Neck flexor muscle fatigue is side specific in patients with unilateral neck pain

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Abstract

Despite the evidence of greater fatigability of the cervical flexor muscles in neck pain patients, the effect of unilaterality of neck pain on muscle fatigue has not been investigated. This study compared myoelectric manifestations of sternocleidomastoid (SCM) and anterior scalene (AS) muscle fatigue between the painful and non-painful sides in patients with chronic unilateral neck pain. Myoelectric signals were recorded from the sternal head of SCM and the AS muscles bilaterally during sub-maximal isometric cervical flexion contractions at 25% and 50% of the maximum voluntary contraction (MVC). The time course of the mean power frequency, average rectified value and conduction velocity of the electromyographic signals were calculated to quantify myoelectric manifestations of muscle fatigue. Results revealed greater estimates of the initial value and slope of the mean frequency for both the SCM and AS muscles on the side of the patient’s neck pain at 25% and 50% of MVC. These results indicate greater myoelectric manifestations of muscle fatigue of the superficial cervical flexor muscles ipsilateral to the side of pain. This suggests a specificity of the effect of pain on muscle function and hence the need for specificity of therapeutic exercise in the management of neck pain patients.

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1. Introduction

Greater myoelectric manifestations of muscle fatigue of the sternocleidomastoid (SCM) and anterior scalene (AS) muscles have been demonstrated in chronic neck pain patients with respect to asymptomatic controls (Falla et al., 2003). These results support other clinical studies which have identified a reduction in the strength and endurance capacity of the neck flexor muscles in patients with various neck pain syndromes (Barton and Hayes, 1996; Placzek et al., 1999; Silverman et al., 1991; Treleaven et al., 1994) as well as the findings of muscle biopsy studies of patients with neck pain undergoing spinal surgery, which established an increase in the number of type-IIC transitional fibres suggesting transformation of slow-twitch oxidative type-I fibres to fast-twitch glycolytic type-IIB fibres (Uhlig et al., 1995).

Despite the evidence of greater fatigability of the cervical flexor muscles in neck pain patients, the effect of unilaterality of neck pain on muscle fatigue has not been investigated. There is some evidence available to indicate that unilateral pain may have a particular effect on muscle function ipsilaterally. Larson et al. (1998) demonstrated a significant reduction in trapezius muscle blood flow on the painful side concomitant with reduced electromyographic amplitude and mean power frequency ipsilateral to symptoms in patients with chronic cervico-brachial pain. A reduction in muscle cross-sectional area has also been demonstrated ipsilateral to the side of pain in patients with unilateral back pain (Dangaria and Naesh, 1998; Hides et al., 1994). These results suggest a specific bias in the effect of pain on
muscle function and hence the possible need for specificity of therapeutic exercise in treatment.

The purpose of this study was to identify whether surface electromyographic (sEMG) manifestations of SCM and AS muscle fatigue were influenced by the laterality of pain in patients with chronic unilateral neck pain. Previous research examining the fatigability of the cervical flexor muscles has identified the absence of dominance effects for the right and left SCM and AS muscles in asymptomatic subjects (Falla et al., 2003).

2. Materials and methods

2.1. Subjects

Ten volunteer female subjects aged between 22 and 45 years (mean 32.3, SD 7.2 years) with a history of unilateral neck pain greater than 1 year (mean 5.9, SD 3.7 years), participated in this study. Patients who had either undergone cervical spine surgery, complained of any neurological signs or had participated in a neck exercise program over the past 12 months were excluded from the study. The cervical spine was examined by a trained physiotherapist to confirm the presence of cervical spine dysfunction and to confirm unilaterality of painful joint symptoms (Jull et al., 1988). Subjects completed the neck disability index (NDI) (Vernon and Mior, 1991) and visual analogue scales (VAS) were also used to record the patients’ average intensity of neck pain. Ethical approval for the study was granted by the Medical Research Ethics Committee of The University of Queensland, Australia and subjects provided written informed consent.

