The Influence of Forward Head Posture on Suprahyoid Activity During Oropharyngeal Swallowing: A Surface Electromyographic Analysis

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By

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A capstone project submitted to the Graduate Faculty in Physical Therapy in partial fulfillment of the requirements for the degree of Doctor of Physical Therapy (DPT), The City University of New York

2015
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This manuscript has been read and accepted for the Graduate Faculty in Physical Therapy in satisfaction of the capstone project requirement for the degree of DPT

Tom Holland, PT, PhD

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Chair of Examining Committee (Advisor)

Jeffrey Rothman, PT, Ed.D.

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Executive Officer

THE CITY UNIVERSITY OF NEW YORK
ABSTRACT

THE INFLUENCE OF FORWARD HEAD POSTURE ON SUPRAHYOID ACTIVITY DURING OROPHARYNGEAL SWALLOWING: A SURFACE ELECTROMYOGRAPHIC ANALYSIS

By

BRIANNE CARROLL
SIERRA HUNT
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MARK WNUKOWSKI

Advisor: Tom Holland, PT, PhD

TITLE: The Influence of Forward Head Posture on Suprahyoid Activity During Oropharyngeal Swallowing: A Surface Electromyographic Analysis

STUDY DESIGN: Within subjects repeated measures design.

OBJECTIVE: The aim of this research is to explore the effect that Forward Head Posture has on the mylohyoid muscle during swallowing in a healthy population.

BACKGROUND: Forward Head Posture (FHP) is the most common deviation from ideal head posture, and has become more prominent due to the rise of smart phones and the prevalence of computers in the household and workplace. FHP is associated with a variety of detrimental effects on the musculoskeletal system that arise from the abnormal positioning of the cranial and cervical bones and joints. In particular, the muscles involved in swallowing are placed in an
abnormal biomechanical position that may affect the ease of swallowing. The resultant lengthening of the suprathyoid muscles has been reported in the research literature due to this postural deviation, but few have sought to evaluate the possible consequences imposed on swallowing due to this factor.

**METHODS:** Fourteen healthy adults, ages 20 to 50, were assessed for the purpose of this study. Surface Electromyography (sEMG) was recorded with bipolar synthetic gel surface electrodes placed over the right and left mylohyoid muscles of each subject. Subjects were given a cup filled with 25mL of water to be used as the stimuli bolus. Craniovertebral angles were measured for each subject in their habitual sitting posture (HP) and FHP prior to data collection. Three swallowing trials were recorded in the three different postures: the subject's HP, upright sitting while assuming an exaggerated FHP, and optimal sitting posture (OP) after postural education.

**RESULTS:** The average sEMG duration and amplitude were obtained for each subject during the three trials for each condition. Paired t-tests were used to compare the duration and amplitude of sEMG mylohyoid activity between the three treatment conditions (HP vs. FHP, HP vs. OP, and FHP vs. OP). The mean sEMG duration in the FHP and HP conditions were similar and longer than the OP treatment condition. A higher sEMG amplitude was also observed in the FHP condition. An analysis of correlation revealed that smaller craniovertebral angles in the HP and FHP resulted in a statistically significant ($p = .008$) inverse linear relationship with the amplitude of mylohyoid activity.
CONCLUSION: The preliminary results of this study appear to indicate that FHP leads to progressively larger amplitude and longer duration sEMG activity in the mylohyoid during swallowing. These results suggest that FHP may require a more effortful recruitment of the suprahyoid muscle that can predispose or exacerbate pre-existing dysphagia caused by suprahyoid impairment. Future studies are indicated with a larger sample size to further explore this apparent relationship.
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BACKGROUND

**Forward Head Posture**

Postural abnormalities occur when joints and body segments deviate from their appropriate position relative to the line of gravity. Habitual alterations in position and mal-alignments will result in adaptive changes to muscles, ligaments, joints, and other anatomical structures, due to both the action of gravity and the body's own compensatory methods (Levangie & Norkin, 2011). For example, shortened muscles and ligaments will tend to tighten and limit motion over time. Abnormally lengthened structures present with reduced strength stability, and range of motion due to altered length-tension relationships (Levangie & Norkin, 2011). These imbalances were coined by Janda as the “Upper Crossed Syndrome,” and previous studies have noted these stereotypical deviations in swimmers, dental hygienists, and individuals suffering from work related upper extremity dysfunction (Page, Frank, & Lardner, 2010). Forward head posture is “characterized by increased flexion of the lower cervical and upper thoracic regions, increased extension of the occiput on the first cervical vertebra, and increased extension of the upper cervical vertebrae” (Kisner & Colby, 2012). As a result of FHP, the head protrudes anterior to the trunk, and sits in front of the line of gravity in the sagittal plane (Silva & Johnson, 2013).

