

An endurance-strength training regime is effective in reducing myoelectric manifestations of cervical flexor muscle fatigue in females with chronic neck pain

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Abstract

Objective: The purpose of this study was to investigate whether an endurance-strength training program is effective in reducing myoelectric manifestations of sternocleidomastoid (SCM) and anterior scalene (AS) muscle fatigue which have been found to be greater in people with chronic neck pain.

Methods: Fifty-eight female patients with chronic non-severe neck pain were randomized into one of two 6-week exercise intervention groups: an endurance-strength training regime for the cervical flexor muscles or a referent exercise intervention involving low load retraining of the cranio-cervical flexor muscles. The primary outcomes were a change in maximum voluntary contraction (MVC) force and change of the initial value and rate of change of the mean frequency, average rectified value and conduction velocity detected from the SCM and AS muscles during sub-maximal isometric cervical flexion contractions at 50, 25 and 10% MVC.

Results: At the 7th week follow-up assessment, the endurance-strength training group revealed a significant increase in MVC force and a reduction in the estimates of the initial value and rate of change of the mean frequency for both the SCM and AS muscles ($P < 0.05$). Both exercise groups reported a reduced average intensity of neck pain and reduced neck disability index score ($P < 0.05$).

Conclusions: An endurance-strength exercise regime for the cervical flexor muscles is effective in reducing myoelectric manifestations of superficial cervical flexor muscle fatigue as well as increasing cervical flexion strength in a group of patients with chronic non-severe neck pain.

Significance: Provision of load to challenge the neck flexor muscles is required to reduce the fatigability of the SCM and AS muscles in people with neck pain. Improvements in cervical muscle strength and reduced fatigability may be responsible for the reported efficacy with this type of exercise program.

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1. Introduction

Over the past decade, numerous studies have demonstrated a reduction in the strength and endurance capacity of the cervical flexor muscles in patients with neck pain disorders (Barton and Hayes, 1996; Chiu and Sing, 2002;

Placzek et al., 1999; Ylinen et al., 2004). Collectively, this evidence demonstrates a significant reduction in muscle function as a result of longstanding neck pain and/or cervicogenic headache. Furthermore, in our study which investigated the fatigability and motor unit properties of the cervical flexor muscles using electromyography (EMG), we identified greater myoelectric manifestations of sternocleidomastoid (SCM) and anterior scalene (AS) muscle fatigue in people with chronic neck pain compared to healthy controls (Falla et al., 2003b). This was characterized by a significantly greater rate of change of the mean spectral frequency during sustained cervical flexion contractions at

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25 and 50% of the maximum voluntary contraction for the neck pain patient group. In addition, an increase of the mean spectral frequency at the beginning of the contraction was observed for both the SCM and AS muscles in the neck pain patients. This could be attributed to differences in the recruited motor unit pool during this type of muscle contraction for the patient group or a result of different control strategies employed by neck pain patients and control subjects to maintain force in a sustained contraction.

It has been recommended that general strengthening and endurance exercises for the cervical flexor muscles be prescribed to people with neck pain to improve the strength and reduce the fatigability of their neck muscles (Levoska and Keinanen-Kiukaanniemi, 1993; Ylinen et al., 2003). The exercises commonly described involve resistance training, for example, strengthening the cervical flexor muscles by performing a head lift exercise. A typical exercise program would train the cervical flexors with the controlled head lift exercise and focus on training endurance by increasing the number of repetitions (Levoska and Keinanen-Kiukaanniemi, 1993; Ylinen et al., 2003).

Although several studies have reported a reduction in pain with strengthening exercise for the neck muscles (Berg et al., 1994; Bronfort et al., 2001; Highland et al., 1992; Levoska and Keinanen-Kiukaanniemi, 1993; Ylinen et al., 2003), it is unknown whether this exercise regime would influence the myoelectric manifestations of superficial cervical flexor muscle fatigue which have previously found to be greater (indicating greater fatigability) in a people with chronic neck pain (Falla et al., 2003b).

The purpose of this study was to investigate whether an endurance-strength exercise intervention for the cervical flexors is capable of reducing SCM and AS muscle fatigability in people with chronic neck pain. The endurance-strength protocol was compared with a referent exercise intervention which in contrast to the endurance-strength protocol, used a low load exercise regime aimed at training the deep cranio-cervical flexors while minimizing activation of SCM and AS muscles (Jull et al., 2004), and has been shown to be effective for neck pain reduction (Jull et al., 2002). This allowed us to identify whether provision of a load to challenge the neck flexor muscles is required to induce a change in these fatigue parameters in people with neck pain, rather than simply a reduction in pain.

2. Methods

2.1. Subjects

Fifty-eight female participants with a history of chronic neck pain of greater than 3 months duration participated in this study. Sample size (26 per group plus 10% drop out allowance) was based on the difference in rate of change of the EMG mean frequency between a group of neck pain and asymptomatic subjects (mean difference 0.65, SD 0.83,

power 90%) (Falla et al., 2003b). Thus, the study was powered to detect a difference in ability of the program to change endurance parameters and not to compare the efficacy of the approach to reduce pain and disability.