2.2. Instrumentation and measurements

Surface electromyographic (sEMG) recordings were made from the sternal head of SCM and AS muscles bilaterally using a linear array of four electrodes (silver bars 10 mm apart, 5-mm long, 1-mm diameter) in single differential configuration (Bergamo et al., 1999; Merletti et al., 1999). The electrodes were connected to a front-end amplifier via a high input impedance and a low output impedance stage incorporated in the probe. A ground reference was strapped around the wrist. Signals were recorded and differentially amplified with a gain of 2000, passed through a 10–450 Hz bandwidth filter (40 dB/decade slope on each side) and sampled at 2048 Hz (ASE16-16 channel amplifier, LISiN Centro di Bioingegneria, Politecnico di Torino, Italy). The samples were digitised by a 12 bit A/D converter and stored on a personal computer for signal processing (EMGACQ, LISiN Centro di Bioingegneria, Politecnico di Torino, Italy).

A custom designed cervical flexion force measuring device was anchored to a plinth (Fig. 1). With this apparatus, the subject’s head rested on a padded head support and an adjustable Velcro strap was fastened across the forehead, acting to stabilise the head and provide resistance during cervical flexion isometric contractions. The aluminium frame housed two load cells (CCT Transducers, Torino, Italy) with a full scale of 250 N each. The electrical signals from the load cell were amplified (MISO1, LISiN Centro di Bioingegneria, Politecnico di Torino, Italy) and relayed to a visual feedback device. This allowed sub-maximal targets to be set and provided the subject with feedback of the force level produced during contractions. Each force transducer was capable of recording both compression and tension and by this means, the offset could be adjusted to accommodate for the weight of the subject’s head. Excellent repeatability (Intraclass Correlation Coefficient = 92.5%) and good repeated measure precision (normalised standard error of the mean = 8.7%) have been demonstrated for repeated measures of cervical flexion force obtained during maximum voluntary contractions (MVC) using this device (Falla et al., 2002c).

2.3. Experimental procedure

Subjects were comfortably positioned in supine crook lying with their arms crossed over their chest. The starting position of the head and neck was standardised in a mid-position such that the subject’s forehead and chin were in a horizontal plane and an imaginary line, which extended from the tragus of the ear to bisect the neck longitudinally was parallel to the plinth (Falla et al.,...
The vertical height of the force measuring apparatus could be adjusted as required to achieve this position.

Prior to application of the electrode arrays, each subject performed three maximum voluntary isometric cervical flexion contractions of 3-s duration with an interval of 5 min between each repetition. Verbal encouragement was provided to induce the subject to reach their highest level in each trial. The highest value of force recorded over the three attempts was selected as the reference MVC allowing sub-maximal targets to be set on the visual feedback display.

The subject’s skin was prepared by gentle local abrasion using medical sandpaper (3 M Red Dot™) and cleaned with an alcohol wipe prior to attachment of the surface electrodes (Hermens et al., 2000). Electrode arrays were positioned along the length of the SCM and AS muscles bilaterally on one side of the innervation zone following published guidelines for correct electrode placement for these muscles (Falla et al., 2002b). A thin film of conductive electrode gel was applied to the electrodes to ensure good electrode contact for the duration of the experiment. The electrodes were fixed using a Fixomull® extensible dressing (Beiersdorf).

Once optimal sEMG signals were achieved, the subject was requested to perform a sub-maximal cervical flexion contraction in the supine lying position at 25% MVC for 20 s and at 50% MVC for 15 s using the visual display for feedback of the force output. A 5-min rest period was given between each contraction.

2.4. Data management

The initial values and rate of change of the mean power frequency (MNF), average rectified value (ARV) and conduction velocity (CV) were computed off-line with numerical algorithms (Merletti et al., 1989; Merletti et al., 1990) using non-overlapping signal epochs of 0.5 s thereby generating 40 estimates of each variable during the 20-s contractions and 30 estimates during the 15-s contractions.

