprioception in healthy controls?

3. Does neck fatigue affect wrist proprioception in participants with chronic subclinical neck pain?

4. For participants with chronic subclinical neck pain, does cervical treatment improve proprioception at the wrist?
1.4 Hypothesis

1) Participants with chronic subclinical neck pain will exhibit less accurate wrist joint position matching scores when compared to healthy controls (Haavik & Murphy, 2011).

2) Cervical extensor fatigue influences elbow joint position sense (Zabihhosseinian et al., 2015), and we hypothesized that this effect would also be seen more distally, at the wrist in both the control and healthy groups.

3) Cervical manipulation in subclinical neck pain participants improves elbow joint position sense (Haavik & Murphy, 2011). We hypothesized that a single cervical treatment consisting of joint mobilizations and soft tissue techniques would improve accuracy during wrist joint position matching tasks for subclinical neck pain participants. We did not expect to see improved accuracy for the control group.
2.0 Literature Review

2.1 Neck Anatomy

2.1.1 Bones and Joints

The neck consists of seven vertebrae. The atlas, or the first cervical vertebrae, articulates with the occipital bone of the skull to form the atlanto-occipital joint and is classified as a synovial joint. The atlanto-occipital joint is a bi-axial joint, permitting cervical flexion and extension (nodding) as well as lateral flexion (head tilt). The axis, or the second cervical vertebrae, articulates with the atlas forming the atlanto-axial joint (AAJ). The AAJ has three distinct joints; two lateral atlantoaxial joints and a median atlantoaxial joint. The lateral AAJ’s are formed by the inferior facets of the atlas and the superior facets of the axis and allow only gliding movements. The median AAJ is formed by the dens of the axis and the anterior arch of the atlas and allows rotation of the atlas upon the axis. The cervical vertebrae three through seven make up the remaining bones of the neck.

2.1.2 Muscles of the Neck

The neck is very complex, with many muscles contributing to its stability and functionality (Figure 1). Some of the major contributors to cervical range of motion and stability include the cervical extensors (splenius capitus and splenius cervicis, semispinalis capitus, cervicis, and thoracis), scalene (anterior, posterior, and middle) sternocleidomastoid (clavicular head and sternal head), trapezius, and levator scapulae (Figure 1). The scalene muscles laterally flex the neck, and the anterior scalene anteriorly flex the neck. The sternocleidomastoid anteriorly flexes and also rotates the neck. The
trapezius muscle has three parts (superior, middle, and inferior) and acts to laterally flex the neck. The trapezius muscle also contributes to neck extension during bilateral contraction. While these muscles can be considered some of the major contributors to cervical motion and stability, they are often also involved in cervical injuries.
Figure 1: Neck musculature (source: http://opentextbc.ca)
2.2 Wrist Anatomy

2.2.1 Bones and Joints

The wrist comprises many bones including: the distal radius and ulna, the carpal bones, and the bases of the metacarpals. The carpal bones are divided into a proximal and distal row. The proximal row of carpal bones houses the scaphoid, lunate, triquetrum, and pisiform. The distal row of carpal bones includes the trapezium, trapezoid, capitate, and hamate. The metacarpals are named numerically (I-V), beginning with the first metacarpal – the thumb metacarpal.

The wrist is divided into three joint regions; distal radioulnar, midcarpal, and the carpometacarpal joints which form the distal border of the wrist (Berger, 1996). The wrist is an ellipsoid type synovial joint, allowing for movement along two axes which allows the wrist to perform flexion and extension as well as abduction and adduction.

2.2.2 Muscles and Ligaments

There are 15 muscles that cross the wrist joint, however, only six of them are dedicated solely to wrist movement. These six muscles include: flexor carpi ulnaris (FCU) which flexes and adducts (ulnar deviation) the wrist; flexor carpi radialis (FCR) which flexes and abducts (radial deviation) the wrist; extensor carpi ulnaris (ECU) which is responsible for wrist extension and ulnar deviation; extensor carpi radialis brevis (ECRB) and extensor carpi radialis longus (ECRL), which both contribute to wrist extension as well as radial deviation. The remaining muscles cross both the wrist and
interphalangeal joints. They are considered to be extrinsic hand muscles, however they produce significant force and therefore large moments at the wrist joint (Bawa, Chalmers, Jones, Søgaard, & Walsh, 2000). These muscles include flexor digitorum superficialis (FDS) and extensor digitorum (ED), whose primary actions are flexing and extending the digits.

Many ligaments cross the wrist joint and function to constrain displacement and guide motion, as well as provide afferent neural input (Berger, 1996). There are two distal radioulnar ligaments, four palmar radiocarpal ligaments, three uninocarpal ligaments, four palmar midcarpal ligaments, two dorsal midcarpal ligaments, as well as one dorsal radiocarpal ligament (Berger, 1996). There are also two interosseous ligaments in the proximal carpal row, and three in the distal carpal row.

2.3 Proprioception

Proprioception is defined as “the perception of joint and body movement as well as position of the body, or body segments, in space” (Han, Waddington, Adams, Anson, & Liu, 2016). Proprioception has two components: joint position sense, the awareness of limb position in space, and kinesthesia; the awareness or sensation of joint movement (Han et al., 2016).

When a limb changes position, the tissues around the relevant joints will be deformed, including muscles, skin, fascia, tendons, joint capsules, and ligaments (Proske & Gandevia, 2012). In order for a joint to maintain proprioceptive function, there are both
anatomical and physiological criteria that need to be met. Sensory end organs (mechanoreceptors) that are reactive to joint pressure, motion, and velocity must be present in the joint capsule, muscles and/or ligaments (Hagert, 2010). These mechanoreceptors; golgi tendon organs (GTO), joint and cutaneous receptors, and muscle spindles (Dukelow et al., 2010) are a crucial component of motor control, body awareness, and regulation of muscle tone as well as postural stability.

A mechanoreceptor is a neuroepithelial structure that is found in the skin, as well as ligamentous, articular, muscular, and tendinous tissue around a joint (Grigg, 1994). Impulses from mechanoreceptors are transmitted to the CNS, relaying information about joint position and joint movement, resulting in afferent proprioception feedback. Mechanoreceptors transduce mechanical and functional deformation into frequency-modulated neural signals, and any increase in deformation results in an increase in afferent discharge of neural signals back to the CNS (Myers et al., 1999). The CNS uses this sensory information from proprioceptors to build up an internal reference frame of the musculoskeletal system (a body schema) (Lackner & DiZio, 2005). This internal representation of the body is used to both determine the position of joints in relation to each other as well as to identify the position of objects in relation to the body (Knox & Hodges, 2005).

Visual inputs play an integral role in proprioception as they can be interpreted by the brain and used to help predict the limbs future position (Proske & Gandevia, 2009). However, it has been shown that even in a dark room humans are able to place their index finger on the tip of the nose (Walsh, Allen, Gandevia, & Proske, 2006). Even without
visual cues, the primary endings of muscle spindles are able to relay information about the sense of position and movement of our limbs (Winter, Allen, & Proske, 2005).

2.3.1 Muscle Spindles and Golgi Tendon Organs

The principal muscle receptor in proprioception is the muscle spindle which includes both primary and secondary endings (Figure 2). Primary endings respond to the size of a muscle length change as well as its speed, and as such, are believed to contribute to the sense of limb position and movement (Proske & Gandevia, 2009). Secondary endings are believed to be sensitive only to changes in muscle length, contributing solely to the sense of position (Proske & Gandevia, 2009). The muscle spindle lies in parallel with extrafusal muscle fibers and has three main components: intrafusal muscle fibers; sensory axons which wrap around the intrafusal fibers and when stimulated project afferent information to the CNS; and motor axons which innervate the intrafusal fibers and regulate the sensitivity of the muscle spindle (Hurd & Snyder-Mackler, 2007) (Figure 2). When intrafusal fibres are stretched, sensory nerve endings are also stretched, increasing their firing rate in direct proportion to the length of the muscle (Hurd & Snyder-Mackler, 2007; Winter et al., 2005). This allows the CNS to collect information about the length of the muscle and consequently the position of the limb (Winter et al., 2005).
Figure 2: (A) Muscle spindle, (B) Intrafusal fibres of the muscle spindle (Kandel, 2013)
GTO’s (Figure 3) are located at the junction between skeletal muscle fibres and the tendon and are positioned in series with extrafusal fibre (Hurd & Snyder-Mackler, 2007; Kandel, 2013). Each tendon organ is innervated by a single 1b axon which branches into many endings inside the capsule that become intertwined with collagen fascicles (Figure 3). When the GTO is stretched (usually a result of a muscle contraction), it causes the 1b afferent axon to be compressed by collagen fibres, increasing its firing rate (Kandel, 2013). Increased activity of GTO afferents causes inhibition of the motor neurons innervating the muscles that were stretched while exciting the motor nerves of the antagonistic muscles (Hurd & Snyder-Mackler, 2007). This causes a relaxation during intense muscle contractions in attempt to prevent injury. While muscle spindles are known to be most sensitive to changes in the length of the muscle, GTO’s are sensitive to changes in muscle tension (Kandel, 2013). The GTO has a high-threshold for mechanical stress, which makes it completely inactive in the immobile joint, but important for detecting extreme ranges of joint movement.
2.3.2 Joint Receptors

Ruffini endings also play a role in proprioception, and are believed to be involved in preparatory control as well as regulation of stiffness of the muscles that surround the joint (Hagert, 2010). Recordings from cat knee intra-capsular ligaments revealed that Ruffini endings are a slowly adapting, low threshold receptor that is constantly reactive during joint motion (Hagert, 2010). Additionally, Ruffini endings have been found to
react to tensile strain and axial loading in ligaments, but not to perpendicular compressive joint forces. This suggests their importance in signaling joint position and rotation rather than direct pressure.

The Pacini corpuscle is opposite to Ruffini endings in that it is a rapidly adapting, high threshold receptor. As such, it is sensitive to joint acceleration and deceleration and is able to sense mechanical disturbances and sudden joint perturbations (Hagert, 2010). Unlike the Ruffini endings, the Pacini corpuscle is sensitive to compressive and not tensile forces. The Pacini corpuscle is abundant in lateral ankle ligaments where it is ideal for reacting to rapid joint perturbations.

2.3.3 Methods of Measuring Proprioception

Researchers often use joint position matching tasks to assess and measure proprioceptive ability. Revel and colleagues (1991) used a head repositioning task to measure cervicocephalic kinesthesia. This method required subjects to wear a helmet with a light beam fixed to the top that pointed toward a target. Subjects were required to wear goggles to occlude vision and were instructed to memorize their initial head position and duplicate it after an active movement of the head (Revel et al., 1991).

Myers and colleagues assessed shoulder proprioception using an active angle – reproduction test (AAR) using a Lido Multi-Joint Isokinetic dynamometer (Myers et al., 1999). Subjects’ arms were secured with a hook-and-loop strap that secured the humerus to a pad positioned on the dynamometer, the wrist was also secured to the lever arm.
Subjects wore a pneumatic air splint, blindfold, and headphones. Examiners moved the subjects’ arm to a reference angle (either internal or external rotation), held the position for ten seconds, and then passively returned it to 0° of rotation. Subjects were then asked to actively reproduce the reference angle. An isokinetic electrogoniometer was used to measure range of motion and absolute error was calculated.

Joint position sense (JPS) involves measuring the ability to replicate a previously presented joint angle and can be tested either actively or passively. Many researchers have used variations of joint position matching tasks to measure proprioceptive ability (Abichandani & Parkar, 2015; Brockett et al., 1997; Haavik & Murphy, 2011; Sandlund et al., 2006). Zabihhosseinian and colleagues (2015) used an elbow joint position sense test to assess proprioception at the elbow. They placed subjects’ right arm in an adjustable sling at 90° of elbow flexion and 80° of shoulder abduction and external rotation. The experimenter passively moved the participants’ forearm to the target elbow joint angle (80°–100°). The position was held for 3 seconds and then passively moved to the rest angle (between 70° and 80° or 100° and 110°). After another three seconds, participants were asked to actively reproduce the target angle. Absolute, constant, and variable error were used to measure the accuracy of angle reproduction.

2.3.4 Matching Error, Variability, and Error Bias

Accuracy for joint position matching can be measured using matching error (ME), variability (V), and error bias (EB) (Marini, Squeri, Morasso, Konczak, & Masia, 2016). Matching Error is used to measure the angular deviation from the proprioceptive target. It
quantifies performance accuracy during active movement. The formula for ME is as follows:

\[
ME = \frac{\sum_{i=1}^{N}(\theta_i - \theta_T)}{N}
\]

where \(\theta_i\) is wrist’s final position of the trial, \(\theta_T\) is the proprioceptive target position, and \(N\) is the number of trials tested in a single DoF.

Variability measures the consistency, or precision, in terms of participant performance. It is the standard deviation across trials. \(V\) is calculated as follows:

\[
V = \text{StD}(\theta_{i=1:N})
\]

Where \(\text{StD}\) is the standard deviation across trials, \(\theta_i\) is wrist’s final position of the trial, and \(N\) is the number of trials tested in a single DoF.

Error Bias provides information about participants’ response bias. It is the directional distance between the proprioceptive target, and the reproduced target. It indicates the participants’ tendency to undershoot (negative error bias) and overshoot (positive error bias) the target. \(EB\) is calculated as follows:

\[
EB = \frac{\sum_{i=1}^{N}(\theta_i - \theta_T)}{N}
\]

where \(\theta_i\) is wrist’s final position of the trial, \(\theta_T\) is the proprioceptive target position, and \(N\) is the number of trials tested in a single DoF.
2.4 Wrist Proprioception

The principle role of wrist stability is to assist the hand in an array of functions ranging from fine motor finger manipulations such as handling tools to sustaining heavy loads. As such, the wrist joint and its complex anatomy is hypothesized to possess inherent sensorimotor functions. Wrist stability is comprised of both static and dynamic elements. While the static aspects of wrist stability comprise the anatomical congruity of joint surfaces, it is the dynamic elements that chiefly concern proprioceptive control during compressive and directional forces acting on a joint (Hagert, 2008).

