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Does increased superficial neck flexor activity in the craniocervical flexion test reflect reduced deep flexor activity in people with neck pain?
ABSTRACT

Background: The craniocervical flexion test assesses the deep cervical flexor muscles (longus capitis, longus colli). Ideally, electromyography (EMG) studies measure activity in both deep and superficial (sternocleidomastoid, anterior scalene) flexors during the test, but most studies confine recordings to superficial muscle activity as the technique to record the deep muscles is invasive. Higher activity of the superficial flexors has been interpreted as an indicator of reduced deep flexor activity in people with neck pain but how close the inverse relationship is during this test is unknown.

Methods: EMG was recorded from the sternocleidomastoid, anterior scalene and deep cervical flexor muscles to quantify their relationship during the craniocervical flexion test, from 32 women (age: 38.0±11.6 yrs) with a history of chronic non-specific neck pain. The range of craniocervical flexion at each of the five test stages was also measured.

Results: A moderate negative correlation was identified (r=-0.45; P<0.01) between the average normalized EMG amplitude of the deep cervical flexors and sternocleidomastoid across all stages of the craniocervical flexion test. There was a moderate although weaker and non-significant negative correlation between deep cervical flexors and anterior scalene activity (r=-0.34; P=0.053).

Conclusions: The results affirm the interpretation that higher levels of activity of the superficial flexor muscles are an indicator of reduced deep cervical flexor activity in the craniocervical flexion test. Further studies of neuromuscular and movement strategies used by people with neck pain to compensate for poorer activation of the deep cervical flexors will inform best clinical assessment.

Key words: craniocervical flexion test, electromyography, neck flexor muscles, longus colli, longus capitis
Highlights

- Analysis of cervical flexor muscle activity in the craniocervical flexion test
- Higher superficial flexor activity correlates with lesser deep flexor activity
- Evaluation of the deeper flexors may rely on superficial flexor evaluation
INTRODUCTION

The craniocervical flexion test is a test which assesses the control of the deep cervical flexor muscles (longus capitis, longus colli) (Jull et al., 2008). Evaluation of test performance involves three components: assessment of the contractile capacity of the deep cervical flexors (ability to flex to five progressively inner range positions of craniocervical flexion), assessment of any increased compensatory activity of the superficial flexors (craniocervical flexion is not the anatomical action of the sternocleidomastoid or anterior scalene muscles) and assessment of the quality and range of head sagittal plane rotation which should proportionally increase with progressive stages of the test (Falla et al., 2003b, Jull et al., 2008). The content validity (Falla et al., 2003a) and reliability of the test have been established (Juul et al., 2013, Jørgensen et al., 2014).

In the research setting, surface electromyography (EMG) is used to quantify the activity of the deep and superficial neck flexors during the test. The longus capitis and longus colli are deep muscles and are unable to be accessed using conventional surface EMG electrodes. Consequently, a novel method is utilized which consists of bipolar electrodes housed within a nasopharyngeal catheter (Falla et al., 2003a). The catheter is inserted via the subject’s nose and is suctioned onto the posterior oropharyngeal wall adjacent to the uvula to directly measure deep flexor muscle activity. This procedure is invasive and not suitable for studying large clinical populations. Hence most clinical laboratory studies of the craniocervical flexion test have confined EMG measurement to the readily accessible sternocleidomastoid and anterior scalene muscles (Zito et al., 2006, Jull et al., 2007, Johnston et al., 2008, Armijo-Olivo et al., 2011). The assumption is that excessive activation of the superficial flexors is compensatory as craniocervical flexion is not their anatomical action. In support of this assumption, Falla et al. (2004c) showed increased activity of the superficial flexors and lower activation of the deep cervical flexors in people with neck pain compared to pain-free individuals and Jull et al. (2009)
demonstrated that an increase in deep flexor activity after training was associated with a decrease in activity of the superficial flexors. However how close the inverse relationship is between the superficial and deep muscles is unknown. The aim of this study was to explore this relationship, to vindicate or not the use of the clinical test method of measuring superficial flexors only.