Conduction velocity was computed as \( e/d \) where \( e \) is the inter-electrode distance (10 mm) and \( d \) is the delay time between the signals obtained from the two double differential arrays spaced 10 mm apart. The delay \( d \) was obtained by identifying the time shift required to minimise the mean square error between the Fourier transforms of the two double differential signals (Merletti et al., 1990).

The correlation coefficient (CC) between the two adjacent double differential signals was obtained and reviewed as evidence of the quality of the signals recorded and to confirm proper electrode positioning. Contractions were excluded from the analysis if the acquired double differential signals displayed a correlation coefficient less than 60%. Signals that demonstrated physiological estimates of CV albeit with a CC in the range 50–60% were included in data reduction. The distribution of the CC for the analysed data (79 signals, from AS and SCM pooled together, out of a total 80 recorded signals) was 31.6% in the range [50–59%], 29.1% in the range [60–69%] and 25.3% in the range [70–79%], and 14.0% for CC values equal or greater than 80%.

To compare the rate of change of different variables and allow comparison between sides, the time course of each sEMG variable was normalised with respect to the intercept of the regression line to produce a “fatigue plot” (Merletti et al., 1995; Rainoldi et al., 1999). Since the patterns of the plot were not curved, linear regression was applied to the data to calculate the initial value and slope of MNF, ARV and CV. The linear regression model was shown to fit the experimental data better than the exponential model. This is a common finding for signals obtained during voluntary contractions, particularly for the time course of MNF and CV (Arendt Nielsen and Mills, 1985; Masuda et al., 1999).

The Wilcoxon paired test was used to identify whether significant differences were evident between the affected and non-affected sides for each sEMG variable. A value of \( p < 0.05 \) was considered statistically significant.

3. Results

Table 1 presents the descriptive statistics for the duration of symptoms for the neck pain patient group, intensity of pain rated on the VAS and the subject’s perceived level of disability measured with the NDIs.

Table 2 reports the values (mean and standard deviation) of the initial values and slopes of the three sEMG variables (CV, MNF and ARV) estimated from the two sub-maximal contractions for the affected and non-affected side. Statistically significant between-side differences were identified for contractions at 25% and 50% of MVC for the initial value and slope of MNF for the AS muscle. For the SCM, between-side differences were identified for the initial value and slope of MNF at 25% MVC and initial value of MNF at 50% MVC. For the SCM muscle contracting at 50% MVC, greater values of the ARV initial value were identified on the side of pain (\( p < 0.05 \)). No significant differences between sides were identified for the initial value and slope of the CV and slope of the ARV for both muscles.

Fig. 2 illustrates an example of fatigue plots obtained from one subject for the sternocleidomastoid muscle on the painful and non-painful side contracting at 50% MVC for the sEMG variables ARV, CV and MNF. The values of each variable are normalised with respect to the intercept of the regression line. Greater myoelectric manifestations of sternocleidomastoid muscle fatigue.
The results of this study revealed greater myoelectric manifestations of muscle fatigue of the SCM and AS muscles ipsilateral to side of pain in patients with chronic unilateral neck pain. This was evidenced by significantly greater estimates of the rate of change of the MNF for the AS muscle at 25% and 50% MVC and for the rate of change of SCM MNF at 25% MVC. Furthermore, initial values of MNF at 25% and 50% MVC for both AS and SCM muscles were greater ipsilateral to the side of pain. These results confirm the hypothesis of a specificity of the effect of pain on muscle function and support previous research findings, which identified muscle dysfunction ipsilateral to the side of pain (Dangaria and Naesh, 1998; Hides et al., 1994; Larsson et al., 1998).

In our previous work (Falla et al., 2003) comparing subjects with bilateral neck pain to asymptomatic controls, greater fatigability of SCM and AS muscles ipsilateral to the side of greatest pain were demonstrated in patients with chronic bilateral neck pain compared to both the right and left SCM and AS muscles of asymptomatic controls. Significantly greater values of the MNF initial value and slope were identified for the neck pain patient group. Possible explanations were proposed to account for the differences identified in the neck flexor muscles of the neck pain patients: (1) greater percentage of type II muscle fibres, (2) modifications of motor unit (MU) synchronisation, (3) a combination of these mechanisms.