It is well known that ligaments stabilizing the wrist contain mechanoreceptors that contribute to proprioceptive ability of the wrist. Immuno-histochemical studies of the wrist ligaments show distinct variation with regard to degree of innervation (Figure 4). Upon observation, the dorsal wrist ligaments: dorsal radiocarpal (DRC), dorsal intercarpal (DIC), scaphotriquetral (STq) and dorsal scapholunate interosseous (dSLI) all showed pronounced innervation, with nerves and mechanoreceptors in all sections of specimens. The volar triquetral ligaments: triquetrocapitate ligament (TqC), triquetrohamate ligament (TqH) and palmar lunotriquetral interosseous ligament (pLTqI) had an intermediate innervation, with nerves and mechanoreceptors in 3 of 5 studied specimens. The remaining volar ligaments were more sparsely innervated, with only nerves and/or occasional mechanoreceptors found. In all cases, nerves and mechanoreceptors were most frequently found in the ligament-bone interface, suggesting that this is an important area for monitoring disturbances in the joint and ligament (Hagert, 2008).
Figure 4: Schematic representation of the wrist ligaments analyzed using immunohistochemical techniques. The DRC (1), DIC (2), STq (3), SLIL (4), ulnocarpal (5), TqH (6), TqC (7), pLTqIL (8), UL (9), SRL (10), LRL (11), RSC (12), RS(13), SC (14), STT (15) ligaments. Pronounced/intermediate innervation (red-orange) = mechanoreceptors found in a majority of specimens studied; limited/occasional (blue-green) = mechanoreceptors in 20% of specimens studied.
While Golgi-type endings were only rarely identified in wrist ligaments, they have been found in the DRC and DIC ligaments. The DRC/DIC ligament complex is proposed to indirectly stabilize the scaphoid and lunate during all ranges of wrist motion (Hagert, 2008). If the function of GTO’s is considered (monitoring tensile strain during extreme ranges of motion), their presence in these ligaments isn’t surprising. Contrarily, the Ruffini endings were the most common mechanoreceptor type found in the wrist ligaments, suggesting the importance of monitoring both wrist positions and motions (Hagert, 2008).

Contrary to its prevalence in the lateral ligaments of the ankle, the Pacini corpuscle is only occasionally identified in the wrist ligaments. This suggests that monitoring of the onset/termination of motion as well as joint velocity is of less importance when considering wrist sensorimotor stability (Hagert, 2008).

Interestingly, it has been found that the ligaments most important to sensory function originate from the triquetrum and are able to monitor and signal during all wrist positions and motions (Hagert, 2008). These findings suggest that the triquetrum and its ligamentous attachments provide the sensorimotor foundation for the wrist.

It has been suggested that degree of innervation in wrist ligaments and the differences in receptor density may be responsible for observed differences in proprioceptive acuity among the degrees of freedom (DoF) in the wrist (Marini et al., 2016).
2.4.1 Robot Aided Assessment of Proprioception

It is well established that our ability to process proprioceptive information is crucial for neural control of movement. In recent years, haptic devices have been used extensively as a novel method for assessing proprioceptive abilities. There are many studies that have used robot-aided devices to examine proprioception in the shoulder (Dukelow et al., 2010; Erickson & Karduna, 2012), elbow (King, Harding, & Karduna, 2013) and lower limb joints such as the ankle (Domingo & Lam, 2014). As haptic devices continue to grow in popularity, researchers have also examined robot-aided assessment of wrist proprioception (Cappello et al., 2015; Hagert, 2010; Marini et al., 2018, 2017, 2016). Work by Cappello and colleagues found that robotic technology used at the wrist can provide insights into motor learning and explain why particular patterns of muscular activation are preferred for a particular task (Cappello et al., 2015).

Marini and collaborators used a joint position matching test to assess proprioceptive acuity of the wrist joint (Marini et al., 2016). Their work showed that acuity for abduction/adduction is significantly higher than other DoF and that accuracy is higher at the limits of joint range of motion (ROM). Additionally, they found that participants had a tendency to overshoot the target in the direction of abduction/adduction, while there were consistent patterns of both undershooting and overshooting the target in the direction of flexion/extension. Furthermore, their work also demonstrated that a robotic device is a highly suitable tool for assessing wrist proprioception, providing clear and concise information about joint sensitivity. Work completed by these researchers provides the groundwork to justify the use of robotic
devices in assessing wrist proprioception.

More recently, Marini and colleagues used the WristBot to implement an ipsilateral joint matching task and investigate the mechanisms participants adopt to locate spatial positions during proprioception tasks (Marini et al., 2018). Specifically, they investigated whether participants had better abilities during proprioceptive tasks that require position control strategies or during tasks that require amplitude control strategies. Participants were separated into two groups of 15 and were asked to complete one of two experiments. The first experiment aimed to test proprioceptive joint position identification (position control strategy) and required participants to move towards a fixed target that started from different positions and had different lengths. The second experiment tested kinaesthetic movement reproduction (amplitude control strategy) and participants were asked to match target positions that had different locations in space, but this time were passively shown through movements of the same length. Participants were blindfolded in each experiment. Their results indicated better performances in matching accuracy and matching precision in the joint position matching experiment, which suggested a preference for identification of joint positions. Additionally, they demonstrated that participants who completed the kinaesthetic movement reproduction task had a greater tendency to overshoot the target. Their findings suggest that participants have stronger abilities in proprioceptive identification of joint position rather than in kinaesthetic movement reproduction.
2.5 Wrist Robotics

Robot-aided rehabilitation is increasing in popularity. Robotic devices can provide repetitive, task specific treatment, and can also be programmed to assist on a when needed basis (Frisoli et al., 2012). As a result, many researchers have investigated the use of robotic therapy for rehabilitation purposes. Early work with robot assisted rehabilitation focused mainly on restoring upper limb function in stroke survivors (Frisoli et al., 2012; Masiero, Celia, Rosati, & Armani, 2007; Takahashi, Der-Yeghiaian, Le, Motiwala, & Cramer, 2008). More recent work has focused on using robotics to assess proprioceptive function in the wrist (Cappello et al., 2015; Cuppone, Squeri, Semprini, Masia, & Konczak, 2016; Hagert, 2010; Marini et al., 2018, 2017, 2016).

2.5.1 WristBot

The Wristbot (Figure 5) is a robotic exoskeleton that was designed and built by the Italian Institute of Technology (IIT) (Figure 4). The device provides three degrees of freedom, allowing for range of motion in flexion/extension (±70°), radial/ulnar deviation (± 35°), and pronation/supination (± 80°) (Masia, Casadio, Giannoni, Sandini, & Morasso, 2009). The WristBot was designed with virtual reality software that allows researchers to display a target on a computer screen that participants can track. Additionally, the robot records and stores kinesthetic data from each participant trial. The robot is equipped with high resolution sensors and precision actuators, which provide researchers with a high level of repeatability and accuracy when measuring subjects’ performances (Marini et al., 2018). The robotic device is equipped with brushless motors in each plane of movement (Masia et al., 2009). These motors allow the researcher to
apply forces either against or with participants’ movements. Furthermore, this technology allows the device to be locked in any one plane of movement, allowing researchers to focus on only one degree of freedom at a time. The versatility of the WristBot allows researchers to manipulate the device in several different ways, making it a valuable tool for both researchers and clinicians alike.

Figure 5: IIT WristBot

2.6 Neck Pain and Proprioception

It has been shown that subjects with neck pain demonstrate less accurate and precise position sense of the head and the upper limbs (Knox & Hodges, 2005; Sandlund et al., 2006). The high concentration of muscle spindles in the neck and cephalic muscles supports the importance of neck muscle receptors for motor control (Sandlund et al.,
It has been proposed that pain may affect fusimotor drive and thus the sensitivity of muscle spindles.

It has also been suggested that if the quality of input from any part of the body deteriorates due to chronic injury, disease, or normal aging, the CNS may increase the weighting of input from other locations (Paulus & Brumagne, 2008). Consequently, proprioceptive deficits found in subjects with neck pain may be a result of re-weighting of sensory signals; where the CNS responds by down-weighting signals from the neck muscles and up-weighting other sensory inputs, for example, signals from trunk muscles (Paulus & Brumagne, 2008).

Additionally, it has been shown that pain can lead to central plastic changes throughout the sensorimotor system (Wall, Xu, & Wang, 2002) and plastic changes have been shown to alter CNS function. As such, any altered input from neck muscles may affect the sensory inputs to the CNS and affect upper limb proprioception.

Many researchers have examined the effects of chronic neck pain on cervical kinesthetic sensibility (Feipel, Salvia, Klein, & Rooze, n.d.; Heikkilä & Wenngren, 1998; Lee, Wang, Yao, & Wang, 2008; Revel, Andre-Deshays, & Minguet, 1991). In 1991, Revel and colleagues investigated the effects of neck pain on cervicocephalic kinesthetic sensibility (Revel et al., 1991). Their protocol required subjects to wear a helmet with a light beam fixed to the top that pointed toward a target. Subjects were asked to wear googles to occlude vision. They were instructed to memorize their initial head position and duplicate it after active movement of the head and neck in left rotation, right rotation, extension, and flexion. Their results were two-fold; 1) that this method is both easily
performed and reproducible and permits a quantification of alterations in cervicocephalic
kinesthesia, and 2) that subjects with cervical neck pain demonstrated significantly less
accuracy during the head repositioning task. Revel and colleagues argued that it is
probable that cervicocephalic kinesthesia is connected to information coming from the
articular and muscular proprioceptive system of the neck and that there are alterations in
this proprioceptive sensibility in patients with neck pain (Revel et al., 1991).

Feipal and colleagues examined 29 patients suffering from WAD’s and 26 healthy
subjects (Feipel et al., n.d.). Subjects completed a head repositioning task and the two
groups were compared. Their results showed that subjects that had previously suffered
from a WAD had significantly increased head repositioning errors (HRE) when compared
to healthy subjects.

Heikkilä and Wenngren examined cervicocephalic kinesthetic sensibility in
patients with whiplash injuries (Heikkilä & Wenngren, 1998). Using the same head
repositioning task as Revel and colleagues, they recruited 27 subjects who had been
diagnosed with whiplash one to two years previously and compared them to a healthy
control group. Their results showed that there was a repositioning dysfunction in 62% of
the subjects with whiplash two years after the trauma had occurred.

Sandlund and colleagues looked further down the chain, and investigated whether
patients suffering from WAD’s demonstrate alterations in shoulder proprioception
(Sandlund et al., 2006). They examined 37 patients with WAD and 41 healthy
participants and had them complete an ipsilateral arm position matching task. Their
results indicated reduced shoulder position sense in the WAD patients when compared
with their control group.

Abichandani and Parkar measured repositioning error in the shoulder, elbow and wrist joints in 30 women, 15 of whom suffered from chronic mechanical neck pain (Abichandani & Parkar, 2015). Subjects were asked to perform three movements: shoulder abduction to 30 degrees, elbow flexion to 30 degrees, and wrist extension to 30 degrees. Their results showed a statistically significant decrease in wrist and shoulder proprioception in the neck pain group when compared to the healthy control group.

Huysmans and colleagues examined 23 subjects with neck and upper extremity pain and 26 healthy controls to measure the effects of upper extremity pain on position acuity sense of the upper extremity. All subjects were asked to complete a position acuity sense test where they pointed at targets under a digitized tablet with their hands. They were also asked to complete a second task that included tracking a moving dot that was presented on a computer screen on a separate, digitized tablet. Their results showed that subjects with neck and upper extremity pain demonstrated impaired position sense acuity and reduced tracking precision. Additionally, the pain group reported the tracking test was more physically demanding than the control group (Huysmans, Hoozemans, van der Beek, de Looze, & van Dieen, 2010).

2.7 Fatigue and Proprioception

Fatigue describes the gradual decrease in the force capacity of a muscle (Enoka & Duchateau, 2008). Fatigue can occur as a result of intensive repetitive maximal contractions, or by repeating submaximal contractions over a longer period of time. According to Enoka and Duchateau, performing submaximal muscle contractions at
lower stimulation frequencies tends to cause muscles to exhibit a long-lasting decline in force production as well as a slower recovery time (Enoka & Duchateau, 2008). Muscular fatigue can be categorized into two categories; central and peripheral fatigue. Central fatigue occurs when the central nervous system fails to ‘‘drive’’ the motor neurons. Peripheral fatigue involves biochemical changes within the working muscle, nerve, or neuromuscular junction (Amann, 2011).

Fatigue can alter afferent feedback from muscles (Zabihhosseinian et al., 2015) and the sense of position can be disturbed by muscle fatigue (Allen & Proske, 2006). It has been suggested that fatigue disturbs the sense of movement, which is produced by muscle spindles, and the position-matching task is subsequently affected (Letafatkar, Alizadeh, & Kordi, 2009). Many researchers have investigated the effects of muscle fatigue on proprioception (Allen & Proske, 2006; Brockett et al., 1997; Fortier et al., 2010; Gandevia et al., 1996; Myers et al., 1999; Vuillerme et al., 2005; Zabihhosseinian et al., 2015).

Brockett and colleagues investigated the effects of both concentric and eccentric elbow exercises on forearm position sense (Brockett et al., 1997). They fatigued the elbow flexors eccentrically on one arm and concentrically on the other arm and then asked subjects to perform an elbow position sense test. Their results showed changes in position sense after eccentric exercise suggesting that subjects perceived the eccentrically exercised muscles to be shorter than they actually were. They stated that eccentric exercise affects muscle receptors and as such, the ability of muscle spindles to detect muscle length was altered.
Myers examined the effects of muscle fatigue on shoulder proprioception (Myers et al., 1999). They had 32 participants complete an active angle-reproduction test (AAR) both before and immediately following a fatigue protocol using concentric internal and external rotation exercises. Their results indicated decreased proprioception of the shoulder following fatigue as the absolute angle error for the experimental group increased from pretest to posttest.

