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Altered activity of the serratus anterior during unilateral arm elevation in patients with cervical disorders

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ABSTRACT

Altered activity in the axioscapular muscles is considered to be an important feature in patients with neck pain. The activity of the serratus anterior (SA) and trapezius muscles during arm elevation has not been investigated in these patients. The objectives of this study was to investigate whether there is a pattern of altered activity in the SA and trapezius in patients with insidious onset neck pain (IONP) ($n = 22$) and whiplash associated disorders (WAD) ($n = 27$). An asymptomatic group was selected for baseline measurements ($n = 23$).

Surface electromyography was used to measure the onset of muscle activation and duration of muscle activity of the SA as well as the upper, middle, and lower trapezius during unilateral arm elevation in the three subject groups. Both arms were tested.

With no interaction, the main effect for the onset of muscle activation and duration of muscle activity for serratus anterior was statistically significant among the groups. Post hoc comparison revealed a significantly delayed onset of muscle activation and less duration of muscle activity in the IONP group, and in the WAD group compared to the asymptomatic group. There were no group main effects or interaction effects for upper, middle and lower trapezius.

This finding may have implications for scapular stability in these patients because the altered activity in the SA may reflect inconsistent or poorly coordinated muscle activation that may reduce the quality of neuromuscular performance and induce an increased load on the cervical and the thoracic spine.

1. Introduction

Normal stability of the scapula includes the ability to maintain normal orientation of the scapula with the arms by the side and during all activities of the upper limb. The muscular system is primarily responsible for scapular orientation because the sternoclavicular joint is the only bony-ligament attachment of the shoulder girdle to the trunk. All muscles that are attached to the shoulder girdle contribute to its stability, but in different degrees (Comerford and Mottram, 2010). Altered scapular orientation most frequently occurs because of altered activity or poor neuromuscular patterns in the serratus anterior and trapezius (scapular stability muscles) as well as altered activity and extensibility of the pectoralis minor, levator scapulae and rhomboids that may compromise the muscle balance (scapular mobility muscles) (Mottram, 1997; Sahrmann, 2002; Kibler and McMullen, 2003; Mottram et al., 2009; Comerford and Mottram, 2010).

The activity of the main stabilisers of the scapula, the serratus anterior and trapezius, depends not only on force production but also on neuromuscular control and recruitment that requires a precise co-ordinated activity occurring at the right moment, creating the right amount of force, maintained for the right length of time. This proper firing pattern and recruitment requires coupling of the serratus anterior muscle with the upper, middle and lower trapezius that results in "force couples" which are considered necessary for normal scapular orientation (Inman et al., 1996; Mottram, 1997; Kibler and McMullen, 2003). Appropriate activity of these muscles depends on proprioception which is linked to the sensation of position and movement of the joints, the sensation of force, effort and heaviness associated with the muscular activity; and the perceived timing of muscle contraction (Gandeviaa et al., 1992; Comerford and Mottram, 2010). Muscle recruitment deficits are manifested by an altered pattern of recruitment or an altered timing (early/delayed muscle onset) (Comerford and Mottram, 2010).

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The presence of neck pain is known to alter the activity of the upper and lower trapezius during upper limb tasks (Szeto et al., 2005a; Falla et al., 2007; Wegner et al., 2010) and alter scapular orientation (Szeto et al., 2002, 2005b; Yip et al., 2008; Helgadottir et al., 2010, 2011). Biomechanical reasoning indicates that altered activity in the axioscapular muscles associated with altered scapular orientation may induce detrimental load on the cervical spine (Behrsin and Maguire, 1986; Janda, 1994; Jull et al., 2004). Studies have shown that increased tension in muscle such as the levator scapulae through its attachment to the upper four cervical segments may directly induce compressive, rotational and shear forces on cervical motion segments (Behrsin and Maguire, 1986). Altered stability of the scapula may therefore create or sustain symptomatic mechanical dysfunction in the cervical spine, and influence the recurrence of neck pain (Janda, 1994; Jull et al., 2004, 2008; Sahrmann, 2011).