The results of the current study offer further confirmation of these hypotheses in addition to identifying the specificity of the changes in patients with unilateral neck pain. As demonstrated in Fig. 3, modifications of CV and MNF parameters are quite similar on the non-painful side, thus MNF variations can be entirely explained as a consequence of the CV variations. On the contrary, on the painful side, modifications of the rate of change of MNF cannot be solely attributed to the modifications of CV: some other factors must be responsible for the greater rate of change of MNF.

The increase of MNF initial values could be explained as a consequence to modifications of the recruited motor unit pool in which the number of type II (or larger) fibres is increased with respect to the type I (or smaller) fibres in the neck flexor muscles, resulting from the neck pathology. These findings are in accordance with results of muscle biopsy studies of subjects during contractions at 25% and 50% MVC. Significantly greater slopes were consistently identified for the MNF with respect to the CV for the painful side only. This difference was identified for both muscles and at both levels of contraction.

### 4. Discussion

Table 1 Descriptive statistics for the neck pain patients (N = 10)

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Mean ± SD</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of pain (years)</td>
<td>5.9 ± 3.7</td>
<td>6.0</td>
<td>1.0–11.5</td>
</tr>
<tr>
<td>Average intensity of pain (VAS)</td>
<td>5.0 ± 2.1</td>
<td>5.0</td>
<td>2.0–8.0</td>
</tr>
<tr>
<td>NDI (score out of 50)</td>
<td>11.8 ± 5.1</td>
<td>10.5</td>
<td>6.0–24.0</td>
</tr>
</tbody>
</table>

Duration of symptoms, intensity of pain rated on visual analogue scale (VAS, where 0 is no pain and 10 is worst pain imaginable) and subject’s perceived level of disability measured with the neck disability index (NDI).

Table 2 Absolute values (mean and standard deviation) of the initial values (IV) and slopes (SLO) of the estimated EMG variables (CV, MNF and ARV) for the two muscles [sternocleidomastoid (SCM) and anterior scalenes (AS)] contracting at 25% and 50% of the maximum voluntary contraction (MVC)

