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Evaluation of Novel High-Density EMG Feedback Parameters on the Spatial Distribution of Trapezius Muscle Activity

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Evaluation of Novel High-Density EMG Feedback Parameters on the Spatial Distribution of
Trapezius Muscle Activity

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A Thesis

Presented to

the Faculty of Engineering and Computer Science

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Brecca M. Gaffney

June 2013

Advisor: Bradley S. Davidson, PhD

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Title: Evaluation of novel high-density EMG feedback parameters on the spatial
distribution of trapezius muscle activity
Advisor: Bradley S. Davidson, PhD
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Abstract

Each year, 17.9% of adults working in a computer-dominated work environment develop an episode of chronic neck and shoulder pain. An effective treatment method for chronic pain is postural correction through therapist. The understanding of the relation between cervicoscapular posture and trapezius muscle activity is not fully understood because the anatomy of the scapula is not accessible for direct observation. Until recently, the spatial distribution of trapezius muscle activity could not be measured due to the limitation in size of detection zone in traditional bipolar electrodes. The primary goal of postural correction when treating cases of chronic neck and shoulder pain is to shift the distribution of trapezius muscle activity inferior. However, treatment methods of chronic musculoskeletal diseases are often inefficient due to the inability of the participant to permanently alter posture and activation patterns.

The first goal of this project was to determine the relation between cervicoscapular posture and the distribution of trapezius muscle activity. To accomplish this, cervicoscapular posture and trapezius muscle activity were recorded while participants adopted three unique shoulder postures. Because scapular position cannot be measured *ex vivo*, the position of the acromion process relative to C7 was used as a surrogate.

Finally, a biofeedback intervention using HDsEMG feedback parameter was developed for real-time postural correction during computer use. Biofeedback is an effective strategy for rehabilitation application to retrain muscle activation patterns through motor unit re-education. The HDsEMG biofeedback interface was developed to shift trapezius muscle activity inferior. This interface provides the opportunity to provide a more effective treatment to chronic neck pain by permanently shifting trapezius muscle activity inferiorly.

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1. Introduction

Chronic neck and shoulder pain is a growing condition, most commonly affecting people who work in a computer-dominated environment. During any 6-month period, 54% of adults suffer from chronic neck pain and 4.6% of adults experience disabling cases of neck pain (Côte et al., 2004). Of patients suffering from chronic neck pain, only 6.3% of individuals reported that their pain was non-recurrent. Furthermore, most individuals with chronic neck pain do not experience cessation of their symptoms and disabilities.

A more complete understanding of cervicoscapular posture and the spatial distribution of trapezius muscle activity may allow for better treatment methods to chronic pain. However, due to the complexity of these conditions, rehabilitation approaches are often inefficient at providing permanent treatment to pain. Chapters 2-5 further discuss the prevalence of chronic neck pain and possible effective treatment solutions.

The overall goal of this project is to implement novel high-density surface electromyography (HDsEMG) feedback parameters on the spatial distribution of trapezius muscle activity for rehabilitation applications. This project is divided into two objectives:

Objective #1: To characterize the relation between cervicoscapular posture and the spatial distribution of trapezius muscle activity.

Objective #2: To evaluate the effectiveness of postural education with and without biofeedback intervention guided by HDsEMG feedback parameters designed to redistribute trapezius muscle activity during a functional typing task.

This thesis is organized in the following manner. Chapter 2 presents previous investigations of musculoskeletal disorders and an overview of investigations using electromyography (EMG) for rehabilitation application. Chapter 3 proposes a method to determine the effect of cervicoscapular posture on the spatial distribution of trapezius muscle activity. Chapter 4 presents an overview of biofeedback interventions and previous investigations in which novel biofeedback interventions were used for rehabilitation application. Chapter 5 proposes a method to investigate the effectiveness of postural education guided by a biofeedback intervention using HDsEMG feedback parameters. Chapter 6 provides a summary of the results and suggestions for future work.

2. Musculoskeletal Disorders and Electromyography

2.1 Introduction

Computer use in the workplace and at home is becoming more widespread as technology advances in developed countries. As a result, neck pain is a growing ergonomic problem and becoming an economic burden due to its complexity and the difficulty to maintain a permanent treatment. Although recent technological advances provide easier and more accurate methods of diagnosing of neck pain, equal progress has not been made in providing long-lasting treatment solutions. This review examines two common causes of work-related neck pain as well as a measurement technique used to investigate muscle activation of shoulder and neck stabilizers.

2.2 Trapezius Myalgia

Chronic pain is very complex due to plastic changes of the pain transmission system and by modifications of multiple physiological factors (Rosendal et al., 2004). Chronic musculoskeletal disorders of the neck and shoulder regions are a growing concern for workers in a computer-dominated work environment. Because these types of chronic pain disorders are difficult to treat, employers often assume the resulting medical expenses. Approximately 90% of office workers use computers on a daily basis and 40% of those

workers occupy a computer for more than four hours per day (Gerr et al., 2004). Croft et al., (2001) reported that 17.9% of adults experience at least one episode of neck pain over the duration of one year and 9.0% of adults experience disabling neck pain in a one year period (Côté et al., 2004). Workers who perform monotonous work tasks, which require continuous low levels of muscle activity (i.e. computer work), are at a higher risk of developing chronic musculoskeletal myalgia than workers who do not work in this condition (Veiersted et al., 1993).

Because the muscle architecture in the trapezius is complex and varied across the regions, it is susceptible to chronic pain (Lindman et al., 1991). Fibers in the superior of the trapezius muscle originate at the external occipital protuberance, the medial third of the superior nuchal line of the occipital bone, and the ligamentum nuchae. The superior fibers descend laterally and insert onto the posterior border of the lateral third of the clavicle. Fibers in the middle portion of the trapezius originate at the spinous process of the seventh cervical (C7) and the spinous processes of the first, second and third thoracic vertebrae (T1-T3). The fibers ascend laterally and are inserted into the medial margin of the acromion and the superior lip of the posterior border of the spine of the scapula. Fibers in the inferior portion of the trapezius originate from the spinous processes of the lower portion of the thoracic vertebrae (T4-T12). The fibers ascend superiorly and laterally to insert near the scapula (Figure 2.1).

Figure 2.1. Posterior view showing trapezius muscle architecture.

Occupations with repetitive or monotonous work tasks, even muscle activity levels below 5% of maximal voluntary electrical activity (Thorn et al., 2002), place the user at risk to develop chronic pain disorders. In a common typing task, it is only necessary to continuously activate the superior portion of the trapezius due to the anatomical subdivisions of the trapezius, the non-uniform fiber orientations of the three subdivisions, and non-uniform motor unit recruitment (Falla et al., 2007; Holtermann et al., 2009; Dellve et al., 2011). Tasks requiring repeated or sustained muscle activity and in activities which the same motor units are used extensively, muscle fatigue is known to develop (Faucett, 2002). Fatigue and continuous low-level activation of the upper trapezius, coupled with weakness and inhibition of the middle and lower regions of the trapezius, may lead to chronic trapezius myalgia over time (Veiersted et al., 1993; Cools et al., 2007) . Women are more likely than men to develop musculoskeletal disorders in the neck and shoulder regions due to lower muscle strength which requires a larger fraction of their muscular capacity during a given task (Jensen et al., 2002; Karlqvist et al., 2002). Symptoms of trapezius myalgia include local pain as well as weakness in the

neck-shoulder region (Larsson et al., 1999). Strength training, muscle endurance

training, and coordination training are all common rehabilitative treatment methods used

within physiotherapy (Waling et al., 2000); however, these methods often provide only

temporary relief to pain symptoms.

2.3 Cervical Posture and Neck Pain

Enwemeka et al. (1986) reported that patients who experience chronic neck pain

exhibit a forward head positions (Fig. 2.1). The forward head position is likely a

combination of lower cervical flexion (C7-C4) and upper cervical extension (C3-C1)

(Szeto et al., 2002). This particular posture may increase chronic neck pain symptoms

due to the increased static load placed upon the upper trapezius by the weight of the head

(Larsson et al., 1999). Increased flexion in the cervical spine may contribute to neck pain

with this postural habit (Edmondston et al., 2011). Maintaining the head in this posture

requires excessive activation of the upper trapezius, which increases the risk of

developing chronic trapezius myalgia. Although there is an apparent correlation between

poor posture and neck pain, the cause-and-effect relationship between the two remains

unclear.
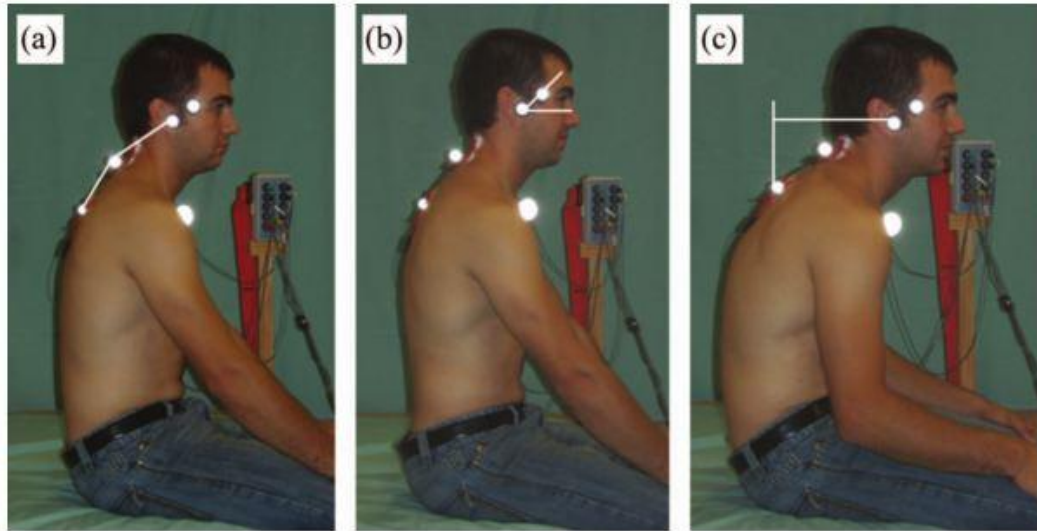
Figure 2.2: Cervicoscapular posture (a) habitual posture (b) ergonomically correct posture and (c) "hunched" posture (Image taken from Edmondston et al., 2011).

In computer settings, the position of the workstation screen has a direct effect on cervical posture. A previous report (Straker & Mekhora, 2000) provides evidence that lower cervical flexion in response to looking down upon a computer screen increases the static load placed upon the stabilizing muscles of the neck.

2.4 Scapular Posture and Neck pain

Abnormal scapular kinematics are believed to contribute to shoulder pain and pathology (Ludewig & Cook, 2000; Vermeulen et al., 2002). Clinical theory contends that aberrant scapular posture and altered patterns in muscle activity have been linked to pain (Behrsin & Macguire, 1986). Wegner et al., (2010) demonstrated that computer workers who displayed poor scapular posture had higher pain levels in the cervical spine region. Griegel-Morris et al., (1992) determined a relation between cervical pain and

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inter-scapular pain. Falla et al. (2007) reported that individuals with chronic neck pain tend to have greater difficulty maintaining proper posture in the cervicoscapular region for an extended period of time compared to healthy individuals. However, measuring scapular position is difficult to do because of the substantial soft-tissue covering it. A recent investigation demonstrated that using location of the acromion process is an accurate surrogate of scapular movement in the sagittal plane (Van Andel et al., 2009). Tracking the accurate location of the scapula is clinically meaningful when scapular position is related to pain in the neck and shoulder region. Although spatial distribution of trapezius muscle activity and cervicoscapular posture both have an effect on the development of chronic trapezius myalgia, the correlation between the two remains unclear.

2.5 Electromyography

Electromyography (EMG) is a common technique used to record the changes in electric potentials produced by skeletal muscles. These potentials are in response to an impulse sent to the central nervous system (CNS) through a motoneuron. The changes in electric potentials are caused by an electrochemical reaction in which the initial action potential is produced by an influx of sodium across the fiber membrane which reverses the polarity of the membrane. Potassium is then flushed across the membrane as the potential of the membrane is reversed, which repolarizes the muscle membrane. Following repolarization, there is an incursion of potassium causing a voltage undershoot. The motor unit action potential (MUAP) is composed of the sum of all

electrical activity of the activated muscle fibers within a given motor unit. The change in electric potential across a muscle membrane is measured via electromyography.

EMG is traditionally measured through surface electrodes. Surface electrodes are a noninvasive technique for measuring changes in the electric field potentials by placing electrodes on the muscle in question. The quality of the signal recorded through surface electrodes can be quantified by the signal-to-noise ratio (SNR), which compares the background noise against the actual signal. A bipolar configuration is commonly used to determine limited temporal and spatial resolution of the skeletal muscle. The resulting signal between the two electrodes, commonly referred to as a single differential configuration, has a lower SNR than monopolar recordings.