Subjects were recruited by advertisements in the local press. To be included, subjects had to score ≤ 15 (out of a possible 50) on the neck disability index. (Vernon and Mior, 1991). People with more severe pain were excluded as this group may have increased symptoms from the strengthening exercise regime. Subjects had to also have palpable cervical joint tenderness upon manual examination of the cervical spine (Jull et al., 1988). Subjects were not considered if they had undergone cervical spine surgery, presented with any neurological signs or had participated in a neck exercise program in the past 12 months. Participants were screened for inclusion and exclusion criteria. Ethical approval for the study was granted by the Institutional Medical Research Ethics Committee and all procedures were conducted according to the Declaration of Helsinki. Written informed consent was provided before participation.

2.2. Exercise interventions

Patients with chronic neck pain were randomized by an independent body into two exercise groups: endurance-strength training of the cervical flexor muscles and a referent exercise intervention consisting of low load training of the cranio-cervical flexor muscles. The later exercise regime has been shown to reduce pain and improve function but would not be expected to substantially change strength and fatigability of the superficial neck flexors as the aim of the exercise is to decrease the relative activity of these muscles during performance of the tasks. Exercise regimes were conducted over a 6-week period and patients in each group received personal instruction and supervision by an experienced physiotherapist once per week for the duration of the trial. None of the exercise sessions were longer than 30 min. Although subjects were asked to refrain from seeking any other form of specific intervention for their neck, any medication currently taken by a participant was not withheld. All subjects were supplied with an exercise diary and requested to practice their respective regime twice per day for the duration of the trial. The exercise occupied a period of no longer than 10–20 min/day. The exercises were to be done without any provocation of neck pain and with particular attention to performance of smooth uniplanar movements.

2.2.1. Endurance-strength training intervention

The endurance-strength training regime consisted of a progressive resistance exercise program for the neck flexors. Performed in supine, with the head supported in a comfortable resting position, patients were instructed to lift their head so that cervical flexion was performed while maintaining a neutral upper cervical spine. Patients were to slowly move the head and neck through as full a range of

motion as possible without causing discomfort or reproduction of their symptoms. This exercise regime was a two-stage program. The first stage lasted for 2 weeks and the second for 4 weeks as recommended for initiating a weight program in previously untrained individuals (McArdle et al., 1996). In stage one, the subjects performed 12–15 repetitions with a weight that they could lift 12 times on the first training session (12 repetitions maximum) and progressed to 15 repetitions. They were maintained at this level for the remainder of the 2 week period. In stage two, the subjects performed 3 sets of 15 repetitions of the initial 12 repetitions maximum load. One-minute rest intervals were provided between sets. If repetitions were easily achieved, weighted sandbags were applied to the patient's forehead in 0.5 kg increments as required. If the patient was unable to perform repetitions of the head lift maneuver then the neck flexors were de-loaded by reducing the vertical component of the head weight vector. That is, the upper body (trunk and neck) was inclined up from the horizontal such that the patient could perform the required repetitions of the movement.

2.2.2. Cranio-cervical flexion exercise intervention

The referent exercise intervention consisted of low load exercise for the cranio-cervical flexor muscles. As stated, this low load exercise of cranio-cervical flexion, despite its efficacy for relief of neck pain (Jull et al., 2002), would not be expected to substantially change strength and fatigability of the superficial neck flexors. The low load training of the cranio-cervical flexor muscles followed the protocol described by Jull et al. (2004). The exercise targets the deep flexors of the upper cervical region, the longus capitis and colli, rather than the superficial flexors, SCM and AS muscles, which flex the neck but not the head. The patient is instructed to perform and hold progressive, inner range cranio-cervical flexion contractions while trying to keep the SCM and AS muscles relaxed. The subjects were first taught to perform a slow and controlled cranio-cervical flexion action. They then trained to be able to hold progressive increasing ranges of cranio-cervical flexion using feedback from an air-filled pressure sensor (Stabilizer™, Chattanooga Group, Inc., Chattanooga, TN) placed behind the neck.

3. Outcome measures

A series of measures were taken at baseline and in the week immediately after intervention (week 7). The investigator was blinded to subject group for the outcome assessments.

3.1. Electromyography

Surface EMG signals were recorded from the sternal head of SCM and AS muscles bilaterally using linear

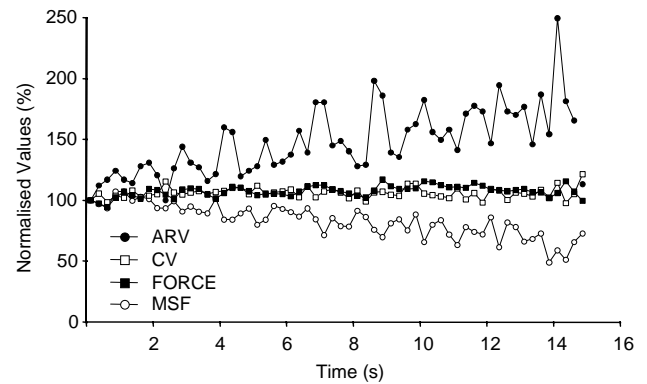


Fig. 1. Example of a fatigue plot. The time course of mean spectral frequency (MSF), average rectified value (ARV), conduction velocity (CV) and force are combined to produce a 'fatigue plot'. Plots are obtained by normalizing each variable with respect to the initial value of its own regression line. Myoelectric manifestations of fatigue are identified by an increase in ARV values with time and a decrease in MSF and CV values.