Zabihhosseinian and colleagues were among the first to investigate the effects of cervical extensor muscle (CEM) fatigue on elbow joint position sense (Zabihhosseinian et al., 2015). Participants performed two elbow joint position sense (JPS) trials, followed by a CEM fatigue protocol. Immediately after the fatigue protocol, participants completed one set of three elbow JPS trials. This study was the first to demonstrate that neck muscle fatigue can impact upper limb proprioception. Their results showed a decrease in elbow JPS accuracy following CEM fatigue. For all trials, reproduced angles were smaller than the target angles, indicating that participants deviated more towards elbow flexion. Given the predominance of neck injuries in the workplace, these findings are of utmost relevance as they highlight the impact that alterations in the neck can have on upper limb proprioception.

2.8 Cervical Treatment and Proprioception

Many researchers have examined the effects of cervical spine treatment on upper limb proprioception (Haavik & Murphy, 2011; Haavik-Taylor & Murphy, 2007; Palmgren, Sandström, Lundqvist, & Heikkilä, 2006; Taylor & Murphy, 2008; Yang, Lee, & Kim, 2015). To date, most research focuses on the effects of cervical spine
manipulation on head repositioning tasks. A pilot study conducted by Rogers examined the effects of cervical spine manipulation compared to cervical stretching on a head repositioning skill in subjects with chronic neck pain (Rogers, 1997). After intervention, Rogers reported a 41% improvement in the head positioning skill in the manipulation group and only a 12% improvement in the stretching group. Rogers argues that manipulations affect the deep intraarticular muscles, which house a large number of mechanoreceptors.

Palmgren and colleagues examined the effects of chiropractic therapy on head repositioning accuracy (HRA) in subjects with chronic neck pain (Palmgren et al., 2006). Their treatment included high-velocity and low-amplitude techniques, spine-stabilizing exercises that targeted hypomobile zygapophyseal joints in the cervical region as well as myofascial techniques. They reported a significant improvement in all aspects of the HRA following treatment. They hypothesized that the observed effects in their study were related to changes in mechanoreceptor afferent input as the muscles in the neck contain both nociceptive and mechanoreceptive nerve endings which are significant for proprioception.

Haavik and Murphy examined the effects of cervical spine manipulation on elbow joint position sense (JPS) in subjects with chronic neck pain (Haavik & Murphy, 2011). Their results showed that a single session of joint manipulation on dysfunctional cervical joints improved JPS scores significantly. Their results suggest that spinal dysfunction not only affects central proprioceptive processing at the spine itself, but also of the upper limb.
3.0 Study

3.1 Methods

3.1.1 Participants

A total of 24 right handed participants were recruited for this study; 12 participants with chronic subclinical neck pain and 12 healthy controls. Participants were aged 19 years and older (mean age 25.2 ± 4.9 years), and there was a total of 7 males and 5 females in each group. Upon arrival to the lab, participants completed a neck pain disability index (NDI) and chronic pain grading scale to evaluate which group they should be placed in. Neck pain was graded between Grade 1 and Grade 3 on the chronic pain grading scale (Von Korff, Ormel, Keefe, & Dworkin, 1992) which categorizes pain intensity and disability between a grade 0, meaning the participant experienced minimal neck pain and no disability in the previous six months and a grade IV, which meant that the participant had experienced severe neck pain and disability in the previous six months. To be included, participants were required to have a history of reoccurring neck pain or stiffness. However, we required that participants be pain free at the time of the experiment. Exclusion criteria included the following: specific diagnosis of the cervical spine; traumatic spinal cord injury; any medical condition affecting the sensory system; and any wrist injury within the last 12 months. Participants were also excluded if they have had any recent (within the last three months) treatment for neck pain.

3.1.2 Experimental Setup

Once participants entered the lab for their first visit, the primary researcher reviewed the consent form with them, outlining the experimental protocol. Once the
consent was reviewed and all questions were adequately answered, the participant was asked to sign the consent form. In addition to the consent form, participants also completed a form outlining any previous upper extremity injuries and were asked to sign a consent for the use of photographs and video.

After the participant signed the forms, they were familiarized with the robotic device that was used during the experiment (Figure 6). The Wristbot is a robotic exoskeleton that was created and custom built by the Italian Institute of Technology (IIT). The device provides three degrees of freedom, allowing for range of motion in flexion/extension (±70°), radial/ulnar deviation (± 35°), and pronation/supination (± 80°) (Masia, Casadio, Giannoni, Sandini, & Morasso, 2009). The robotic device is equipped with brushless motors in each plane of movement (Masia et al., 2009). These motors allow the researcher to apply forces either with or against participants’ movements while compensating for the weight and inertia of the device (Marini et al., 2016). Furthermore, this technology allows the device to be locked in any one plane of movement, allowing researchers to focus on only one degree of freedom at a time. The robot provides and stores kinematic data from each participant trial.
Figure 6: Experimental Setup: tracking monitor (left), system interface (middle), Wristbot (right)
3.1.3 Experimental Protocol

The experiment included two visits to the lab, separated by at least 48 hours to minimize any potential muscle soreness from the fatigue protocol. On the first day, each participant completed two proprioception sessions separated by an isometric cervical muscle fatigue protocol. Each proprioception session consisted of 12 randomized trials, 6 in the wrist flexion direction and 6 in the wrist extension direction. On the second day, each participant completed the same proprioception session an additional two times.

Once the participants completed the first proprioception session, the control group was asked to rest for 20 minutes, and the subclinical neck pain group received a 20-minute treatment from a certified athletic therapist (CAT(C)) (the principal student investigator). Once participants completed either the treatment session or the 20-minute rest period, they were asked to return to the robot and complete a fourth and final proprioception session. At this point the experiment was completed, participants were debriefed and given the opportunity to ask any questions they may have had about the protocol for the researchers. We chose to separate the visits by at least 48 hours to minimize any learning effects, as well as to ensure the participants had fully recovered from the effects of the fatigue protocol.

Day 1

Proprioception Trial # 1

Participants performed 12 randomized JPS trials. Participants’ wrist started in a neutral anatomical position (0° of flexion, 0° of extension). The robot then passively moved the participants’ hand to a pre-set, randomized target and held the position for
three seconds. After three seconds, the robot provided an auditory cue, passively moved the participant back to the neutral position and provided a second auditory cue which signalled the participant to actively move their wrist to the same position with no assistance from the robot (Figure 7). Participant’s vision was occluded with googles so as to eliminate visual feedback of the target and their wrist. They also wore noise cancelling headphones to cue each movement (both passive and active) with an audible signal.

Two degrees of freedom (DoF) (flexion and extension) were tested during the experiment and targets were set at a distance no greater than 80% of the wrist’s total functional ROM in order to ensure all participants could actively match the targets. Proprioceptive targets were presented six times for each DoF for a total of 12 trials. During each trial, the robot allowed movement in only one DoF (i.e. when participants were moved into flexion, extension was locked).
Figure 7: Flexion/Extension joint position matching test, passive reaching phase (left), Active matching phase (middle), Return phase (right) (Marini et al., 2016)
Fatigue Protocol

Participants in both the control and subclinical neck pain group completed a neck extensor isometric task to fatigue the cervical extensor muscles (Edmondston et al., 2011) (Figure 8). Participants were asked to lay prone on a plinth, with their arms at their side and their head over the edge of the table. Their head was supported by the examiner for the duration of the setup. A Velcro strap was fixed around the head with an inclinometer (Autoutlet Digital Inclinometer, 0.01degree resolution) attached to the band over the occiput. A 2-kg weight was suspended from the headband and the weight hung just short of the floor. The participants head was positioned in neutral in the sagittal plane. The test began once the examiner removed support from the participants head. The participant was required to hold the cervical spine in the neutral position for as long as possible. The test was terminated if the participant could no longer hold the position due to fatigue or pain, if the weight returned to the floor, or if the neck position changed more than five degrees (as measured by the inclinometer). The holding time was measured in seconds.
Figure 8: Cervical extensor fatigue protocol (Edmondston et al., 2011)

**Proprioception Trial #2**

Immediately after the fatigue protocol, participants were asked to complete the same proprioception protocol a second time. They were given no rest period between the fatigue protocol and the second proprioception trial.
Day 2

Proprioception Trial # 1

Participants were asked to return to the lab 48 hours after their initial visit. Upon arrival, they were reminded of the experimental protocol for the second day. Once they were comfortable with the protocol, they were asked to complete the same proprioception sessions from day one.

Cervical Treatment

After completing the proprioception protocol, the subclinical neck pain group received treatment from a certified athletic therapist (CAT(C)). Prior to treatment, the CAT(C) took a thorough history from each participant. Additionally, each participant’s neck was evaluated for restricted range of motion (ROM) at each joint and for muscle tension. Joint restriction was tested by the examiner passively moving the participant’s head into maximum range of lateral flexion (both left and right) while palpating each cervical joint for restriction. Muscle tightness was examined by palpation. ROM was assessed by the participant moving their neck actively through each neck range of motion (flexion, extension, left lateral flexion, right lateral flexion, left rotation, right rotation) and the CAT measuring pre-determined landmarks (Clarkson, 2013). To measure flexion and extension, the participant was asked to either flex or extend their neck to their limit of motion, the CAT then measured from the tip of the chin to the suprasternal notch. To measure left and right lateral neck flexion, the participant was asked to move to their end ROM and the CAT measured from the mastoid process of the skull to the lateral aspect of the acromion process. The landmarks used for left and right rotation were the tip of the
chin and the lateral aspect of the acromion process. All ranges were measured in centimeters. Once assessed, the CAT began treatment which consisted of joint mobilizations to restricted joints as well as myofascial techniques for identified muscle stiffness. Treatments were 20 minutes in length and active ROM measurements were taken post treatment to compare. The control group did not receive treatment.

**Proprioception Trial #2**

Once treatment was completed (or the 20 minutes had passed for healthy controls), participants were asked to complete the same proprioception session for the final time. Figure 9 outlines the entire experimental protocol.
Figure 9: Experimental Protocol
3.2 Data Analysis

Matching Error, Variability, and Error Bias

In order to evaluate the proprioceptive acuity of the wrist as well characterize overall performance, the actual (participant’s active re-creation of the target), and the desired (the actual target position) wrist positions were compared. Three measures were then calculated to provide detailed information about participants’ performance: matching error (ME), variability (V), and error bias (EB) (Marini et al., 2016).

Matching Error was used to measure the angular deviation from the proprioceptive target. It was calculated by averaging the number of trials (N=12) across the same condition (ie same DOF and phase). ME quantified performance accuracy during the active (or actual) movement. The formula for ME was as follows:

\[
ME = \frac{\sum_{i=1}^{N}(\theta_i - \theta_T)}{N}
\]

where \(\theta_i\) is wrist’s final position of the trial, \(\theta_T\) is the proprioceptive target position, and \(N\) is the number of trials tested in a single DoF.
Variability measures the participants consistency (or precision) across the whole experiment. It is the standard deviation across trials. $V$ was calculated as follows:

$$V = \text{StD}(\theta_i)$$

Where $\text{StD}$ is the standard deviation across trials, $\theta_i$ is wrist’s final position of the trial, and $N$ is the number of trials tested in a single DoF.

Error Bias provided information about participants response bias. It is the directional distance between the proprioceptive (desired) target and the reproduced (actual) target. It indicates the participants tendency to undershoot (negative error bias) and overshoot (positive error bias) the target. $EB$ was calculated as follows:

$$EB = \frac{\sum_{i=1,N}(\theta_i - \theta_T)}{N}$$

where $\theta_i$ is wrist’s final position of the trial, $\theta_T$ is the proprioceptive target position, and $N$ is the number of trials tested in a single DoF.

ME defines error amplitude, and directly measures proprioceptive acuity. $EB$ provides supplemental information about performance as it describes the directional deviation from the target. The two measurements together, however, do not provide information about participant’s consistency across the 12 repetitions in each trial. As such, variability was calculated to evaluate how similar participants perform across the entire trial.
3.3 Statistical Analysis

Three separate 3-way repeated measures mixed ANOVA [2 groups (healthy, pain) X 2 DOF (wrist extension, wrist flexion) X 2 conditions (pre-fatigue, post-fatigue)] were used to evaluate the effect of neck muscle fatigue on wrist proprioception in healthy controls as well as in the pain group based on matching error scores, error bias scores, or variability scores.

Three additional 3-way repeated measures mixed ANOVA [2 groups (healthy, pain) X 2 DOF (wrist extension, wrist flexion) X 2 conditions (pre-treatment, post-treatment)] were used to evaluate the effect of cervical treatment on wrist proprioception in the pain group when compared to no cervical treatment in the control group based on matching error scores, error bias scores, or variability scores.

Pairwise comparisons were completed to examine interactions among conditions using a Bonferroni correction. All results are expressed as Mean ± SD, error bars in figures represent standard error (SE) and significance was set at p < 0.05.

3.4 Results

Two participants were removed after analysis of the data due to outlier scores. As such, the results from a total of 22 participants (11 healthy controls and 11 pain) are presented. No significant three-way interactions were found.
3.4.1 Neck Pain Demographics

Participants in the neck pain group scored between I and IV on the chronic pain grading scale. The average time to fatigue for the neck pain group was 10:00 ± 0.13 minutes, while the control group time to fatigue was 12:42 ± 0.11 minutes. After treatment, there were improvements in all active cervical spine ROM measures; flexion and extension improved by 1.0 ± 1.23 cm, left rotation by 3.0 ± 1.55 cm, right rotation by 2.0 ± 1.02 cm, and right and left lateral flexion by 1.0 ± 0.94 cm.

3.4.2 Group differences for Wrist Proprioception

Matching Error

There was an overall main effect of group (p<0.05) for matching error (figure 10). ME was significantly greater for the pain group than for the control group (ME pain = 4.42 ± 1.32°; ME control = 3.13 ± 0.42°)
There was an overall main effect of group (p<0.05) for error bias (figure 11). EB was significantly different for the pain group when compared to the control group (EB pain = -0.863 ± 1.06° EB control = 0.773 ± 1.62°). Interestingly, an opposite effect was found in directionality of error between the groups. A negative error bias indicates an undershooting of the target in the pain group, and a positive error bias indicates an overshoot of the target in the control group.

