Masterclass

Unravelling the complexity of muscle impairment in chronic neck pain

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Abstract

Exercise interventions are deemed essential for the effective management of patients with neck pain. However, there has been a lack of consensus on optimal exercise prescription, which has resulted from a paucity of studies to quantify the precise nature of muscle impairment, in people with neck pain. This masterclass will present recent research from our laboratory, which has utilized surface electromyography to investigate cervical flexor muscle impairment in patients with chronic neck pain. This research has identified deficits in the motor control of the deep and superficial cervical flexor muscles in people with chronic neck pain, characterized by a delay in onset of neck muscle contraction associated with movement of the upper limb. In addition, people with neck pain demonstrate an altered pattern of muscle activation, which is characterized by reduced deep cervical flexor muscle activity during a low load cognitive task and increased activity of the superficial cervical flexor muscles during both cognitive tasks and functional activities. The results have demonstrated the complex, multifaceted nature of cervical muscle impairment, which exists in people with a history of neck pain. In turn, this has considerable implications for the rehabilitation of muscle function in people with neck pain disorders.

1. Introduction

Chronic neck pain is becoming increasingly prevalent in society. Estimations indicate that 67% of individuals will suffer neck pain at some stage throughout life (Cote et al., 1998). With an increasing sedentary population, especially with reliance on computer technology in the workplace, it is predicted that the prevalence rate will continue to rise. Effective management of this condition is vital, not only for the relief of symptoms but perhaps more importantly, for the prevention of recurrent episodes of cervical pain, personal suffering and lost work productivity.

It is estimated that the osseoligamentous system contributes 20% to the mechanical stability of the cervical spine while 80% is provided by the surrounding neck musculature (Panjabi et al., 1998). The ligaments’ role in stabilization occurs mainly at end of range postures (Harms-Ringdahl et al., 1986) while muscles supply dynamic support in activities around the neutral and mid-range postures, which are commonly adopted during functional daily tasks. In the presence of injury or pathology, the role of the muscular system becomes even greater which highlights the need to address the muscle system during both the assessment and rehabilitation of patients with neck pain.

Exercise interventions are deemed essential for the effective management of patients with neck pain. In the past however, there has been a lack of consensus on optimal exercise prescription. This results from a paucity of studies to quantify the precise nature of impairment in both the deep and superficial cervical muscles in neck pain patients.

Anecdotal evidence (Janda, 1994) suggests the cervical flexor muscles become dysfunctional in the presence of neck pain. Furthermore, simple clinical mechanical measures have demonstrated a reduction in the strength and endurance capabilities of the cervical flexor muscles in neck pain patients (Silverman et al., 1991; Vernon et al., 1992; Watson and Trott, 1993; Barton and Hayes, 1996; Placzek et al., 1999). However, such basic mechanical measures may oversimplify the deficits.
within the muscle system in people with neck pain disorders.

Detection, recording and analysis of myoelectric signals with surface electromyography (EMG) provides a more sophisticated means of determining aberrant muscle function. Although EMG has been used to analyse superficial cervical muscle function in the past, such investigations are infrequent and regular inconsistencies in the applied methodology limits the interpretation of results. Moreover, the inaccessibility of the deep cervical flexor (DCF) muscles has rendered the use of conventional surface EMG measures inappropriate.

Recent research has refined the application of surface EMG for the assessment of the cervical flexor muscles. This has involved optimizing the application of surface EMG for the assessment of the superficial cervical flexors (sternocleidomastoid and the scalenes) (Falla et al., 2002a, b) and secondly establishing a new EMG electrode and technique for obtaining a direct measure of the DCF muscles (Falla et al., 2003a).

Upon developing the methodology we investigated cervical flexor muscle function in patients with neck pain in three main areas of EMG assessment (1) myoelectric manifestations of cervical muscle fatigue (2) analysis of the cervical flexor muscle activation patterns and (3) analysis of cervical neuromotor control. This paper will present this recent evidence from our laboratory of the complexity of cervical muscle impairment in neck pain patients and in turn will highlight the implications for rehabilitation.