adhesive arrays of 4 electrodes (bar electrodes, 5 mm × 1 mm size, 10 mm apart; LISiN-SPES Medica, Italy). The detection surface was separated from the skin by a small cavity (~1 mm deep) filled with 20–30 μL of conductive gel. Myoelectric signals were amplified (ASE16, 16-channel amplifier, LISiN Centro di Bioingegneria, Politecnico di Torino, Italy), filtered (–3 dB bandwidth, 10–450 Hz), sampled at 2048 Hz, and converted to 12-bit digital samples.

The initial values and rate of change of the mean spectral frequency (MSF), average rectified value (ARV) and conduction velocity (CV) were computed off-line with numerical algorithms (Merletti et al., 1989, 1990) using non-overlapping signal epochs of 0.5 s. 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 minimize the mean square error between the Fourier transforms of the two double differential signals (Merletti et al., 1990).

To compare the rate of change of different variables and allow comparison between subjects, the time course of each EMG variable was normalized with respect to the intercept of the regression line to produce a 'fatigue plot' (Fig. 1). Linear regression was applied to the data to calculate the initial value and rate of change of MSF, ARV, and CV (Arendt Nielsen and Mills, 1985; Masuda et al., 1999). Repeatability and repeated measure precision have been demonstrated for measures of cervical flexion force and EMG variables for the SCM and AS muscles during sub-maximal cervical flexion contractions in our previous work (Falla et al., 2002b).

3.2. Measures of pain, disability and perceived benefit

Patients' perceived pain and disability were monitored pre and postintervention. Patients completed the neck disability index (NDI) (Vernon and Mior, 1991) (score out of 50) to provide a measure of perceived impairments resulting from their neck pain. Average intensity of neck pain was measured on a 10 cm numerical rating scale (NRS) anchored with 'no pain' and 'the worst possible pain imaginable'. Patients rated their perceived benefit of the exercise program for neck pain on a NRS anchored with '0' and '100%'.

4. Experimental procedure

Subjects were comfortably positioned in supine crook lying with their arms crossed over their chest and their head rested on a padded head support of a custom designed cervical flexion force measuring device (Fig. 2). The aluminum frame housed two load cells (CCT Transducers, Torino, Italy) with a full scale of 250 N each. 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. The starting position was standardized by placing the cranio-cervical and cervical spine in a mid-position (Falla et al., 2003a). The vertical height of the force measuring apparatus could be adjusted as required to achieve this position. An adjustable Velcro strap was fastened across the forehead,

acting to stabilize the head and provide resistance during cervical flexion isometric contractions. 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 which allowed sub-maximal targets to be set and provided the subject with feedback of the force level produced during contractions.

The adhesive arrays were positioned in the distal 1/3 of the SCM and AS muscles bilaterally, along the line of the muscle belly in accordance with published guidelines for electrode placement (Falla et al., 2002a) and following careful skin preparation. A reference electrode was placed on the upper thoracic spine. Subjects were requested to perform a brief isometric cervical flexion contraction (3–5 s) allowing the quality of the myoelectric signals to be evaluated. As described in our previous work (Falla et al., 2002a), the criteria included: (a) detection of propagating single motor unit action potentials, (b) absence of innervation zones and (c) estimation of mean values of the muscle fiber conduction velocity within the physiological range.

Each subject performed three maximum voluntary isometric cervical flexion contractions of 3 s duration. Verbal encouragement was provided to induce the subject to reach a higher level in each trial. An interval of 5 min was provided between each repetition. The highest value of force recorded over the three maximum contractions was selected as the reference maximum voluntary contraction (MVC) and used to calculate sub-maximal targets. Subjects then performed sub-maximal isometric cervical flexion contractions at 10% for 30 s, 25% MVC for 20 s and at 50% MVC for 15 s. Sub-maximal forces of 50 and 25% MVC were selected based on our previous work which demonstrated differences between patients with neck pain and control subjects at these levels (Falla et al., 2003b). In addition, a contraction at 10% was included to provide a lower level contraction. A 5 min rest period was given between contractions.

For the 7th week follow up session, the procedure was repeated with sub-maximal targets set based on the subjects' baseline MVC score.

4.1. Statistical analysis

The independent variables for this study were the subject groups (between subjects factor), and within subject factors, the force level (three measurements), the muscles examined (two muscles) and the side of muscle (two sides). The dependant variables were the initial values and rate of change of the CV, ARV, and MSF for each muscle in each condition. A repeated measures General Linear Model was used to identify whether estimates of CV, ARV, and MSF were different between the two subject groups. Significant main or interaction effects were further evaluated by examining means and 95% confidence intervals for each muscle in each condition between groups.