Current therapeutic guidelines for patients with neck pain and related disorders include analyzes and correction of the function of the scapular muscles and scapular orientation (Jull, 1997; Mottram, 1997; Jull et al., 2004, 2008; Wegner et al., 2010; Andersen et al., 2011). These guidelines are primarily based on the results of studies on shoulder patients as investigations of the scapular stability system in patients with neck pain are sparse. The activity and recruitment properties of the serratus anterior and trapezius during arm elevation have not been investigated in patients with neck pain before. Since a difference may exist in the impairment between patients with insidious onset neck pain (IONP) and whiplash associated disorders (WAD) (Nederhand et al., 2002; Falla et al., 2004; Elliott et al., 2008; Kristjansson and Oddsdottir, 2010) this study included both groups of patients. The aim of the study was to investigate whether there is a pattern of altered activity of the serratus anterior and trapezius during arm elevation in patients with IONP and WAD compared to asymptomatic subjects. The hypothesis was that patients with neck pain will demonstrate altered activity in these muscles.

2. Method

2.1. Participants

Twenty-two patients with IONP (20 women and 2 men) and twenty-seven patients with WAD grade II, (24 women and 3 men) following a motor vehicle accident were recruited on a voluntary basis. WAD grade II, is described as neck complaint of pain, stiffness, or tenderness and musculoskeletal signs which include decreased range of motion and point tenderness (Spitzer et al., 1995). A sample of convenience consisting of twenty-three asymptomatic people (18 women and 5 men) served as controls (Table 1). All participants were right handed.

The study was introduced at 15 physical therapy clinics in the Reykjavik municipal area. The physical therapists were asked to screen the patients according to the inclusion/exclusion criteria. Inclusion criteria were: age 18–55, a score of at least 10 on the Neck Disability Index (NDI) and neck symptoms that had lasted more than six months. NDI is a self-reporting instrument for the assessment of activities of daily living of sufferers of disabling neck pain. Score below 10 (of 100) on the NDI are scored as ‘no disability’ (MacDermid et al., 2009) and symptoms that have lasted more than six months are considered chronic (Hartling et al., 2001). Participants were allocated to one of the two following groups: Group 1 consisted of patients with IONP with no history of any accident or whiplash injury. Group 2 consisted of patients diagnosed with a WAD that had no prior history of symptoms in the neck area before the motor vehicle accident. Group 3 included the controls, age range 18–55, with neither cervical or shoulder dysfunction. The subjects in the control group were selected to match the subjects in the symptomatic groups, according to their height, weight, age, gender and physical activity level. Physical activity level was assessed by asking whether the subject engaged in some kind of physical activity on regular bases (sports, exercises etc.). If the answer was yes the subject was asked what kind of physical activity and how many times per week. The cervical spine was examined by a physical therapist trained in manual therapy, to confirm the presence or absence of cervical segmental joint dysfunction in patients with neck pain and controls, respectively. The glenohumeral joints were examined for pain, restriction, and impingement signs (Magee, 1987). Based on the recruitment procedure all patients had received physical therapy treatment prior to the measurements. Exclusion criteria for all the groups were: any known pathology or impairment in the shoulder joint, history of head injury or spinal fractures, systemic pathology and serious psychological condition.

Table 1
Demographic details of participants.

	Control group	IONP group	WAD group
Sex n (women, men)	18.5	20.2	24.3
Age (years)	30 ± 8 (21–51)	35 ± 8 (25–54)	33 ± 10 (18–50)
Height (cm)	172 ± 8 (155–188)	171 ± 6 (158–183)	170 ± 5 (160–180)
Weight (kg)	69 ± 10 (56–100)	73 ± 16 (53–128)	71 ± 10 (51–92)
NDI*	0	29 ± 10 (12–49)	38 ± 18 (12–80)
VAS*	0	4.8 ± 1 (2–8)	6 ± 2 (2–10)

Abbreviations: IONP, insidious onset neck pain; NDI, Neck Disability Index; VAS, Visual Analogue Scale; WAD, whiplash-associated disorder. A higher score on the NDI and VAS indicates greater pain and disability. Data, except for sex of participants, are expressed as mean SD (range).
* Significant difference was found in the NDI and VAS between the symptomatic groups $P < 0.05$.