2. Muscle fatigability

Numerous studies have demonstrated a reduction in the strength and endurance capacity of the cervical flexor and extensor muscles in patients with neck pain (Watson and Trott, 1993; Treleaven et al., 1994; Barton and Hayes, 1996; Placzek et al., 1999). With advances in EMG technology, more sophisticated measures have been used to quantify cervical muscle fatigability in patients with neck pain (Falla et al., 2003b, 2004e, f; Gogia and Sabbahi, 1994). In a recent study (Falla et al., 2003b) we examined fatigability of the sternocleidomastoid (SCM) and anterior scalene (AS) muscles during sustained cervical flexion contractions at 25% and 50% of the maximum voluntary contraction (MVC) in patients with chronic neck pain compared to controls. Greater myoelectric manifestations of SCM and AS muscle fatigue were identified for the neck pain patient group as indicated by a significantly greater slope of the mean frequency (Fig. 1). Whilst the results of our study...
confirmed greater fatigability of the cervical flexors at moderate loads (50% MVC) which was identified by Gogia and Sabbahi (1994), our results also established greater cervical flexor muscle fatigability during low load sustained contractions (25% MVC) in the patient group which reflects the clinical observation of reduced endurance in the cervical flexors in neck pain patients (Treleaven et al., 1994; Watson and Trott, 1993; Barton and Hayes, 1996; Placzek et al., 1999). Furthermore, an increase of the mean frequency at the beginning of the contraction was observed for both muscles in the neck pain group. This could be attributed to modification of the recruited motor unit pool in which the number of type II fibres is increased with respect to the type I fibres. These findings were in accordance with results of muscle biopsy studies of subjects with neck pain undergoing spinal surgery, which established an increase in the number of type-IIC transitional fibres in the neck flexor muscles resulting from transformations of slow-twitch oxidative type-I fibres to fast-twitch glycolytic type-IIB fibres (Uhlig et al., 1995).

Subsequent to these results, the specificity of this aberrant muscle function was analysed (Falla et al., 2004e). In examining for differences in the fatigability of SCM and AS muscles between the painful and non-painful sides in patients with chronic unilateral neck pain, results revealed greater estimates of the initial value and slope of the mean frequency for both the SCM and AS muscles ipsilateral to the side of pain at 25% and 50% of MVC. These results indicate the need to address fatigability of the cervical flexor muscles when prescribing therapeutic exercise for neck pain patients. The outcomes advocate the need for specificity and perhaps a unilateral bias to therapeutic exercise in the management of patients with unilateral neck pain to attain optimal muscle rehabilitation. Of interest, the duration of neck pain does not appear to correlate with the extent of SCM and AS muscle fatigability in patients with chronic neck pain. This finding would suggest that the greater fatigability of the cervical flexor muscles, which has been identified in patients with neck pain, occurs early with the onset of neck pain and does not worsen with time (Falla et al., 2004f).

3. Muscle activation patterns during cognitive tasks

Whilst direct evidence of deep cervical extensor muscle dysfunction has been identified in neck pain patients (Hallgren et al., 1994; McPartland et al., 1997), until recently, there was no succinct evidence that described impairment in the DCF muscles. The DCF muscles, including the longus colli, longus capitis, rectus capitis anterior and rectus capitis lateralis, are histologically and morphologically designed to provide support to the cervical lordosis and the cervical joints (Winters and Peles, 1990; Mayoux-Benhamou et al., 1994; Conley et al., 1995; Vasavada et al., 1998; Boyd Clark et al., 2001, 2002). Accordingly, our research has been orientated towards the identification and quantification of deficits in the DCF muscles in patients with neck pain disorders.

Our interest commenced with the development of the cranio-cervical flexion (C-CF) test (Jull et al., 1999; Jull, 2000), which is a low load task, based on the anatomical action of the deep longus capitis and colli muscles. The C-CF test was considered to provide an indirect measure of DCF muscle activation and endurance capacity, which could be utilized in a clinical environment. The test is performed in crook lying, and requires the person to perform a head nod action (cranio-cervical flexion) in five incremental stages of increasing range and hold each position for 5–10 s. Performance is guided by feedback from a pressure sensor, which is positioned sub-occipitally to monitor the flattening of the cervical lordosis, which occurs with the contraction of longus colli (Mayoux-Benhamou et al., 1994, 1997).