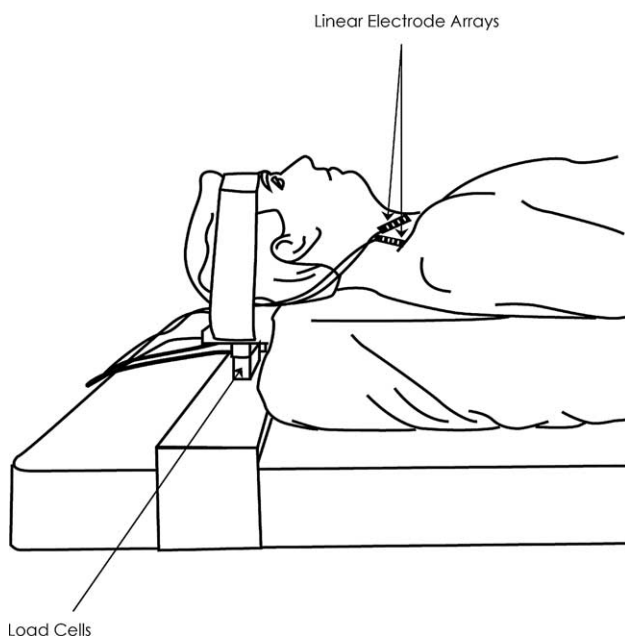


Fig. 2. Custom designed cervical flexion force measuring device. The subject's head rests on a padded head support and an adjustable Velcro strap is fastened across the forehead acting to stabilize the head and provide resistance during cervical flexion isometric contractions.

Paired sample *t* tests were conducted to determine if MVC, NDI and NRS were significantly different pre to post for both groups and independent sample *t* tests were conducted to compare for group differences. Results are reported as mean and standard deviation. All statistical analyses were performed using SPSS 10.0 for Windows. A value of $P < 0.05$ was used as an indicator of statistical significance.

5. Results

Of the 58 subjects recruited for this study, none were lost to follow up assessment. Subject descriptives are presented in Table 1. Baseline characteristics of EMG estimates and of subjects' pain and disability levels, were not different between the two intervention groups (all $P > 0.05$) (Tables 1 and 2). All participants in the endurance-strength training group and cranio-cervical flexion training group received the full 6 treatments. According to the patient diaries, compliance with exercise was $91.0 \pm 0.12\%$ for the endurance-strength training group and $94.8 \pm 0.06\%$ for the cranio-cervical flexion training group.

5.1. Measures of strength

Preintervention, the endurance-strength training group, and cranio-cervical flexion training group had a cervical flexion MVC force of 75.5 ± 17.9 and 78.2 ± 19.1 N, respectively, ($P > 0.05$). Following intervention, the endurance-strength training group demonstrated a greater increase in MVC force (10.1 ± 17.3 N) compared to the cranio-cervical flexion training group (1.8 ± 10.6 N) ($P < 0.05$).

5.2. EMG variables

A significant interaction effect was identified between force, muscle and group ($P < 0.05$) for the initial values of MSF. Furthermore, the rate of change of the MSF was dependent on the interaction between force and group ($P < 0.001$). Upon examining for change in the MSF for each muscle at each force level, the endurance-strength

training group demonstrated a significant reduction of the MSF initial value and rate of change across all force levels following treatment ($P < 0.05$; Fig. 3), which was significantly different to the cranio-cervical flexion training group ($P < 0.05$).

For the ARV, significant interaction effects were identified for force and group for both the initial values ($P < 0.05$) and rate of change ($P < 0.05$). As demonstrated in Fig. 4, a significant reduction of the ARV initial value was present across all force levels ($P < 0.05$) and a significant decrease was present for the ARV rate of change at 25 and 50% MVC ($P < 0.05$) for the endurance-strength group following training.

No significant change in the ARV or MSF initial value or rate of change were identified for the cranio-cervical flexion training group. In addition, no significant change was identified for the initial value and rate of change of the CV for either intervention group ($P > 0.05$).

5.3. Measures of pain, disability, and perceived benefit

Both intervention groups demonstrated a reduction in average intensity of pain (cranio-cervical flexion training intervention, -0.9 ± 2.3 ; endurance-strength training intervention -1.1 ± 2.8), and NDI score (cranio-cervical flexion training intervention, -3.5 ± 4.8 ; endurance-strength training intervention -2.8 ± 4.0). However, there was no difference between groups for change in pain (NRS) or disability (NDI) ($P > 0.05$). Perceived benefits of the exercises for neck pain were $46.7 \pm 33.5\%$ for the cranio-cervical flexion training group and $37.6 \pm 37.5\%$ for the endurance-strength training group and were not significantly different between the two intervention groups ($P > 0.05$). No patients reported any adverse events.