<table>
<thead>
<tr>
<th>IV</th>
<th>Painful side</th>
<th>Non-painful side</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNF IV (Hz)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS 25% MVC</td>
<td>124.13 ± 19.07</td>
<td>97.21 ± 14.19</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>AS 50% MVC</td>
<td>127.39 ± 18.24</td>
<td>107.56 ± 18.19</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>SCM 25% MVC</td>
<td>125.71 ± 25.11</td>
<td>108.14 ± 21.74</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>SCM 50% MVC</td>
<td>130.62 ± 24.19</td>
<td>116.82 ± 18.16</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>MNS SLO (Hz/s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS 25% MVC</td>
<td>−0.86 ± 0.63</td>
<td>−0.31 ± 0.48</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>AS 50% MVC</td>
<td>−1.67 ± 1.31</td>
<td>−0.50 ± 0.73</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>SCM 25% MVC</td>
<td>−0.89 ± 0.80</td>
<td>−0.57 ± 0.52</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>SCM 50% MVC</td>
<td>−1.62 ± 1.30</td>
<td>−1.18 ± 0.62</td>
<td>NS</td>
</tr>
<tr>
<td>CV IV (m/s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS 25% MVC</td>
<td>3.79 ± 0.33</td>
<td>3.91 ± 0.62</td>
<td>NS</td>
</tr>
<tr>
<td>AS 50% MVC</td>
<td>3.81 ± 0.68</td>
<td>3.78 ± 0.33</td>
<td>NS</td>
</tr>
<tr>
<td>SCM 25% MVC</td>
<td>4.01 ± 0.36</td>
<td>4.09 ± 0.48</td>
<td>NS</td>
</tr>
<tr>
<td>SCM 50% MVC</td>
<td>4.25 ± 0.19</td>
<td>4.09 ± 0.45</td>
<td>NS</td>
</tr>
<tr>
<td>CV SLO (m/s²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS 25% MVC</td>
<td>−0.00 ± 0.02</td>
<td>−0.01 ± 0.03</td>
<td>NS</td>
</tr>
<tr>
<td>AS 50% MVC</td>
<td>−0.02 ± 0.03</td>
<td>−0.02 ± 0.02</td>
<td>NS</td>
</tr>
<tr>
<td>SCM 25% MVC</td>
<td>−0.01 ± 0.02</td>
<td>−0.01 ± 0.02</td>
<td>NS</td>
</tr>
<tr>
<td>SCM 50% MVC</td>
<td>−0.02 ± 0.04</td>
<td>−0.02 ± 0.02</td>
<td>NS</td>
</tr>
<tr>
<td>ARV IV (μV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS 25% MVC</td>
<td>87.32 ± 40.87</td>
<td>89.93 ± 66.68</td>
<td>NS</td>
</tr>
<tr>
<td>AS 50% MVC</td>
<td>114.54 ± 47.58</td>
<td>129.99 ± 79.90</td>
<td>NS</td>
</tr>
<tr>
<td>SCM 25% MVC</td>
<td>132.64 ± 58.58</td>
<td>114.43 ± 65.72</td>
<td>NS</td>
</tr>
<tr>
<td>SCM 50% MVC</td>
<td>180.62 ± 72.77</td>
<td>144.41 ± 64.85</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>ARV SLO (μV/s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS 25% MVC</td>
<td>1.92 ± 1.49</td>
<td>1.78 ± 1.10</td>
<td>NS</td>
</tr>
<tr>
<td>AS 50% MVC</td>
<td>4.20 ± 2.97</td>
<td>4.93 ± 5.06</td>
<td>NS</td>
</tr>
<tr>
<td>SCM 25% MVC</td>
<td>1.61 ± 1.31</td>
<td>1.19 ± 1.21</td>
<td>NS</td>
</tr>
<tr>
<td>SCM 50% MVC</td>
<td>4.46 ± 3.43</td>
<td>3.95 ± 2.71</td>
<td>NS</td>
</tr>
</tbody>
</table>

The p values of the Wilcoxon paired test for the analysis of differences between the affected and non-affected side are also reported for the 10 patients.

are evident ipsilateral to the side of pain as characterised by the faster rate of change of the MNF over time.

Fig. 3 presents Box and Whisker plots of the normalised slopes for the MNF and CV obtained for SCM and AS recorded from the painful and non-painful sides.
with neck pain undergoing spinal surgery, which estab-
lished an increase in the number of type-IIC transitional
fibres in the neck flexor muscles suggesting transfor-
mations of slow-twitch oxidative type-I fibres to fast-
twitch glycolytic type-IIB fibres (Uhlig et al., 1995).
The surgical approach in this latter muscle biopsy
study would most likely be from the painful side, pre-
cluding comment on the possibility of any side-to-side

Fig. 2. Example of fatigue plots obtained from one subject from the sternocleidomastoid muscle on the painful and non-painful side contracting at
50% of the MVC for the sEMG variables average rectified value (ARV), conduction velocity (CV) and mean frequency (MNF). The values of each
variable are normalised with respect to the intercept of the regression line. Greater myoelectric manifestation of fatigue of the sternocleidomastoid
muscle is evident ipsilateral to the side of pain as characterised by the faster rate of change of the MNF over time.