Error Bias

Figure 10: ME (degrees ± SE) for both the pain and control group. * = significant main effect between the groups.
3.4.3 Neck Muscle Fatigue and Wrist Proprioception

Matching Error

There was a significant group x time interaction (p<0.05) for matching error (figure 12). ME was significantly greater at baseline for the pain group than the control group (ME pain = 4.42 ± 1.32°, ME control = 3.13 ± 0.42°). After the fatigue protocol, the pain group’s error scores decreased from baseline, while the control groups error scores increased (ME pain = 3.88 ± 0.64°, ME control = 3.78 ± 1.12°).
There was also a significant time x DOF interaction (p<0.05) for matching error (figure 13). ME scores for wrist extension were lower at baseline than ME scores for wrist flexion (ME ext = 3.23 ± 0.79°, ME flex = 4.31 ± 1.34°). After the neck fatigue protocol, ME scores for extension increased from baseline, and ME scores for flexion decreased (ME ext = 3.90 ±1.08°, ME flex = 3.76 ± 0.74°).
Figure 12: Changes in ME (degrees ± SE) from baseline (pre-fatigue) to post-fatigue for both control and pain groups. * = significant main effect between the groups. * with a line indicates post-hoc comparisons.
Figure 13: Changes in ME (degrees ± SE) from baseline to post-fatigue for both DOF (Extension and Flexion). * = significant difference between DOF for pre-fatigue. * with a line indicates post-hoc comparisons.
Error Bias

There was an overall main effect for time (p<0.05) for error bias (figure 14). EB was significantly different at baseline than post-fatigue (EB baseline = -0.552 ± 1.40°, EB post-fatigue = 0.463 ± 1.35°). Overall, participants tended to undershoot the target at baseline, and overshoot the target after the fatigue protocol. There was no significant time x group interaction, however, the pain group consistently undershot the target and the control group consistently overshot the target.

Figure 14: Changes in EB (degrees ± SE) from baseline to post fatigue. Data represents both control and pain group. * = significant main effect of time (pre-post fatigue).
Variability

Variability did not differ significantly across the trials.

3.4.4 Cervical Treatment and Wrist Proprioception

Matching Error

There was a significant group x time interaction (p<0.05) for matching error (figure 15). After cervical treatment, the pain group’s error scores decreased from baseline (ME pain baseline = 3.77 ± 1.06°, ME pain treatment = 2.88 ± 0.77°), while the control group’s error scores increased (ME control baseline = 3.65 ± 0.57°, ME control rest = 4.19 ± 1.47°).
Figure 15: Changes in ME (degrees ± SE) pre and post cervical treatment for control and pain groups. * with a line indicates post-hoc comparisons for the interaction.
Error Bias

There was also a main effect for DOF (p<0.05) for error bias (figure 16). EB was significantly different for extension compared to flexion (EB extension = 0.44 ±1.25°, EB flexion = 1.94 ±1.55°), indicating a greater overshoot of the target in flexion than in extension.

There was a significant time x group interaction (p<0.05) for error bias (figure 17). Before treatment, both groups overshot the target, but the pain group significantly less (EB pain = 0.42 ± 1.64°, EB control = 1.34 ± 1.81°). After treatment, the pain group’s EB score decreased, while the controls increased (EB pain = 0.386 ± 1.20°; EB control = 2.61 ± 1.59°), indicating that the pain group’s tendency to overshoot the target decreased, while the controls tendency to overshoot the target increased.

Figure 16: EB (degrees ± SE) for both DOF across both trials from day two. * indicates a significant main effect of DOF (ext vs flex).
Figure 17: Changes in EB (degrees ± SE) pre and post cervical treatment for control and pain group. * indicates a significant difference between groups (pain vs control) for both pre and post treatment.
Variability

Variability did not differ significantly across the trial.

3.5 Discussion

This study investigated the effects of neck pain, cervical treatment, and neck muscle fatigue on joint position sense of the wrist. To our knowledge, this study is the first to examine the effects of neck muscle fatigue on wrist joint position sense (JPS) as well as a single cervical treatment session for neck dysfunction on wrist joint position sense (JPS). Previous work has examined the effect of neck pain on neck (Revel et al., 1991) and shoulder joint position sense (Myers et al., 1999; Sandlund et al., 2006). Recent work has also shown that neck muscle fatigue alters joint position sense at the elbow (Zabihhosseinian et al., 2015) in healthy participants. Additionally, researchers have investigated the effect of cervical manipulation on elbow joint position sense and found that a single session treatment of spinal manipulations improved joint position sense at the elbow (Haavik & Murphy, 2011). Our findings provide evidence that neck pain and neck muscle fatigue not only have an effect on proprioception of the shoulder and elbow, but that these effects also extend to the wrist. These findings, in consideration with the previous literature, provide evidence that dysfunction at the neck can affect the entire upper kinetic chain. Furthermore, this work shows that a single cervical treatment session, including joint mobilizations and myofascial techniques, can improve joint position sense at the wrist in subclinical neck pain patients.
Neck Pain and Wrist Proprioception

In the present study, ME scores for the control group were significantly lower at baseline than ME scores for the pain group (ME pain = 4.42 ± 1.32°; ME control = 3.13 ± 0.42°, p< 0.05). These results indicate, that overall, the control (healthy) group had a better ability to match the target than the pain group. Our findings coincide with previous research that has demonstrated that neck pain affects JPS at the neck and shoulder (Revel et al., 1991; Sandlund et al., 2006). There is evidence in the literature to suggest that muscle impairment occurs early in the onset of neck complaints and that this muscle impairment does not automatically resolve when neck pain symptoms disappear (Sterling, Jull, Vicenzino, Kenardy, & Darnell, 2003). It has been postulated that pain or dysfunctional spinal joint segment may represent a state of altered afferent input, resulting in ongoing central plastic changes (Wall, Xu, & Wang, 2002). Furthermore, plastic changes have been shown to alter CNS function. As such, any altered input from neck muscles may affect the sensory inputs to the CNS and affect upper limb JPS.

The high concentration of muscle spindles in the neck and cephalic muscles supports the importance of neck muscle receptors for motor control (Sandlund et al., 2006). The present findings that participants with chronic subclinical neck pain have significantly worse wrist JPS accuracy compared to healthy controls supports these hypotheses.

Interestingly, work by Sandlund and colleagues (2006) showed lower proprioception error scores at the shoulder (VE WAD-group = 2.03°, VE control = 1.51°) compared to our wrist error scores (ME pain = 4.42 ± 1.3°; ME control = 3.13 ± 0.4°).
These differences could suggest that the differences in error between the pain and healthy groups are larger more distally (at the wrist) than proximally (at the shoulder). Given this information, we can speculate that neck dysfunction may have an even larger effect as you move down the kinetic chain. This is extremely important if we consider that the hand or wrist provides the last degree of freedom for corrections or adjustments in reaching tasks.

When examining the direction of error, the pain group consistently undershot the target while the control group consistently overshot the target. To our knowledge, there is no previous literature to support or refute differences in the tendency to overshoot and undershoot the target in a healthy vs. pain population. Previous research focusing on wrist proprioception using a haptic robotic device found variable results in flexion and extension, with no consistent patterns of undershooting and overshooting the target in a healthy population (Marini et al., 2016). However, when compared to other DOF at the wrist (abduction/adduction, pronation/supination), flexion and extension scores yielded undershooting of the target (EB = −0.73 ± 0.61°) (Marini et al., 2016).

**Neck Fatigue and Wrist Proprioception**

This study is the first to demonstrate that neck muscle fatigue impacts JPS at the wrist. After completing the CEM fatigue protocol, ME scores for the control group increased and ME scores for the pain group decreased, indicating a decrease in performance for the control group (ME control baseline = 3.13 ± 0.42°, ME control fatigue = 3.78 ± 1.1°, increase of 0.65°; ME pain baseline = 4.42 ± 1.3°, ME pain fatigue
= 3.88 ± 0.6°, decrease of 0.54°). Our results are in accordance with Zabihhosseinian and colleagues whose findings demonstrated reduced elbow JPS after a CEM fatigue protocol (Zabihhosseinian et al., 2015) in healthy participants. The decreased performance as a result of the CEM fatigue protocol is likely due to altered afferent input from the neck that subsequently impacted body schema. It is well understood that JPS is mediated largely by muscle spindles and GTO’s, and it has been hypothesized by some researchers that the decline in JPS of one joint, following fatigue of another, may be due to decreased muscle spindle performance (of the neck) (Gear, 2011). As a result, the sense of movement is disturbed and a position matching task can be altered (Letafatkar et al., 2009). These findings support our hypothesis that neck muscle fatigue affects wrist JPS in healthy controls. Although participants attempted to recreate the target as accurately as possible, altered afferent feedback to the CNS due to the CEM fatigue protocol impacted the ability to accurately reproduce the target. It has been suggested that altered input from the neck is sufficient enough to lead to a distorted body schema following fatigue, causing a distorted perception of elbow JPS (Zabihhosseinian et al., 2015). The present study confirms that these effects are also seen more distally at the wrist.

Interestingly, after the fatigue protocol, ME scores for the two groups were very similar, suggesting similar performance. These findings indicate that the neck muscle fatigue protocol had a larger impact on wrist JPS in the control group than the pain group. This suggests that the physiological mechanisms required to complete tasks that involve acuity at the wrist may not be altered by neck muscle fatigue for individuals already suffering from chronic subclinical neck pain. Contrarily, the same wrist JPS task was
influenced by neck muscle fatigue for individuals who do not suffer from chronic subclinical neck pain (healthy controls).

One theory behind these results is that chronic subclinical neck pain causes the c-spine to be in a constant state of dysfunction. That is, chronic injury at the neck can result in overuse of key stabilizing muscles, such as the cervical extensors. It is well understood that overuse in muscles leads to a chronic state of fatigue. As such, a fatigue protocol may not affect a group of muscles that is already functioning in a chronic state of fatigue as much as it may affect a healthy group of muscles. Additionally, it can be hypothesized that due to the chronic state of fatigue of the CEM’s, the body has been conditioned to recruit additional surrounding muscles during tasks that may be fatiguing for the neck, relieving any potential stress on the neck muscles. This is commonly seen in many different types of chronic injuries.

In this study, the time to fatigue for the control group was higher (12:42 ± 0.11 minutes) than for the pain group (10:00 ± 0.13 minutes). Based on our results, it is likely that the altered afferent pathways found in a neck pain population are not further impaired by the fatigue protocol.

Our findings suggested that, overall, participants tended to undershoot the target at baseline and overshoot the target after the CEM fatigue protocol (regardless of being in the pain or control group). Although not significant, we found that the control group consistently overshot the target, and the pain group consistently undershot the target after the CEM fatigue protocol. These findings are not in accordance with results from Zabihhosseinian (2015) who found that healthy participants tended to provide negative
error scores (undershoot) when completing an elbow JPS task after an isometric neck muscle fatigue. Walsh (2006) had participants perform an unsupported elbow JPS task before and after an eccentric elbow fatigue protocol and also found that after fatigue, participants tended to undershoot the target. There are some differences in methods between the two studies listed above and our work; Zabihhosseinian used a different fatigue protocol than we did, and Walsh used an eccentric fatigue protocol at the elbow. However, the differences in results could imply that neck muscle fatigue has varying effects on JPS as you move further down the kinetic chain.

Although based on subjective feedback from participants, and visual inspection of our criteria, we can conclude that our fatigue protocol was successful. However, muscle activity of the CEM was not measured during the fatigue protocol. Without EMG or other physiological measures, it is hard to speculate that the two groups reached the same level of fatigue.

**Cervical Treatment and Wrist Proprioception**

The present study found that after one treatment session from a CAT, wrist JPS accuracy for the pain group significantly improved (ME pain baseline = 3.77° ± 1.06°, ME pain treatment = 2.88° ± 0.77°, ME control baseline = 3.65° ± 0.57°, ME control Rest = 4.19 ± 1.47°). Previous work by Haavik and Murphy (2011) showed improvements in elbow JPS in a SCNP group after a single session of joint manipulation, and suggested that high-velocity, low-amplitude adjustments of dysfunctional areas of the spine normalizes altered afferent input from the dysfunctional segment to the CNS.
Furthermore, a study examining the effects of both manipulations and spine stabilizing exercises and on HRA, in subjects with chronic neck pain, found a significant improvement in HRA after treatment (Palmgren et al., 2006). The authors hypothesized that the observed effects in their study were related to changes in mechanoreceptor afferent input as the muscles in the neck contain both nociceptive and mechanoreceptive nerve endings which are significant for proprioception. Additionally, researchers have shown that high-velocity, low-amplitude adjustments of dysfunctional areas of the spine in a SCNP group improved JPS at the elbow (Haavik & Murphy, 2011).

In the present study, we aimed to investigate the effects of a less invasive treatment option that consisted of soft tissue techniques and joint mobilizations. It has been suggested that manipulations affect the deep intraarticular muscles, which house a large number of mechanoreceptors (Rogers, 1997). The present findings may suggest that joint mobilizations and myofascial techniques also affect these deep structures housing important mechanoreceptors for JPS.

3.6 Limitations

This work has some limitations that should be addressed. First, muscle activity (EMG) of the CEM was not recorded during our fatigue protocol. This resulted in using subjective measures of fatigue and a visual inspection to ensure that the fatigue protocol was effective. Muscle activity of the CEM would have provided insight for a comparison of fatigue between the two groups as well as the tendency to recruit additional muscles for the fatigue task. Future work should include EMG of the CEM to monitor changes in muscle activity. Despite this, we feel that the fatigue protocol was effective, as visual
inspection and termination of the test due to a participant no longer being able to hold the load was often the case.

One interesting finding was that the control group’s error scores increased after the control intervention (ME control baseline = 3.65 ± 0.57°, ME control Rest = 4.19 ± 1.47°). This is in accordance with previous work by Haavik and Murphy (2011), who hypothesized that the worsening in performance could be due to a boredom effect. During the control intervention in our study, participants were asked to rest for 20 minutes. It can be speculated that during this time they may have lost interest in the study as a result of not being actively engaged. Interestingly, Haavik and Murphy implemented “sham” treatments during their control intervention and found the same results. This should be addressed in future work.