Forward head posture is associated with a variety of detrimental sequelae that result from the abnormal positioning of these joints and bones. The immediate mechanical stresses imposed result in pain that can be relieved by activity (also known as postural pain syndrome), but strength and flexibility tend to develop within FHP, allowing the body to maintain this abnormal posture (Kisner & Colby, 2012). Constant tonic contraction of the capital extensors is needed to support the head upright against gravity in this position, possibly leading to ischemia of these
muscles or herniation of the nucleus pulposus of the cervical intervertebral (IV) discs (Levangie & Norkin, 2011). FHP also tends to produce an excessive increase in the cervical lordosis, causing narrowing of the intervertebral foramen (C4-C5 & C5-C6), zygapophyseal joint compression, posterior compression of the annulus fibers of the IV discs, and compression of the cervical vertebrae posteriorly at the apex of the curve (Levangie & Norkin, 2011; Donatelli, 2011). Studies have shown that correction of FHP in patients with cervical radiculopathy has demonstrated significant improvements in pain (Diab & Moustafa, 2011). Furthermore, adaptive changes in length will also occur to muscles and ligaments as a result of this excessive lordosis. Specifically, the posterior ligaments of the spine shorten over time while the anterior ligaments lengthen (Levangie & Norkin, 2011). Headaches have been documented as a possible finding, secondary to nerve or vertebral artery entrapment, as well as C1 nerve root irritation (Donatelli, 2011).

Upper extremity dysfunction has been correlated to FHP by causing alterations in scapular mechanics and scapulo-thoracic muscular activity, which may or may not be a driver for possible impingement or other means of shoulder pain (Thigpen et al., 2010). Medial rotation of the scapulae is often linked with FHP secondary to the presence of thoracic kyphosis and increased internal rotation of the glenohumeral joints commonly seen in the slouched posture. This deformity becomes more difficult to correct as the musculature of the anterior shoulder become increasingly taut over time, while the scapular retractors weaken due to chronic lengthening. Medial scapular rotation further exacerbates the dorsal kyphosis of the upper thoracic spine, causing a reduction in vertical height and vital capacity of the lungs (Levangie & Norkin, 2011).
It has been indicated that FHP pulls the mandible into retrusion due to the stretch imposed on the suprahyoid muscles, and thus causes trauma to the retrodiscal pad of the jaw and can lead to temporal mandibular joint dysfunction (Levangie & Norkin, 2011). Since proper functioning of the suprahyoid muscles is crucial in order to elevate the hyolaryngeal complex, this information suggests that FHP can negatively influence swallowing mechanics when under this stress.

Forward head posture is the most common deviation from ideal head posture, and has become more prominent due to the rise of smart phones and the prevalence of computers in the household and workplace (Park & Yoo, 2012; Kang et al., 2012). One study found that patients with neck pain of non-traumatic origin exhibited more FHP in standing compared to pain-free patients (Silva, Punt, Sharples, Vilas-Boas, & Johnson, 2009). Another comparative study indicated that older adults tend to have higher frequency of FHP compared to younger adults, possibly due to age related changes occurring in the spine (Kuo, Tully & Galea, 2009).

The prevalence and detrimental consequences of FHP speak to its clinical significance and the importance of prompt correction and treatment. While some sources discuss the resultant lengthening of the suprahyoid muscles (i.e. anterior and posterior digastric, geniohyoid, mylohyoid and stylohyoid) due to this postural deviation, few have sought to evaluate the possible consequences imposed on swallowing due to this factor. Considering the frequency of FHP among the majority of people, and especially the prevalence of FHP among the aging population, the aim of this research is to explore the effect that FHP may have on the muscles involved in swallowing within a healthy population. Our rationale is that if FHP is not corrected over time, then any and all swallowing consequences may potentially worsen with age as the spine deteriorates and exacerbates the faulty position of the head and neck.
Suprhyoid Involvement in Swallowing