METHODS

Participants

Thirty two women (age, mean ± SD: 38.0 ± 11.6 yrs) with a history of chronic non-specific neck pain participated in this study. Patients were recruited by advertisements in the local press and were included if they were between the ages of 18-60 years, reported a history of neck pain of greater than 6 months duration, scored 5 points (Vernon, 1996) or greater out of a possible 50 points on the Neck Disability Index (NDI) (Vernon and Mior, 1991), and demonstrated positive findings on a physical examination of the cervical spine (altered joint motion and painful reactivity to palpation on manual examination of the spine (Jull et al., 1988)). Patients were excluded if they had undergone cervical spine surgery, presented with any neurological signs in the upper limb or had participated in a neck exercise program in the past 12 months.

Ethical approval for the study was granted by the Institutional Ethics Committee and the procedures were conducted according to the Declaration of Helsinki. Participants provided written informed consent. Data collected from this sample has been partially previously reported (Falla et al., 2011) albeit with a focus on the relation to patient self-reports of pain intensity.

Pain and disability

The average intensity of current neck pain was measured on a 10 cm Numerical Rating Scale (NRS) anchored with “no pain” and “the worst possible pain imaginable”. The NDI was
used to assess neck pain-related disability (10 items) (Vernon and Mior, 1991); each item is scored from 0 to 5, and the total score out of 50 points is summated.

Electromyography

EMG was recorded from the deep cervical flexor muscles unilaterally on the side of greatest pain, which was the right side for 7 of the 32 patients. The apparatus consisted of bipolar silver wire electrode contacts (2 mm × 0.6 mm, 10-mm inter-electrode distance) attached to a suction catheter (size 10FG), with a heat sealed distal end, which was inserted via the nose to the posterior oropharyngeal wall with the patient in supine (Falla et al., 2003a, Falla et al., 2006). The validity and reliability of this technique has been established previously (Falla et al., 2006). The electrode was positioned ~1cm lateral to the midline at the level of the uvula and the location was confirmed by inspection through the mouth. The electrode contacts were fixed to the mucosal wall with a suction pressure of 30 mmHg via a portal between the two contacts. Before insertion, the nose and pharynx were anaesthetized with three metered doses of 2% Xylocaine ® spray (lidocaine, Astra Pharmaceuticals, Sweden) administered via the nostril and to the posterior oropharyngeal wall, via the mouth.

Surface EMG signals were recorded from the sternal head of sternocleidomastoid and the anterior scalene muscles bilaterally using Ag/AgCl electrodes (Grass Telefactor, Astro-Med Inc.) following skin preparation and guidelines for electrode placement (Falla et al., 2002). The reference electrode was placed on the upper thoracic spine. EMG data were amplified (Gain = 1000), band-pass filtered between 20Hz – 1kHz and sampled at 2kHz. Data were sampled with Spike software using a micro1401 data acquisition system (Cambridge Electronic Design, Cambridge, UK) and converted into a format suitable for signal processing with Matlab (MathWorks, Inc. MA, USA).

Procedure
Subjects were comfortably positioned in supine, with their knees bent, their head and neck in a mid-position. They were instructed to perform a craniocervical flexion action. The task consisted of five incremental movements of increasing craniocervical flexion range of motion (Jull et al., 2008). Performance was guided by visual feedback from an air-filled pressure sensor (Stabilizer™, Chattanooga Group Inc. USA) placed sub-occipitally behind the subject’s neck and inflated to a baseline pressure of 20 mmHg. During the task, subjects were required to perform gentle nodding motions of craniocervical flexion that progressed in range to increase the pressure by five incremental levels, with each increment representing 2 mm Hg (Jull et al., 2008).