Pain intensity was evaluated with a 10-cm Visual Analogue Scale (VAS) anchored by no pain and pain as bad as it can be. The VAS was used to indicate the average intensity of neck pain experienced over the past seven days. The patients also shaded the location of their pain distribution on a body chart to find out side differences. According to the body charts twenty-six participants had bilateral symptoms (13 WAD and 13 IONP), ten participants (6 WAD and 4 IONP) had more symptoms on the right side and thirteen participants (8 WAD and 5 IONP) had more symptoms on the left side. This study was approved by the Bioethics Committee of Landspitali University Hospital and all participants signed a consent form.

2.2. Equipment

EMG data were collected using four sensors from Kine, Hafnarfjordur, Iceland. The signal is pre-amplified using amplifier with input impedance of 10 Giga Ohm and a common mode rejection ratio of 110 dB. The signal is sampled at 1600 Hz, after going through a band pass filter with a cut-of frequency 16 Hz and 482 Hz (3 dB). The signal is digitized at approximately 3 mm from the skin, and transmitted wirelessly in digital form. After reception, the signal is filtered using high pass filtering with cut-off frequency at 30 Hz to remove movement artifacts and signal from heartbeat. Attached to the sensors were disposable disc shaped (10 mm Ø) triode surface electrodes (Ag–AgCl) with an interelectrode distance of 20 mm (Thought Technology Ltd., Quebec, Canada).

Three-dimensional kinematic data were collected at 40 Hz with a three-Space Fastrak (Polhemus, Colchester, VT). The manufacturer has reported an accuracy of 0.8 mm and 0.15° for this device.

The Fastrak system used in this study consisted of a global transmitter attached to a back of a chair and a sensor mounted on the posterior aspect of the arm, in line with the long axis of humerus. The electronic unit determined the relative orientation and position of the sensor through the electromagnetic field emitted by the global transmitter. Both the sensor and the global transmitter were hardwired to the Fastrak electronic unit that collected information about the position of the arm. The information was sent to a computer with a software system synchronized with the EMG. The collection of the kinematic data is run on a separate computer from the computer used for EMG recording, ensuring maximum speed of the kinematic collection.

The collection of the kinematic data and time synchronization to EMG is based on a sync box (Kine, Hafnafjordur, Iceland) that gives out a 5 Volt signal indicating start and stop of EMG sampling. The signal is used to initiate and terminate collection of the kinematic data from the Fastrak system. The collection of the kinematic data from the Fastrak system is done so that as soon as the start signal from the EMG sync box is received, a data sample is requested from the Fastrak, as soon as this sample is received; a new data sample is requested. This process is repeated until the stop signal is received. Timing is ensured by registering the time at reception of each sample from the Fastrak.

The coordinate system of the global transmitter was used in this study because the only component needed from the Fastrak system was the exact time the sensor on the humerus started to move into elevation relative to the global transmitter and to determine the end of arm descend.