Normal swallowing is a complex volitional and reflexive process involving the sequential contraction of 25 muscles in the upper digastric tract (Steele & Miller, 2010). The basic mechanism of swallowing can be divided into four stages: the oral preparatory stage, oral propulsive stage, oropharyngeal stage, and esophageal stage. In the voluntary oral preparatory stage, the bolus is pushed from the mouth into the oropharynx by volitional contraction of the tongue. In the oral propulsive stage, the bolus passes into the upper pharynx through further contraction of the tongue. This is followed by the oropharyngeal stage, where the bolus is transported through the pharynx and through the esophageal sphincter by an involuntary synchronous muscular contraction of the suprahyloid muscle complex. Following the oropharyngeal stage is the final esophageal stage in which peristaltic contraction of the pharyngeal constrictor muscles forces the bolus down the esophagus and into the stomach for digestion (Steele & Miller, 2010).

Contraction of the suprahyloid muscles allows for appropriate excursion of the hyolaryngeal complex during the oropharyngeal phase of deglutition. The suprahyloid muscles all originate superior to the hyoid bone and distally insert on the hyoid bone itself; these muscles include the anterior digastric, geniohyoid and mylohyoid. The hyolaryngeal complex is comprised of the hyoid bone, along with the thyrohyoid membrane and laryngeal cartilages. The laryngeal cartilage also serves as an attachment for the cricopharyngeus muscle, which forms the upper esophageal sphincter.

During the pharyngeal phase, the soft palate elevates, the pharynx widens to receive the bolus, and the suprahyloids contract to pull the hyolaryngeal complex superiorly and anteriorly. This anterior and superior displacement of the hyolaryngeal complex pulls open the esophageal
sphincter for the oncoming bolus (Matsuo & Palmer, 2008). Consequently, the integrity of the suprathyroid muscle complex is of concern for patients experiencing dysphagia and the source of this dysphagia may be related to suprathyroid dysfunction.

A number of research studies have been conducted to investigate the kinematic sequencing of the suprathyroid muscles. Numerous studies and kinematic analyses to determine muscle sequencing have concluded that superior movement precedes anterior movement of the hyoid (Steele, Thrasher & Popovic, 2007). On a muscular level, the mylohyoid has been found to contract 30-40 msec before contraction of the remaining suprathyroids (Steele et al., 2007). Since the superior movement of the hyoid complex appears to be paralleled by mylohyoid activity, it can be inferred that the mylohyoid is primarily responsible for the upward excursion of the hyoid.

The force generated by each suprathyroid muscle has also been tested to determine the relative importance of each muscle during hyoid excursion. This was determined by analyzing the cross sectional area of a cadaver specimen’s muscles to identify which have the greatest force potential to displace the hyoid (Pearson, William, Langmore, & Zumwalt, 2011). The mylohyoid was determined to be the primary superior mover and the geniohyoid was determined to be the primary anterior mover of the hyoid bone. Another study corroborated this finding by using percutaneous electrical stimulation on the suprathyroids to test each muscle’s contribution during swallowing; bilateral stimulation of the mylohyoid and thyrohyoid produced 50% superior excursion and the geniohyoid contributed most significantly to the anterior displacement of the hyolaryngeal complex (Steele et al., 2007). It is also generally assumed that the anterior and posterior digastrics concurrently contract (counterbalancing forces in the sagittal plane) to assist in elevating the hyoid (Pearson et al., 2011).
In addition to the sequencing and relative force of excursion of the hyolaryngeal complex, Perlman, Palmer, McCulloch & Vandaele (1999) concluded that activation of the submental muscles (i.e. the geniohyoid, mylohyoid, and anterior digastric) is synchronized with an inhibition of the cricopharyngeous muscle, allowing the esophageal sphincter to open. Therefore, due to the concomitant relaxation of the cricopharyngeous muscle, the anterior and superior excursion of the hyolaryngeal complex (primarily via the geniohyoid and mylohyoid, respectively) and the pressure of the descending bolus distending the upper esophageal sphincter, the bolus is able to pass through the esophageal sphincter to end the pharyngeal phase of swallowing (Matsuo & Palmer, 2008).