6. Discussion

This study suggests that an endurance-strength training regime for the cervical flexor muscles in people with chronic neck pain, results in an increase in cervical flexion force and a decrease in the initial value and rate of change of the MSF for both the SCM and AS muscles

Table 1

Baseline characteristics for patients with chronic neck pain randomized into a cranio-cervical flexion exercise intervention or endurance-strength exercise intervention

	Cranio-cervical flexion exercise intervention ($n = 29$)			Endurance-strength exercise intervention ($n = 29$)		
	Mean \pm SD	Median	Range	Mean \pm SD	Median	Range
Age	37.7 ± 9.9	38.0	22.0–55.0	38.1 ± 10.7	38.0	22.0–55.0
Length of neck pain history (years)	7.5 ± 5.9	7.0	0.5–21.0	8.3 ± 7.0	5.5	1.0–30.0
Neck pain intensity (0–10)	3.6 ± 2.0	3.4	0.7–7.1	4.7 ± 2.0	4.5	1.8–9.0
Neck disability index (0–50)	9.8 ± 3.3	10.0	2.0–14.0	10.4 ± 3.4	10.0	3.0–15.0
Onset (% idiopathic)	82.8	–	–	86.2	–	–

Mean \pm standard deviation (SD), median and range are shown.

Table 2

Cranio-cervical flexion and endurance-strength training group baseline values for the of the initial value (IV) and rate of change of the mean spectral frequency, average rectified value and conduction velocity for the sternocleidomastoid (SCM) and anterior scalene (AS) muscles contracting at 50, 25 and 10% of the maximum voluntary contraction (MVC)

Task	Group	Mean spectral frequency		Average rectified value		Conduction velocity	
		IV (Hz)	Rate of change (Hz/s)	IV (μV)	Rate of change (μV/s)	IV (m/s)	Rate of change (m/s ²)
SCM 50% MVC	Cranio-cervical flexion	126 ± 16.9	-1.56 ± 0.44	80.2 ± 30.7	1.62 ± 1.31	4.35 ± 0.61	-0.01 ± 0.07
	Endurance-strength	129 ± 10.3	-1.67 ± 0.38	90.1 ± 34.4	1.91 ± 1.28	4.32 ± 0.62	-0.02 ± 0.06
SCM 25% MVC	Cranio-cervical flexion	121 ± 17.5	-0.82 ± 0.28	51.0 ± 19.9	0.57 ± 0.40	4.24 ± 0.65	-0.01 ± 0.04
	Endurance-strength	125 ± 9.05	-0.87 ± 0.25	61.9 ± 29.7	0.67 ± 0.44	4.21 ± 0.51	0.00 ± 0.02
SCM 10% MVC	Cranio-cervical flexion	116 ± 19.3	-0.10 ± 0.19	32.9 ± 16.9	0.17 ± 0.22	4.28 ± 0.70	0.00 ± 0.02
	Endurance-strength	116 ± 14.9	-0.16 ± 0.21	41.3 ± 30.5	0.18 ± 0.15	4.10 ± 0.58	0.00 ± 0.01
AS 50% MVC	Cranio-cervical flexion	129 ± 20.5	-1.30 ± 0.27	76.6 ± 31.9	1.85 ± 1.49	3.96 ± 0.68	-0.02 ± 0.03
	Endurance-strength	131 ± 15.6	-1.35 ± 0.38	84.8 ± 36.1	2.03 ± 1.36	3.91 ± 0.57	-0.02 ± 0.03
AS 25% MVC	Cranio-cervical flexion	125 ± 18.6	-0.73 ± 0.26	48.6 ± 22.4	0.64 ± 0.50	3.89 ± 0.66	0.00 ± 0.06
	Endurance-strength	124 ± 17.8	-0.72 ± 0.25	56.1 ± 29.7	0.72 ± 0.47	4.06 ± 0.61	-0.03 ± 0.11
AS 10% MVC	Cranio-cervical flexion	115 ± 20.2	-0.08 ± 0.25	32.3 ± 17.1	0.17 ± 0.24	3.94 ± 0.70	-0.01 ± 0.02
	Endurance-strength	113 ± 18.7	-0.13 ± 0.27	38.1 ± 27.5	0.17 ± 0.16	3.83 ± 0.53	0.00 ± 0.04

Data for the left and right side have been pooled together.

contracting at moderate and low levels of intensity. The finding of a reduction in the MSF rate of change in the endurance-strength training group is consistent with reduced muscle fatigability. Despite the fact that only the endurance-strength training group improved on measures of these parameters, there was no difference in pain or disability measures between the intervention groups at the end of training. This latter point suggests that improvements in strength and a reduction in muscle fatigue may not be solely mediated by improvement in symptoms.

6.1. Change in muscle strength and fatigability

The change in muscular strength and MSF parameters for the endurance-strength training group postrehabilitation most likely represents a physiological adaptation in the neuromuscular system. In particular, a lower initial value of MSF for the endurance-strength group posttreatment may reflect a modification of the recruited motor unit pool in which the number of type I fibers is increased with respect to the type II fibers compared to the recruitment pattern utilized prerehabilitation (Gerdle et al., 1991).