Bipolar surface electrodes are unable to measure potentials of deep muscles due to the detection zone between electrodes. The detection zone in bipolar recordings is not small enough to discriminate between individual motor units; the recorded signal is instead the summation of multiple motor units. Increasing thickness of subcutaneous tissue causes a significant decay in in the action potential of a muscle (Cescon et al., 2008). Intramuscular electrodes are an alternative procedure used to measure deeper and/or smaller muscles. Intramuscular electrodes are inserted into the muscle using a fine-wire needle and are able to monitor the activity of one or more individual MUs (Blok et al., 2002; Merletti et al., 2008). Identification of individual motor units via intramuscular EMG is only possible if each action potential uniquely represents its respective motor unit (Roberto Merletti et al., 2008). Both fine-wire and bipolar electrode configurations

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present significant limitations by their lack of ability to represent the true spatial activation patterns of the muscle in question.

High-density surface EMG (HDsEMG) is a non-invasive technique used to measure changes in the electrical field potential evoked by active muscle fibers with multiple closely spaced electrodes overlying a large portion of the muscle. HDsEMG allows a more accurate representation of spatial EMG activity of an entire muscle, which expands the possibilities to further explore muscle characteristics, such as overall recruitment and distribution patterns (Drost et al., 2006). In contrast to traditional bipolar signals, HDsEMG provides two recordings in the spatial dimension as well as one recording in the temporal dimension (Roberto Merletti et al., 2008). HDsEMG recordings provide a topographical map of the spatial and temporal characteristics of the muscle. Topographical maps created from HDsEMG change with force level (Holtermann et al., 2005), indicating that motor unit recruitment is not spatially uniform in the muscle. Changes in heterogeneity caused either by motor unit recruitment or substitution cannot be determined from traditional bipolar EMG (Farina et al., 2008; Rojas-Martínez et al., 2012). Identifying changes in heterogeneity may reflect muscle compartmentalization, which is advantageous in muscles with complex architecture (e.g. trapezius) (Johnson et al., 1994).

HDsEMG can be used to detect pathologic changes at the individual motor unit level (van Dijk et al., 2008). De Luca et al. (2006) recently develop, an algorithm that automatically identifies the recruitment patterns of individual motor units. Identifying individual motor unit characteristics (location, spatial orientation, and endplate zone) has

many clinical and physiologic benefits. This is especially beneficial because individual

motor unit patterns provide information regarding how they are controlled by the central

nervous system (CNS).

2.6 HDsEMG and Trapezius Myalgia

Musculoskeletal myalgia is most commonly detected and diagnosed through bipolar

EMG recordings (Larsson et al., 2000; Lundberg et al,, 1994; Røe et al., 2001; Veiersted

1994; Öberg et al., 1992). However, assumptions made upon the limited spatial resolution

of bipolar recordings are restricted to the detection zone of the electrode placement.

HDsEMG can be used in multiple clinical applications involving muscle fatigue,

motor neuron diseases, neuropathies, myopathies, spontaneous muscle activity, and

motor unit firing rates. HDsEMG also allows the recording of endplate zone, depth, size

and position of individual motor units, as well as spatial and temporal characteristics of

muscle activity. Further understanding of motor unit firing patterns of adults experiencing

chronic trapezius myalgia in a computer-dominated workplace may provide insight on

permanent treatment solutions. Henneman (1985) determined that there is an orderly

recruitment pattern of motor units during a contraction in which MUs are recruited based

on size, smallest to largest, as contraction levels increase. Recruitment patterns are

applicable in cases of chronic pain because continuous activity resulting in overloading of

specific MUs has the potential to result in pain caused by myalgia (Zennaro et al., 2003).

Investigations that involve the behavior of individual motor units (MUs) during a

continuous sustained contraction are becoming increasingly common due to the need to

further understand the complexity of motor unit firing patterns in relation to chronic musculoskeletal myalgia.

In cases of trapezius myalgia, the heterogeneity of muscle activation of the upper trapezius is expected to be higher due to the continuous, low-level activation of the superior fibers of the upper trapezius. Using HDsEMG recordings, the heterogeneity of the muscle can be determined.

Using HDsEMG to investigate muscle activity over the span of an entire muscle expands many new possibilities of muscle characteristics that have not yet been explored. In the context of trapezius myalgia, HDsEMG recordings can provide insight into activity and distribution patterns throughout the three regions of the trapezius. Clinically, HDsEMG is extremely advantageous to diagnose and treat many conditions, as well as conditions at the individual motor unit level, including trapezius myalgia.

3. Effect of cervicoscapular position on the spatial distribution of trapezius muscle activity

3.1 Introduction

Workplace-related chronic neck pain is a growing problem in the United States that accounts for 56% to 65% of all occupational disabling injuries (Piligian et al., 2000). Fifty-four percent of working adults suffer from chronic neck pain within any six-month period and 4.6% of working adults report that neck pain causes significant performance inhibitions of daily activities (Côté et al., 2004). This epidemic of chronic neck pain has been linked to altered activation patterns of the trapezius due to long-term computer use (Lindegård et al., 2012). Falla et al. (2004) found that patients with chronic neck pain in static sitting postures, such as computer work, demonstrated greater activity patterns of the upper trapezius compared to asymptomatic controls.

Patients suffering from chronic neck pain have demonstrated abnormal cervicoscapular positions during computer work (Szeto et al., 2002). This adopted posture may be a mechanism to cope with the symptoms, however, assuming these postures may contribute or enhance chronic neck and shoulder pain symptoms (Behrsin & Macguire, 1986). Previous investigations have described how patients experiencing chronic neck and shoulder pain exhibit increased cervical flexion, or "poor" posture

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(Enwemeka et al., 1986). In this position, the stabilizing muscles of the neck and shoulder region are subject to "over-activation" due to the increased static load created by the head (Szeto et al., 2005). Abnormal scapular postures and muscle activity contribute to pain in the neck and shoulder region (Ludewig & Cook, 2000; Vermeulen et al., 2002); therefore, retraining proper scapular posture is commonly used in rehabilitation in patients with neck and shoulder pain (Dickens et al., 2005; Mottram et al., 2009). Wegner et al., (2010) demonstrated that patients who applied postural correction of the scapula during typing generated higher activation patterns in the middle and lower portions of the trapezius than compared to activation in the upper trapezius.

The cranial-vertebral angle is a commonly used metric to describe cervical posture (Ankrum & Nemeth, 2000; Breen et al., 2009; Yip et al., 2008; Yoo & Kim, 2010; Edmondston et al., 2011; Ma et al., 2011). Cervical posture is most often described by the angle between a vertical line from C7 to the tragus (Figure 3a), which is commonly known as the cranial-vertebral (CV) angle or the C7-tragus angle (Ankrum & Nemeth, 2000). The average cranial-vertebral angle with respect to vertical during good posture is 43.7° during a functional typing task (Ankrum & Nemeth, 2000). Maintaining a cranial-vertebral angle greater than 45° for an extended period of time places a continuous static load on the stabilizing muscles of the neck and shoulder, which may cause over-activation in the muscles of the neck and shoulder (e.g. trapezius) and has the potential to cause chronic neck pain (Breen et al., 2009; Larsson et al., 1990). When using motion capture technology, the position of the scapula cannot be accurately measured because of the substantial soft-tissue covering it. As a surrogate, Van Andel et

al. (2009) demonstrated that placing a marker on the acromion was an accurate method of measuring scapular position.

Although there is an apparent relation between cervicoscapular kinematics and spatial distribution of trapezius muscle activity, quantitative evidence regarding the relation between the two is limited. When correlating cervical posture and trapezius muscle activity, the cranial-vertebral angle is only directly correlated with the ascending fibers of the upper trapezius; yet the cranial-vertebral angle is often used to describe cases of neck pain caused by changes in trapezius muscle activation patterns. The scapula is known to have a significant effect on trapezius muscle activity (Wegner et al., 2010), yet the correlation between the direct location of the scapula and spatial distribution patterns of trapezius muscle activity is not well understood.

The first aim of this investigation was to determine how three different shoulder postures (scapular adduction, scapular adduction and depression, and scapular elevation) affected cervicoscapular position. We hypothesized that each posture would affect scapular position and only scapular elevation would affect cervical posture. The second aim of this investigation was to determine the correlation between scapular position and cervical posture. We hypothesized that there would be no correlation between scapular and cervical posture. The third aim of this investigation was to determine the correlation between cervicoscapular posture and the distribution of trapezius muscle activity. We hypothesized that there would be no correlation between cervical posture and the distribution of trapezius muscle activity. We also hypothesized that a superior location of the scapula will yield a more superior distribution of trapezius muscle activity.

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3.2 Methods

3.2.1 Participants

Twenty participants (Table 3.1) without a history of chronic neck or shoulder pain participated in the investigations. Participants were recruited from the university and local community. All participants provided a written, informed consent in accordance with the Colorado Multiple Institutional Review Board (COMIRB) prior to the start of the experimental session. Participants visited the laboratory for one data collection in which cervicoscapular posture and trapezius muscle activity were collected during three directed postures.

Table 3.1. Participant demographic data.

	Male		Female	
	Mean	SD	Mean	SD
Age (years)	30.4	9.9	36.5	13.9
Height (cm)	183.8	8.0	171.7	5.9
Weight (kg)	84.1	12.8	77.5	9.5
Dominant Hand (right\left)	9\1	-	9\1	-

3.2.2 Instrumentation

Participants were instrumented with 25 reflective markers (Figure 3.1a) used to record motion with eight cameras surrounding the motion capture area (Vicon, Centennial, CO). HDsEMG signals were recorded from two semi-disposable adhesive electrode arrays (ELSCH064NM2 Pin Out, OT Bioelettronica, Torino, Italy). The superior electrode array was placed overly the upper trapezius (UT) and middle trapezius (MT), and the inferior electrode array was placed overlying the MT and lower trapezius

(LT) (Figure 3.1b). Each electrode array was composed of 64 electrodes, in a 13x5

orientation with an 8-mm inter-electrode distance (IED) and a 3-mm electrode diameter.

There is one missing electrode in the inferior-lateral corner of each array, which

represents the origin that describes electrode position (Figure 3.2a). EMG signals were

amplified (64 channel surface EMG-USB2 amplifier, OT Bioelettronica, Torino, Italy;

bandwidth 10-500 Hz) by a factor of 5000, sampled at 2048 Hz, and converted to digital

form by a 12-bit A/D converter. Visual inspection of the raw EMG signals was

performed in post-processing to identify any channels with poor contact or short circuits

and signals were linearly interpolated using adjacent channels (Gallina et al., 2013).

(a)

(b)
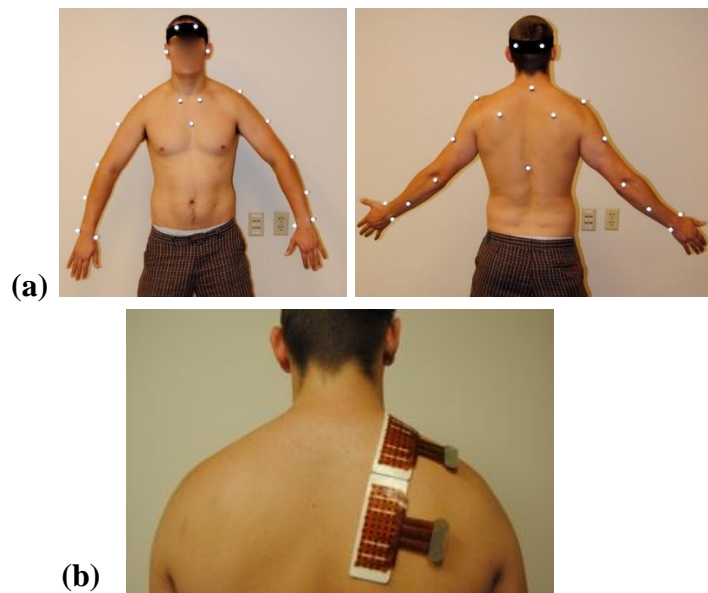
Figure 3.1. (a) Marker placement (b) HDsEMG electrode array placement.
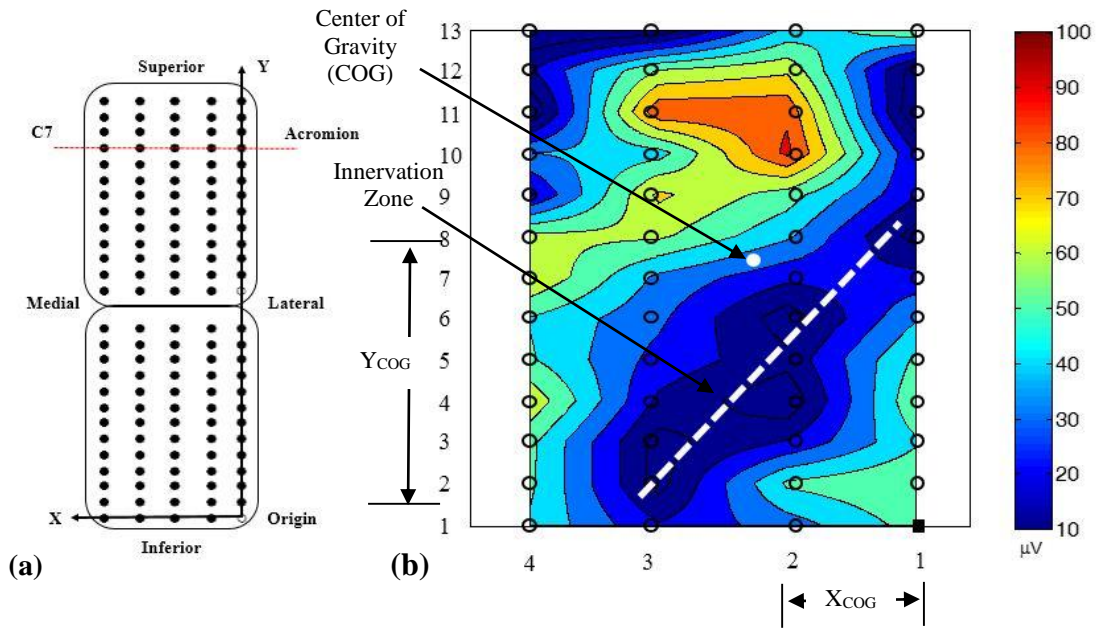
Figure 3.2. (a) Schematic of HDsEMG electrode array with position on trapezius (b) example of topographical map (interpolation by a factor of 8) of 51 bipolar average rectified values of superior array with center of gravity (white dot) and innervation zone (white dashed line)