Participants practiced targeting the five test levels (22-30 mmHg; increments of 2 mmHg) in two practice trials before the electrodes were applied. EMG data were then collected for 10 s during a standardized manoeuvre for EMG normalization purposes. The task involved cervical and craniocervical flexion to lift and hold the head just clear of the bed (reference voluntary contraction). Subjects then performed the five incremental stages (22-30 mmHg) of the craniocervical task to the best of their abilities, maintaining the pressure steady on each target for 10 s. EMG data collection for all muscles commenced when the subject reached the pressure target. A 30 s rest was given between stages.

Craniocervical flexion range of motion was recorded for each test stage using a digital imaging method as previously described (Falla et al., 2003b). Briefly, anatomical markers were positioned on the tragus of the ear, the mental protuberance of the mandible and the lateral aspect of the neck — seven centimeters inferior to the mastoid process. A digital camera was positioned on a tripod horizontally parallel to the subject’s head/neck region at a distance of 80 cm. An initial photograph was taken of the subject in the starting neutral position, followed by a photograph at the full range of active craniocervical flexion available in this position. Subsequent photos were taken when the subject reached each level of the craniocervical flexion test.
Data Analysis

The EMG signal amplitude was estimated as the root mean square (RMS) value computed over intervals of 1 s during each 10-s contraction. The values of RMS were expressed as a percentage of the maximum RMS value during the reference voluntary contraction (head lift) and then were further averaged across the five stages of the task. Since the RMS values of the sternocleidomastoid and anterior scalene were comparable between sides, the average across both sides was taken for further analysis.

A custom designed analytical software (LabVIEW 6i, National Instruments) was utilized to measure craniocervical flexion range of motion. From the photograph the angle between the tragus of the ear, the mental protuberance of the mandible and the lateral aspect of the neck was obtained. Full craniocervical flexion range of motion was calculated by subtracting the mean angle of full active craniocervical flexion from the mean angle of the starting position. The relative range of craniocervical flexion obtained at each stage of the craniocervical flexion test was obtained by expressing each angle as a percentage of full range of craniocervical flexion.

Statistical Analysis

Pearson product-moment correlation coefficients were used to determine the association between the average normalized RMS of the deep cervical flexors across all stages of the craniocervical flexion test and (i) average normalized RMS of the sternocleidomastoid across all stages of the craniocervical flexion test (ii) average normalized RMS of the anterior scalene across all stages of the craniocervical flexion test. The average activity of each muscle across all stages was chosen for statistical analysis to avoid multiple comparisons and provide a more general indication of muscle activation during the test. The mean range of craniocervical flexion was calculated for each stage of the test. Statistical significance was set at P < 0.05.
Correlations from 0.00–0.29 were regarded as weak, 0.30–0.59 as moderate and >0.6 as strong (Cohen, 1988).

**RESULTS**

Patient descriptive data are presented in Table 1. The patients’ average score for the Neck Disability Index (range, 0-50) was 11.0 ± 2.6 and their average pain intensity rated on a visual analogue scale (0-10) was 4.7 ± 1.8.

**Table 1:** Characteristics of the participants with chronic non-specific neck pain

<table>
<thead>
<tr>
<th></th>
<th>Descriptive</th>
<th>Mean ± SD</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of History</td>
<td>9.9 ± 8.8</td>
<td>7.0</td>
<td>1.5-40</td>
<td></td>
</tr>
<tr>
<td>Neck Pain Intensity</td>
<td>4.7 ± 1.8</td>
<td>4.7</td>
<td>1-9</td>
<td></td>
</tr>
<tr>
<td>Neck Disability Index</td>
<td>11.0 ± 2.6</td>
<td>11.0</td>
<td>5-16</td>
<td></td>
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</tbody>
</table>

**Table 2:** The average of the normalized root mean square (nRMS) values for the deep cervical flexors (DCF), sternocleidomastoid (SCM) and anterior scalene (AS) muscles across all stages of the craniocervical flexion test as well as the mean ± SD of the nRMS and the percent of full range craniocervical flexion (%CCF ROM) measured at each stage of the test for the 32 participants.