Earlier clinical research demonstrated significantly inferior performance on the C-CF test in patients with idiopathic neck pain and with neck pain after a whiplash injury (Jull et al., 1999; Jull, 2000). In general, patients demonstrated a reduced ability to reach and maintain the targets of pressure in the cuff under the cervical spine. Furthermore, surface EMG recordings of the superficial cervical flexor (sternocleidomastoid) indicated that performance on the test was associated with significantly higher EMG amplitude of this muscle compared with controls (Jull, 2000; Jull et al., 2004b). Based on this research it was hypothesized that impaired performance on the C-CF test (1) reflected a deficit in motor control of C-CF in patients with neck pain (2) reflected poor activation of DCF muscles and (3) reflected poor muscle support of cervical joints (Jull, 2000). The difficulty in substantiating these hypotheses was related to the difficulty in obtaining a direct recording of the DCF muscles due to their depth and close proximity to nearby structures such as the lymphatic system, the sympathetic chain, vagus nerve and the carotid artery. However, our recent research (Falla et al., 2003a) led to the development of an electrode capable of recording DCF muscle activity (Fig. 2) without the need for fine wire EMG and thus provided the opportunity to corroborate or refute these hypotheses.

Utilizing this new EMG technique, we investigated activation of the DCF muscles in patients with and without chronic neck pain during performance of the C-CF test (Falla et al., 2004c). The results demonstrated reduced activation of the DCF muscles for the neck pain patient group across all stages of the C-CF test with the difference becoming statistically significant at the higher levels of the test (representing increasingly inner range...
positions of C-CF (Fig. 3). Furthermore, the neck pain patient group demonstrated reduced C-CF range of motion across all stages of the C-CF test (Fig. 3). This finding suggests that the pressure increase in the cuff under the cervical spine of neck pain patients was induced by a different movement strategy such as head/neck retraction, which is commonly observed clinically. Based on the results of this study it was concluded that neck pain patients have a disturbance in the neck flexor synergy, where impairment in the deep muscles, important for segmental control and support, appears to be compensated for by increased activity in the superficial muscles (SCM and AS).

### 4. Neuromuscular efficiency

Increased EMG activity of the superficial cervical musculature which has been identified in people with neck pain during performance of the C-CF test (Jull, 2000; Jull et al., 2004b), could be considered an inefficient neuromuscular activation pattern. This concept was explored recently by investigating the neuromuscular efficiency (NME) of the SCM and AS muscles, defined as the quotient of force and the integrated EMG (van der Hoeven et al., 1993), during cervical flexion contractions at 25% and 50% of MVC in patients with and without chronic neck pain (Falla et al., 2004b). The results of our study confirmed less NME for the SCM and AS muscles contracting at 25% MVC in the neck pain patient group. Reduced NME indicates that the neck pain patients required...
greater muscular electrical activity to produce an equivalent amount of force as compared to the control subjects, or conversely, with a comparable amount of electrical activity, neck pain patients would produce a lower force output (Falla et al., 2004b). The greater SCM and AS EMG activity recorded for the neck pain group could theoretically be attributed to (1) greater excitability of the motoneuronal pool, (2) modification of neural activation patterns accommodating for weakness or inhibition of another muscle, or (3) a combination of these mechanisms.

5. Muscle activation during functional tasks

Until now, the evidence of cervical muscle impairment presented within this manuscript corresponds to altered muscle function identified during prescribed motor tasks. In particular, research has demonstrated the presence of overactivity or neuromuscular inefficiency of the superficial cervical muscles under conditions of low biomechanical load (Jull, 2000; Falla et al., 2004b, c). However, this altered pattern of neuromuscular activation has been detected during non-functional tasks. Therefore, extrapolation of these findings to function must be done so with caution.

In order to assess whether the presence of increased EMG activity of the superficial cervical flexor muscles was present during functional activities in people with neck pain, we investigated activity of the SCM and AS muscles during a low load, functional upper limb task (Falla et al., 2004a). Subjects were asked to perform a repetitive unilateral task, which involved marking three targets, positioned on a desk in front of them, using their right hand. Their left forearm rested motionless on the desk in front of them. Previous research using this task has demonstrated higher co-activation of the upper trapezius muscle in neck pain patients compared to controls during performance of the task and a decreased ability to relax the upper trapezius muscle on completion of the task (Nederhand et al., 2000).