Finally, due to the nature of the fatigue protocol and the length of our proprioception sessions (which took participants on average 90 seconds to complete), it is likely that participants started to recover from the fatigue protocol before they completed the proprioception trials. Once the fatigue protocol was complete, the strap securing the thoracic spine had to be removed by the researcher and participants had to take off the head strap and move back to the robot, at which point they needed to put on their headphones, blindfolds, and be positioned correctly. Future work could address this by shortening the proprioception trial post fatigue.

3.7 Future Directions

The wrist is a very complex joint. Future work should examine joint position error scores during more complex wrist tasks (ie a task which combines all ROM at the wrist).
Additionally, it would be beneficial to implement a task that would allow errors at joints along the entire kinetic chain to be measured simultaneously (i.e., at the shoulder, elbow and wrist). It would also be beneficial for future work to include multiple treatments over a longer time period, as it is possible that with prolonged treatment the error scores would decrease further.

3.8 Conclusions

This study confirms that chronic subclinical neck pain and neck fatigue affects JPS at the wrist. Additionally, our results confirm that a single treatment session consisting of soft tissue techniques and joint mobilizations can improve JPS at the wrist in our pain group (subclinical neck pain). These findings, combined with the previous literature that has been presented, provide strong evidence that neck pain and neck muscle fatigue may result in altered sensory processing. This ultimately leads to decreased proprioception of the entire upper kinetic chain, from the neck to the wrist. These alterations can have significant consequences for upper extremity task performance for work, leisure, and sport. However, these consequences may be remedied by neck treatments provided by qualified clinicians.
References


Manipulative and Physiological Therapeutics, 29(2), 100–106. 


Brock University Research Ethics Board (REB)

Application for Ethical Review of Research Involving Human Participants

If you have questions about or require assistance with the completion of this form, please contact the Research Ethics Office at (905) 688-5550 ext. 3035, or reb@brocku.ca.

Selecting a Research Ethics Board

Files will be allocated to one of two REB panels based upon the type of research to be undertaken.

If your research involves any of the following, submit to the Bioscience Research Ethics Board (BREB):

- physiological measures such as EEGs, heart rate, GSR, temperature, blood pressure, respiration, vagal tone, x-rays, MRIs, CT or PET scans;
- ingestion or other use of food, beverages, food additives, or drugs, including alcohol and tobacco;
- medical techniques or therapies, including experimental medical devices;
- physical exertion beyond normal walking;
- physical movement in participants who have medical vulnerabilities (e.g., spinal cord injury, osteoporosis);
- human biological materials (e.g., tissues, organs, blood, plasma, skin, serum, DNA, RNA, proteins, cells, hair, nail clippings, urine, saliva, bodily fluids);
- interventions with the potential for physiological effects (e.g., diet, exercise, sleep restriction); and/or
- use of medical or official health records (e.g., hospital records).

If none of the above points are characteristic of your research, submit to the Social Science Research Ethics Board (SREB)

Indicate which REB panel is appropriate for this application:

☑ Bioscience (BREB) OR ☐ Social Science (SREB)
DOCUMENT CHECKLIST

<table>
<thead>
<tr>
<th>2 complete sets of the following documents (one original + one copy)</th>
<th>✔ if applicable</th>
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<td>Recruitment Materials</td>
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<td>• Letter of invitation</td>
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<td>• Verbal script</td>
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<td>• Telephone script</td>
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<td>• Advertisements (newspapers, posters, SONA)</td>
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<td>• Electronic correspondence guide</td>
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<td>• Transcriber confidentiality agreement</td>
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<td>Data Gathering Instruments</td>
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<td>• Questionnaires</td>
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<td>• Interview guides</td>
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<td>• Tests</td>
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<td>Feedback Letter</td>
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<td>Letter of Approval for research from cooperating organizations, school board(s), or other institutions</td>
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<td>Any previously approved protocol to which you refer</td>
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<td><strong>Request for use of human tissue sample in research</strong> Please Note: this form is required for all research projects involving human tissue, bodily fluids, etc.</td>
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<td>Signed Application Form</td>
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SIGNATURES

PLEASE NOTE: The title “principal investigator” designates the person who is “in charge” of the research. In this position, the principal investigator is assumed to have the abilities to supervise other researchers, be responsible for the financial administration of the project, have the authority to ensure that appropriate guidelines and regulations are followed, and be competent to conduct the research in the absence of faculty supervision. The restriction of the term “principal investigator” to faculty or post-doctoral fellows does not have implications for ownership of intellectual property or publication authorship.

Given the above consideration, a student cannot be identified as a “principal investigator”. However, for the purpose of recognizing a student’s leadership role in the research, a faculty member may designate a “principal student investigator” below.

INVESTIGATORS:

Please indicate that you have read and fully understand all ethics obligations by checking the box beside each statement and signing below.

☒ I have read Section III: 8 of Brock University’s Faculty Handbook pertaining to Research Ethics and agree to comply with the policies and procedures outlined therein.
☒ I will report any serious adverse events (SAE) to the Research Ethics Board (REB).
☒ Any additions/changes to research procedures after approval has been granted will be submitted to the REB.
☒ I agree to request a renewal of approval for any project continuing beyond the expected date of completion or for more than one year.
☒ I will submit a final report to the Office of Research Services once the research has been completed.
☒ I take full responsibility for ensuring that all other investigators involved in this research follow the protocol as outlined in this application.

Principal Investigator

Signature _____________________________________________ Date: October 9, 2018

Principal Student Investigator (optional)

Signature _____________________________________________ Date: October 9, 2018

Co-Investigators:

Signature _____________________________________________ Date:
Signature _____________________________________________ Date:
__________________________________________

FACULTY SUPERVISOR:

Please indicate that you have read and fully understand the obligations as faculty supervisor listed below by checking the box beside each statement.

☒ I agree to provide the proper supervision of this study to ensure that the rights and welfare of all human participants are protected.
☒ I will ensure a request for renewal of a proposal is submitted if the study continues beyond the expected date of completion or for more than one year.
☒ I will ensure that a final report is submitted to the Office of Research Services.
☒ I have read and approved this application and proposal.

Signature _____________________________________________ Date: October 9, 2018
SECTION A – GENERAL INFORMATION

1. **Title of the Research Project:** Investigating neuromuscular control using haptic feedback

2. **Investigator Information:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Position (e.g., faculty, student, visiting professor)</th>
<th>Dept./Address</th>
<th>Phone No.</th>
<th>E-Mail</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Principal Investigator</strong></td>
<td>Michael Holmes</td>
<td>Assistant Professor</td>
<td>9056885550 x4398</td>
<td><a href="mailto:michael.holmes@brocku.ca">michael.holmes@brocku.ca</a></td>
</tr>
<tr>
<td><strong>Principal Student Investigator</strong></td>
<td>Ashley Reece</td>
<td>Graduate Student</td>
<td>2899295231</td>
<td><a href="mailto:ar10ha@brocku.ca">ar10ha@brocku.ca</a></td>
</tr>
<tr>
<td><strong>Co-Investigator(s)</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Faculty Supervisor(s)</strong></td>
<td>Michael Holmes</td>
<td>Assistant Professor</td>
<td>9056885550 x4398</td>
<td><a href="mailto:michael.holmes@brocku.ca">michael.holmes@brocku.ca</a></td>
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3. **Proposed Date of commencement:** ☑ upon approval, OR ☐ other. Please provide date

   (dd/mm/yyyy) ______

   **Proposed Date of completion (dd/mm/yyyy): December 1, 2019**

4. **Indicate the location(s) where the research will be conducted:**

   - Brock University ☑
   - Community Site ☐ Specify ______
   - School Board ☐ Specify ______
   - Hospital ☐ Specify ______
   - Other ☐ Specify ______

5. **Other Ethics Clearance/Permission:**

   (a) Is this a multi-centered study? ☐ Yes ☑ No
   (b) Has any other University Research Ethics Board approved this research? ☐ Yes ☑ No

80
If YES, there is no need to provide further details about the protocol at this time, provided that all of the following information is provided:

- Title of the project approved elsewhere: ______
- Name of the Other Institution: ______
- Name of the Other Board: ______
- Date of the Decision: ______
- A contact name and phone number for the other Board: ______

Please provide a copy of the application to the other institution together with all accompanying materials, as well as a copy of the clearance certificate / approval.

If NO, will any other University Research Ethics Board be asked for approval? □ Yes □ No

Specify University/College ______

(c) Has any other person(s) or institutions granted permission to conduct this research? □ Yes □ No

If yes, specify (e.g., hospital, school board, community organization, proprietor) provide details and attach any relevant documentation. ______

If NO, will any other person(s) or institutions be asked for approval? □ Yes □ No

Specify (e.g., hospital, school board, community organization, proprietor) ______

6. Level of the Research:

- □ Undergraduate Thesis  ☑ Masters Thesis/Project  □ Ph.D
- □ Post Doctorate  □ Faculty Research  □ Administration
- □ Undergraduate Course  □ Graduate Course  □ Other (specify course)
  Assignment (specify course) ______  Assignment (specify) ______

7. Funding of the Project: NSERC Discover Grant (Holmes)

(a) Is this project currently being funded? □ Yes □ No
(b) If No, is funding being sought? □ Yes □ No

If Applicable:

(c) Period of Funding (dd/mm/yyyy): From: 2015 To: 2020

(d) Agency or Sponsor (funded or applied for):

- □ CIHR  ☑ NSERC  □ SSHRC  □ Other (specify): ______

(e) Funding / Agency File # (not your Tri-Council PIN) RGPIN 2015-05765

8. Conflict of Interest:
(a) Will the researcher(s), members of the research team, and/or their partners or immediate family members receive any personal benefits related to this study – Examples include financial remuneration, patent and ownership, employment, consultancies, board membership, share ownership, stock options. Do not include conference and travel expense coverage, possible academic promotion, or other benefits which are integral to the general conduct of research.

☐ Yes  ☒ No

If Yes, please describe the benefits below.

_______

(b) Describe any restrictions regarding access to or disclosure of information (during or at the end of the study) that the sponsor has placed on the investigator(s).

_______

SECTION B – SUMMARY OF THE PROPOSED RESEARCH

9. Rationale:

Briefly describe the purpose and background rationale for the proposed project, as well as the hypothesis(es)/research question(s) to be examined.

**Background rationale:** Neck and upper limb disorders are two of the most common musculoskeletal conditions. It is reported that two thirds of the population will experience neck pain in their lives (Abichandani & Parkar, 2015). According to the Workplace Insurance and Safety board (WSIB), almost half of all lost time claims registered with WSIB are related to musculoskeletal disorders. Occupational injuries place a huge burden on the Ontario healthcare system, with the combined direct and indirect costs estimated to be $19 billion from 1996-2006 (Musculoskeletal Disorders and Ergonomics).

Chronic mechanical neck pain is defined as pain in the anatomical region of the neck where there is no specific pathological cause (Abichandani & Parkar, 2015). It can include neck pain that is present with or without pain in the upper limb and it is prevalent in 60-70% of the general population. Typical symptoms can include limited range of motion, pain, cervicogenic headaches, or radiculopathy. Neck pain has also been shown to alter postural activity of cervical muscles, lead to balance instabilities, and alter upper limb proprioception (Brumagne, Janssens, Knapen, Claeys, & Suuden-Johanson, 2008).

Many occupational tasks require not only upper limb strength, but upper limb proprioception as well. Proprioception is broadly defined as the awareness of the body in space. Intact limb proprioception is essential for many aspects of motor control such
as interlimb coordination, for the formation of muscle synergies, and for correcting and updating movement strategies (Marini et al., 2017).

Neck muscles are rich in sensory receptors and as such are known to play a very important role in sensory input to the central nervous system (CNS). It has been shown that the CNS uses the position of the head and neck to interpret the position of the upper limb. As such, any altered input from neck muscles may affect the sensory inputs to the CNS and affect upper limb proprioception.

To date, most research into the effects of pain and fatigue on upper limb proprioception has focused primarily only on the joint affected. This, however, is not necessarily always applicable to everyday demands. Our bodies require multiple joints and muscles to work together in order to complete complex tasks. Damage anywhere along a muscular chain can potentially impact the ability of that entire chain to function adequately. Researchers have investigated and shown that alterations at the neck can lead to decreased proprioception in the elbow and shoulder joint (Myers et al., 1999; Zabihhosseinian et al., 2015). However, no research exists on the effects that neck pain or fatigue may have on wrist proprioception. Due to the demands of most occupational tasks, investigation into the effects of neck pain and fatigue on wrist proprioception is also necessary. Additionally, little research exists that examines the effect of cervical treatment in subjects with subclinical neck pain on wrist proprioception.

**Purpose:** One purpose of this study is to investigate the effect of chronic subclinical neck pain and fatigue on wrist proprioception. The second purpose is to investigate the effect of cervical joint mobilizations and myofascial techniques for participants with subclinical neck pain on wrist proprioception.

**Research questions:** How does chronic subclinical neck pain affect proprioception at the wrist? Does neck fatigue affect wrist proprioception in healthy controls differently than participants with chronic subclinical neck pain? For participants with chronic subclinical neck pain, does cervical treatment improve joint position matching at the wrist?

10. **Methods:**

Are any of the following procedures or methods involved in this study? Check all that apply.

- [ ] Questionnaire (mail)
- [ ] Questionnaire (email/web)
- [ ] Questionnaire (in person)
- [ ] Interview(s) (telephone)
- [ ] Interview(s) (in person)
- [ ] Secondary Data
- [ ] Computer-administered tasks
- [ ] Focus Groups
- [ ] Journals/Diaries/Personal Correspondence
- [ ] Audio/video taping
- [ ] Observations
- [x] Non-invasive physical measurement (e.g., exercise, heart rate, blood pressure)
- [ ] Analysis of human tissue, body fluids, etc. (Request for Use of Human Tissue)
Describe sequentially, and in detail, all of the methods involved in this study and all procedures in which the research participants will be involved (paper and pencil tasks, interviews, questionnaires, physical assessments, physiological tests, time requirements, etc.)

Attach a copy of all questionnaire(s), interview guides or other test instruments. If reference is made to previous protocols, please provide copies of relevant documentation.