<table>
<thead>
<tr>
<th></th>
<th>22 mmHg</th>
<th>24 mmHg</th>
<th>26 mmHg</th>
<th>28 mmHg</th>
<th>30 mmHg</th>
<th>Average (22-30 mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DCF nRMS</strong></td>
<td>19.6 ± 9.3</td>
<td>28.7 ± 8.9</td>
<td>30.7 ± 11.3</td>
<td>33.8 ± 10.2</td>
<td>43.5 ± 15.1</td>
<td>31.2 ± 5.4</td>
</tr>
<tr>
<td><strong>SCM nRMS</strong></td>
<td>10.2 ± 7.3</td>
<td>20.7 ± 10.7</td>
<td>34.0 ± 18.2</td>
<td>53.0 ± 24.4</td>
<td>69.7 ± 23.0</td>
<td>37.5 ± 14.0</td>
</tr>
<tr>
<td><strong>AS nRMS</strong></td>
<td>11.7 ± 9.9</td>
<td>24.6 ± 16.3</td>
<td>40.0 ± 25.8</td>
<td>61.4 ± 30.7</td>
<td>85.3 ± 39.1</td>
<td>44.6 ± 22.5</td>
</tr>
<tr>
<td><strong>%CCF ROM</strong></td>
<td>19.9 ± 6.9</td>
<td>35.6 ± 9.1</td>
<td>50.3 ± 10.3</td>
<td>62.8 ± 10.4</td>
<td>70.9 ± 8.9</td>
<td></td>
</tr>
</tbody>
</table>
Table 2 presents the normalized RMS values for the deep cervical flexors, sternocleidomastoid and anterior scalene averaged across all stages of the craniocervical flexion test as well as the mean and SD of the normalized RMS values and the mean percentage of full range craniocervical flexion measured at each stage of the craniocervical flexion test. A significant negative correlation \( r = -0.45; P < 0.01; \) Fig 1 was identified between the average normalized RMS of the deep cervical flexors and average normalized RMS of the sternocleidomastoid across all stages of the craniocervical flexion test. The negative correlation between the average normalized RMS of the deep cervical flexors and average normalized RMS of the anterior scalene across all stages of the craniocervical flexion test was close to statistical significance \( r = -0.34; P = 0.053; \) Fig 2.

**Figure 1**: Scatter plot (including 95% confidence interval) showing the correlation \( r = -0.45; P < 0.01 \) between normalized deep cervical flexor root mean square (RMS) values and normalized sternocleidomastoid RMS values recorded during the craniocervical flexion test. Data presented are the average values across all five stages of the test.
Figure 2: Scatter plot (including 95% confidence interval) showing the correlation (r=-0.34; P=0.053) between normalized deep cervical flexor root mean square (RMS) values and normalized anterior scalene RMS values recorded during the craniocervical flexion test. Data presented are the average values across all five stages of the test.

DISCUSSION

Numerous studies have evaluated craniocervical flexion test performance in people with neck pain. These studies reveal increased activation of the sternocleidomastoid and/or the anterior scalene muscles in several chronic neck pain patient populations including people with cervicogenic headache (Zito et al., 2006, Jull et al., 2007), those with pain induced secondary to whiplash injury (Sterling et al., 2003, Jull et al., 2004) and occupational factors (Johnston et al., 2008), as well as groups with non-specific neck pain (Jull et al., 2004). In these studies, the observation of increased superficial muscle activity was interpreted as compensatory for reduced activation of the deep cervical flexor muscles. However, the direct relationship between the activation of the deep cervical flexors and sternocleidomastoid and the anterior scalenes had not been investigated.