As demonstrated in Fig. 4, the altered pattern of muscle activation identified for both idiopathic neck pain and whiplash patients was characterized by increased EMG amplitude for the AS and SCM muscles bilaterally throughout performance of the functional activity. Furthermore, neck pain patients demonstrated a decreased ability to relax the SCM and AS muscles on completion of the task. It was suggested that the altered pattern of muscle activation identified for the neck pain groups represents an altered motor strategy to minimize activation of painful muscles or compensate

![Boxplots representing (25th quartile, mean, 75th quartile and 95% confidence intervals) normalized root mean square (RMS) values for the left (L) and right (R) SCM and AS muscles in patients with whiplash associated disorder (WAD), idiopathic neck pain and control subjects. Values are given for conditions 10, 60 and 120 s into the performance of a repetitive upper limb task and 10 s after completion of the repetitive upper limb task (post). *Indicate significant differences between groups calculated from the logarithm values of the data set. Statistical significance was defined as the mean value for one group falling outside the 95% confidence interval of the comparison group. (Adapted from Fig. 1 in Falla et al., 2004a).](image-url)
for inhibited muscles and might represent a functional correlate of performance on the C-CF test (Falla et al., 2004a).

6. Muscle activation during postural perturbations

Evidence was starting to reveal specific deficits within the cervical flexor muscles in patients with neck pain. This was identified during performance of prescribed motor tasks and during functional activities. The next stage of our research was to identify whether the automatic function of the cervical muscles was impaired in people with neck pain.

We know from research in healthy individuals that during performance of rapid arm movements which induce a postural perturbation, the cervical muscles are co-activated within 50 ms of the onset of deltoid activity. This indicates that this response is too fast to be mediated by even the fastest reflexes. Instead these responses are considered to be preplanned by the nervous system and are termed “feed-forward” adjustments (Gurfinkel et al., 1988; van der Fits et al., 1998; Falla et al., 2004g).

In reference to the lumbar spine model, a significant delay has been identified for the transversus abdominis muscle in patients with low back pain during rapid arm movements (Hodges and Richardson, 1996). Utilizing the same experimental model we aimed to determine whether a deficit in the timing of the cervical muscles would be present in people with chronic neck pain. The results of our study confirmed the hypothesis of delayed onset of the DCF and the SCM and AS muscles in people with a history of neck pain compared to control subjects (Fig. 5) (Falla et al., 2004d).

Although each of the neck muscles demonstrated some difference in onset time between groups, the DCF demonstrated the most significant deviation during rapid shoulder flexion. The relative latency of the DCF contraction exceeded the criteria for feed-forward contraction during movements in both directions in the neck pain group, which indicates a significant deficit in the automatic feed-forward control of the cervical spine. Considering the deep cervical muscles, longus colli and longus capitis, are fundamentally important for the provision of support for the cervical lordosis and the cervical joints (Mayoux-Benhamou et al., 1994; Conley et al., 1995; Vasavada et al., 1998), it was concluded that a change in the feed-forward response might leave the cervical spine vulnerable to strain (Falla et al., 2004d).

7. Implications for rehabilitation

In summary, contemporary research has demonstrated impairment in the deep cervical muscles, which are considered to be functionally important for joint support and control (Jull, 2000; Falla et al., 2004c, d), deficits in muscle co-ordination which could result in poor support and potential overload on cervical structures (Jull, 2000; Falla et al., 2004a), insufficiency in the pre-programmed activation of cervical muscles (Falla et al., 2004d), inefficient neuromuscular activation (Falla et al., 2004b), and greater fatigability of superficial cervical muscles in people with chronic neck pain (Gogia and Sabbahi, 1994; Falla et al., 2003b, 2004)}
2004c). In consideration of the evidence, it would seem apparent that there is a need for specificity when prescribing therapeutic exercise in the management of people with neck pain.

There is some evidence to indicate that deficits in the motor system occur early in the history of onset of neck pain (Sterling et al., 2003) and does not resolve automatically with lessening or resolution of symptoms (Jull et al., 2002; Sterling et al., 2003). This would suggest that therapeutic exercise forms an essential component of the rehabilitation of patients with neck pain, as a reduction of pain alone would seem insufficient to fully restore muscle function. Moreover, it emphasizes the importance of early rehabilitation of muscle function in people with neck pain disorders.

When developing exercises for treatment, it is necessary to have an understanding of abnormalities in the muscular system associated with painful dysfunctional joints. The results of recent research have significantly advanced our understanding of the impairment in the deep and superficial cervical flexor muscles in patients with neck pain syndromes. This knowledge provides the foundation to further develop and evaluate specific exercises for the management of this condition.