To standardize electrode array placement across all participants, the superior electrode array was placed in relation to the innervation zone (Farina et al., 2002). Prior to placement of the superior electrode array, the main innervation zone of the upper trapezius was identified using a dry linear array (SA 16/5, OT Bioelettronica, Torino, Italy) that consists of: 16 silver bar electrodes, 5-mm IED, 1 mm width. The superior electrode array was placed with the 4th electrode row along the C7-acromion line with the most medial electrode column 10-mm distant from the innervation zone, parallel to muscle fiber direction (Figure 3.2a) (Farina et al., 2008). Skin beneath the electrode arrays was lightly abraded. A reference electrode was placed at the right wrist.

3.2.3 Experimental Protocol

Each participant was coached by a researcher on how to sit with correct posture. The participant was instructed to maintain a "neutral" posture in which their trunk was upright, chin was tucked, and shoulder blades were slightly depressed and adducted. Participants held this posture for one minute. Each participant was then directed to assume three unique shoulder postures, which include a scapular elevation, scapular adduction, and scapular adduction and depression. These postures are presumed to individually activate the upper, middle, and lower portions of the trapezius (A Holtermann et al., 2009). The participants were instructed to sit in an upright position, with feet centered between the left and right acromion, and ears directly over shoulders. Each participant was instructed to perform each posture to the end of range of movement and hold for thirty seconds. Differences between cervicoscapular posture and the distribution of trapezius muscle activity in all three postures with respect to their respective average in the coached neutral posture was determined.

3.2.4 Data Processing

Cervicoscapular posture was quantified during each typing task by two measures: cranial-vertebral angle and scapular position. Marker data was filtered with a 4th order, zero phase lag Butterworth filter with lowpass cutoff frequency of 5 Hz. The cranial-vertebral angle was calculated as the angle of a line from the C7 to the tragus with respect to a vertical reference (Figure 3.3a). The CV angle was determined using the C7 marker and the mean location between markers placed on each tragus (Figure 3.3a). Scapular

position is difficult to measure because it is obstructed by several muscles in the rotator cuff (supraspinatus, infraspinatus, teres major, teres minor) and the deltoid. As a surrogate, scapular position was quantified by the location of the acromion process of the dominant side of the participant relative to C7, and was expressed in a torso-fixed coordinate system (Figure 3.3b). Scapular position adduction and abduction (θ_{AB}) was quantified by the angle between C7 and the acromion process with respect to the horizontal. Positive θ_{AB} angles indicate scapular abduction while negative θ_{AB} angles indicate scapular adduction. Scapular elevation and depression was quantified by the angle between C7 and the acromion process with respect to the vertical. Positive θ_{EL} angles indicate scapular elevation while negative θ_{EL} angles indicate scapular depression.
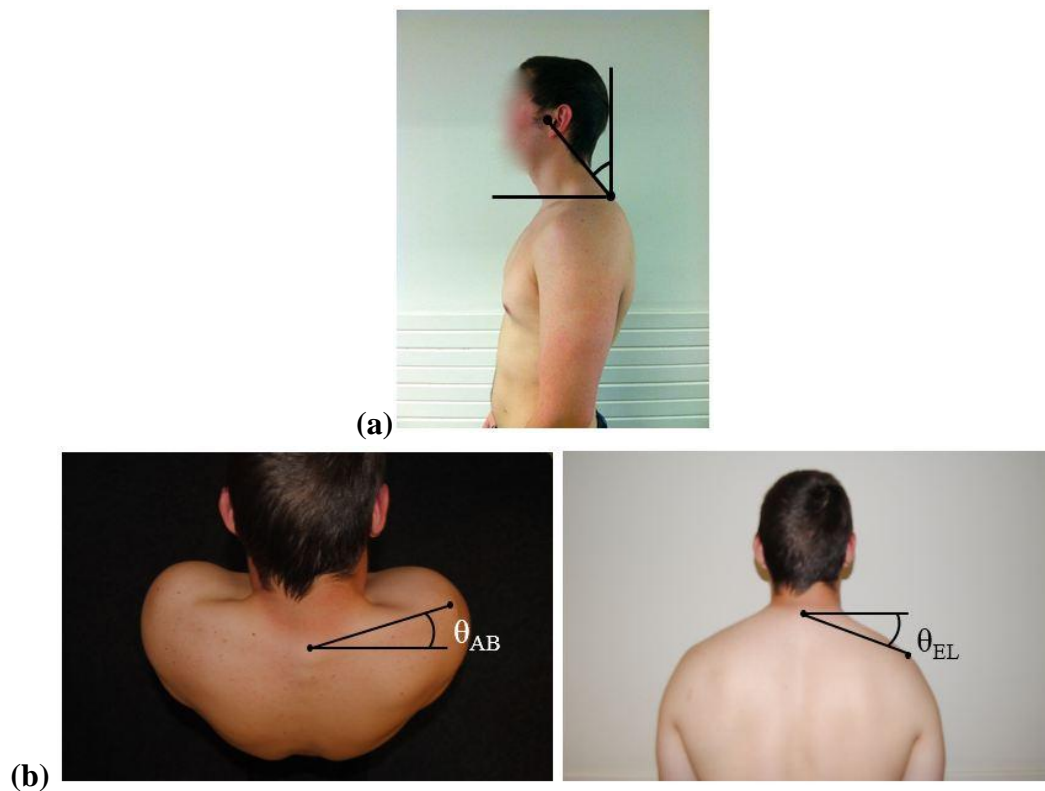

(a)

(b)

Figure 3.3. (a) CV angle (b) scapular position angles (θ_{AB}, θ_{EL}). A local coordinate system origin was placed on the marker on the C7.

EMG signals were post-processed in Matlab and filtered using a 4th order, zero phase lag, lowpass Butterworth filter with 5 Hz cutoff frequency. Fifty-one bipolar signals were calculated from each electrode array. The average rectified value (ARV) was computed from each bipolar recording from adjacent, non-overlapping signal epochs of 0.5 second duration. To characterize the spatial distribution of trapezius muscle activity, the center of gravity (COG) of activity in the medial-lateral (X_{COG}) and in the inferior-superior direction (Y_{COG}) (Figure 3.2b) was calculated from the 51 bipolar ARV recordings (Farina et al., 2008).

3.2.5 Statistical Analysis

All variables were taken in reference to their respective average values from the coached neutral posture. Small values indicate similarity to the coached neutral posture. Independent variables included: θ_{AB} and θ_{EL}; dependent variables included: CV angle, X_{COG}, and Y_{COG}. Independent *t*-tests were used to determine if changes in cervicoscapular posture (θ_{AB}, θ_{EL}, CV angle) were different from the neutral posture in all three shoulder postures. Pearson product-moment correlation [95% confidence interval] was used to quantify the relation between scapular position (θ_{AB}, θ_{EL}) and cervical posture (CV angle). Pearson product-moment correlation [95% confidence interval] was used to quantify the relation between cervicoscapular position (θ_{AB}, θ_{EL}, CV angle) and trapezius muscle activity (X_{COG}, Y_{COG}). A single factor analysis of variance (ANOVA) was used to assess the effect of cervicoscapular posture on the distribution of trapezius muscle

activity and was followed with paired *t*-test post hoc tests. The level of significance was set at $\alpha=0.05$.

Cervicoscapular posture and trapezius muscle activity were averaged across a window length of 15 seconds during the posture (Figure 3.4). This window length begins at 10 seconds, which ensures the participant has adopted the posture to their maximum anatomical position for at least 5 seconds.
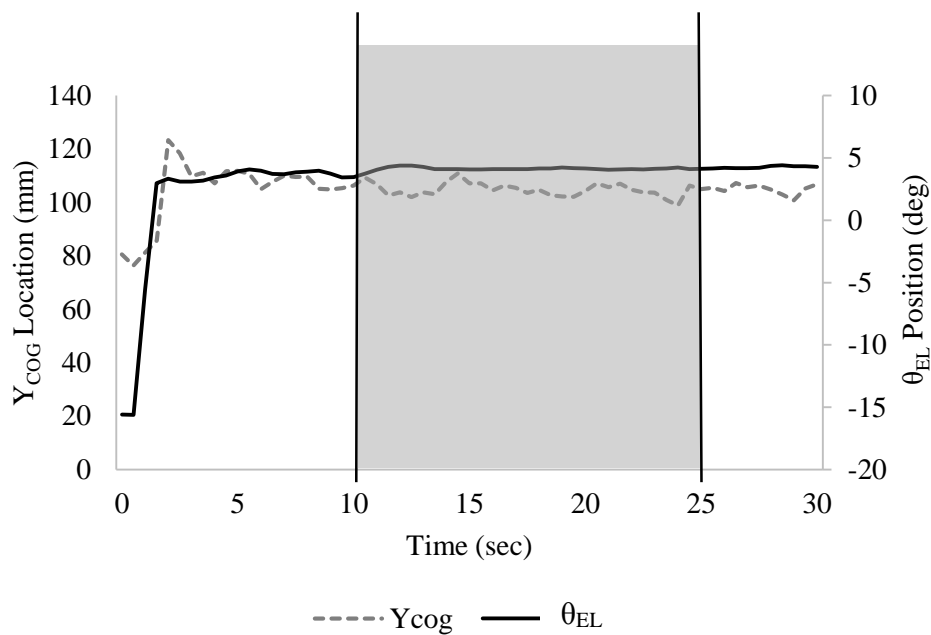
Figure 3.4. Relation between scapular position and Y_{COG} location during scapular elevation posture of Subject 11. Marker data and EMG data were averaged from 10 to 25 seconds. This window ensures each participant has adopted the posture to maximum anatomical position for at least 5 seconds.

3.3 Results

3.3.1 Changes in Cervicoscapular Posture

The changes in cervicoscapular posture with respect to the neutral posture during each posture can be found in Figure 3.5. The change in θ_{AB} was different than the neutral posture in scapular adduction, scapular adduction and depression, and scapular elevation ($P = 0.0001$, $P = 0.013$, $P = 0.0002$, respectively). The change in θ_{EL} was different than the neutral posture during scapular adduction and scapular elevation ($P = 0.013$, $P < 0.0001$, respectively), but was not different during scapular adduction and depression ($P = 0.406$). The change in cranial-vertebral angle was different than the neutral posture during scapular adduction and scapular adduction and depression ($P < 0.0001$, $P = 0.018$, respectively) but was not different during scapular elevation ($P = 0.067$).

Figure 3.5. Change in cervicoscapular posture (θ_{AB}, θ_{EL}, CV angle) with respect to coached neutral posture during each posture.

3.2 Correlation between Cervical and Scapular Posture

A moderate correlation was found between scapular position in the sagittal plane (θ_{AB}) and cervical posture ($r = 0.40$ [0.15, 0.59]). A low correlation was found between scapular position in the frontal plane (θ_{EL}) and cervical posture ($r = 0.14$ [-0.13, 0.39]).