**Dysphagia**

Weakness or dysfunction of the suprahyoids, particularly the geniohyoid and mylohyoid, as indicated by current research, can cause dysphagia and result in aspiration. Dysphagia is a general term for any disorder of the swallowing mechanisms resulting in difficulty transporting food from one’s mouth to the stomach. It includes the behavioral, sensory, and motor actions that prepare and complete swallowing. The most commonly reported form of dysphagia results from delayed initiation during the pharyngeal phase and reduced swallowing strength, causing an incomplete hyolaryngeal excursion (Steele et al., 2007). In a similar fashion to FHP, dysphagia is not limited to one population, nor is it secondary to any single pathology. Like FHP, dysphagia is notably prevalent in patients following strokes and in the elderly, but affects the larger population as well. Since FHP displaces the normal position of the hyoid and mandible bones, the natural kinematics of the suprahyoid muscles may be disrupted in patients presenting with FHP. This finding may further increase the risk of aspiration in elderly patients with dysphagia,
and it is for this reason that we will investigate any connection between the two phenomena in our research study.

According to Spieker (2000), dysphagia is prevalent in 7-10% of people over the age of 50, 25% of all hospitalized patients, and 30-40% of nursing home patients. Spieker also notes that dysphagia is among the top fifty reasons that people seek medical treatment. Furthermore, these numbers are believed to be artificially low because many patients suffering from dysphagia fail to recognize that it is a treatable condition. Therefore, these patients do not report symptoms, and cannot seek treatment for it. As a result of dysphagia, the quality of life in these patients is reduced compared to patients without dysphagia (Cohen & Manor, 2011). The prevalence of dysphagia among the elderly can also be related to the incidence of diseases such as Alzheimer’s Disease, Parkinson’s Disease, diabetes, certain medications, and poor dentition. Another study also found dysphagia appears to be under reported in the elderly, with 32.5% of subjects with current swallowing disorders and 40% of subjects experiencing impaired deglutition at some point (Roy, Stemple, Merrill, & Thomas, 2007).

Dysphagia’s onset can be acute, such as in cases of stroke, spinal cord injury, traumatic brain injury, and brainstem or cranial nerve injury. The onset of dysphagia may also be chronic and/or progressive, such as in age-related changes in aero-digestive structures, tumor growth, and neurological disorders including Cerebral Palsy, Poliomyelitis, or Gullian-Barre syndrome (Roy et al., 2007 & Logemann, 1998). Dysphagia can also result from a tracheostomy and mechanical ventilation, especially in quadriplegics (Seidl, Nusser-Muller-Busch, Kurzweil & Neideggen, 2010). Other causes, such as xerostomia (dry mouth) and reduced saliva production, and cause dysphagia due to paresis of the swallowing muscles. This can also be caused by Parkinson’s Disease and Multiple Sclerosis (Bogaardt, 2008).
Dysphagia should be considered a serious medical issue, not only for its physical and psycho-social risks, but also for its severe impact on quality of life. Dysphagia can lead to dehydration, malnutrition, pneumonia, and reduced mobility. Normally, a bolus (food or liquid) is safely transported through laryngeal elevation and epiglottal closure. Interruptions in this sequence can result in choking and death (Reddy, Simcox & Gupta, 2000). Dysphagia can also cause anxiety with meals and avoidance of public eating, which can severely impact quality of life by diminishing socialization (Roy et al., 2007). Diminished socialization can increase feelings of loneliness; in seniors, loneliness has been found to contribute to depression, morbidity, and mortality (Singh & Mirsa, 2009).