3. Experimental procedure

The overall flow of the experiment procedure was as follows. The subject was instructed to sit in a comfortable upright position such that the sacrum was in contact with the back of the chair with feet placed parallel on the floor. The global transmitter was attached to the back of the chair and the Fastrak sensor was placed on the posterior aspect of humerus in vertical line with olecranon. The area of EMG electrode placement was cleaned with alcohol swabs to lower the electrical impedance. The electrodes for the serratus anterior were placed parallel to the muscle fibers right in front of the anterior border of latissimus dorsi at rib levels 6–8 (Fig. 1) (Basmajian and Blumenstein, 1989). The SENIAM recommendation for electrodes location was followed for trapezius. Electrodes were placed in line with the muscle fibers over the following locations: upper trapezius, at the midpoint of the lead line between the acromion and the spinous process of C7, in the direction of the line between the acromion and the C7; middle trapezius, between the medial border of the scapula and the spine, at the level of T3, in the direction of the line between T5 and the acromion; lower trapezius at 2/3 on the line from the trigonum spinea to the T8, in the direction of the line between T8 and the acromion (Hermens et al., 2000, 2009). When the electrode placement was completed the signal quality of all the muscles was tested. The following instructions were verbalized to each subject: "Visually focus on a point directly ahead on the chart in front of you. Allow your hands, shoulders and arms to assume the position they would normally assume while you sit in a relaxed fashion". The subject was instructed to maintain the position. A flat vertical surface was positioned along the lateral aspect of the subjects' arm to maintain the arm motion in the scapular plane, defined 30 degrees anterior to the frontal plane. The back of the hand gently contacted the vertical surface. To control the speed of the arm elevation a metronome set at 60 beats per minute was used and each subject exercised an elevation of a straight arm to a count of three seconds and lowering along the same path to a count of three, without stopping at top level (>140 degrees of arm elevation). Before and in-between each elevation and lowering of the arm the subject was instructed to relax for 3 s. Following the practice trials synchronized EMG and kinematic data were simultaneously collected during one elevation and descend of each arm.

When testing was completed on one side the experimental procedure was repeated on the opposite side. The testing of the left and right sides was counterbalanced.

3.1. Analysis

The main parameters of interest were the onset of muscle activation when elevation of the arm began and the duration of muscle activity in arm elevation and descend, for the serratus anterior and the trapezius.

The kinematic data, consisting of numbers demonstrating the amount of arm elevation and descend in degrees, were imported into Excel where the exact time for each value was displayed in seconds. By a visual observation the beginning of arm elevation (time point 1) was defined as the first incremental value at the end of a resting period before the arm was elevated. The end of arm descend (time point 2) was defined as the first value beginning a resting period after the movement ceased. The time between time point 1 and 2 was calculated.

The EMG data were rectified, imported into Excel in a raw text form and processed with an excel macro onset filter (KINE, Hafnarfjordur, Iceland) with a threshold adjusted at two standard deviations above a resting value for more than 50 ms (Hodges and Bui, 1996; Silfies et al., 2009). The muscle onset was determined when the RMS of each muscle had reached that threshold and the time of muscle activation was the time each muscle maintained that threshold. The time interval between the moment the arm started to elevate and the time when each muscle had reached the threshold was calculated with a computer program and displayed in seconds. Duration of muscle activity was calculated by dividing the time of muscle activation by the time it took the arm to elevate and descend (between time point 1 and 2).

The synchronization of the EMG and Fastrak as well as the definition of muscle onset that was used in the in the current study may explain why positive values (i.e., onset after movement) were more generally observed instead of negative values (i.e., onset prior to movement) when using LED markers and a definition of 5% of maximum amplitude. It should also be considered that studies reporting onset of muscle activity occurring prior to movement investigate the athletic population instead of the non-athletic population.

3.2. Statistics

The SPSS version 18 (Statistical Package for the Social Sciences, SPSS Inc. 2009, Chicago, IL) was used for statistical analysis. The age, weight and height between the three groups were compared by one-way ANOVA. For each group, means and standard error were calculated for the eight dependent variables on each side. For the serratus anterior and three parts of trapezius on the side of elevation, four dependent variables were onset of muscle activation and four dependent variables were duration of muscle activity. The data for the onset of muscle activation were skewed and was therefore transformed by first adding the absolute value of the smallest value for each electrode and then raising to the power of 0.45, to meet the criteria for normal distribution. Because the Shapiro test did not reject normal distribution of the residuals, parametric tests were used for statistical analysis.