3.3 Effect of Cervicoscapular Posture on Distribution of Trapezius Muscle Activity
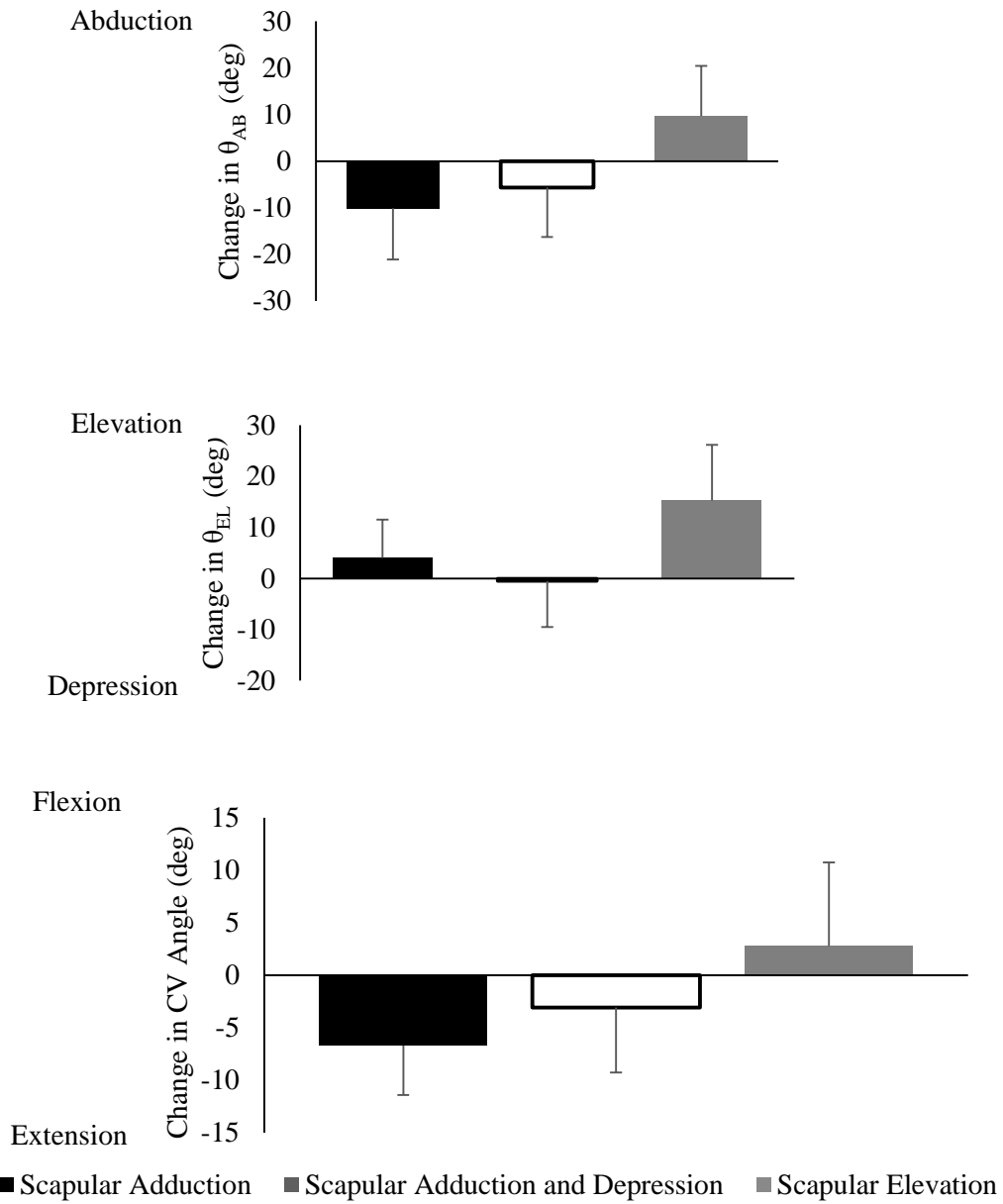
Changes in cervical posture had a low correlation with changes in X_{COG} ($r = -0.02$ [-0.29, 0.24]). Changes in cervical posture were moderately correlated with changes in Y_{COG} ($r = 0.21$ [-0.09, 0.42]). Changes in CV angle did not affect trapezius muscle activity (X_{COG}, Y_{COG}) ($F = 0.10$, $P = 0.76$; $F = 2.19$, $P = 0.14$, respectively). Changes in CV angle were different between scapular adduction and scapular elevation ($P < 0.001$) and between scapular adduction and depression and scapular elevation ($P = 0.016$).

The change in spatial distribution of trapezius muscle activity with respect to the coached neutral posture was significantly affected by changes in scapular posture. Low correlations were found between the change in θ_{AB} and the distribution of trapezius muscle activity (X_{COG}, Y_{COG}) ($r = -0.16$ [-0.41, 0.14], $r = 0.18$ [-0.09, 0.42], respectively). Changes in θ_{AB} did not affect trapezius muscle activity (X_{COG}, Y_{COG}) ($F = 0.56$, $P = 0.46$; $F = 1.27$, $P = 0.27$, respectively). Changes in Y_{COG} were different between scapular adduction and depression and scapular elevation ($P = 0.006$).

No correlation was found between the change in θ_{EL} and the change in X_{COG} ($r = -0.13$ [-0.38, 0.14]) while a moderate correlation was found between the change in θ_{EL} and the change in Y_{COG} ($r = 0.47$ [0.15, 0.59]). The change in θ_{EL} did not affect changes in

X_{COG} ($F = 0.25$, $P = 0.619$), but it did affect changes in Y_{COG} ($F = 13.07$, $P = 0.0007$).

θ_{EL} was different between scapular adduction and scapular elevation ($P < 0.001$) and between scapular adduction and depression and scapular elevation ($P < 0.001$). The correlation between the change in θ_{EL} and Y_{COG} can be found in Figure 3.6.
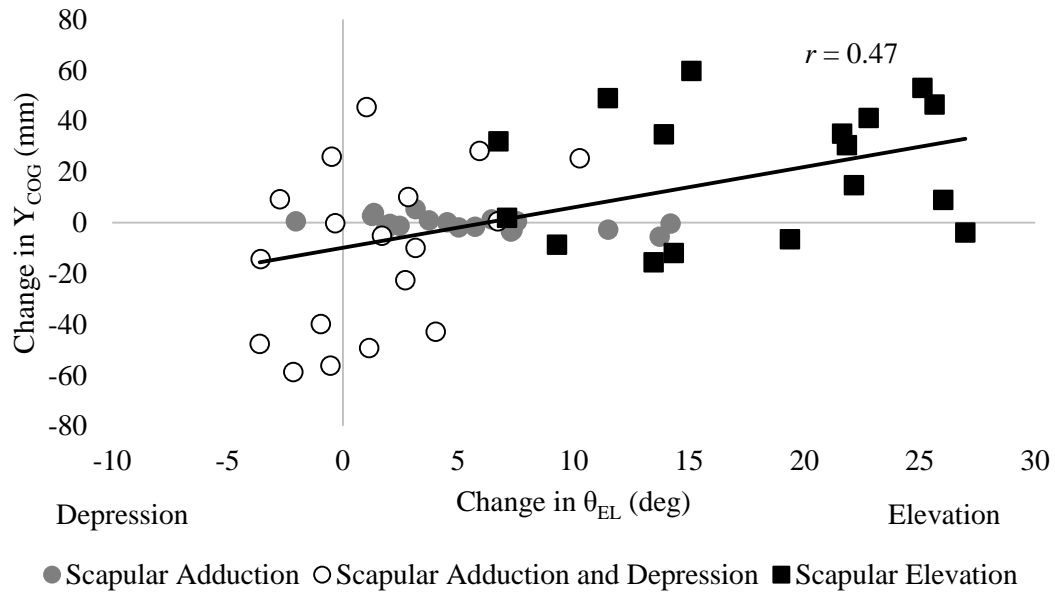
Figure 3.6. Correlation between changes in Y_{COG} and θ_{EL} with respect to the coached neutral posture.

3.4 Discussion

The aim of this study was to quantify the correlations between scapular positions and the spatial distribution of trapezius muscle activity using HDsEMG. The current study showed no correlation between cervical posture and trapezius muscle activity, but did find correlations between scapular posture and the distribution of trapezius muscle activity.

The effect of cervicoscapular posture on the spatial distribution of trapezius muscle activity has not been widely investigated. This investigation demonstrated that scapular elevation strongly affects the distribution of trapezius muscle activity in the inferior-superior direction. These findings are consistent with previous reports indicating that the change in the distribution of trapezius muscle activity is most significant in the inferior-superior direction (Falla & Farina, 2007). Because individuals who experience chronic neck pain in the upper trapezius exhibit more superior activation patterns of the trapezius muscle, it may be argued that these individuals also exhibit greater scapular elevation than compared to non-pathologic patients. The large differences among subjects in the amount of shift in the center of gravity location in the inferior-super direction is consistent with previous investigations (Farina et al., 2008). These large variations may be due to individual motor unit recruitment as control strategies among each participant during each contraction.

This investigation showed that scapular movement in the frontal plane (abduction and adduction) affected cervical posture. Greater scapular adduction yielded smaller cranial-vertebral angles while greater scapular abduction yielded larger cranial-vertebral angles. Because individuals who experience chronic neck pain exhibit forward head positions (Enwemeka et al., 1986; Larsson et al., 1999; Ahlgren et al., 2001), the results of this study suggest that individuals with neck pain may also exhibit greater scapular abduction. However, the cranial-vertebral angle is limited because the forward head position is a combination of lower cervical flexion (C7-C4) and upper cervical extension (C3-C1) (Szeto et al., 2002). Upper cervical extension is most often seen in computer

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users who adopt a "hunched" posture, requiring them to look up at the computer screen (Edmondston et al., 2011). This position increases the load placed on the muscles of the neck and shoulder, making these individuals more susceptible to trapezius myalgia than individuals who sit in an ergonomically correct posture. The cranial-vertebral angle is an angle of the entire cervical spine (C7-C1) and therefore is not sensitive to position changes within individual sections of the neck. Future work will investigate determining a more accurate measure that is sensitive to upper cervical extension to describe cervical posture.

This investigation showed no correlation between cervical posture and trapezius muscle activity in any direction. Electromyographic signals were not recorded on the muscles surrounding the cervical spine because the aim of this study was to investigate the effect of cervicoscapular posture in relation to the spatial distribution of trapezius muscle activity. Specifically, this investigation was investigating the area of the trapezius that is susceptible to trapezius myalgia (Lindman et al., 1991; K.B. Veiersted, 1994). Based on the results of this study, using the cranial-vertebral angle in reference to trapezius muscle activity is not appropriate, unless being used in relation the ascending fibers of the upper trapezius.

3.4.1 Limitations

In the current study, fatigue was not taken into consideration. In skeletal muscles, fatigue causes a decrease in frequency and an increase in signal amplitude (Merletti et al., 1990; Farina et al., 2002; Maluf & Enoka, 2005; Madeleine & Farina, 2008). In this

investigation, isometric contraction length was 30 seconds and was not a maximum voluntary contraction (MVC). This contraction length may induce fatigue in pathologic patients, but the subject pool in this investigation had no symptoms of chronic neck or shoulder pain.

Holtermann et al., (2009) demonstrated that participants were able to selectively activate the lower trapezius voluntarily. However, the participants practiced the task until selective activation of the lower trapezius was accomplished. In the current study, the participant was verbally and physically coached by a researcher on the posture, but no electromyographic signals were recorded to determine if the participant was successfully activating the lower trapezius. This lack of time for the participant to familiarize themselves with the posture explains the lower number of participants who demonstrated significant correlations between scapular position and trapezius muscle activity in the inferior-superior direction.

The selected postures were not specific for each individual subdivision of the trapezius, thus the correlation between cervicoscapular posture and trapezius muscle activity may have been affected by surrounding muscles (e.g. rotator cuff and deltoid) rather than the trapezius.

The assumptions made regarding scapular position in this investigation were made by using a surrogate marker placed on the acromion. It is not possible to measure the true position of the scapula using reflective markers *ex vivo* because it is covered by the stabilizing muscles of the shoulder.

3.5. Conclusion

The findings in the current study indicate that scapular position in both medial-lateral direction and inferior-superior is correlated with trapezius muscle activity in the inferior-superior direction. Individuals who adopt poor ergonomic postures, or a "hunched" posture (scapular elevation and abduction), are at greater risk of developing chronic neck pain due to the adverse effects this position has on cervical posture and the distribution of trapezius muscle activity. These results indicate that altering scapular position in a rehabilitative setting will alter the distribution of trapezius muscle activity, which is beneficial in cases of chronic neck and shoulder pain.

4. Biofeedback Based Interventions

4.1 Introduction

In developed countries, computer use dominates the work environment. Because of this, there is a higher prevalence of chronic neck pain seen amongst workers, as high as 67% in computer workers (Tornqvis et al. 2009), which may be the result of chronic long term computer use. Chronic musculoskeletal disorders such as neck pain can have multifactorial origins and complex physiological parameters (Voerman et al. 2007). As a result, they are particularly difficult to treat with success. The Cinderella hypothesis, based on findings of orderly motor unit recruitment (Henneman, 1985), implies that chronic pain can be caused by continuous activity of small motor units activated during low-level contractions (Zennaro et al. 2003). Sustained computer use demands low-level neck muscle contraction and often leads to poor cervical posture. Eltayeb et al. (2007) reported 54% of computer users had at least one episode of neck or shoulder pain throughout a 12-month period.

Biofeedback-based rehabilitation therapies have been developed to address both muscle activation and posture, and have demonstrated effectiveness at re-educating muscle recruitment patterns through motor learning. To obtain a permanent treatment solution in patients with chronic pain, retraining and re-acquisition of motor skills may be

especially critical. This review examines rehabilitation using biofeedback and the effectiveness of these interventions on chronic pain.