Based on the muscle deficits considered to occur in neck pain, two types of exercise programs have been proposed in the literature to address cervical flexor muscle impairment. These two types of exercise programs are focused on two different functional requirements. The first exercise regime consists of general strengthening and endurance exercises for the neck flexor muscles (Berg et al., 1994; Highland et al., 1992; Jordan et al., 1998; Bronfort et al., 2001). These exercises involve high load training and thus recruit all the muscle synergists that is, both the deep and superficial muscles. For example, strengthening the neck flexor muscles is achieved by performing a head lift movement which would recruit all muscles capable of contributing to this action including, SCM, AS, longus colli and longus capitis. A typical exercise program would train the cervical flexors with the controlled head lift exercise and focus on training endurance and increasing the number of repetitions. Although several studies have reported a reduction in pain and improvement in function with this style of exercise (Highland et al., 1992; Berg et al., 1994; Bronfort et al., 2001), critical reviews and meta-analyses have generally concluded that further well-designed randomized controlled trials are warranted (Aker et al., 1996; Kjellman et al., 1999; Panel, 2001).

The second exercise regime has been designed to focus on the muscle control aspects and aims at improving control of the muscles within the neck flexor synergy (Jull et al., 2004a). In contrast to more traditional high load strength and endurance exercises, low load exercise is used to train the coordination between the layers of neck flexor muscles. With this protocol, patients perform and hold progressively inner ranges of C-CF while trying to minimize activation of the superficial flexors. This exercise approach is based on biomechanical evidence of the functional interplay of the deep and superficial neck muscles and on physiological and clinical evidence of impairments in these muscles in neck pain patients. The efficacy of this emphasis on retraining the C-CF action in association with similar exercises for the shoulder girdle was tested recently in a randomized controlled clinical trial of physiotherapy management for cervicogenic headache (Jull et al., 2002). The results indicated that the specific exercise program significantly reduced the frequency of headache and neck pain and results were maintained in the long term at the 12-month follow-up. General strengthening exercises are not recommended in the early stages in this exercise approach as it is considered that general exercise will not necessarily address the dysfunction between the deep and superficial muscles (Jull, 2000). Thus specific emphasis is first placed on reeducating the deep and postural muscles and general strengthening exercises are only introduced once the imbalance between the deep and superficial neck synergists has been addressed.

However, the results of recent research have created an interesting situation. There is evidence of reduced activation capacity of the DCF muscles with concurrent increased activity in the superficial muscles. Conversely, the superficial muscles have demonstrated greater fatigability and there is evidence of less strength. Therefore, there is some indication that both exercise regimes may be beneficial in the management of cervical muscle dysfunction in neck pain patients.

Although clinical trials of both exercise regimes have produced results to suggest a decrease in neck pain, the physiological mechanisms of efficacy of cervical flexor muscle retraining regimes remain uncertain. For example, an improvement in DCF muscle activation would be expected following an exercise program based on retraining the activation capacity of the deep muscles. However, would this program influence the fatigability or neuromuscular efficiency of the superficial cervical flexor muscles? Similarly, we would expect a training regime focused on high load resistance training to enhance superficial cervical flexor muscle strength and reduce fatigability, but would it alter the neuromotor control of the DCF muscles? There is a paucity of good clinical studies regarding the efficacy of therapeutic exercise in neck pain patients, precluding any consensus on the most effective exercise prescribed. Although both exercise regimes are based on sound theoretical rationale, the mechanism of efficacy for either program is unclear. Further research is warranted to evaluate the physiological factors that change with each exercise intervention and to compare the different exercise
modalities in order to identify the most effective means to induce these changes. This work is currently underway.

8. Conclusion

In recent years, research has started to unravel the complexity of muscle impairment, which occurs in people with neck pain disorders. These findings have considerable implications for the prescription of therapeutic exercise. Whilst knowledge of the pathophysiology underlying cervical muscle dysfunction remains somewhat imprecise, the results of recent research have contributed greatly to our understanding of the impairment in the cervical muscles in people with neck pain, which has lead to an improved understanding and direction for the management of this condition. Further research is now necessary to clarify the physiological mechanisms of efficacy of cervical muscle retraining to ensure evidence based, optimal practice is embraced in modern practice.

References