**Participants**

This study will involve recruiting from two populations. One healthy group and another with subclinical neck pain. Upon arrival to the lab, participants will complete a neck pain disability index and chronic pain grading scale to evaluate what group they should be placed. Neck pain will be graded between Grade 1 to Grade 3 on the chronic pain grading scale (Guzman, et al., 2009; Von Korff, et al., 1992), which categorizes pain intensity and disability between a grade of 0, meaning the participant experienced minimal neck pain and no disability in the previous six months, and a grade of 3, which meant that the participant experienced severe neck pain and disability in the previous six months. Exclusion to participate will include major structural injuries or anomalies to the cervical spine including disk herniation or fracture. As well, participants will be excluded if they had received manual therapy or care for their neck in the previous three months (this is our classification of “Sub-clinical neck pain”). Recurrent pain, days that can be pain free and the individuals have not yet sought treatment. Pain and treatment, adds confounding variables to the data collection process.

**Experimental Protocol**

**Day 1**

*Experiment #1 - Proprioception Trial # 1*

Participants will perform 12 randomized joint position matching trials using a haptic robotic device. Participants’ wrist will start in a neutral anatomical position (0° of flexion, 0° of extension). The robot will then passively move the participants wrist to a pre-set, randomized target and hold the position for three seconds. After three seconds, the robot will passively move the participants wrist back to the neutral position and the participant will be requested to actively move their wrist to the same position with no assistance from the robot. Two degrees of freedom (DoF) (flexion and extension) will be tested during the experiment and targets will be set at a distance no greater than 80% of the wrist’s total functional ROM to assure all participants can actively match the targets. Proprioceptive targets will be presented six
times for each DoF, for a total of 12 trials. During each trial, the robot will allow movement in only one DoF (i.e. when participants are moved into flexion, extension and other axis will be locked). Participant’s vision will be occluded with googles as to eliminate visual feedback to the target and their wrist. They will also wear noise cancelling headphones to mask any noise from the robot.

Experiment #2 - Fatigue Protocol

Participants in both the control and subclinical neck pain group will complete an isometric task to fatigue the cervical extensor muscles (Edmondston et al., 2011). Participants will lay prone on an examination table, with their arms at their side and head over the edge of the table. The head will be supported by the examiner for the duration of the setup. A Velcro strap will be fixed around the head with an inclinometer attached to the band over the occiput. A 2-kg weight will be suspended from the headband and the weight will land just short of the floor. A second strap will be fixed around the thorax (at T6) to control thoracic extension. The participants head will be positioned in a neutral sagittal plane. The test will begin once the examiner removes support from the participants’ head. The participant will be required to hold the cervical spine in the neutral position for as long as possible, resisting against the 2kg weight. The test will be terminated if the participant can no longer hold the position due to fatigue or discomfort, if the weight returns to the floor, or if the neck position changes more than five degrees (as measured by an inclinometer). The holding time will be measured in seconds.

Experiment #3 - Proprioception Trial #2

Immediately after the fatigue protocol, participants will be asked to complete the same proprioception protocol (Experiment 1, day 1) a second time. They will be given no rest period between the fatigue protocol and the second proprioception trial.

Day 2

Experiment #4 - Proprioception Trial #1

Participants will be asked to return to the lab at least 48 hours after their initial visit. Upon arrival, they will be reminded of the experimental protocol for the second day. Once they are comfortable with the protocol, they will be asked to complete the same proprioception trial (Experiment 1, day 1).

Experiment #5 - Cervical Treatment

After completing the proprioception protocol, the subclinical neck pain group will receive treatment from a Certified Athletic Therapist (CAT(C)). Before treatment, each participant’s neck will be evaluated for restricted range of motion (ROM) at each joint and for muscle tension. Joint restriction will be tested by the CAT passively moving the participants head into maximum range of lateral flexion (both left and
right) while palpating each cervical joint for restriction. Muscle stiffness will be examined by palpation and ROM will be assessed by participant’s active ROM into each range (flexion, extension, left lateral flexion, right lateral flexion, left rotation, right rotation). Once assessed, the CAT will begin treatment which will consist of joint mobilizations to restricted joints as well as myofascial techniques for identified muscle stiffness. Treatments will be 20 minutes in length. The control group will not receive treatment, but will have a 20-minute break.

Experiment #6 - Proprioception Trial #2

Once treatment is completed (or the 20 minutes has passed for the control group), participants will be asked to complete the same proprioception trial (Experiment 1, day 1).

Instrumentation

Haptic wrist device

The experimental device used for these studies is a three degrees-of-freedom (DoF) haptic wrist manipulandum (Figure 1). It is a mechanical system that can deliver torque (forces) to the human hand that is interacting with the device and is integrated with a virtual reality environment and computer display. This device is used extensively in our research and has been approved in such REB files as # 16-263. The device is controlled by custom programs and cannot deliver forces larger than maximum isometric wrist torques of a human adult. The device allows for movements along the three DoFs of the human joint: flexion/extension (F/E), radial/ulnar deviation (R/UD) and pronation/supination (P/S). The motors powering the device are 4 brushless motors chosen in such a way to provide an accurate haptic rendering and compensate for the weight and inertia of the device or even overcoming muscular contraction. The continuous torque ranges at the different wrist axes are 1.53 Nm on F/E, 1.63 Nm on R/UD and 2.77 Nm on P/S. The range of motion (RoM) in the three DoF approximately matches the RoM of a normal human wrist: 65/70º of F/E, 19/30º of RUD; ±80º of PS, in a typical human subject, vs. ±72º of F/E, 45/27º of RUD; ±80º of PS, in the wrist robot. Thus, taking the haptic device to its full range of motion, wouldn’t result in stress or strain on the human hand as our human ranges are typically greater than the end range of the device. The forces capable from the device are all programmed using custom software and the forces applied to the participants in our study are very low. These forces are much lower than forces experienced while holding a power tool or sudden displacement of the hand in sports.

In each experiment, participants will sit in front of the three DoFs wrist manipulandum and hold the handle with their dominant hand. With the hand relaxed, lightly gripping the handle, the robot will move the participant to a location that the participant will eventually have to recreate.
Figure 1: The haptic wrist exoskeleton that will be used in these studies. Participants will rest their arm on the device and hold the handle.

Fatigue Protocol

Prior to commencing the fatigue protocol, participants will be fitted with a Velcro headband that will be equipped with an inclinometer attached to the head over the occiput. A 2 kg weight will be suspended from the headband. This weight is less than head mass and has been used extensively in the literature as a successful means for generating cervical extensor muscle fatigue.

Data Analysis:

During each proprioception trial, the WristBot will collect the participant’s kinematic data. Data will be processed by a third-order Savitzky-Golay low-pass filter (cut-off frequency of 10 Hz). To characterize overall performance and estimate the proprioceptive ability of the wrist, actual (active) and desired (passive) positions will be compared. Accuracy for joint position matching will be measured using matching error (ME), variability (V), and error bias (EB).

Statistics: The primary focus of this study is to evaluate differences in joint position matching between the trials and groups. Separate repeated measures analysis of variance will be used to compare wrist joint error in between the pain and control groups and between the groups with and without cervical extensor fatigue. The alpha level will be set to 0.05 for all statistical analyses (SPSS v19.0, IBM Corporation, Somers, NY, USA).

Sometimes a certain photograph clearly demonstrates a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific conference or in a publication. Therefore, photographs or video may be taken during the data collection. We will ask that participants sign our consent for photographs form prior to allowing us to use such images.

11. Professional Expertise/Qualifications:
Does this procedure require professional expertise/recognized qualifications (e.g., registration as a clinical psychologist, first aid certification)?

☑ Yes specify: ______

☐ No

If YES, indicate whether you, your supervisor, or any members of your research team have the professional expertise/recognized qualifications required? ☑ Yes ☐ No

The subclinical neck pain group will receive treatment from a Certified Athletic Therapist (CAT(C)), who is the student investigator on this project.

12. Participants:

Describe the number of participants and any required demographic characteristics (e.g., age, gender).

20 general working aged volunteers (17-55 years of age) will be used in this study. 10 males and 10 females. They will primarily be sourced from the Brock community. Undergraduate/graduate students as well as faculty of staff. Given the amount of computer and mobile device use in this population, it is anticipated based on previous experience that we will be able to find our neck pain group easily.

13. Recruitment:

Describe how and from what sources the participants will be recruited, including any relationship between the investigator(s), sponsor(s) and participant(s) (e.g., family member, instructor-student; manager-employee).

*Attach a copy of any poster(s), advertisement(s) and/or letter(s) to be used for recruitment.*

The participants will be sourced from the Brock undergraduate and graduate student as well as faculty and staff population via information posters around campus (attached). When a potential participant contacts the research team, the study will be fully explained and potential participants will be repeatedly reminded that they are free to choose whether they wish to participate in the study. When contact is first made, we will try to determine what group (healthy or neck pain) the participant thinks they should be in. We will send potential participants the consent form and screening questions in advance, so they can become familiar with the process prior to arriving at the lab.

After that, we will confirm with the already described questionnaires in person at the first visit. They will be reminded that not participating in the study will in no way, now or ever, negatively impact either their grade in a course, performance in a lab, reference letter recommendations and/or thesis evaluation. Dr. Holmes is a professor in the Faculty of Applied Health Sciences and it is likely that students in that program will be participants. The written consent form clearly states that the participant may withdraw from the study at any point without prejudice. In the event that a participant
withdraws from the study, the data collected on them will be deleted. Participants are free to withdraw from the study at any time without question or prejudice. If they are taking a course with the aforementioned professor their grade will not be affected should they withdraw from the study. However, since this may be an intimidating decision for students to make, all efforts will be made to recruit participants who are not students of the investigators, or participation will be handled by the student researcher. In the event of a student volunteer, all correspondence and data collection will be done in the presence of the research assistant only.

14. Compensation:

a) Will participants receive compensation for participation? ☑ Yes ☐ No
b) If yes, please provide details.

Participants will be reimbursed for participation with a $5 Tim Hortons gift card for each day that they complete. Thus, compensation can total $10 if participants attend both sessions. If a participant withdraws and can no longer complete session #2, the will still receive the $5 compensation for the first session.

SECTION C – DESCRIPTION OF THE RISKS AND BENEFITS OF THE PROPOSED RESEARCH

15. Possible Risks:

1) Indicate if the participants might experience any of the following risks:

a) Physical risks (including any bodily contact, physical stress, or administration of any substance)? ☑ Yes ☐ No

b) Psychological risks (including feeling demeaned, embarrassed worried or upset, emotional stress)? ☑ Yes ☐ No

c) Social risks (including possible loss of status, privacy, and / or reputation)? ☐ Yes ☑ No

d) Are any possible risks to participants greater than those that the participants might encounter in their everyday life? ☐ Yes ☑ No

e) Is there any deception involved? ☑ Yes ☐ No

f) Is there potential for participants to feel obligated to participate or coerced into contributing to this research (because of regular contact between participants and the researcher, relationships that involve power-dynamics, etc.)? ☑ Yes ☐ No
2) If you answered Yes to any of 1a – 1f above, please explain the risk.

**A. Physical risks:**
The position matching task is a simple wrist movement with no resistance. However, during the fatigue protocol, there might be some post experiment muscle soreness (resulting from fatigue protocol or treatment session). This will likely be similar given the isometric nature of the fatigue protocol. If any soreness does occur it is likely to be similar to any low – moderate intense exercise.

**F. Feeling Coerced:**
If participants are taking a course with the aforementioned professor their grade will not be affected should they withdraw from the study. However, since this may be an intimidating decision for students to make, all efforts will be made to recruit participants who are not students of the investigators. In the event of a student volunteer, all correspondence and data collection will be done in the presence of the research assistant only.

3) Describe how the risks will be managed and include the availability of appropriate medical or clinical expertise or qualified persons. Explain why less risky alternative approaches could not be used.

All risks are on site only and all participants will be closely watched by the investigators to ensure safety. Participants will be consistently reminded throughout the duration of the protocol that, should they become too uncomfortable, they are free to withdraw from the study at any point.

For post-session muscle soreness, we will advise participants to call the researcher, and/or the Campus Wellness Centre.

If participants are taking a course with the aforementioned professor their grade will not be affected should they withdraw from the study. However, since this may be an intimidating decision for students to make, all efforts will be made to recruit participants who are not students of the investigators. In the event of a student volunteer, all correspondence and data collection will be done in the presence of the research assistant only.

16. **Possible Benefits:**

Discuss any potential direct benefits to the participants from their involvement in the project. Comment on the (potential) benefits to the scientific community/society that would justify involvement of participants in this study.

The primary benefit to participants in this study will be that it will expose them to the research environment and also to a number of different research technologies. This is of importance given that some of the participants will likely be kinesiology...
students who will be learning about the techniques in the classroom, thus gaining practical experience. The scientific community will benefit from this research because these findings may help to better understand the impact that chronic neck pain may have on structures further down the kinetic chain. This knowledge may help to ensure safety in the workplace as many occupational tasks require upper limb strength as well as joint position awareness. At the end of the testing session, all participants will be given an opportunity for ‘debriefing’ where one of the researchers will answer any questions they may have about the protocol or results obtained in their data collection session. Participants will learn a little about haptic devices, biomechanics and ergonomics.

SECTION D – THE INFORMED CONSENT PROCESS

17. The Consent Process:

Describe the process that the investigator(s) will be using to obtain informed consent. Include a description of who will be obtaining the informed consent. If there will be no written consent form, explain why not. For information about the required elements in the letter of invitation and the consent form, as well as samples, please refer to: http://www.brocku.ca/researchservices/forms/index.php

If applicable, attach a copy of the Letter of Invitation, the Consent Form, the content of any telephone script, and any other material that will be utilized in the informed consent process.

Once participants express an interest in participating in the study they will be contacted and the study will be briefly explained to them again. If they still have an interest in participating, then a time will be set-up for them to come to the lab. When contact is first made, we will try to determine what group (healthy or neck pain) the participant thinks they should be in. After that, we will confirm with the already described questionnaires in person at the first visit. During this lab session, the study will be explained in more detail and participants will be given the opportunity to ask any questions they may have about the study. Once all questions are answered, participants will then be given the informed consent form to read. They will also be reminded that if they have any questions while reading the form to feel free to ask them. After reading the consent form and having any additional questions answered, if participants are willing to take part in the study they will be asked to sign the informed consent form. Their witnessed signature on this form will provide evidence of their informed consent to participate in the study.