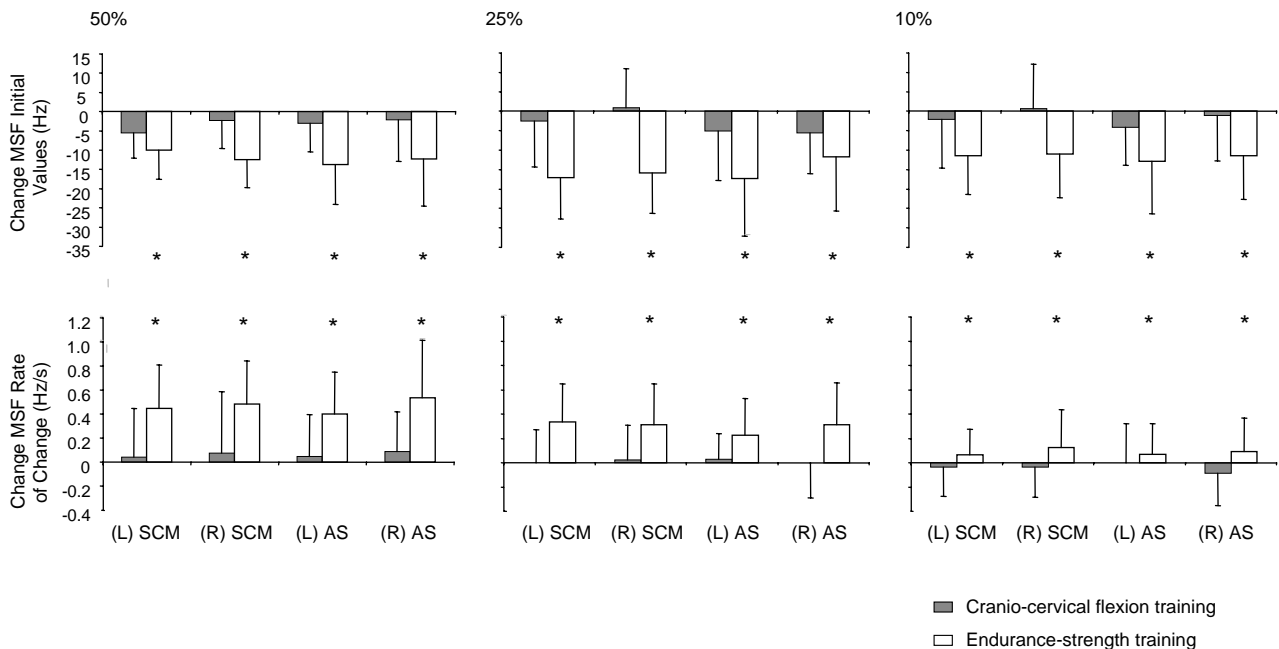


Fig. 3. Group data for change in initial value and rate of change of the mean frequency. Mean and standard deviation are shown for the change in initial value and rate of change of the mean spectral frequency (MSF) (pre to postintervention) for the left (L) and right (R) sternocleidomastoid (SCM) and anterior scalene (AS) muscles contracting at 50, 25 and 10% of the maximum voluntary contraction. Data are shown for both the endurance-strength training group and cranio-cervical flexion intervention group. * Indicates $P < 0.05$ between groups.