This study affirms the inverse relationship between the activity of the deep and superficial cervical flexor muscles during the performance of the craniocervical flexion test and supports the
interpretation that higher levels of superficial flexor muscle activity is an indicator of reduced deep cervical flexor activity. This is an important finding for interpretation of the test in both research and clinical settings. The relationship was stronger for activity in the sternocleidomastoid muscles where there was a moderate negative correlation with deep cervical flexor activity, while there was a fair to moderate negative, albeit non-significant relationship between deep muscles and the anterior scalene muscles. Considering the non-significant relation between anterior scalene and deep cervical flexor activity, measurement of sternocleidomastoid muscle activity might be sufficient in future studies to interpret activation of the deep cervical flexor activity. However compensatory strategies may vary across individuals (Gizzi et al., 2015) and although on average sternocleidomastoid muscle activity was more strongly correlated to deep cervical flexor activity, some individuals may still display a stronger compensation from the anterior scalene muscles rather than the sternocleidomastoid.

It could be questioned why there was not an even stronger negative correlation between the superficial and deep cervical flexors in the test. However, as said, individuals adapt differently to pain (Muceli et al., 2014, Gizzi et al., 2015) and people with neck pain likely use various strategies in attempts to reach the five progressive levels of the test. For instance, although many individuals compensate with the sternocleidomastoid muscles, some others may compensate with the anterior scalene muscles or even the hyoid muscles which would weaken the correlation between deep cervical flexor muscle activation and any one particular superficial muscle.

Subtle retraction rather than a pure sagittal rotation is one compensation strategy often observed in clinical practice (Jull et al., 2008). In line with an altered movement strategy, the individuals with neck pain in this study flexed the craniocervical region on average 5% less at each stage of the test than previously recorded for asymptomatic individuals (Falla et al., 2003b). This aberrant movement likely reflects the altered motor strategy for the task. Other
compensation strategies include increased velocity of movement, jaw opening and head lifting, however, detailed kinematics of head and neck movement were not monitored in this study.

The demographics and mean pain (NRS) and disability scores (NDI) of participants with persistent neck in this study were similar to those in other studies of mechanical neck pain (Walker et al., 2008, Bahat et al., 2015). However, it should be noted that higher activity of the sternocleidomastoid muscle during the craniocervical flexion test has been seen in people with moderate to severe pain following a whiplash trauma compared to those with milder symptoms (Sterling et al., 2003). Moreover, a significant relationship between the level of activity of the superficial neck flexor muscles during the craniocervical flexion test and neck pain intensity has been reported for people with non-specific neck pain (O'Leary et al., 2011) and higher levels of pain were associated with lower amplitude of deep cervical flexor muscle activation during performance of the craniocervical flexion test (Falla et al., 2011). Thus it could be speculated that an even stronger correlation between superficial and deep cervical flexor muscle activity would be observed in people with higher pain/greater neuromuscular dysfunction.

Although this study shows that higher levels of superficial flexor muscle activity are an indicator of reduced deep cervical flexor activity in the craniocervical flexion test, this does not imply that this relationship holds true for different tasks. Other studies have observed increased activity of the sternocleidomastoid and anterior scalene muscles in people with neck pain during other isometric (Falla et al., 2004b, Falla et al., 2010, Lindstrøm et al., 2011) and dynamic tasks (Falla et al., 2004a) but the findings of the current study cannot be used to interpret that data.

This study included female participants only. While the results cannot automatically be extrapolated to males, other studies indicate that there is no gender effect on performance in this low load, craniocervical flexion test (Chiu et al., 2005, Juul et al., 2013).

CONCLUSION
This study affirms the interpretation that higher levels of activity in the superficial flexor muscles are an indicator of reduced deep cervical flexor activity in the craniocervical flexion test. Future studies should measure and investigate further, the possible motor control strategies that persons with neck pain use to compensate for poorer activation of the deep cervical flexors in the test to inform best assessment in clinical practice.
REFERENCES


Highlights

• Analysis of cervical flexor muscle activity in the craniocervical flexion test
• Higher superficial flexor activity correlates with lesser deep flexor activity
• Evaluation of the deeper flexors may rely on superficial flexor evaluation