18. Consent by an authorized party:

If the participants are minors or for other reasons are not competent to consent, describe the proposed alternative source of consent, including any permission form to be provided to the person(s) providing the alternative consent.
19. **Alternatives to prior individual consent:**

If obtaining individual participant consent prior to commencement of the research project is not appropriate for this research, please explain and provide details for a proposed alternative consent process.

20. **Feedback to Participants:**

Explain what feedback/information will be provided to the participants after participation in the project. This should include a more complete description of the purpose of the research, and access to the results of the research. Also, describe the method and timing for delivering the feedback.

Due to the fact that data will potentially be published/disseminated, all participants will be entitled to feedback on the future publication of the data. More specifically, they will be provided with a feedback letter that outlines some interesting reading material, the contact information (email address) of Dr. Holmes and will be told that if they are interested in receiving future information regarding the study, they may contact the researchers directly. The feedback letter will also state that we will share the results to those who have requested once the data is analyzed. They will be given the opportunity to leave their contact information (email address) so that we may share our results. This contact information (email address) will be provided to the participants within the consent form. It will be explained to participants that published work can take a long time (6+ months) to become available. If they wish to see individual data along the way, they are also encouraged to contact the investigators.

21. **Participant withdrawal:**

a) Describe how the participants will be informed of their right to withdraw from the project. Outline the procedures that will be followed to allow the participants to exercise this right.

The investigators will verbally explain the study, procedures and risks to each participant. The investigators will be available to answer any questions the participants may have prior to signing the informed consent. At this time, the investigators will reiterate to participants that their participation is voluntary. They are free to withdraw or discontinue the study at any time, without consequence. We will also remind participants that they will be reimbursed for their time (even if they do not complete the entire study).
b) Indicate what will be done with the participant’s data should the participant choose to withdraw. Describe what, if any, consequences withdrawal might have on the participant, including any effect that withdrawal may have on participant compensation.

Any participant that withdraws from this study will have their data permanently discarded and all paper copies (consent form, etc.) will be destroyed. There will be no consequences for a participant if they choose to withdraw, even once the study is over their data can still be destroyed.

SECTION E – CONFIDENTIALITY & ANONYMITY

Confidentiality: information revealed by participants that holds the expectation of privacy. This means that all data collected will not be shared with anyone except the researchers listed on this application.

Anonymity of data: information revealed by participants will not have any distinctive character or recognition factor, such that information can be matched (even by the researcher) to individual participants. Any information collected using audio-taping, video recording, or interview cannot be considered anonymous. Please note that this refers to the anonymity of the data itself and not the reporting of results.

22. Given the definitions above:

   a) Will the data be treated as confidential? ☒ Yes ☐ No
   b) Are the data anonymous? ☐ Yes ☒ No

   c) Describe any personal identifiers that will be collected during the course of the research (e.g., participant names, initials, addresses, birth dates, student numbers, organizational names and titles etc.). Indicate how personal identifiers will be secured and if they will be retained once data collection is complete.

   Participants will be identified only with subject codes. No participant names, initials or identifying markers will be used. Participants will be referred to as “subject 01”, “02”, etc. on all data collection computers. Once the study is completed, all data will be retained, but moved from the data collection computer to a secured hard drive in the PI’s office. All signed consent forms (personal identifiers) will be secured in a locked filing cabinet in a locked room, inside the locked Neuromechanics and Ergonomics Lab (TH144).

   d) If any personal identifiers will be retained once data collection is complete, provide a comprehensive rationale explaining why it is necessary to retain this information, including the retention of master lists that link participant identifiers with unique study codes and de-identified data.
e) State who will have access to the data.

Only the principal investigator and the principal student investigator will have access to the data.

f) Describe the procedures to be used to ensure anonymity of participants and/or confidentiality of data both during the conduct of the research and in the release of its findings.

The identity of each participant will be kept confidential, only available to the researchers. All data, including written records and electronic data, will be placed in a locked cabinet or stored on a secured computer in the locked office of the principal investigator. Data will be originally recorded on a computer that is password protected and only available to the researchers in a locked and secure room. The data will remain at this institution. The data will not be linked with any other data set and the data will not be sent outside of the institution where it is collected. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces. The data are electronic signals, which will be coded by participant number and stored on a password-protected computer. All data will be reported through average/mean measurements, or, if necessary by using participant numbers for individual reporting. Participants will also be asked to consent to photos and/or videos as part of this study. Any images and/or videos we release will remain confidential by blurring out any identifying factors of any of the participants involved.

g) If participant anonymity and/or confidentiality is not appropriate to this research project, explain, in detail, how all participants will be advised that data will not be anonymous or confidential.

N/A

h) Explain how written records, video/audio tapes, and questionnaires will be secured, and provide details of their final disposal or storage, including how long they will be secured and the disposal method to be used.

All data will be in digital form. Our data collection software allows for written notes during data collection if particular trials or conditions should not be included in the final analysis. All documents (ie consent forms) will be stored in a locked filing cabinet, and electronic information will be stored on a password-protected computer. After the study, everything will be transferred to Dr. Holmes’ office. We have no
immediate plans to reanalyze the data at this time. However, analyze techniques and ideas change over time and we would prefer to have access to the data should a new analysis be performed. In addition, sometimes publication of results can take years to complete and we prefer to hold on to data in case there are ever questions about the quality or integrity of our data.

SECTION F -- SECONDARY USE OF DATA

23. 
   a) Is it your intention to reanalyze the data for purposes other than described in this application?


   b) Is it your intention to allow the study and data to be reanalyzed by colleagues, students, or other researchers outside of the original research purposes? If this is the case, explain how you will allow your participants the opportunity to choose to participate in a study where their data would be distributed to others (state how you will contact participants to obtain their re-consent)

N/A

   c) If there are no plans to reanalyze the data for secondary purposes and, yet, you wish to keep the data indefinitely, please explain why.

We have no immediate plans to reanalyze the data at this time. However, analyze techniques and ideas change over time and we would prefer to have access to the data should a new analysis be performed. In addition, sometimes publication of results can take years to complete and we prefer to hold on to data in case there are ever questions about the quality or integrity of our data.

SECTION G -- MONITORING ONGOING RESEARCH

It is the investigator’s responsibility to notify the REB using the “Renewal/Project Completed” form, when the project is completed or if it is cancelled.
http://www.brocku.ca/researchservices/forms/index.php

24. Annual Review and Serious Adverse Events (SAE):

   a) MINIMUM REVIEW REQUIRES THE RESEARCHER COMPLETE A “RENEWAL/PROJECT COMPLETED” FORM AT LEAST ANNUALLY. Indicate whether any additional monitoring or review would be appropriate for this project.
*Serious adverse events* (negative consequences or results affecting participants) must be reported to the Research Ethics Officer and the REB Chair, as soon as possible and, in any event, no more than 3 days subsequent to their occurrence.

25. **COMMENTS**

If you experience any problems or have any questions about the Ethics Review Process at Brock University, please feel free to contact the Research Ethics Office at (905) 688-5550 ext 3035, or reb@brocku.ca
Informed Consent

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Date: November 2019  
Project Title: The effect of chronic neck pain, cervical treatment, and neck muscle fatigue on wrist proprioception.

Principal Investigator (PI):  
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Principal Student Investigator:  
Ashley Reece, MSc. Graduate Student Brock University  
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INVITATION

You are invited to participate in a study that involves research if you are a male or female adult (free of injury to the upper extremity) and between the ages of 17-35. We are looking for both healthy and neck pain participants and depending on how you respond to a questionnaire, you will be placed into one of those categories.

Chronic neck pain is defined as pain in the region of the neck where there is no specific pathological cause (Abichandani & Parkar, 2015). It can include neck pain that is present with or without pain in the upper limb and is prevalent in 60-70% of the general population. Typical symptoms can include limited range of motion, pain and headaches. Neck pain has also been shown to alter muscle activity, lead to balance instabilities and alter upper limb proprioception (awareness of where your limb is in space) (Brumagne, Janssens, Knapen, Claeys, & Suuden-Johanson, 2008).

Many occupational tasks require not only upper limb strength, but also upper limb proprioception. Proprioception is broadly defined as the awareness of the body in
space. With your eyes closed, you are able to touch our finger to your nose. This is a crude example of proprioception.

Neck muscles are rich in sensory receptors (these receptors help us get feedback to physical stimulus in the environment, like touching an object) and as such are known to play a very important role in inputs to the central nervous system (CNS). It has been shown that the CNS uses the position of the head and neck to interpret the position of the upper limb. As such, any altered input from neck muscles may affect upper limb proprioception.

There is currently a poor understanding of the relationship between neck pain, fatigue and wrist proprioception. Additionally, little research exists that examines the effect of neck treatment in people with neck pain on wrist proprioception.

One purpose of this study is to investigate the effect of neck pain and fatigue on wrist proprioception. The second purpose is to investigate the effect of neck pain treatment for participants with neck pain on wrist proprioception (awareness of joint position in space).

WHAT’S INVOLVED

As a participant, you will be asked to perform a total of four (4) wrist proprioception tasks using a robotic device. You will also be asked to complete a neck muscle fatigue protocol. Some participants will also receive one treatment session from a Certified Athletic Therapist (CAT).

Experiment Protocol

Upon arrival to the lab, the investigators will explain and demonstrate all tasks involved in the protocol to you. We will also familiarize you with the equipment being used and verbally explain and review the consent form. You will complete a neck pain disability index and chronic pain grading scale (short questionnaires) to evaluate what group you will be placed in.

The protocol for this study is as follows:

Day 1

Experiment #1- Proprioception Trial # 1

You will sit with your dominant forearm attached to a haptic wrist device (exoskeleton) while holding a handle connected to the device. The haptic device will move your hand to a predetermined wrist joint angle, hold for a total of three seconds and then the device will return your hand to the starting (neutral) position. You will then be asked to move the device yourself (exerting muscle activity and effort) to the angle that the device previously completed. There will
be two joint angle position matching tasks: 1) moving into wrist flexion, 2) moving into wrist extension. All wrist joint angles will be randomized. The haptic device will record your wrist joint angles and we will be able to calculate wrist joint angle accuracy to the target. Your vision will be occluded with googles as to eliminate visual feedback of the target and your wrist. You will also be asked to wear noise cancelling headphones.

Experiment #2 - Fatigue Protocol

Once you have completed the first proprioception trial, you will be asked to complete a fatigue protocol. The cervical extensor muscles (the muscles on the back of your neck) will be fatigued using an isometric (no movement) fatigue protocol. This task involves you laying prone (on your stomach) on an examination table, with your arms to your side. The primary researcher will support your head for the duration of the set up. A Velcro strap will be fixed around your head with an inclinometer attached to the band over the occiput. A 2-kg weight will be suspended from the headband and the weight will land just short of the floor. A second strap will be fixed around your trunk to control thoracic (upper back) extension. Your head will be positioned in a neutral position. You will be required to hold your neck in the neutral position for as long as possible, resisting against the 2kg weight. The test will be terminated if you can no longer hold the position due to fatigue or pain, if the weight returns to the floor, or if the neck position changes more than five degrees (as measured by the inclinometer).

Experiment # 3- Proprioception Trial #2

Immediately after the fatigue protocol, you will be moved back to the haptic device and asked to complete the same proprioception protocol (day 1, experiment 1) a second time. You will not be given a rest period between the fatigue protocol and the second proprioception trial.

Day 2

Experiment # 4 - Proprioception Trial # 1

You will be asked to return to the lab at least 48 hours after your initial visit. Upon arrival, you will be reminded of the experimental protocol for the second day. Once you are comfortable with the protocol, you will be asked to complete the same proprioception trial (day 1, experiment 1).

Experiment # 5 - Cervical Treatment

After completing the proprioception protocol, some participants will receive treatment from a CAT. If you are selected to receive treatment, you will be evaluated for restricted range of motion (ROM) at each cervical joint in the neck
and for muscle tension before treatment begins. Joint restriction will be tested by the CAT passively moving your head into maximum range of lateral flexion (both left and right) while palpating each cervical joint for restriction. Muscle stiffness will be examined by palpation and ROM will be assessed by you actively moving your neck each range (flexion, extension, left lateral flexion, right lateral flexion, left rotation, right rotation). Once assessed, the CAT will begin treatment which will consist of joint mobilizations to restricted joints as well as myofascial techniques for identified muscle stiffness. Treatments will be 20 minutes in length. If you do not receive treatment you will receive a rest period of twenty minutes.

Experiment # 6 - Proprioception Trial #2

Once treatment is completed (or a rest period of twenty minutes has passed), you will be asked to complete the same proprioception trial (day 1, experiment 1) for the last time.

Instrumentation

Haptic Device

The experimental device used for these studies is a three degrees-of-freedom (allowing movements along three actions of the wrist - flexion/extension, abduction/adduction, and pronation/supination) haptic wrist manipulandum. It is a mechanical system that can deliver forces to the human hand that is interacting with the device and is integrated with a virtual reality environment and computer display. The device is controlled by custom programs and cannot deliver forces larger than maximum isometric wrist torques of a human adult.

Sometimes a certain photograph clearly demonstrates a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific conference or in a publication. Therefore, photographs or video may be taken during the data collection. We will ask that you sign our consent for photographs form prior to allowing us to use such images.

Eligibility

Males and females are eligible to participate (age range, 17-35 years). You are eligible to participate in our control group if you have not had upper extremity injury in the past 12 months. If you have any history of chronic pain or neurological impairment to the upper extremity, we will discuss eligibility with you. Any neurological disorders or chronic injuries reported warrant exclusion from participation in this study. Exclusion to participate as a neck pain participant will include major structural injuries or anomalies to the cervical spine including disk herniation or fracture. As well, you will be excluded if you have received manual therapy or care for the neck in the previous three months. This exclusion criterion
has been put in place mainly to ensure the safety of our participants, as well as to avoid any confounding variables during data collection. Your eligibility as a pain group participant will be determined based on the results of our questionnaires, administered when you first arrive to the lab.