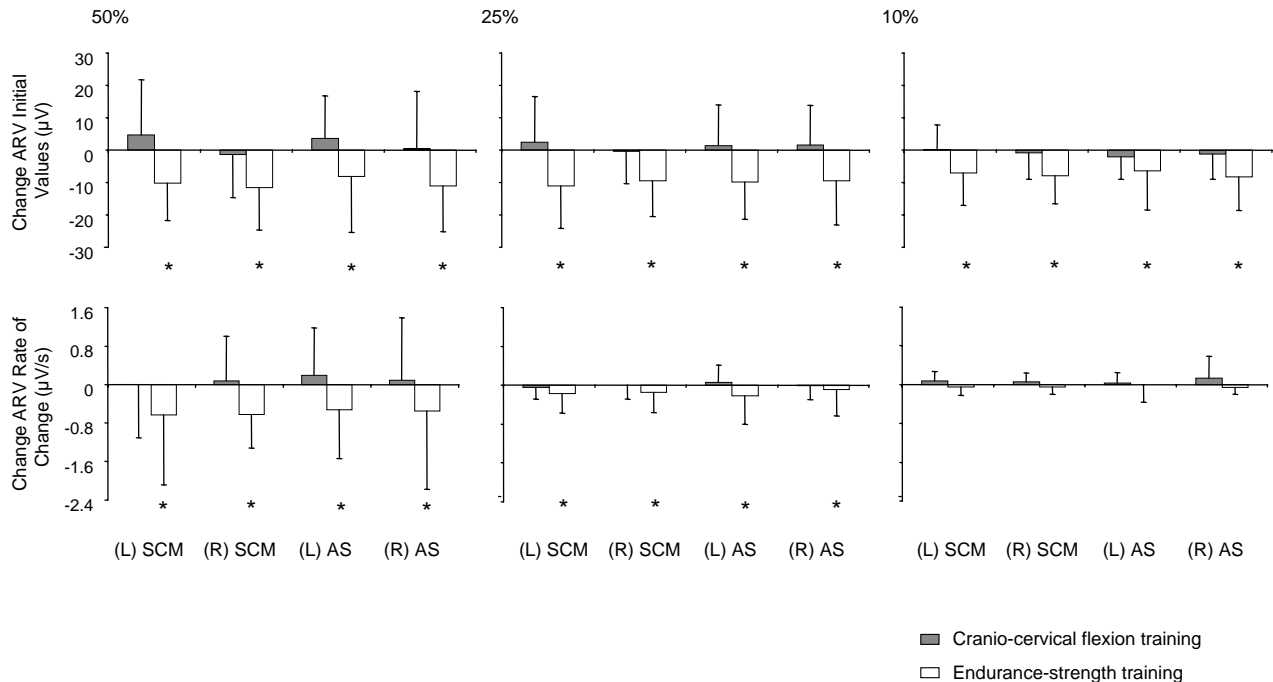


Fig. 4. Group data for change in initial value and rate of change of the average rectified value. Mean and standard deviation are shown for the change in initial value and rate of change of the average rectified value (ARV) (pre to postintervention) for the left (L) and right (R) sternocleidomastoid (SCM) and anterior scalene (AS) muscles contracting at 50, 25 and 10% of the maximum voluntary contraction. Data are shown for both the endurance-strength training group and cranio-cervical flexion intervention group. * Indicates $P < 0.05$ for the between groups comparison.

In addition to changes in peripheral conditions of the neuromuscular system, changes in control strategies could provide another explanation for the reduction in myoelectric manifestations of SCM and AS muscle fatigue for the group of neck pain patients who participated in the endurance-strength training group (Merletti et al., 1990). The patients within this group may have employed a more effective strategy to maintain force during the isometric tasks, for example, limiting additional motor unit recruitment in the SCM and AS muscles during the isometric tasks. The reduced rate of change of the ARV postendurance-strength training supports this hypothesis. Other possible mechanisms such as changes in fear avoidance following treatment cannot be ruled out, although it has been demonstrated that fear avoidance scores do not influence between group differences in levels of muscle activation in whiplash and control subjects (Sterling et al., 2003).

It must be noted that the magnitude of co-activation of the antagonists that is, the cervical extensor muscles, was not monitored in this study. Elimination or reduction of co-activation would have increase the measured MVC and reduced myoelectric manifestations of agonist muscle fatigue (SCM and AS). Future investigations should monitor antagonist muscle activity to further examine this. However, our finding of greater strength and less fatigue following strength-endurance training which was identified for people with neck pain is consistent with observations

reported in the literature for trunk muscles following training (Mooney et al., 1997; Roy et al., 1995).

In our previous work we were not able to detect differences in the initial value and rate of change of the CV for the SCM and AS muscles between people with neck pain and control subjects, despite a significant difference in the rate of change and initial value of MSF (Falla et al., 2003b). Consistent with this finding, in this study we did not identify any significant change in CV estimates postendurance-strength training even though CV estimates were stable and within the range of normal physiologic values (2.5–6.5 m/s; Table 2) (Falla et al., 2002b). This finding confirms that the significant differences observed in the initial values and rate of change of MSF cannot be attributed exclusively to differences in CV, and therefore changes in muscle fiber membrane properties. In agreement with our previous work (Falla et al., 2003b), we can speculate that the observed variations of the initial value and rate of change of MSF are due to modifications of other factors such as the motor unit action potential (MUAP) CV distribution (Falla et al., 2004d). That is, the same average CV could be obtained from different values of individual MUAP CV with different distributions around the mean.

A reduction in fatigability may also be attributed to an increase in cervical flexion force, which was identified for the endurance-strength group following intervention. The increase in maximum voluntary contraction force identified

for the endurance-strength group following intervention was approximately 12%. This is lower than previously reported for changes in cervical strength following training (Berg et al., 1994; Highland et al., 1992; Portero et al., 2001). For example, Portero and colleagues (2001) demonstrated a 35% increase in cervical lateral flexion force following an 8 week lateral flexion isometric strength training protocol. The smaller increase in cervical force which was identified in this study compared to others, most likely reflects a combination of different factors such as patient population, duration of training, type of training, speed of training and direction of movement tested.

Previous studies have also demonstrated a training-induced hypertrophy of the cervical muscles, which was associated with large increases in strength (Conley et al., 1997; Pollick et al., 1993; Portero et al., 2001). Portero and colleagues (2001) reported a 6.4–12% increase in SCM and trapezius muscle hypertrophy following 8 weeks of resistance training whilst Conley and colleagues (1997) demonstrated a 13% increase in total neck cross-sectional area following 12 weeks of resistance training. These data suggest that the cervical muscles are capable of an increase in size in response to strength training. In our study, the cross-sectional areas of SCM and AS were not measured which precludes conclusion on the precise mechanism of force increase, which was identified. However, it is well established that the underlying mechanisms behind increases in torque after the initial weeks of strength training are mostly due to adaptive changes in neural activation and thereafter, due to muscular hypertrophy (Moritani and de Vries, 1979). Given that the training period in our study was 6 weeks duration, the increase in cervical flexion force output identified following endurance-strength training most likely reflects neural adaptation factors such as improved coordination and increased activation of muscles or the acquisition of skill in performing the task, rather than an increase in the size or intrinsic strength of the muscles (Moritani and de Vries, 1979; Narici et al., 1989; Rasch and Morehouse, 1957; Rutherford and Jones, 1986). In addition, the effect of repeated testing and measurement variability cannot be entirely ruled out.