**Electromyography**

Electromyography (EMG) is a procedure that uses electrodes, either within the tissues (needle electrodes) or upon the body's surface (surface electrodes), to record the body's own myoelectricity in order to provide information on muscle recruitment (Stepp, 2012). Motor unit action potentials (MUAP) are produced as a summation of the discharge of each muscle fiber within the motor unit, and will therefore become larger as more motor units are recruited (Hecox, Holland, Krasilovsky (y instead of i, also change in bibliography) & Weisberg, 2006). The integrated EMG displays the activity of the desired muscle, and recorded information is proportional to the extent of contraction (Hecox et al, 2006). Intramuscular EMG can be used with needle electrodes and has more specificity for the muscle being observed (Stepp, 2012). However, surface EMG (sEMG) is more practical for clinical and diagnostic purposes, as it is noninvasive, allows for easier application, provides real time information about muscle activity, and is more comfortable for patients (Hecox et al., 2006; Stepp, 2012).
Recently, there has been more interest in pursuing sEMG studies concerning the muscles of speech, swallowing, and respiration (Stepp, 2012). Some of these studies have addressed the role of the supranyoid muscles during these functions, specifically during swallowing. One study used sEMG along with pharyngeal manometric sensors to confirm that there was a significant change in both supranyoid sEMG amplitudes and pharyngeal pressures during an effortful swallow versus a normal swallow (Huckabee, Butler, Barclay & Jit, 2005). Another study used sEMG while subjects swallowed different volumes of tea, and concluded that bolus volume mainly influences supranyoid activity patterns during the early period of swallowing (Y. Miyaoka, Ashida, Kawakami, Tamaki & S. Miyaoka, 2010). Sakuma & Kida (2010) indicated that shorter durations and smaller amplitudes recorded during supranyoid/infrahyoid evaluation by sEMG indicates easier swallowing for healthy individuals. Many of these supranyoid sEMG swallow studies state or imply that the “chin up” position unanimously makes swallowing less effective and more difficult versus any other head position while in neutral posture in healthy individuals (Eretkin et al., 2001; Tsukada, Taniguchi, Ootaki, Yamada, & Inoue, 2009; Sakuma & Kida, 2010). However, to the best of our knowledge, no one has attempted to evaluate the supranyoid muscle activity or ease of swallowing in FHP, as this posture implies a relatively upward chin position in relation to the neck.
PURPOSE/OBJECTIVE

The effect of FHP on swallowing needs to be further investigated because dysphagia and FHP are a common co-occurrence in the geriatric population. Forward head posture may exacerbate dysphagia by placing the suprathyroid muscles in a kinematically disadvantageous position, causing these muscles to contract more forcefully in order to attain adequate hyolaryngeal excursion during swallowing. This study will place surface electrodes on the mylohyoid, since an altered position of this superficial muscle may significantly reduce the superior excursion of the hyolaryngeal complex.

Therefore, the aim of this study was to compare the ease of swallow among healthy subjects in three different controlled scenarios. These scenarios include one’s habitual posture, FHP, and optimal posture. We hypothesized that the sEMG activity from the mylohyoid would yield both a larger amplitude and duration in the FHP when compared to habitual and optimal postural positions, suggesting a more effortful and less effective swallow.
METHODS

Subjects

Fourteen healthy adults, ages 20 to 50, were assessed for the purpose of this study. The exclusion criteria were as follows: history of palatal, pharyngeal, or laryngeal surgery; neuromuscular disease; or any speech, chewing, or swallowing pathologies. In addition, subjects were excluded if they had any history of cervical disc herniation, cervical radiculopathy, spinal abnormalities, or neck/back surgeries. All participating subjects were recruited by information fliers and volunteered at their own discretion. The purpose of this study and the precise methodology were explained to all subjects; all participating subjects agreed to and signed the notice of informed consent. Subjects were free to withdraw from the study at any time. This study was submitted to and approved by the IRB Hunter College Human Research Protection Program.

Protocol

For the purpose of data collection, subjects were seated in a chair that provided back support. Surface EMG was recorded utilizing electrodes from BIOPAC systems (BIOPAC Systems, Inc. EL504). Before electrode placement, the skin was swabbed with an alcohol pad to improve surface electrode adhesion. This method was recommended for sEMG studies, reducing skin impedance by 70% and is well tolerated by the skin of the neck and face (Stepp, 2012). Male subjects were required to shave to improve skin to electrode conduction prior to data collection. Bipolar synthetic gel surface electrodes were placed over the right and left mylohyoid muscles, on the anterior, submental surface of each subject. Surface electrodes were placed adjacent to the midline portion of the submental area without overlapping one another. The degree of each subject’s FHP was classified using the craniovertebral angle. The points used
to create this angle were the tragus of the ear, vertebra prominens (spinous process of C7), and a horizontal line from the C7 spinous process parallel to the floor. This measurement allowed for a standardized method to determine the subject’s degree of forward head within his or her habitual posture and assumed FHP, as done by previous studies (Kang et al., 2012; Diab & Moustafa, 2011).