4.2 Forms of Biofeedback

Biofeedback is defined as a method of treatment that requires the use of electromechanical instruments to accurately measure, process and provide feedback to individuals in forms of auditory and/or visual feedback signals (Dursun et al. 2004). Biofeedback is particularly effective in treatment of cases of chronic pain and stroke because of the information it provides which allows for motor skill learning. There are various forms of effective biofeedback used in rehabilitation applications, all of which have significantly proved their effectiveness as a rehabilitation tool.

Biofeedback providing information on body segment positioning, or motion biofeedback, is particularly useful in coordination training. Pressure or force biofeedback can be effective when a force produced to or from a segment of a body is needed. Nichols (1997) effectively provided force platform biofeedback through center of pressure (COP) location to patients recovering from stroke to guide balance retraining. Ferdjallah et al. (2002) used force biofeedback to provide awareness of the contribution of transverse body rotation during quiet standing, which is critical for balance in cases of cerebral palsy. To improve head stabilization in children with cerebral palsy, Leiper et al. (1981) provided an auditory cue when the head position of participant reached a threshold of a predetermined angle. The auditory cue allowed participants to adequately control the position of the head and trunk, which is crucial in maintaining balance. Biofeedback

regarding joint positioning is advantageous in rehabilitation, injury prevention and strength training. Goniometers placed on the knee joint and synced to recognize predetermined angles can provide biofeedback to patients to prevent the hyperextension of the knee (Ceceli et al., 1996). Segment coordination training through motion biofeedback is effective at both injury prevention and re-training body segments disabled or altered by various conditions.

Thermal biofeedback is often used to monitor peripheral vessels which can help treat various circulatory disorders. Marcus et al. (1998) applied thermal biofeedback for migraine headache prevention techniques. Blanchard et al. (1990) used thermal biofeedback to guide cognitive therapy as a relaxation technique to improve symptoms of vascular migraines. Scharff et al. (2002) used thermal biofeedback through hand warming biofeedback to improve pediatric migraine symptoms. Chapman (1986) demonstrated the effectiveness of thermal biofeedback in decreasing chronic muscle contractions which cause migraines.

The most common form of biofeedback in rehabilitation application is electrical feedback (electroencephalography (EEG) or electromyography (EMG)). Biofeedback using EEG signals from brainwaves can be applied to various neurological disorders including epilepsy (Egner & Gruzelier, 2004). EMG biofeedback provides information regarding the activation of skeletal muscles. Rokicki et al. (1997) applied EMG biofeedback and relaxation training to relieve tension headache symptoms. Stuckey S.J. (1986) demonstrated the effectiveness of EMG biofeedback in treating cases of chronic

low back pain through the re-distribution of activity of the stabilizing muscles of the low back.

The particular form of biofeedback applied is dependent upon the specific condition being explored. The application of the various forms of biofeedback are immense, however, biofeedback is particularly useful in the field of rehabilitation because of its proven effectiveness to retrain motor skills.

4.3 Biofeedback as a Rehabilitative Tool

Biofeedback is commonly used as a rehabilitation tool because of its effectiveness to retrain affected muscles through motor unit re-education. In order to reduce pain stemming from hyperactivity, rehabilitative techniques should focus on: muscle tension education levels, situations in which hyperactivity occurs, relaxation methods and application of these relaxation methods to reduce hyperactivity (Spence et al. 1995). A common symptom that chronic pain patients share is abnormal activation of the affected muscles as a response to pain (Vlaeyen et al. 1995). Patients with chronic pain often avoid activating affected muscles or activating muscles nearby as a mechanism to cope with the pain being experienced. Over time, these altered activation patterns will develop consequences of their own and, therefore, the cycle of chronic pain is continued.

Rehabilitation biofeedback is often used to treat stroke symptoms or muscle overuse injuries. Barclay-Goddard (2005) provided visual feedback of gait asymmetry and balance tasks to further advance the rehabilitation of stroke patients for standing balance retraining. Visual feedback regarding standing tasks has also proved effective in

stroke rehabilitation (Van Peppen et al. 2006). Biofeedback used for relaxation training has provided significant results in the decreasing tension in the stabilizing muscles of the neck and shoulder (Voerman et al. 2004). Breen et al. (2009) used biofeedback from an accelerometer placed on the neck to guide postural education in computer workers for an extended period of time. Biofeedback used for rehabilitation has proven to be an efficient tool. Biofeedback is often used as an effective rehabilitation tool because of its ability to retrain altered motor skills.

Various forms of biofeedback are often used for rehabilitation purposes because of their proven effectiveness as permanent treatment solutions. Specifically, EMG biofeedback systems are particularly useful in cases of chronic pain because the awareness and re-education provided to the patient have proven extensively to allow permanent reactivation patterns of affected muscles, which is crucial in the treatment of chronic pain.

4.4 EMG Biofeedback

EMG biofeedback provides real-time information about muscle activation patterns (Ng et al. 2008). EMG biofeedback is most commonly used in rehabilitation because it is extremely effective at both muscle re-education and relaxation (Wolf & Binder-MacLeod, 1983). It is advantageous to use EMG biofeedback because the signal represents the neuromuscular control required to complete a particular task. For example, Palmerud et al. (1995) applied EMG biofeedback to allow participants to voluntarily reduce and redistribute muscle activity of the stabilizing muscles of the neck during

various static arm positions. The voluntary redistribution of muscle activity using EMG biofeedback is ergonomically significant because of correlation between muscle activity and computer work.

EMG biofeedback provides muscle awareness that is not otherwise obtainable in other forms of biofeedback. In cases of chronic pain resulting from muscle overuse, EMG biofeedback is particularly useful because of the awareness it provides to the patient. Hermens & Hutten (2002) used an EMG biofeedback system to provide greater awareness regarding undesirable muscle activation and found significant results that indicate real-time EMG biofeedback results in almost immediate change of muscle activation patterns. The awareness that EMG biofeedback provides regarding skeletal muscles allows the ability to redistribute or change activity patterns of affected muscles. Voerman et al. (2007) used two forms of biofeedback (EMG and counseling) in patients with work-related neck and shoulder pain. They found significant decreases in pain intensity scores between both biofeedback groups and the control. EMG biofeedback has also proved to provide significant improvements of plantar flexor muscles and muscle joint activation patterns in children with cerebral palsy (Dursun et al. 2004). Lin et al. (2012) provided EMG biofeedback to rehabilitate stroke patients through cycling exercise. They also found significant improvements in muscle activity in groups provided the visual EMG biofeedback. While it is scientifically still somewhat unclear as to the true cause of its effectiveness of altering muscle activation patterns, the awareness EMG biofeedback provides have proven useful as a rehabilitative tool.

It is important to understand and prove the effectiveness of EMG biofeedback that is not otherwise obtainable through other rehabilitative methods. While EMG biofeedback has proven to be effective, the acquisition and implementation of these systems can be more difficult than other common forms of rehabilitation. Ryan & Gevirtz (2004) compared the effects of EMG biofeedback to that of other common rehabilitative techniques including: progressive relaxation training and breathing retraining and determined that the EMG biofeedback intervention provided the most significant results in altered muscle activation patterns which resulted in symptom reduction of patients experiencing chronic neck pain. Dellve et al. (2011) compared EMG biofeedback to a strength training program in female workers with chronic neck pain and found significant results in the decreasing of pain in both groups. While the strength training program is more easily implemented in a rehabilitative setting, the biofeedback group showed a decrease in pain immediately and had more lasting improvements of workability. The effectiveness of EMG biofeedback has proven to be an efficient tool at treating chronic pain symptoms.

To date, only one investigation has implemented high-density surface EMG (HDsEMG) feedback parameters for real-time biofeedback (Samani et al., 2010). This investigation studied the spatio-temporal effects (uniformity of muscle activation patterns and degree of amplitude) of muscle activity by inducing active and passive pauses on trapezius muscle activity. The active pause consisted of isometric bilateral shoulder elevations (approximately 30% MVC) and the passive pause consisted of muscle relaxation. The biofeedback interface developed in this investigation implemented a

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fuzzy-logic inference from HDsEMG inputs. These inputs consisted of root mean square (RMS) and permutated sample entropy (PeSaEn) of ipsilateral clavicular and descending portion of the upper trapezius. The participants in this investigation performed three, 10-minute typing tasks. During these tasks, if one of the variables from the HDsEMG biofeedback interface was continuously the same for more than 40 seconds, a feedback alarm was given to the participant to instruct them to perform either the active or passive pause, depending on the task. This advanced biofeedback interface was able to alter the spatial organization of muscle activity during computer work as described by changes in the location of the center of gravity of activity across and changes in the uniformity of activation patterns the electrode array.

Biofeedback interventions using HDsEMG signals have not yet been thoroughly investigated for use in postural correction. HDsEMG biofeedback interventions appear advantageous because of the ability to provide feedback of the overall spatial activity of a muscle. In cases of neck and shoulder pain, particularly in the workplace, HDsEMG will be particularly useful because it can provide awareness to shift trapezius muscle activity inferior, which has proven to be effective in treating cases of trapezius myalgia.

5. Evaluation of Novel EMG Biofeedback for Postural Correction during Computer Use

5.1 Introduction

Chronic neck pain is a growing disorder, in which 48.5% of the world population experiences at least one occurrence of pain in the neck or shoulder region in their lifetime (Fejer et al., 2006). Neck pain is most commonly seen in women working in a computer-dominated work environment (Bassols et al., 1999). Treatments of chronic neck and shoulder pain have low success rates because of the complexity of the disorder (Dellve et al., 2011). Because neck pain is associated with a computer-dominated work environment, a large economic burden is placed on employers because of workers compensation costs (Côté et al., 2008). At-risk workers may benefit from novel rehabilitation designed to prevent and provide permanent treatment to work-related neck and shoulder pain.

Because it is difficult to pinpoint a specific cause of chronic pain disorders, there are many rehabilitation strategies in place for chronic musculoskeletal disorders; however, these interventions often provide only temporary pain relief (Mikeladze et al., 2003; He et al., 2004). The most common rehab strategies include strength training of the stabilizing muscles of the neck and shoulder, manipulation, massage, and thermal agents (Feine & Lund, 1997).

Patients with trapezius myalgia experience prolonged and increased muscle activity of the neck and shoulder muscles (Sandsjö et al., 2000; Veiersted, 1994). Continuous hyperactivity of the upper trapezius coupled with inadequate rest time contributes to muscle pain (Vasseljen & Westgaard, 1995). In the workplace, computer use requires physically repetitive movements with a continuous low level of muscle activity, which have been linked to the development of musculoskeletal disorders (Blangsted et al., 2004). Hodges and Moseley (2003) demonstrated that changes in activation patterns may be a response to pain.

Reducing the continuous activation in the upper trapezius through postural re-education may be a treatment solution to chronic neck and shoulder pain. In the computer-dominated workplace, proper posture is emphasized because it provides musculoskeletal balance to the stabilizing muscles of the neck and shoulder (Griegel-Morris et al., 1992) because "poor" head and neck posture correlates with neck pain symptoms (Yip et al., 2008). The primary goal of postural correction is to shift the activation patterns away from the upper trapezius toward the middle and lower trapezius (McLean, 2005). Patients with neck and shoulder pain demonstrate altered postural position during computer use (Wegner et al., 2010). Szeto et al., (2002) found that symptomatic computer users demonstrated an increased head tilt and more scapular protraction than compared to asymptomatic patients.

EMG biofeedback, which provides a real-time assessment of muscle activity levels, may be an effective method of postural re-education used to treat chronic neck and shoulder pain. Biofeedback provides information which could help selectively activate

individual neck and shoulder muscles (Faucett et al., 2002; Hermens & Hutten, 2002).

For example, Palmerud et al. (1995), demonstrated that patients with neck pain can

redistribute muscle activity to shoulder muscles through biofeedback intervention.

Gaining the ability to selectively activate and redistribute activity to other muscles of the

neck and shoulder regions may create balanced muscle activity levels throughout the

trapezius (Holtermann et al., 2010). Nord et al. (2001) trained computer users to

voluntarily control their neck and shoulder muscles through shifting activity patterns

inferiorly using EMG biofeedback.

EMG biofeedback is traditionally applied through bipolar surface EMG

recordings. Although this configuration records muscle activity, the recording is limited

to a small area of the muscle and may not characterize activations well in a muscle with

complex architecture (e.g. trapezius). To our knowledge, only one other investigation has

used high-density surface EMG (HDsEMG) feedback parameters in a real-time

biofeedback for investigation (Samani et al. , 2010).

The objective of this investigation was to assess the effectiveness of postural

correction using a biofeedback interface guided by HDsEMG feedback during computer

work. We hypothesized that an HDsEMG interface would (1) improve cervicoscapular

posture as measured by the cranial-vertebral angle and scapular elevation and (2) result in

a more uniform and inferior distribution of trapezius muscle activity compared to

traditional postural biofeedback.