**Timeline**

Including instrumentation and experimental setup, it is expected that you will be in the biomechanics laboratory (TH 141) for approximately 45 minutes each day, for a total of two days.

**POTENTIAL BENEFITS AND RISKS**

Aside from exposure to the research environment, there are no known or anticipated direct benefits to you for your involvement in this project. The scientific community will benefit from this research because these findings may help to better understand the impact that chronic neck pain may have on structures further down the kinetic chain. This knowledge may help to ensure safety in the workplace as many occupational tasks require upper limb joint position awareness. At the end of your session you will be debriefed, at which point the investigators will answer any questions you might have about the experimental protocol.

There may be minimal risk associated with this study. You may experience some mild muscle soreness as a result of the fatigue protocol used during our study, or from treatment should you receive it. However, these activities can be considered similar to activities of daily living often experienced at home.

All tasks being simulated for this study are considered to be minimal risk. They involve simple wrist movements and little resistance (during the isometric fatigue protocol). Due to the nature of the experiments, you may experience some mild muscle weakness (up to 24 hours following the experiment). Additionally, you may experience delayed onset muscle soreness (DOMS) 24-48 hours’ post experimentation. In the very unlikely event of injury (for example, you may experience discomfort in the neck), we encourage any individuals with persistent irritation or discomfort to please visit the Campus Wellness Centre or your healthcare provider.

You are free to withdraw or discontinue the study at any time without consequence. Your withdrawal from the study will not affect your standing at Brock University or otherwise. Any participant who has any interaction with an experimenter involved with the study (such as a student in a class under the involved experimenters – Ie. A professor or Teaching Assistant) can participate and / or withdraw from the study at any given time and should understand that
this will have no effect on your academic pursuits or otherwise at Brock University.

CONFIDENTIALITY

Your identity will be kept confidential and only made available to the researchers. You will be identified only by a subject identification code during the data collection phase of this study. All data, including written records and electronic data, will be placed in a locked cabinet or stored on a secured computer in the locked office of the principal investigator. Data will be originally recorded on a computer that is password protected and only available to the researcher’s in a locked and secure room. The data will remain at this institution. The data will not be linked with any other data set and the data will not be sent outside of the institution where it is collected. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participant’s faces. As a result, the data is not anonymous, due to collecting identifying information. However, all identifying markers will be removed when appropriate.

Should you request that your images or video not be released, they will be withheld from public release with no consequence to you. Data will be kept indefinitely. Sometimes analysis techniques and ideas change over time and we would prefer to have access to the data should a new analysis be performed. In addition, sometimes publication of results can take years to complete and we prefer to hold on to the data in case there are ever questions about the quality or integrity of our data. After 1 year, all subject identification codes will be removed from the data.

Access to this data will be restricted to Dr. Holmes and the graduate student involved in this work.

VOLUNTARY PARTICIPATION

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. If you are a Brock student, withdrawing from the study will in no way affect your academic standing. If you wish to withdraw during the study, simply tell the investigator that you no longer wish to participate. Participation, non-participation or withdrawal from the study will not affect one’s standing at Brock University. If you are a student of the principal investigator (they are your Professor or Teaching Assistant), testing and recruitment will be handled by a third-party individual to avoid real or perceived coercion that you may feel. Also, if you withdrawal from the study prior to completion or wish to
have your data not included in the analysis after collection, all data will be disposed. However, once data analysis is complete and the results are published, this cannot be done.

COMPENSATION FOR PARTICIPATION

You will receive a $10 Tim Horton’s gift card for participating in this study. Should you need to withdraw from the study and you can no longer complete session #2, you will still receive the $5 compensation for the first session.

PUBLICATION OF RESULTS

Results of this study may be published in professional journals and presented at conferences. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces. Feedback about the details of this study and your participation will be available to you by contacting Dr. Holmes at the address included at the top of the form or completing the attached feedback letter after your participation has been completed. Should you withdraw from the study, feedback will be available to you at that time if you wish to receive it. Results should be made available approximately 6 months after your completion of the study. The results will be group data about the main findings of the study. If you wish to know learn about individual data, we can arrange to meet.

CONTACT INFORMATION AND ETHICS CLEARANCE

If you have any questions about this study or require further information, please contact Dr. Holmes using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University

(File # 18-113). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.

Thank you for your assistance in this project. Please keep a copy of this form for your records.

CONSENT FORM

I agree to participate in this study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted regarding the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

Name: ________________________________________________________________
Neuromuscular Mechanics and Ergonomics Laboratory
Participant screening/participation form

Subject ID ___________________________________
Date of Birth _________________________________
Date _______________________________________

Questions:
1. Male or Female? (circle)

2. Age: ___________

3. Previous upper extremity injury? Yes / No (circle)
   If Yes, please identify (list) any injuries that you have had in the past 12 months and when it occurred (e.g. sprained wrist, 2 months ago):
   Some examples may include, but are not limited to: muscle strain/sprain, ligament strain/strain, bone/joint pain, neurological impairments, etc.
DATA COLLECTION - DAY 1

Participant Information

Name______________________________________ Date____________________

Height: _____ (cm) Weight: ______ (Kg) Age: ______ Handedness: R / L

Pain Grading Scale Score: ____________

NDI Score: ____________

Checklist

Pain Free (Pain Group)? Y / N

Protocol reviewed with participant ☐

Familiarization with Robot ☐

Familiarization with proprioception task ☐

Protocol

<table>
<thead>
<tr>
<th>Proprioception Trial #1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue Protocol</td>
<td>Time held:</td>
</tr>
<tr>
<td>Proprioception Trial #2</td>
<td></td>
</tr>
</tbody>
</table>
DATA COLLECTION - DAY 2 (CONTROL GROUP)

Name______________________________________
Date____________________________

**Protocol**

<table>
<thead>
<tr>
<th>Trial Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proprioception Trial #1</td>
<td></td>
</tr>
<tr>
<td>Rest (20 minutes)</td>
<td></td>
</tr>
<tr>
<td>Proprioception Trial #2</td>
<td></td>
</tr>
</tbody>
</table>
DATA COLLECTION - DAY 2 (PAIN GROUP)

Name__________________________________________________________
Date____________________________

Pain Free? Y / N

Pre – Treatment ROM:

Flexion:
Extension:
LR:
RR:
LSB:
RSB:

Protocol

<table>
<thead>
<tr>
<th>Proprioception Trial #1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment/ Treatment</td>
<td></td>
</tr>
<tr>
<td>Proprioception Trial #2</td>
<td></td>
</tr>
</tbody>
</table>

Post – Treatment ROM:

Flexion:
Extension:
LR:
RR:
LSB:
RSB:

SOAP Notes complete: Y / N
For the following questions with a scale of 1-10 please circle one number only

1. How would you rate your pain on a 1-10 scale at the present time, that is right now, where 0 is “no pain” and 10 is “pain as bad as could be”?

<table>
<thead>
<tr>
<th>No pain</th>
<th>Pain as bad as could be</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

2. In the past six months, how intense was your worst pain rated on a 0-10 scale where 0 is “no pain” and 10 is “pain as bad as could be”?

<table>
<thead>
<tr>
<th>No pain</th>
<th>Pain as bad as could be</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

3. In the past six months, on average, how intense was your pain rated on a 1-10 scale, where 0 is “no pain” and 10 is “pain as bad as could be”? (That is, your usual pain at times you were experiencing pain.)

<table>
<thead>
<tr>
<th>No pain</th>
<th>Pain as bad as could be</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

4. About how many days in the last six months have you been kept from your usual activities (work, school or housework) because of this pain?

<table>
<thead>
<tr>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6 days</td>
</tr>
<tr>
<td>7-14 days</td>
</tr>
<tr>
<td>15-30 days</td>
</tr>
<tr>
<td>31 or more days</td>
</tr>
</tbody>
</table>

5. In the past six months, how much has this pain interfered with your daily activities rated on a 1-10 scale where 0 is “no interference” and 10 is “unable to carry on activities”?

<table>
<thead>
<tr>
<th>No interference</th>
<th>Unable to carry on activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

6. In the past six months, how much has this pain changed your ability to take part in recreational, social and family activities where 0 is “no change” and 10 is “extreme change”?

<table>
<thead>
<tr>
<th>No change</th>
<th>Extreme change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

7. In the past six months, how much has this pain changed your ability to work (including housework) where 0 is “no change” and 10 is “extreme change”?

<table>
<thead>
<tr>
<th>No change</th>
<th>Extreme change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Appendix B - Scoring The Chronic Pain Grade

**Pain Intensity** : a 0-100 score derived from questions 1-3, calculated as follows:

\[ \text{Mean (question 1 + question 2 + question 3) x 10} \]

**Disability Score** : a 0-100 score derived from questions 5-7, calculated as follows

\[ \text{Mean (question 5 + question 6 + question 7) x 10} \]

**Disability Points** : a score from 0-6 derived from the disability score re-coded plus question 4 recoded.

*Re-coding for disability score* :

<table>
<thead>
<tr>
<th>Score</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-29</td>
<td>0 points</td>
</tr>
<tr>
<td>30-49</td>
<td>1 point</td>
</tr>
<tr>
<td>50-69</td>
<td>2 points</td>
</tr>
<tr>
<td>70+</td>
<td>3 points</td>
</tr>
</tbody>
</table>

*Re-coding for question 4* :

<table>
<thead>
<tr>
<th>Days</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6 days</td>
<td>0 points</td>
</tr>
<tr>
<td>7-14 days</td>
<td>1 point</td>
</tr>
<tr>
<td>15-30 days</td>
<td>2 points</td>
</tr>
<tr>
<td>31+ days</td>
<td>3 points</td>
</tr>
</tbody>
</table>

**Chronic Pain Grade Classification**

- **Grade 0**  
  Pain Intensity = 0, and Disability Points = 0

- **Grade I**  
  Pain Intensity < 50, and Disability Points < 3

- **Grade II**  
  Pain Intensity ≥ 50, and Disability Points < 3

- **Grade III**  
  Disability Points = 3 or 4, regardless of Pain Intensity

- **Grade IV**  
  Disability Points = 5 or 6, regardless of Pain Intensity

Acknowledgements
We are grateful to Dr Michael Von Korff for his help with the use of the Chronic Pain Grade questionnaire and for his assistance with the preparation of this paper.

References

# Neck Disability Index

This questionnaire is designed to help us better understand how your neck pain affects your ability to manage everyday life activities. Please mark in each section the one box that applies to you. Although you may consider that two of the statements in any one section relate to you, please mark the box that most closely describes your present-day situation.

<table>
<thead>
<tr>
<th>Patient Name</th>
<th>Score</th>
<th>Benchmark -5 =</th>
<th>Date</th>
</tr>
</thead>
</table>


## Section 6 – Concentration
- ✗ I can concentrate fully without difficulty.
- ✗ I can concentrate fully with slight difficulty.
- ✗ I have a fair degree of difficulty concentrating. ✗ I have a lot of difficulty concentrating.
- ✗ I have a great deal of difficulty concentrating. ✗ I can’t concentrate at all.

## Section 1 – Pain Intensity
- ✗ I have no pain at the moment.
- ✗ The pain is very mild at the moment.
- ✗ The pain is moderate at the moment.
- ✗ The pain is fairly severe at the moment.
- ✗ The pain is very severe at the moment.
- ✗ The pain is the worst imaginable at the moment.

## Section 2 – Personal Care
- ✗ I can look after myself normally without causing extra pain.
- ✗ I can look after myself normally, but it causes extra pain.
- ✗ It is painful to look after myself, and I am slow and careful.
- ✗ I need some help but manage most of my personal care. ✗ I need help every day in most aspects of self-care.
- ✗ I do not get dressed. I wash with difficulty and stay in bed.

## Section 7 – Sleeping
- ✗ I have no trouble sleeping.
- ✗ My sleep is slightly disturbed for less than 1 hour.
- ✗ My sleep is mildly disturbed for up to 1-2 hours.
- ✗ My sleep is moderately disturbed for up to 2-3 hours. ✗ My sleep is greatly disturbed for up to 3-5 hours.
- ✗ My sleep is completely disturbed for up to 5-7 hours.

## Section 3 – Lifting
- ✗ I can lift heavy weights without causing extra pain. ✗ I can lift heavy weights, but it gives me extra pain. ✗ Pain prevents me from lifting heavy weights off the floor but I can manage if items are conveniently positioned, i.e. on a table. ✗ Pain prevents me from lifting heavy weights, but I can manage light weights if they are conveniently positioned.
- ✗ I can lift only very light weights.
- ✗ I cannot lift or carry anything at all.

## Section 8 – Driving
- ✗ I can drive my car without neck pain.
- ✗ I can drive as long as I want with slight neck pain.
- ✗ I can drive as long as I want with moderate neck pain. ✗ I can’t drive as long as I want because of moderate neck pain.
- ✗ I can hardly drive at all because of severe neck pain. ✗ I can’t drive my car at all because of neck pain.
SECTION 9 – READING
× I can read as much as I want with no neck pain.
× I can read as much as I want with slight neck pain.
× I can read as much as I want with moderate neck pain. ❌ I can’t read as much as I want because of moderate neck pain.
× I can’t read as much as I want because of severe neck pain.
× I can’t read at all.

SECTION 4 – WORK
× I can do as much work as I want.
× I can only do my usual work, but no more.
× I can do most of my usual work, but no more. ❌ I can’t do my usual work.
× I can hardly do any work at all.
× I can’t do any work at all.

SECTION 5 – HEADACHES
× I have no headaches at all.
× I have slight headaches that come infrequently.
× I have moderate headaches that come infrequently. ❌ I have moderate headaches that come frequently.
× I have severe headaches that come frequently.
× I have headaches almost all the time.

SECTION 10 – RECREATION
× I have no neck pain during all recreational activities.
× I have some neck pain with all recreational activities.
× I have some neck pain with a few recreational activities. ❌ I have neck pain with most recreational activities.
× I can hardly do recreational activities due to neck pain. ❌ I can’t do any recreational activities due to neck pain.