To compare the onset of muscle activation and the duration of muscle activity among the three groups, a mixed model of a two-way ANOVA was used with one between subject factor (three

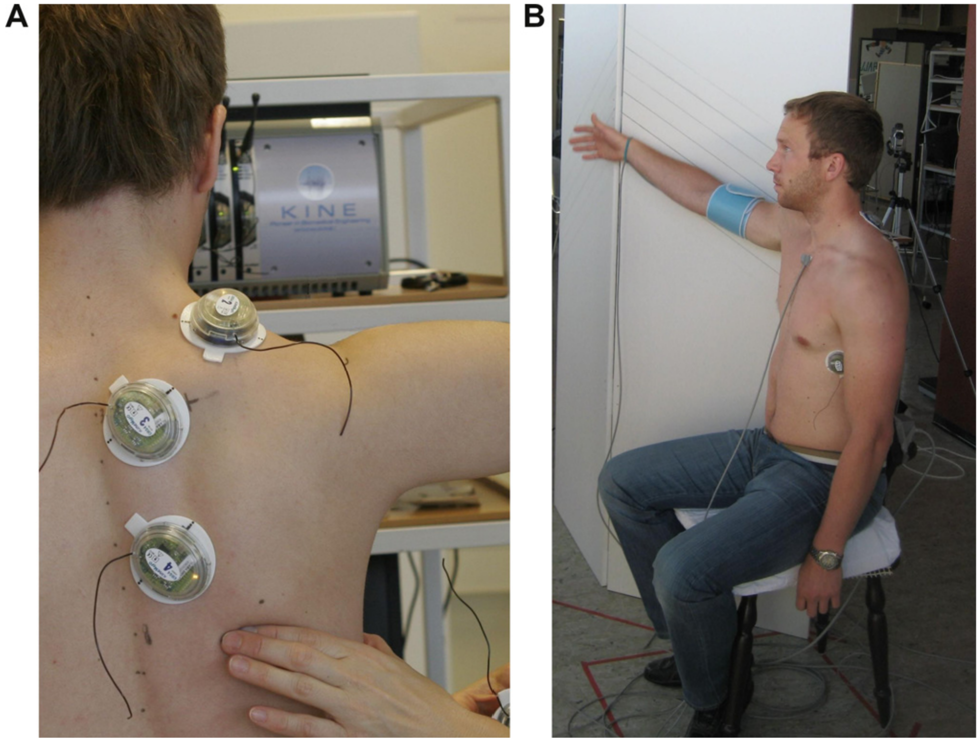

Fig. 1. Electrode location and experimental set up. Disposable disc shaped (10 mm Ø) triode surface electrodes were placed at the trapezius and serratus anterior. Sensors attached to the electrodes digitized the signal at approximately 3 mm from the skin, and transmitted the signal wirelessly in digital form (A). A flat vertical surface was positioned along the lateral aspect of the subjects' arm to act as a guide to maintain the arm motion in the scapular plane (B).

groups: IONP, WAD and Controls) and one within subject factor (sides, representing arm dominance). Full factorial model was used. Interaction effects for sides were tested first to determine any potential influence on group effects. In the absence of interactions, main effects of group (collapsed across sides) were of interest. Bonferrroni correction was used to control for type 1 error. The significance level for all tests was set at 0.05.

The scores on the NDI and the VAS were compared between the symptomatic groups by independent *t*-test. Pearson correlation between the dependent variables and the scores on the NDI and VAS were also assessed.

4. Results

There was no significant difference in age, weight and height between the three groups but a significant difference was found in the level of disability and pain between the symptomatic groups, where the WAD group had a significantly higher disability (NDI) ($P = .04$) and pain level (VAS) ($P = .03$) compared to the IONP group (Table 1).