5.2 Methods

5.2.1 Participants

Twenty participants (Table 5.1) without a history of chronic neck or shoulder pain participated in the investigations. Participants were recruited from the university and local community. All participants provided a written, informed consent in accordance with the Colorado Multiple Institutional Review Board (COMIRB) prior to the start of the experimental session. Participants visited the laboratory for one data collection in which cervicoscapular posture and trapezius muscle activity were collected during three directed postures.

Table 5.1. Participant demographic data.

	Male		Female	
	Mean	SD	Mean	SD
Age (years)	30.4	9.9	36.5	13.9
Height (cm)	183.8	8.0	171.7	5.9
Weight (kg)	84.1	12.8	77.5	9.5
Dominant Hand (right\left)	9\1	-	9\1	-

5.2.2 Instrumentation

Participants were instrumented with 25 reflective markers (Figure 5.1a) used to record motion with eight cameras surrounding the motion capture area (Vicon, Centennial, CO). HDsEMG signals were recorded from two semi-disposable adhesive electrode arrays (ELSCH064NM2 Pin Out, OT Bioelettronica, Torino, Italy). The superior electrode array was placed overly the upper trapezius (UT) and middle trapezius (MT), and the inferior electrode array was placed overlying the MT and lower trapezius

(LT) (Figure 5.1b). Each electrode array was composed of 64 electrodes, in a 13x5

orientation with an 8-mm inter-electrode distance (IED) and a 3-mm electrode diameter.

There is one missing electrode in the inferior-lateral corner of each array, which

represents the origin that describes electrode position (Figure 5.2a). EMG signals were

amplified (64 channel surface EMG-USB2 amplifier, OT Bioelettronica, Torino, Italy;

bandwidth 10-500 Hz) by a factor of 5000, sampled at 2048 Hz, and converted to digital

form by a 12-bit A/D converter. Visual inspection of the raw EMG signals was

performed in post-processing to identify any channels with poor contact or short circuits

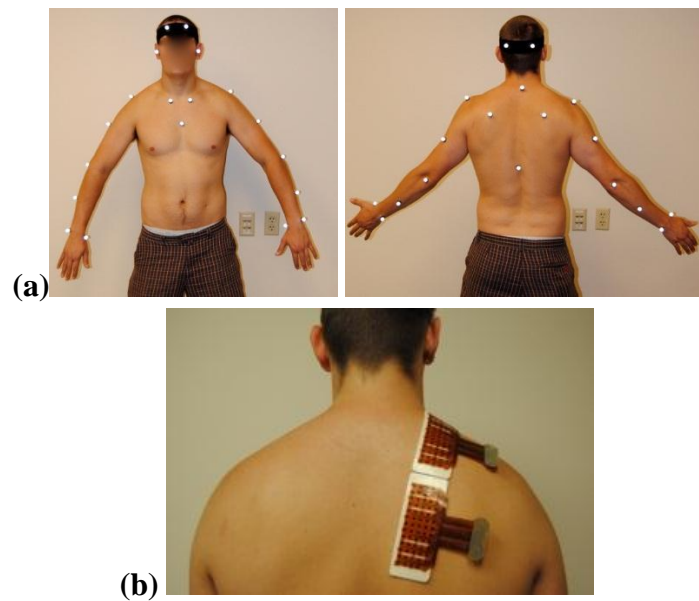and signals were linearly interpolated using adjacent channels (Gallina et al., 2013).

(a)

(b)

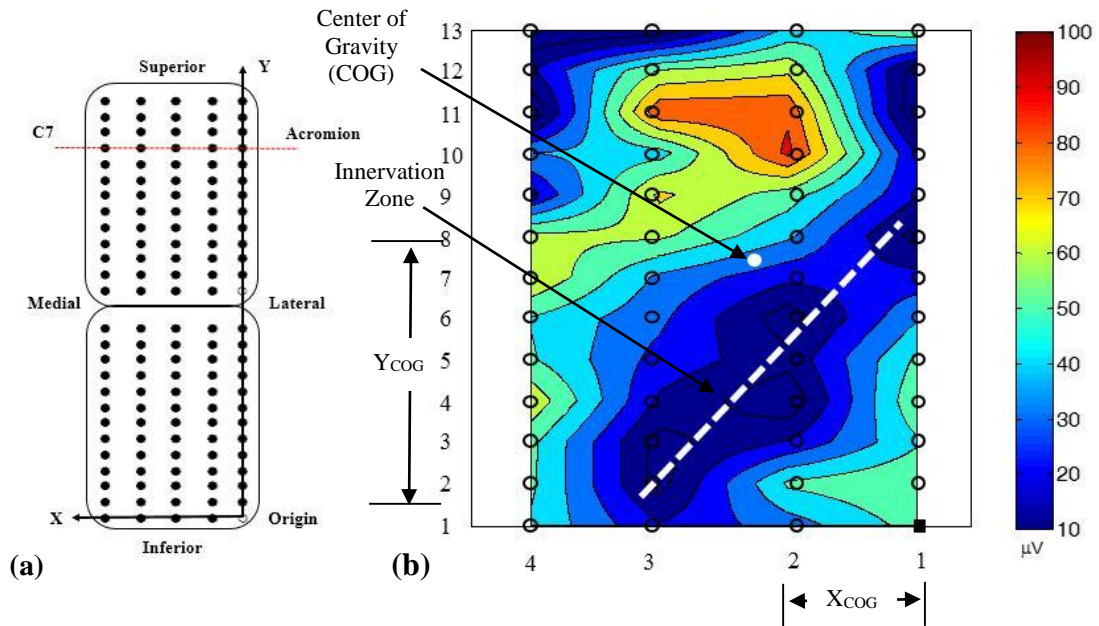**Figure 5.1.** (a) Marker placement (b) HDsEMG electrode array placement.

Figure 5.2. (a) Schematic of HDsEMG electrode array with position on trapezius (b) example of topographical map (interpolation by a factor of 8) of 51 bipolar average rectified values of superior array with center of gravity (white dot) and innervation zone (white dashed line)

To standardize electrode array placement across all participants, the superior electrode array was placed in relation to the innervation zone (Farina et al., 2002). Prior to placement of the superior electrode array, the main innervation zone of the upper trapezius was identified using a dry linear array (SA 16/5, OT Bioelettronica, Torino, Italy) that consists of: 16 silver bar electrodes, 5-mm IED, 1 mm width. The superior electrode array was placed with the 4th electrode row along the C7-acromion line with the most medial electrode column 10-mm distant from the innervation zone, parallel to muscle fiber direction (Figure 5.2a) (Farina et al., 2008). Skin beneath the electrode arrays was lightly abraded. A reference electrode was placed at the right wrist.

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5.2.3 Experimental Protocol

Each participant performed two 15-minute typing tasks with postural instruction with and without biofeedback. Prior to the start of the typing tasks, a researcher coached each participant on how to sit with correct posture during typing. The participant was instructed to maintain a "neutral" posture in which their trunk was upright, chin was tucked, and shoulder blades were slightly depressed and adducted. Adopting this posture enacts an inferior shift in trapezius muscle activity (Wegner et al., 2010). The participant practiced this posture for one minute with corrective feedback from the researcher.

Two types of postural instruction for each typing task were given to the participant in a random order. The two types of instruction were (1) verbal feedback from the research regarding the neutral posture prior to the start of the typing task and (2) verbal feedback from the researcher plus visual feedback of HDsEMG signals during the typing task.
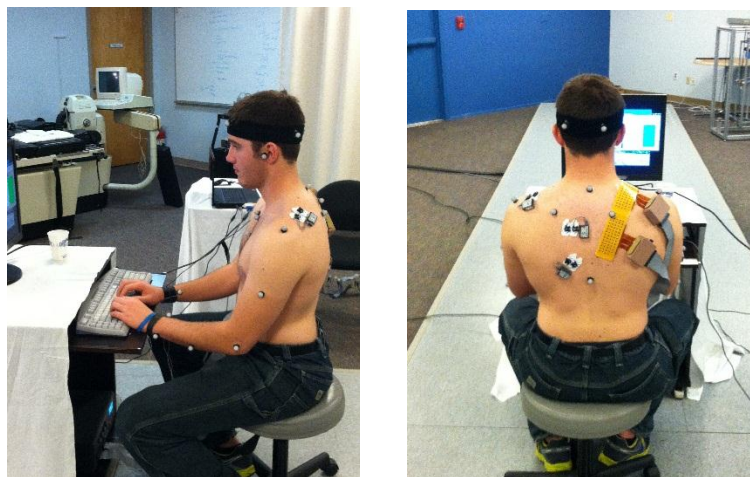

Figure 5.3. Experimental set up using reflective markers to record motion and HDsEMG electrodes to record trapezius muscle activity during computer use.

5.2.4 Biofeedback Interface

The biofeedback intervention displayed a real-time onscreen indicator of trapezius muscle activity (Figure 5.4). The activity ratio (AR) indicated how muscle activity was distributed between the superior and inferior fibers of the trapezius; therefore an increase in the AR was associated with greater relative activation of the upper fibers of the trapezius. Real-time EMG signals from both HDsEMG arrays were bandpass filtered (4th order Butterworth, 10-500 Hz). The signals were summed across all electrodes in each array, and the ratio of signal amplitude (superior/inferior) was calculated. The average AR recorded during the coached neutral posture was the threshold for the biofeedback interface. When the real-time AR exceeded this threshold, the participant received an onscreen visual alert (Figure 5.2b) to alter the distribution of their trapezius muscle activity through postural correction.
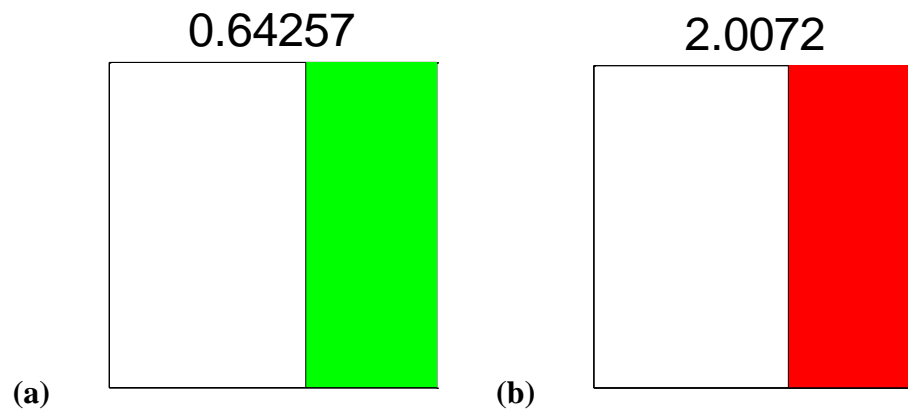

(a)   **(b)**

Figure 5.4. Biofeedback interface displaying real-time activity ratio (a) below threshold and (b) above threshold.

5.2.5 Data Processing

Cervicoscapular posture was quantified during each typing task by two measures: cranial-vertebral angle and scapular position. Marker data was filtered with a 4th order, zero phase lag Butterworth filter with lowpass cutoff frequency of 5 Hz. The cranial-vertebral angle was calculated as the angle of a line from the C7 to the tragus with respect to a vertical reference (Figure 5.3a). Scapular position is difficult to measure because it is obstructed by several muscles in the rotator cuff (supraspinatus, infraspinatus, teres major, teres minor) and the deltoid. As a surrogate, scapular position was quantified by the marker placed on the acromion process on the dominate side of the participant. Scapular position was expressed in a local coordinate system fixed in the torso reference frame with an origin placed at C7 (Figure 5.3b). Scapular position in the frontal plane (θ_{AB}) was quantified by the angle between C7 and the acromion process with respect to the horizontal. Positive θ_{AB} angles indicate scapular abduction while negative θ_{AB} angles indicate scapular adduction. Scapular position in the sagittal plane was quantified by the angle between C7 and the acromion process with respect to the vertical. Positive θ_{EL} angles indicate scapular elevation while negative θ_{EL} angles indicate scapular depression (Figure 5.5b).

(a)

(b)
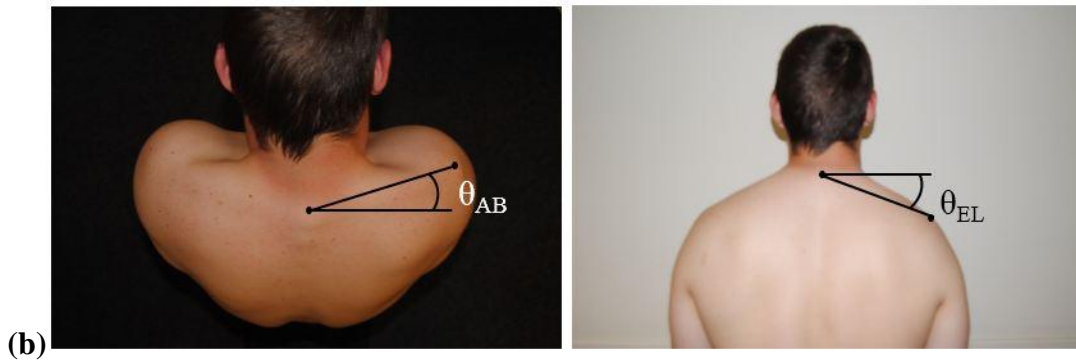
Figure 5.5. (a) CV angle (b) scapular position angles (θ_{AB}, θ_{EL}). A local coordinate system origin was placed on the marker on the C7.