**Image 1.** To the left is a sagittal representation of the craniovertebral angle. The pivot point of this angle lies at the C7 spinous process, while the dynamic and static arms of this angle extend through the tragus of the ear and across the horizontal, respectively. Past studies have used this angle to classify forward head posture, and some of these studies have determined that an angle below 50 degrees suggests a need for corrective intervention (Kang et al., 2012; Diab & Moustafa, 2011).

Subjects were given a cup filled with 25mL of water to be used as the stimuli and bolus. Three trials of data were recorded in three different postural positions for each patient: the subject's habitual sitting posture, upright sitting while assuming an exaggerated FHP, and optimal sitting posture after postural education. In each trial, the subject was instructed to swallow the bolus in one natural gulp. Each subject rested one minute between successive swallows, with appropriate additional time after each third swallow to allow for proper postural education or changes of position. The subject was cued verbally to swallow the water bolus.
RESULTS

The average duration was obtained for each subject among the three trials for each condition. Paired t-tests were used to compare the duration of sEMG mylohyoid activity between three treatment conditions (Habitual vs. FHP, Habitual vs. Optimal, and FHP vs. Optimal). The same was repeated for the amplitude of mylohyoid activity, with average results among three trials used to compare among the three treatment conditions.

The craniovertebral angle of each subject in the Habitual and FHP groups were combined and compared to the duration and the amplitude of mylohyoid activity. A lower craniovertebral angle corresponds to a greater degree of FHP (Diab & Moustafa, 2011). A linear regression was conducted to determine the relationship between head position versus duration and amplitude.

**Duration comparison**

<table>
<thead>
<tr>
<th></th>
<th>Mean (seconds)</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>Habitual</td>
<td>1.688562857</td>
<td>14</td>
<td>.5355186792</td>
</tr>
<tr>
<td></td>
<td>FHP</td>
<td>1.686035238</td>
<td>14</td>
<td>.7397144755</td>
</tr>
<tr>
<td>Pair 2</td>
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<tr>
<td></td>
<td>Optimal</td>
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<td>14</td>
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</tr>
<tr>
<td>Pair 3</td>
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<td>Optimal</td>
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<td>14</td>
<td>.4611615652</td>
</tr>
</tbody>
</table>

**Table 1:** Standard deviation and standard error mean comparison between treatment conditions for sEMG duration.
As seen in Table 1, the mean duration of FHP, Habitual Posture, and Optimal Posture were 1.686, 1.689, and 1.239 seconds, respectively. The mean duration of FHP and Habitual posture were similar. Insignificant differences between FHP and Optimal posture may be attributed to the large standard deviation (.739) within the FHP group. Comparison of results yielded a statistically significant difference between the duration of mylohyoid activation during a swallow in the Habitual and Optimal posture conditions, $p = 0.012$ (Table 2).

<table>
<thead>
<tr>
<th>Pair</th>
<th>Posture Comparison</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
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</thead>
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<td>.991</td>
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<tr>
<td>Pair 2</td>
<td>Habitual – Optimal</td>
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<td>.012</td>
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<td>Pair 3</td>
<td>FHP – Optimal</td>
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<td>.054</td>
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**Table 2:** Paired t-test comparison of two-tailed statistical significance between treatment conditions.
Amplitude Comparison

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<th>Mean (mV)</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
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<td>1</td>
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<td>.0019994101</td>
<td>.0005343648</td>
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<td></td>
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<td>FHP</td>
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</table>

Table 3: Standard deviation and standard error mean comparison between treatment conditions for sEMG amplitude.

<table>
<thead>
<tr>
<th>Pair</th>
<th>Posture</th>
<th>t</th>
<th>Df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
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<tr>
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<td>.050</td>
</tr>
<tr>
<td>3</td>
<td>FHP – Optimal</td>
<td>1.172</td>
<td>13</td>
<td>.262</td>
</tr>
</tbody>
</table>

Table 4: Paired t-test comparison of two-tailed statistical significance between treatment conditions.