Fig. 2 and Table 2 demonstrate the mean (SEM) of the onset of muscle activation and Fig. 3 and Table 3 the mean (SEM) for duration of muscle activity in the three groups.

With no interaction, the main effect for the onset of muscle activation for serratus anterior was statistically significant among the groups [$F(2,70) = 5.214$, $p < .01$]. Post hoc comparison revealed a significantly delayed onset of muscle activation in the IONP group ($P < .05$), and in the WAD group ($P < .01$) compared to the asymptomatic group. No statistical difference was found between the symptomatic groups ($P = .93$).

With no interaction, the main effect for duration of muscle activity for serratus anterior was statistically significant among the groups [$F(2,69) = 5.784$, $p < .01$]. Post hoc comparison revealed a significantly less duration of muscle activity in the IONP group ($P < .02$), and in the WAD group ($P < .01$) compared to the asymptomatic group. No statistical difference was found between the symptomatic groups ($P = .73$). There were no group main effects or interaction effects for upper, middle and lower trapezius in onset of muscle activation or the duration of muscle activity.

The correlation between the EMG onset and duration of muscle activity of the serratus anterior muscle and the scores on the NDI and VAS was below 0.3 on both sides.

5. Discussion

The results of the study partially support our hypothesis that patients with neck pain may demonstrate a pattern of altered activity of the scapular stabilizers as a significantly delayed onset of muscle activation and less duration of muscle activity was found in the serratus anterior in these patients compared to asymptomatic people (Figs. 2 and 3 and Table 2 and 3). This finding may have implications for scapular stability because it may reduce the quality of neuromuscular performance and compromise the normal

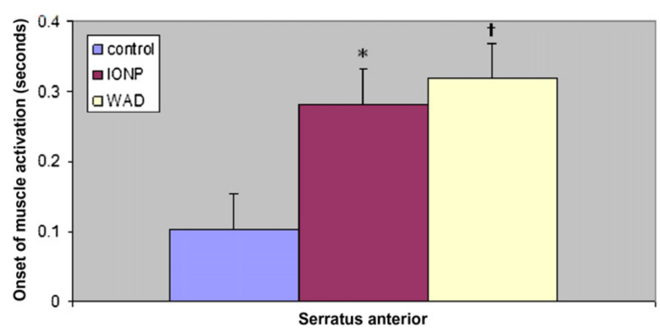

Fig. 2. Mean (SEM) onset of muscle activation for the serratus anterior. IONP = insidious onset neck pain, WAD = whiplash associated disorder. *Statistically significant difference between IONP and control ($P < 0.05$). †Statistically significant difference between WAD and control ($P < 0.01$).

Table 2
Summary group data for the right and left side, demonstrating the mean in seconds (SEM) of the onset of muscle activation for the Upper Trapezius (UT), Middle Trapezius (MT), Lower Trapezius (LT) and the Serratus Anterior (SA).

		Control Mean	SEM	IONP Mean	SEM	WAD Mean	SEM
Right	UT	0.11	0.04	0.15	0.06	0.10	0.06
	MT	0.55	0.09	0.50	0.13	0.54	0.12
	LT	0.34	0.07	0.43	0.10	0.47	0.10
	SA	0.07	0.06	0.24	0.09	0.33	0.09
Left	UT	0.11	0.04	0.16	0.06	0.12	0.06
	MT	0.57	0.11	0.60	0.15	0.70	0.15
	LT	0.36	0.05	0.48	0.08	0.43	0.07
	SA	0.14	0.05	0.30	0.07	0.29	0.07