Differences in the initial value and rate of change of the MSF were not observed for the patient group participating in the cranio-cervical flexion training intervention program. As stated in our original hypothesis, the low load exercise of cranio-cervical flexion, despite its efficacy for relief of neck pain (Jull et al., 2002), would not be expected to substantially change strength and fatigability of the superficial cervical flexors as the aim of the exercise is to decrease the relative activity of these muscles during performance of the exercise tasks. It has been proposed that a predominant mechanism by which this exercise approach may well induce its pain relieving effects is by improved coordination between the layers of the cervical flexor muscles and possibly its direct effects on the pain

system rather than increasing strength or fatigability of the superficial cervical flexor muscles (Jull et al., 2004).

6.2. Change in neuromuscular efficiency

The patient group that undertook the endurance-strength training program for the cervical flexor muscles, demonstrated a reduction in the initial value of the ARV following the intervention. Given that subjects performed the sub-maximal contractions based on the baseline MVC for the reassessment session, the reduction in the ARV could be described as an increase in the neuromuscular efficiency of the SCM and AS muscles (van der Hoeven et al., 1993). In our previous work we identified less neuromuscular efficiency (defined as the ratio between MVC and the corresponding ARV of the EMG signal) for the SCM and AS muscles in a group of people with neck pain compared to a group of healthy controls (Falla et al., 2004b). This finding was identified for cervical flexion contractions at 25% MVC but not at 50%. In this study, the results obtained for the endurance-strength training group demonstrated a reduction in the initial value of the ARV (that is, greater neuromuscular efficiency) across all force levels postrehabilitation. This observed increase in SCM and AS neuromuscular efficiency could be attributed to a change in the excitability of the motoneuronal pool or a modification of the neural activation patterns for cervical flexion. Given that the exercises performed in the endurance-strength exercise regime were similar to the test manoeuvre, an improvement in SCM and AS muscle efficiency would be expected.

6.3. Change in pain and perceived disability

After the 6 week training program, average intensity of pain (NRS) and perceived disability (NDI score) improved equally for both intervention groups. Furthermore, both intervention groups recorded a perceived benefit for their neck pain from participation in either exercise program. Although statistically significant, the reduction in pain and perceived disability reported by both groups was relatively small (NRS: cranio-cervical flexion intervention, -0.9 ± 2.3 ; endurance-strength intervention -1.1 ± 2.8 ; NDI score: cranio-cervical flexion intervention, -3.5 ± 4.8 ; endurance-strength intervention -2.8 ± 4.0). However, it is likely that the small effect is related to the fact that the pain and perceived disability were minor to start with for the subjects included in this study (Table 1) in comparison with previous studies (Bronfort et al., 2001; Jull et al., 2002). It is probable that different results would be identified if the protocol was repeated on a group of patients with higher pain levels.

Given that both intervention groups had an equal change in level of perceived average intensity of pain, it is unlikely that pain reduction alone can explain the change in MSF and ARV estimates detected for the endurance-strength training

group. Other physiological mechanisms must account for the observed changes in EMG estimates from the superficial cervical flexor muscles.

6.4. Clinical Implications

The results of this study have demonstrated a significant improvement in cervical flexion force and fatigability of the SCM and AS muscles following a 6 week endurance-strength training program for the cervical flexor muscles. For the 7th week follow up session, isometric cervical flexion contractions was repeated with sub-maximal targets set based on the subjects' baseline MVC score. This was done to allow a direct comparison of muscle function following training. From a functional perspective the results indicate that following 6-weeks of endurance-strength training for the cervical flexor muscles, people with neck pain can produce and sustain the same force as before training with greater efficiency and less fatigability. However, it is unknown whether these changes would be maintained in the long term. Furthermore, it is unknown whether other impairments in cervical muscle function, which have been identified in people with neck pain, such as altered cervical muscle activation during functional tasks (Falla et al., 2004a; Nederhand et al., 2002) and automatic tasks (Falla et al., 2004c), would be influenced by an endurance-strength exercise protocol for the neck flexor muscles.

In this study, therapists were instructed to prescribe the strengthening exercise (head lift) without any provocation of neck pain. Again, the patients included in this study had relatively low levels of neck pain intensity to ensure that this criterion could be met. It is unknown whether such an exercise regime would be as effective in people with chronic neck pain of greater severity or people with an acute episode of neck pain. It is generally accepted clinically that protocols that facilitate strength and endurance adaptation for the cervical flexor muscles should be used as a progression following restoration of muscle function at relatively lower loads (Jull et al., 2004).

7. Conclusion

This study demonstrated that an endurance-strength exercise regime for the cervical flexor muscles is effective in reducing myoelectric manifestations of sternocleidomastoid and anterior scalene muscle fatigue as well as increasing cervical flexion strength in a group of female patients with chronic neck pain. It would seem apparent that a reduction in neck pain alone is not responsible for these changes. Further research is necessary to examine whether these improvements in muscle function would be maintained in the long term and the implications this would have on various features of neck pain including recurrence rate.

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