As seen in Table 3, the mean amplitude of FHP, Habitual Posture, and Optimal Posture were .008, .004, and .005 millivolts respectively. The largest average amplitude was observed in the FHP group. This group also had the largest degree of standard deviation (.0104). The only statistically significant comparison was observed between the Habitual and Optimal conditions, $p = 0.05$ (Table 4). Insignificant differences between FHP and Optimal/Habitual posture groups may be attributed to a large standard deviation within the FHP condition.
Combined forward head position to duration and amplitude

<table>
<thead>
<tr>
<th>Equation</th>
<th>Model Summary</th>
<th>Parameter Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R Square</td>
<td>F</td>
</tr>
<tr>
<td>Linear</td>
<td>.008</td>
<td>.223</td>
</tr>
</tbody>
</table>

**Table 5**: Linear comparison between the degree of craniovertebral angle of FHP and mylohyoid muscle duration.

**Graph 1**: Linear relationship between the degree of the craniovertebral angle and sEMG duration.
Table 6: Linear comparison between the degree of craniovertebral angle of FHP and mylohyoid muscle amplitude.

<table>
<thead>
<tr>
<th>Equation</th>
<th>Model Summary</th>
<th>Parameter Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>R Square: .239, F: 8.173, df1: 1, df2: 26, Sig: .008</td>
<td>Constant: .022, b1: .000</td>
</tr>
</tbody>
</table>

Graph 2: Linear relation between the degree of the craniovertebral angle and sEMG amplitude.

For craniovertebral angle in comparison to sEMG duration among all treatment conditions, there appears to be a slight trend between the amount of FHP and duration of mylohyoid activation, albeit statistically insignificant, $p = 0.641$ (Table 5). A greater degree of FHP, corresponding to a
smaller craniovertebral angle, appears to result in a longer duration of mylohyoid muscle activation, indicated by the negative slope of the linear trend (Graph 1). This trend was also observed during a comparison between FHP and sEMG amplitude (Graph 2); however, this correlation yielded statistically significant results, \( p = .008 \) and a stronger linear correlation (Table 6).
DISCUSSION

The results of the study partially confirmed our hypothesis that FHP correlates with a greater activation of the mylohyoid muscle during swallowing. This is evidenced by the greatest amplitude of muscle activity for swallowing occurring in the FHP as compared to Habitual and Optimal postures. Additionally, although not statistically significant, a linear correlation demonstrates a trend of increasing duration of muscle activity during swallowing with increasing FHP.

We believe that the greatest amplitude of mylohyoid activity for swallowing occurs in FHP, secondary to the excessively lengthened position of this muscle. In FHP, the length-tension relationship of the mylohyoid is altered and the muscle is placed in a passively insufficient position. In this state, the mylohyoid must generate a greater amplitude of force to complete swallowing than is required when the muscle is in its ideal resting position. Comparatively, when the muscle’s position is closer to ideal, such as in one’s optimal posture, it is believed that less force is needed for the mylohyoid to perform its action. This is supported by the results of this study, which revealed lower amplitudes of the mylohyoid muscle during swallowing in both the Habitual and Optimal postures. Furthermore, the only statistically significant comparison of amplitude occurred between the Habitual and Optimal conditions, \( p = 0.05 \) (Table 4). Although the FHP condition demonstrated the greatest mean amplitude, the findings were not significant. This may be attributed to the large standard deviation within this group (SD=0.0104).

Additionally, data analysis of the duration did not support our hypothesis, which stated that the duration of muscle activity of the mylohyoid would be the greatest in FHP. Rather, the results revealed that the greatest duration of muscle activity occurred in the Habitual posture. However, it is interesting to note that the durations of both Habitual and FHP were very similar,
1.688562857 and 1.686035238 seconds, respectively. This finding may be attributed to the prevalence of the majority of our subjects presenting with forward head posture in their habitual posture measurements of their craniovertebral angles. On average, our subjects demonstrated a habitual craniovertebral angle of 48.14° (± 4.15°), which was similar to the FHP average angle of 32.21° (± 5.49°). This may account for the aforementioned similarities in duration between these two conditions. In addition, the results indicated that the lowest mean duration occurred in Optimal posture. This may suggest that the Optimal posture is the most efficient position of the mylohyoid muscle during swallowing. The only statistically significant difference in duration occurred between the Habitual and Optimal posture conditions \( (p = 0.012) \). Although the difference between Optimal and FHP was great, it was not statistically significant \( (p = 0.054) \).

Both linear comparison models demonstrated a correlation of both increased duration and amplitude with increased FHP, noted by a smaller craniovertebral angle. The linear comparison of amplitude to FHP was statistically significant and supports our hypothesis that a greater degree of FHP is correlated with a larger amplitude of mylohyoid activity during swallowing. Although the linear comparison between FHP and duration was not statistically significant, a supportive trend exists: duration and craniovertebral angle are inversely related.