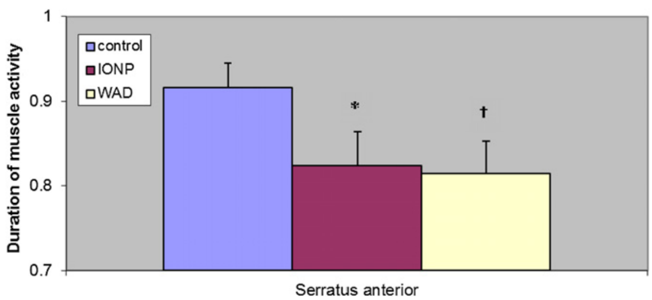

Fig. 3. Mean (SEM) duration of muscle activity for the serratus anterior. Duration of muscle activity was calculated by dividing the time of muscle activation by the time it took the arm to elevate and descend. IONP = insidious onset neck pain, WAD = whiplash associated disorder. *Statistically significant difference between IONP and control ($P < 0.02$). †Statistically significant difference between WAD and control ($P < 0.01$).

Table 3
Summary group data for the right and left side, demonstrating the mean (SEM) of duration of muscle activity for the Upper Trapezius (UT), Middle Trapezius (MT), Lower Trapezius (LT) and the Serratus Anterior (SA). Duration of muscle activity was calculated by dividing the time of muscle activation by the time it took the arm to elevate and descend.

		Control Mean	SEM	IONP Mean	SEM	WAD Mean	SEM
Right	UT	0.89	0.05	0.88	0.07	0.94	0.07
	MT	0.65	0.06	0.65	0.07	0.61	0.07
	LT	0.82	0.04	0.84	0.05	0.83	0.05
	SA	0.92	0.03	0.82	0.04	0.81	0.04
Left	UT	0.98	0.05	0.95	0.07	0.93	0.07
	MT	0.67	0.06	0.68	0.08	0.59	0.08
	LT	0.80	0.04	0.78	0.05	0.76	0.05
	SA	0.91	0.03	0.83	0.04	0.82	0.04

synergistic force couple relation between the serratus anterior and trapezius (Inman et al., 1996; Mottram, 1997; Wadsworth and Bullock-Saxton, 1997; Kibler and McMullen, 2003).

However, the study failed to show altered activity of the upper, middle and lower trapezius in these patients. This is in accordance with other studies which have reported conflicting results on whether neck pain alters the EMG activity of the trapezius (Nederhand et al., 2000, 2002; Falla et al., 2004; Szeto et al., 2005c; Thorn et al., 2007; Strøm et al., 2009).

The serratus anterior muscle is the prime upward rotator of the scapula and needed for complete active arm elevation. The muscle also posteriorly tilts and externally rotates the scapula holding it flat against the thoracic cage during upper limb activities and hinders elevation of the shoulder girdle (Sahrmann, 2002; Ludewig et al., 2009). Research on the shoulder concludes that the serratus anterior is the main stabilizer of the scapula (Kibler and McMullen, 2003). Deficits in the activity and the recruitment of the serratus anterior affects scapular stability and scapular orientation (Inman et al., 1996; Mottram, 1997; Wadsworth and Bullock-Saxton, 1997; Kibler and McMullen, 2003). It has therefore the potential to induce aberrant forces on the cervical and thoracic spine, sustaining symptomatic mechanical dysfunction in the area and may be responsible for maintaining periods of recurrence or exacerbation of neck pain (Behrsin and Maguire, 1986; Jull et al., 2008).

The altered activity of the serratus anterior in patients with cervical disorders corresponds to what has previously been reported in patients with shoulder disorders (Wadsworth and Bullock-Saxton, 1997) and supports the hypothesis that the altered activity in the serratus anterior may be a general response to a chronic pain condition in the cervical- or shoulder area (Kibler and McMullen, 2003). This hypothesis is also supported by the fact that no difference was found between the two symptomatic groups and by studies that report altered activity bilaterally in the scapular muscles in patients with unilateral shoulder disorder (Wadsworth and Bullock-Saxton, 1997; Cools et al., 2003).