Fig. 3. Box and Whisker plots (mean, standard deviation and standard error of the mean) of the normalised slopes for the mean frequency (MNF)
and conduction velocity (CV) obtained for the sternocleidomastoid (SCM) and anterior scalenes (AS) recorded from the painful (P) and non-painful
sides (NP) during contractions at 25% and 50% of the maximum voluntary contraction (MVC). The results of the Wilcoxon paired test are included
to highlight the differences between each estimate.
differences in these changes. The increase in the rate of change of MNF on the side of pain identified in this study, further validates the first hypothesis of fibre type modifications in the neck flexor muscles of neck pain patients. As known, lactate production is related to the percentage of type II fibres in the muscle (Tesch et al., 1983) and is considered as one of the contributing factors for the decline in the CV (and consequently the MNF) during sustained isometric contractions (Brody et al., 1991). Myoelectric manifestations of muscle fatigue are related to factors which include the modification of the muscular CV (De Luca, 1984; Kadefors et al., 1978). Our results did not demonstrate modification of global estimates of the initial value and rate of change of CV. We can speculate that the observed variations of the MNF parameters (initial value and slope) are due to modifications of the motor unit action potential (MUAP) CV distribution. That is, the same average CV could be obtained from different values of individual MUAP CV with different distributions around the mean. According to the muscle biopsy results (Uhlig et al., 1995), the increase of type II (or type II-like) fibres would generate an absolute increase of type II fibres and a decrease of type I fibres. For this reason the fibre type distribution will be skewed towards type II fibres with respect to a more uniform distribution. Under these circumstances, it is reasonable to speculate that a lower number of type I compared to type II fibres will be available for recruitment during the isometric contraction at 25% MVC. Thus, type I fibres will fatigue to a greater extent than type II fibres (because they are recruited first) and as a consequence, a greater rate of change of MNF will be present without modification of the average CV. If this was the case then this first hypothesis would appear to be a good candidate for the interpretation of the results identified in this study.

Different control strategies could provide another explanation for the greater myoelectric manifestations of muscle fatigue for the cervical flexors of the neck pain patients. As described elsewhere (Kleine et al., 2001; Stegeman et al., 2000) motor unit (MU) synchronisation produces a decrease of MNF. Since MU synchronisation is a central mechanism of adaptation, often due to fatigue, this could be an alternative way to explain the greater increase of MNF rate of change observed on the painful side. Greater MU synchronisation for the SCM and AS muscles on the side of pain would result in earlier myoelectric manifestations of fatigue of these muscles and hence, greater values of the slope of MNF. Greater MU synchronisation would also explain the greater values of the ARV initial value on the side of pain for the SCM muscle contracting at 50% MVC. According to the pain-adaptation model (Lund et al., 1991) a painful muscle should become inhibited with a reduced MU firing rate and its lack of activity compensated by the increase of recruitment of accessory muscles. Upon review of the body charts completed by the patients prior to testing, the typical area of pain documented was over the posterior aspect of the neck, not over the SCM and AS muscles. Greater MU synchronisation in the SCM and AS muscles could be explained as a measurable altered muscle strategy for dysfunction in other muscles (Falla et al., 2003).

The greater initial value of ARV ipsilateral to the side of pain in the SCM contracting at 50% of MVC could also be interpreted as a lack of muscular efficiency on the side of pain. The neuromuscular efficiency (NME), defined as “the quotient of force and the integrated EMG” (van der Hoeven et al., 1993) provides an estimate of the amount of electrical activity that each muscle generates to produce a value of force. The significantly greater estimates of ARV initial values for SCM ipsilateral to the side of pain indicates greater muscular electrical activity, that is, less NME on the side of pain. The drawbacks associated with the use of this variable when comparing different subjects with different thickness of subcutaneous tissue has been discussed in previous work (Falla et al., 2003), however, assuming that no differences in subcutaneous tissue thickness would be present between the two sides of the neck, this factor cannot bias the results.

5. Conclusion

The results of this study revealed significantly greater estimates of the initial value and slope of MNF for both the SCM and AS muscles ipsilateral to the side of pain in patients with chronic unilateral neck pain. This suggests a specificity of the effect of pain on muscle function and hence the need for specificity and perhaps unilateral bias to therapeutic exercise in the management of neck pain patients to achieve optimal rehabilitation of muscle function.

Acknowledgements

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References