We have identified the following limitations of our study. First, the mean age of the subjects in our study was 30.2 years old, ± 7.2 years. Second, of the 14 subjects in this study, 60% were female. Due to these demographic factors and the small sample size \( (n = 14) \) this study is not an accurate representation of the general population, nor the geriatric population most at risk for FHP and dysphagia (Kuo, Tully, & Galea, 2009; Spieker, 2000). Therefore, this limits the generalization of our results. The absence of age and gender norms for the craniovertebral angle used in this study further limited data analysis.
The precision of the craniovertebral angle measure used to represent FHP was a potential source of human error. The three landmarks used as mentioned in the protocol were variable due to subject’s anatomy. It was difficult to estimate the location of the C7 spinous process in the sagittal plane, though this landmark was a key portion of the data analysis. In future studies, this measurement could be altered by locating the transverse process of this joint to provide a more accurate lateral landmark. Additionally, the lack of a craniovertebral angle measurement in Optimal posture also limited comparisons between the three postural positions. For the purposes of this study, it was assumed that the optimal posture had a craniovertebral angle value of zero. Lastly, both the measurements of FHP and Habitual posture were taken prior to the first of three trials in each position. It is plausible that the angle may have changed in between trials, and this potential change was not accounted for in our analysis.

Furthermore, potential suprahypoid muscle fatigue (i.e. from eating or drinking large volumes of food or liquids prior to the study) was not taken into consideration. Subjects were not asked to refrain from eating or drinking prior to data collection. The lack of a suprahypoid activity abstinence period may contribute error. Additionally, although ingesting a 25 mL bolus of water is a standard activity, the required delay in swallowing, secondary to the study’s procedure, is not common or habitual, and may have altered results. Despite the verbal command to “swallow normally whenever you are ready” given to each subject, several subjects appeared uneasy with the task. This unease may be attributed to observation by the research team, and the discomfort in the exaggerated FHP and optimized postures. Additionally, since both the exaggerated FHP and Optimal postures were not the habitual posture of the subjects, these positions may have been uncomfortable and difficult to assume. This is a potential cause of a large standard deviation among the average FHP amplitudes. Future studies could alleviate this discomfort by
allowing each subject a greater rest period between trials without requiring the sustained posture. A longitudinal study comparing muscle activity of the mylohyoid during swallowing after postural improvement may demonstrate more accurate results.

The results of this study are also limited by the use of sEMG. The sEMG is a superficial, non-specific measurement of muscle activity. In this study, the electrodes were placed on subjects in their habitual posture and were not altered during the course of trials. The ability of the electrodes to adhere to the skin can affect the accuracy of the data collected. Additionally, this study attempted to measure the muscle activity of the mylohyoid muscle, which is difficult to isolate with sEMG. Future studies should consider the use of needle EMG to more accurately quantify the results of the suprathyloid muscle. In addition, while the results of this study are of the mylohyoid muscle alone, one cannot assume the results of postural positions on this muscle are representative of all muscles involved in swallowing.

The method of obtaining the duration of each swallow was another potential source of human error, as it occasionally required the research team to determine the start and end point of recorded muscle activity. This measurement may have been altered by laughing, speaking, coughing, low amplitude, or a biphasic swallow pattern. During the course of data collection, several subjects demonstrated low amplitude or a biphasic swallow reading on the EMG. This phenomenon complicated data analysis. In future studies with larger sample sizes, subjects who present with this pattern of swallowing should be excluded in order to increase the validity of the sEMG measures.
CONCLUSION

The preliminary results of this study appear to indicate that FHP leads to progressively larger amplitude and longer duration of mylohyoid sEMG activity during swallowing. A greater degree of FHP resulted in a longer average duration and amplitude of mylohyoid activation in comparison to the Optimal Posture condition. In addition, a linear trend towards longer mylohyoid duration and amplitude appears to correspond to a greater degree of FHP; however, only a linear correlation between amplitude and degree of FHP severity was found to be statistically significant. These results suggest that FHP may predispose individuals to, or may exacerbate pre-existing dysphagia. Future studies are indicated with a larger sample size to further explore this apparent relationship.
REFERENCES