The trapezius muscle may be affected differently or more condition specific than the deeper serratus anterior muscle. A recent study conducted by Strøm et al. (2009) suggests that chronic neck pain is associated with vasodilation of the upper trapezius muscle but not with increased muscle activity. This is supported by a study conducted by Westgard et al. (2001) that showed that the muscle activity levels of the upper trapezius over the work day did not increase in service workers with low observed biomechanical exposure, despite high prevalence of shoulder and neck pain. However, decreased ability to relax on completion of an upper limb task has been reported in the upper trapezius muscle in patients with neck pain (Johnston et al., 2008). Interestingly, a difference has been reported between patients with IONP and WAD where WAD patients have a tendency of higher and longer muscle activation patterns in the muscle during upper limb tasks (Nederhand et al., 2002), and a decreased ability to relax after tasks compared to patients with IONP, reflected by significantly higher muscle activity levels (Falla et al., 2004). The increased activity in the upper trapezius in some patients with neck pain may be protective to prevent traction injury to an irritated brachial plexus including its nerve roots (Coppieters et al., 2001; Jull et al., 2008).

It has also been demonstrated that injection of hypertonic saline in the upper trapezius causing experimental pain in "healthy subjects" results in reorganization in the coordination of trapezius during shoulder flexion (Falla et al., 2007). Decreased activity on the painful side was demonstrated in the upper trapezius but increased activity occurred in the lower trapezius. However, the upper trapezius on the contralateral side to the pain demonstrated increased activity. These findings demonstrate that pain in the upper trapezius changes the motor control in the upper and lower trapezius not only on the painful side but also on the contralateral side.

The weak correlation between the dependent variables and the scores on the NDI and the VAS in our study ($r < 0.3$) is in line with many other studies (Heikkilä and Aström, 1996; Rix and Bagust, 2001; Sandlund et al., 2006; Kristjansson and Oddsdottir, 2010), which revealed a weak or fair relationship between the physical outcome measures under investigation and questionnaires measuring short- and long-term impacts of neck pain and disability. A new research study on the content analysis of ten neck-shoulder pain and disability questionnaires ascertained that the correspondence between the symptoms expressed by those affected and the content of the questionnaires was low (Wiitavaara et al., 2009). It is therefore urgent that questionnaires be developed that are specific to the conditions they are supposed to capture (Bombardier and Tugwell, 1987; Hoving et al., 2003).

The main limitation of the present study concerns the possibility of cross-talk when surface EMG is used. However fine wire electrodes measuring only few muscle fibers are not considered a good choice for investigating large muscle groups as the serratus anterior and the trapezius where a more global evaluation of muscle activity is needed. Careful placement of electrodes in line with orientation of muscle fibers is the best way to avoid cross-talk from nearby muscles; however the possibility of a crosstalk has to be taken into consideration even though best common practice to avoid it was used. Secondly, the results present mean values for each group, but great variability was observed within each group. Thirdly the majority of our participants were women as fewer men were referred and because the men referred were more frequently excluded because of shoulder problems and because of history of an injury to the upper extremity. Therefore these findings may not be generalized to all patients with neck pain.

Further studies are needed to provide information concerning the contribution of the scapular muscles in maintaining normal scapular orientation with arms by the sides and during arm elevation, in patients with neck pain. Fine wire electrodes, measuring the activity of the levator scapulae and the rhomboid muscles, while surface EMG measures the activity of the trapezius and the serratus anterior would provide further information about the contribution of each muscle.

6. Conclusions

Patients with IONP and WAD demonstrated a significantly delayed onset of muscle activation and less duration of muscle activity of the serratus anterior on both sides during arm elevation. This finding may have implications for scapular stability in these patients. No difference was revealed between the two symptomatic groups suggesting that the disturbance in the onset of muscle activation of the serratus anterior muscle may occur as a general response to chronic neck pain. However, the trapezius muscle may be affected differently as no between-groups differences were ascertained in our cohort.

7. Ethical approval

This study was approved by the Bioethics Committee of Landspitali University Hospital and all participants signed a consent form.

8. Funding

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Conflict of interest statement

The authors have no financial or personal relationship with other people or organizations that could inappropriately influence their work.

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