Average rectified values (ARV) of EMG signals were calculated over 0.5-s non-overlapping epochs. Fifty-one bipolar systems were obtained from each electrode array (Figure 5.2b) in conjunction with fiber orientation (Farina et al., 2008; C Jensen & Westgaard, 1997). The distribution of trapezius muscle activity was represented by the location of center of gravity of activity in the inferior-super direction (Y_{COG}) across both electrode arrays. Homogeneity in trapezius muscle activation patterns of the trapezius was calculated using a measure of entropy:

$$entropy = -\sum_{i=1}^{102} p^2(i)\log_2(p^2(i))$$

where $p^2(i)$ is the square of the ARV at electrode i normalized by the summation of activity in the squares of the 51 ARV values. Higher values of entropy correspond to a more heterogeneous distribution of muscle activity across the arrays (Samani et al., 2010).

5.2.6 Statistical Analysis

All dependent variables were expressed relative to the coached neutral posture. Dependent variables included: cranial-vertebral angle, scapular position, location of Y_{COG}, and entropy values. Small values indicate similarity to the coached neutral posture. The effect of biofeedback on cervicoscapular posture and the distribution of trapezius muscle activity were examined by comparing dependent variables across typing tasks with a one-tailed paired t-test. To determine the effect of time on the dependent variables, a one-tailed independent t-test was performed to determine if the average slope across all participants was different from zero. The effect of time on dependent variables between tasks was examined using a one-tailed paired t-test on the average slope of dependent variables throughout the duration of each task. Level of significance was set at $\alpha = 0.05$.

5.3 Results

The biofeedback condition resulted in improved cervicoscapular posture and created a more inferior distribution of trapezius muscle activity.

5.3.1 Cervicoscapular Posture

Figure 5.6 demonstrates the changes in cervicoscapular posture when typing with HDsEMG biofeedback for postural correction and when typing without. The change in θ_{AB} was $200.01 \pm 4.90\%$ ($P < 0.001$) lower when typing with HDsEMG biofeedback, indicating that individuals demonstrated greater scapular adduction when typing with the biofeedback interface. The change in θ_{EL} was $20.92 \pm 4.90\%$ ($P < 0.001$) lower when typing with HDsEMG biofeedback, indicating that individuals demonstrated greater scapular depression when typing with the biofeedback interface. The change in the cranial-vertebral angle was $8.40 \pm 28.97\%$ ($P = 0.147$) smaller when typing without biofeedback, indicating that the neck was slightly more flexed when not using HDsEMG biofeedback.
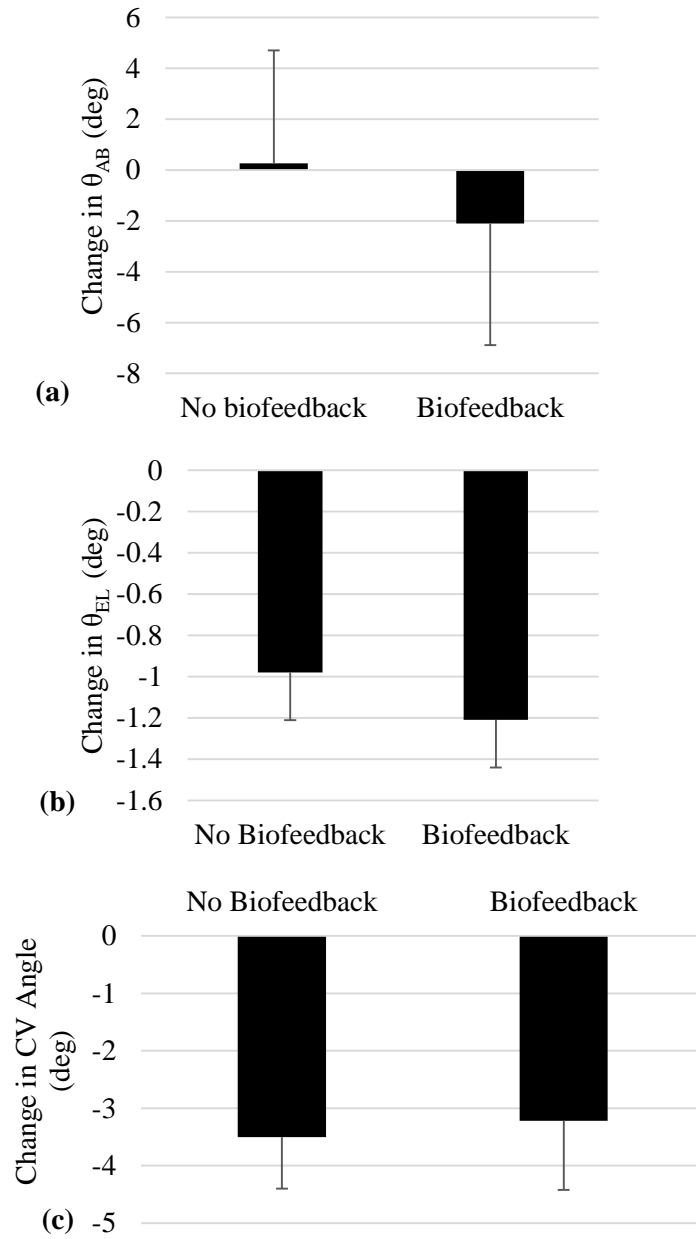
Figure 5.6. Change in cervicoscapular posture in typing tasks with and without HDsEMG biofeedback as described in (a) θ_{AB} angle (b) θ_{EL} angle (c) cranial-vertebral angle. All variables referenced to the coached neutral posture.

5.3.2 Spatial Distribution of Trapezius Muscle Activity

Figure 5.7 shows the changes in the distribution of trapezius muscle activity when typing with only verbal postural coaching and when typing with verbal postural coaching

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and HDsEMG biofeedback. The change in location of Y_{COG} with respect to the coached neutral posture was $208.97 \pm 2.68\%$ ($P < 0.001$) more inferior when typing with HDsEMG biofeedback than compared to typing without. The distribution trapezius muscle activity was $1.26 \pm 57.03\%$ ($P = 0.459$) more heterogeneous when typing with HDsEMG biofeedback than compared to typing without.
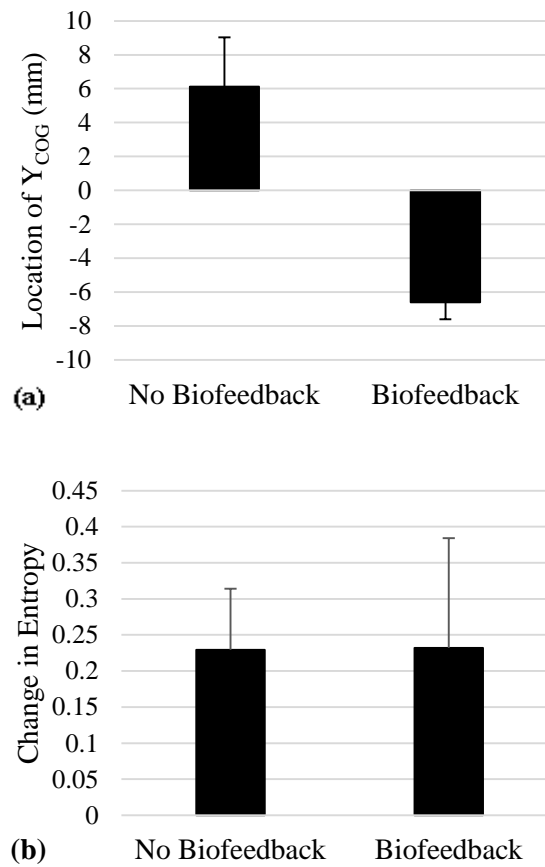
Figure 5.7. Change in trapezius muscle distribution in typing tasks with and without HDsEMG biofeedback as described in (a) location of Y_{COG} and (b) entropy. Both variables referenced to coached neutral posture.

5.3.3 Changes over time of cervicoscapular posture and distribution of trapezius muscle activity

Positive slopes of cervicoscapular posture throughout the duration of each typing task indicate the gradual migration into poor posture (Figure 5.8).

(a)

(b)
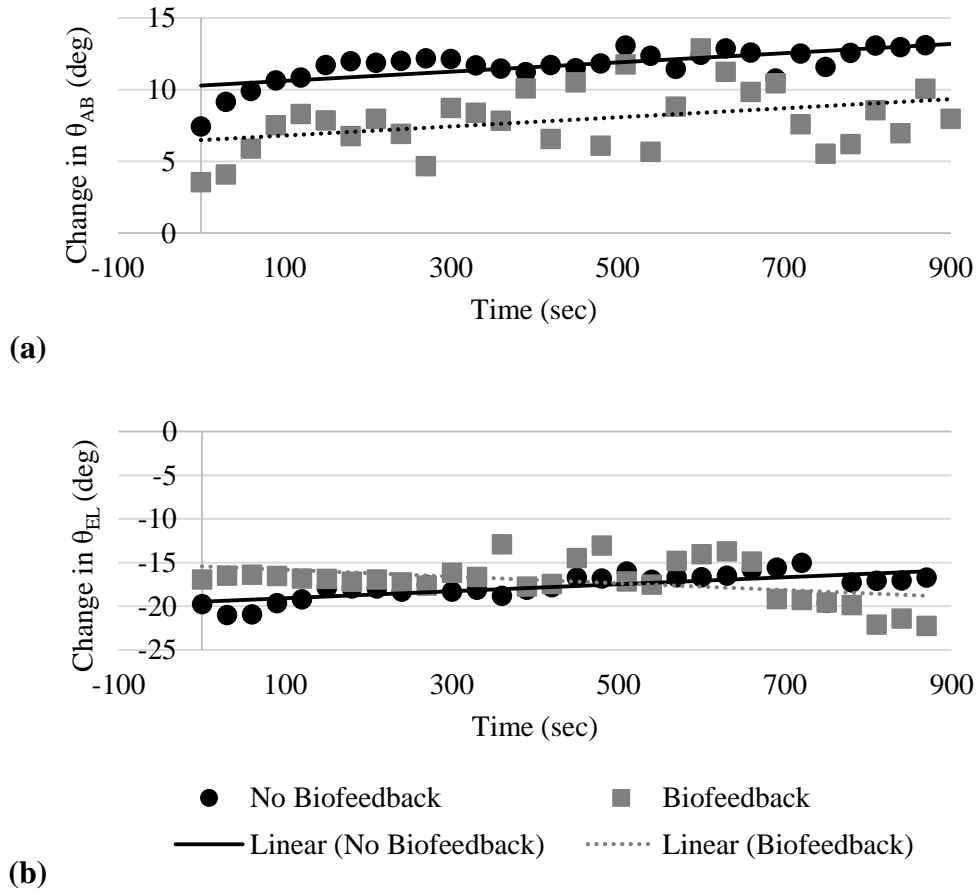
Figure 5.8. Scapular posture (a) θ_{AB} (b) θ_{EL} of Subject 14 throughout the duration of each typing task. Positive slope indicates postural migration into poorer scapular posture.

The average slope of θ_{AB} across all participants did not differ from zero when typing with verbal postural coaching alone or when typing with verbal postural coaching and HDsEMG biofeedback ($P = 0.154$; $P = 0.40$, respectively) (Figure 5.9a). In both typing tasks, θ_{AB} increased throughout the duration of each task, which indicates the

gradual migration into greater scapular abduction. The average slope of θ_{EL} did not differ from zero when typing with verbal postural coaching alone or when typing with verbal postural coaching and HDsEMG biofeedback ($P = 0.197$; $P = 0.970$, respectively) (Figure 5.9b). In both typing tasks, θ_{EL} decreased throughout the duration of each task, which indicates greater scapular depression. The average slope of the cranial-vertebral angle did not differ from zero when typing with verbal postural coaching alone ($P = 0.202$) but did increase when typing with HDsEMG biofeedback ($P = 0.006$) (Figure 5.9c). In both typing tasks, the cranial-vertebral angle decreased throughout the duration of each task, which indicates greater cervical extension in comparison to the coached neutral posture. Average slopes of θ_{AB}, θ_{EL}, and cranial-vertebral angle did not vary across typing tasks ($P = 0.249$; $P = 0.323$; $P = 0.211$, respectively).
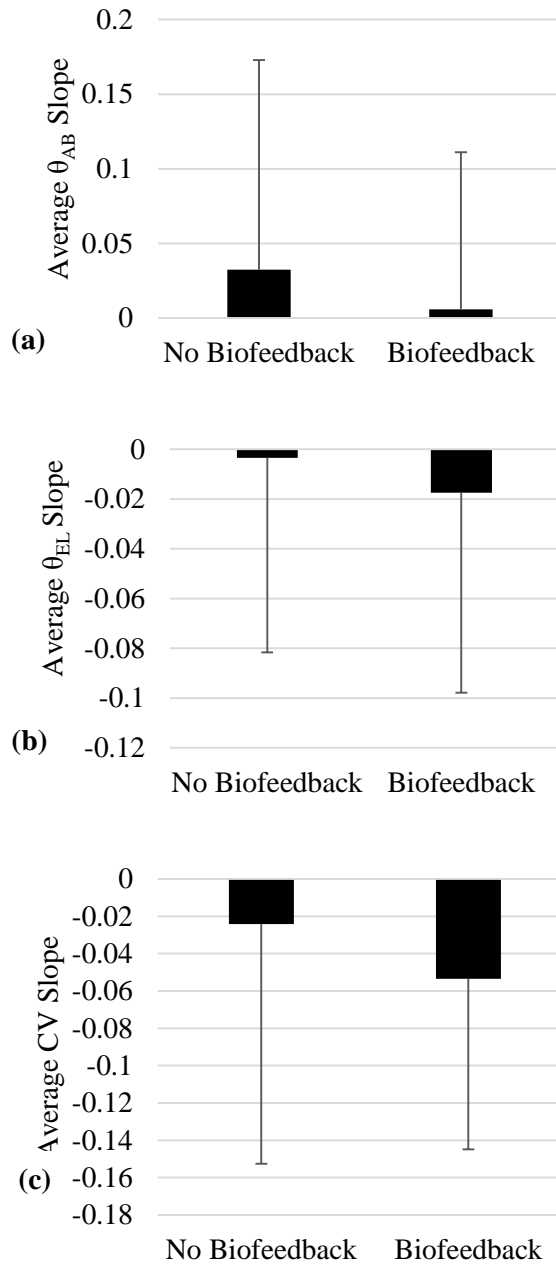
Figure 5.9. Average slope of (a) θ_{AB} (b) θ_{EL} and (c) cranial-vertebral angle across all participants throughout the duration of each typing task.

The average slope of Y_{COG} did not change when typing with verbal postural coaching alone ($P = 0.469$) but did increase when typing with verbal postural coaching and

HDsEMG biofeedback ($P = 0.008$) (Figure 5.10a). The average slope of entropy values did not change when typing with verbal postural coaching alone or verbal postural coaching and HDsEMG biofeedback ($P = 0.420$; $P = 0.116$, respectively) (Figure 5.10b). Average slopes of Y_{COG} and entropy did not vary across typing tasks ($P = 0.078$; $P = 0.283$).

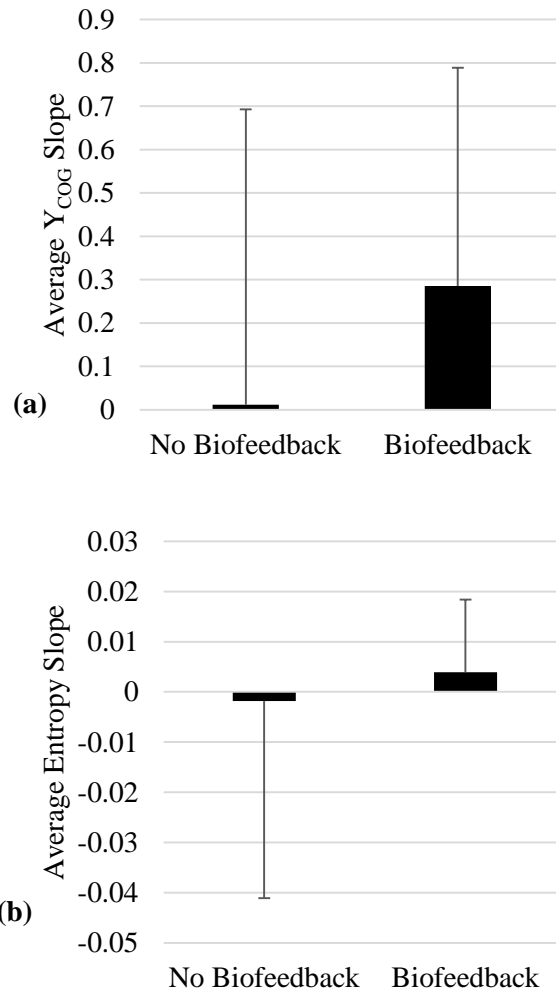**Figure 5.10.** Average slope of (a) Y_{COG} (b) entropy across all participants throughout the duration of each typing task.

5.4 Discussion

Biofeedback guided by HDsEMG feedback parameters used for postural correction during computer work led to improved cervicoscapular posture. HDsEMG biofeedback also altered the distribution of trapezius muscle activity.

HDsEMG biofeedback was successful at altering scapular posture. When typing with the HDsEMG biofeedback, individuals demonstrated greater scapular depression and adduction than compared to when typing with only verbal postural coaching. Individuals were able to maintain more constant scapular position when typing with HDsEMG biofeedback, indicating that the interface was effective at preventing a gradual migration into poor posture. Poor scapular posture is known as scapular elevation and abduction, or a "hunched" posture. Individuals who adopt poor scapular posture are known to be at an increased risk to develop pain in the neck and shoulder regions than compared to individuals who adopt better posture (Cook et al., 2000).

HDsEMG biofeedback was successful at creating an inferior shift in COG location. When typing with no HDsEMG biofeedback, the change in mean change in location of Y_{COG} was positive, indicated that it was located superiorly to that of the coached neutral posture. Alternatively, the mean change in location of Y_{COG} was negative when typing with HDsEMG biofeedback, which demonstrates that the COG location was located inferior to that of the coached neutral posture. The observed findings are in agreement in previous investigations implementing HDsEMG biofeedback (Samani et al., 2010). The current study showed no changes in the location of COG in the medial-lateral direction, which is similar to previous work (Farina et al., 2008; Kleine et al., 2000;

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Madeleine et al., 2006; Samani et al., 2010). Over time, mean changes in the location of Y_{COG} gradually increased in both typing tasks. The correlation between time and change in Y_{COG} was stronger during the biofeedback condition, which shows the ability of participants to maintain a more consistent COG location in the inferior-super direction throughout the duration of the typing task.

In a rehabilitation setting, the goal of postural correction is to shift trapezius muscle activity inferior because the upper trapezius is susceptible to over-activation. Based on the results of the current study, HDsEMG biofeedback was successful at postural correction as evidenced by improved scapular posture. When typing with HDsEMG biofeedback, individuals who demonstrated greater scapular depression and adduction had a more inferior distribution of trapezius muscle activity. Permanently shifting trapezius activation patterns to a more inferior location to the middle and lower trapezius has many benefits, including a possible permanent treatment to chronic neck pain symptoms. Because individuals suffering from trapezius myalgia often experience weakness of the middle and lower portions of the trapezius, this HDsEMG biofeedback interface could also effectively strengthen these muscles in a rehabilitation setting.

Four of the participants were unable to comply with the biofeedback instructions, shown by higher AR with the biofeedback than without. The inability of the four participants who were unable to comply with the biofeedback indicates the inability to voluntarily activate the middle and lower subdivisions of the trapezius. These participants demonstrated more erratic scapular movement, more heterogeneous distribution patterns, and a more superior location of the COG during both typing tasks. No noticeable changes

were observed in the cranial-vertebral angle of these participants. Previous investigations (Westad et al., 2003; Westgaard & De Luca, 1999) have demonstrated that in low-level contractions of the trapezius muscle, there were periods of motor unit inactivity followed by substitution of motor units with higher recruitment threshold. Westgaard & De Luca (1999) concluded that this substitution mechanism is a way to reduce fatigue in the motor units of the trapezius during low-level muscle activity. The increase in recruitment of higher threshold motor units is evidenced by the increase in heterogeneity of the distribution of muscle activity when typing with HDsEMG biofeedback. The recruitment of higher threshold motor units during sustained low-level contractions, such as computer work, may explain the increase in activity ratio of these four participants during the biofeedback condition. Future work may investigate the effecta of retraining these individuals when using HDsEMG biofeedback during computer work.

5.4.1 Limitations

The participants were only allotted a few minutes of time to familiarize themselves with the HDsEMG biofeedback interface. Therefore, this may be the reason of their non-compliance in the biofeedback condition.

The dependent variables chosen to describe the spatial distribution of trapezius muscle activity (COG, entropy) were computed from both electrode arrays. The innervation zone of each subdivision as well as activations within each subdivision may affect the outcome of each variable. However, Farina et al., (2008) reported that these physiologic issues had minimal effects on dependent variables. This investigation only

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used one electrode array placed on the upper trapezius. It was assumed that the effects of the innervation zones and activation patterns of the individual subdivisions of the inferior array would be similar to those seen in the superior array.

The three selected postures are not specific to the three subdivisions of the trapezius. Therefore, the role of surrounding muscles (e.g. deltoid) could have effects on the dependent variables.

Biofeedback guided by HDsEMG may be more effective than EMG biofeedback using bipolar electrode configurations because of the ability to use the entire special activation patterns of the muscle in question. However, comparisons were not made between bipolar and HDsEMG signals in this study.

5.5 Conclusion

This study demonstrated that biofeedback guided by HDsEMG parameters was successful at changing cervicoscapular posture and the spatial distribution patterns of trapezius muscle activity. Participants who were able to comply with the biofeedback demonstrated smaller cranial-vertebral angles, more inferior locations of the scapula and the trapezius muscle distribution, and more homogeneous patterns of trapezius muscle activity.

6. Summary and Recommendations

The objective of this project was to determine the correlation between cervicoscapular posture and to develop an effective treatment method for chronic neck and shoulder pain caused by trapezius myalgia using EMG biofeedback for postural correction. Despite substantial attention from clinicians and researchers, permanent treatment to pain symptoms in musculoskeletal disorders are often inefficient. The results presented here validate the reasoning of postural correction used to alter the distribution of trapezius muscle activity.

6.1 Cervicoscapular Posture and Trapezius Muscle Activity

Proper posture is heavily emphasized in ergonomics because abnormal cervicoscapular posture places the individual at higher risk to develop chronic neck or shoulder pain. Increased scapular elevation created an increase in cervical flexion while scapular depression created greater cervical extension. Because individuals with chronic neck pain symptoms exhibit forward head positions, it can be argued that, based on the results of this investigation, these individuals also exhibit greater scapular elevation and abduction.

The effect of cervicoscapular posture on the spatial distribution of trapezius muscle activity is not well understood. The current study demonstrated a relation between scapular position and the distribution of trapezius muscle activity. To track scapular position throughout the directed postures, a method was developed to measure scapular position relative to C7 in the sagittal and frontal plane. Scapular elevation was correlated with a more superior distribution of trapezius. Cervical posture did not affect the distribution of trapezius muscle activity. In a rehabilitation setting, postural correction emphasizing correct scapular posture will have a greater impact on altering activation patterns of the trapezius.

The true position of the scapula is difficult to measure using motion capture because of the substantial amount of soft-tissue covering it. Future work may investigate the true position of the scapula using biplane fluoroscopy, which provides real-time three-dimensional position of internal structures.

6.2 Real-time Postural Correction using HDsEMG Biofeedback

Real-time postural correction was applied using HDsEMG biofeedback in computer users. The primary goal of postural correction is to minimize stress and strain on the body. When used to treat chronic neck and shoulder pain, postural correction aims to shift trapezius muscle activity from the upper trapezius to the middle and lower trapezius. This method was successful at changing cervicoscapular posture and the distribution of trapezius muscle activity. The addition of EMG biofeedback resulted in postures closer to "proper" posture, as evidenced by closer values to the coached neutral

posture. EMG biofeedback also resulted in a more inferior distribution of trapezius muscle activity. Greater scapular depression and adduction coincided with less muscle activity in the upper trapezius and more activity in the middle and lower trapezius.

Topographical maps created from HDsEMG feedback parameters provide extremely valuable physiologic information. However, these maps often are hard to interpret. Future work may aim to develop a metric to analyze these maps in a more effective manner. Specifically, the area of activation patterns over time of the upper trapezius may provide further insight in fatigue studies.

Four of the participants were unable to comply with the biofeedback intervention (higher activity ratio when typing with HDsEMG biofeedback). This indicates the inability to redistribute muscle activity to the middle and lower trapezius. Future work should investigate the effects of re-training these participants with HDsEMG biofeedback to determine if they are able to successfully able to create a more inferior location of distribution of trapezius muscle activity when typing with the biofeedback.

The results demonstrate considerable promise of this biofeedback intervention's ability to alter cervicoscapular posture and trapezius muscle activity. The participants tested in this study had no symptoms of chronic neck or shoulder pain. Future work should investigate the effects of implementing the HDsEMG biofeedback intervention for rehabilitation application in pathologic individuals. Because trapezius myalgia creates weakness in the middle and lower portion of the trapezius, this biofeedback intervention may also be effective tool to strengthen these weakened muscles. Strengthening the middle and lower portions of the trapezius will allow participants to be able to

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permanently shift activation patterns inferior, and thus creating a possible permanent

treatment to chronic pain symptoms.

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