Axioscapular and neck extensor muscle behavior during isometric shoulder exertions in patients with neck pain with and without a scapular downward rotation posture

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Abstract

Background: A common observation in persons with neck pain is scapular downward rotation (SDR) with altered muscle behavior. Evidence of changes in axioscapular muscles in neck pain patients remains inconclusive, which may reflect population heterogeneity in previous studies.

Research question: Are there differences in behavior of the axioscapular (upper trapezius: UT, lower trapezius: LT and serratus anterior: SA) and neck extensor (NE) muscles during isometric shoulder tasks in patients with neck pain with SDR, patients with no scapular dysfunction and healthy controls?

Methods: Sixty participants with nonspecific neck pain (30 with SDR and 30 without scapular dysfunction) and 30 controls were recruited. Electromyographic signals were recorded unilaterally from the UT, LT, SA and NE during different isometric shoulder tasks (30° flexion, 30°abduction and 30°external rotation) at 20%, 50% and 100% maximal voluntary contraction (MVC). Activity of UT, LT, SA and NE was normalized with respect to reference contractions. The UT/LT, UT/SA and LT/SA ratios were calculated for each task.

Results: The neck pain group with SDR had increased UT activity in 30°flexion (20%MVC) and 30°abduction (20% and 50%MVC) compared to the neck pain and control groups without scapular dysfunction ($p<0.05$). There were no between group differences in LT and SA activity ($p>0.05$). The neck pain groups had greater NE activity in all tasks ($p<0.001$). Finally, the neck pain group with SDR had higher UT/LT and UT/SA ratios in a few tasks at low force levels ($p\leq0.01$).

Significance: Greater UT activity and UT/LT and UT/SA ratios during particularly low force isometric shoulder tasks suggest that SDR is associated with altered axioscapular motor control. Greater NE activity in both neck pain groups suggests altered motor control related to neck pain. Changes in the NE and UT behavior should be considered in management of patients with neck pain with observable SDR.

Keywords: Electromyography; isometric contraction; muscle activity; neck pain; scapula

1. Introduction

Scapular downward rotation (SDR) is an alignment which clinically is associated with short, overactive levator scapulae and rhomboid muscles, lengthened upper trapezius (UT) and serratus anterior (SA) muscles [1] and possible impaired activation or reduced strength of the lower trapezius (LT) [2]. SDR at rest and during arm movement [3-5] is identified as a contributing factor to neck pain and restricted neck movement [6, 7]. Poor levator scapulae and UT function can increase load on the cervical spine [8, 9].

Altered behaviors in neck extensor (NE) and axioscapular muscles may occur in patients with neck pain (NP) [10-14] although evidence for altered activity in the axioscapular muscles is inconclusive [15]. Some studies report higher activity in the NE and UT during upper limb tasks [10, 11, 14] and higher LT activity in the presence of poor scapular posture [12]. Another found similar UT, LT and SA muscle activity during arm movement between NP patients and healthy controls who both presented with scapular dyskinesis [16] . These inconclusive findings may reflect heterogeneity of scapular dysfunction (presence and nature) in NP patients.

Scapular stability is important for shoulder function [17]. SDR may limit the ability of the axioscapular muscles to stabilize the scapula during loaded upper limb tasks which may cause or exacerbate neck pain [18]. Alternatively, neck pain may induce reorganization of neck and axioscapular muscle activity [18] which may perpetuate adverse load and pain. This study investigated the behavior of the axioscapular (UT, LT, and SA) and neck (NE) muscles during isometric shoulder flexion, abduction and external rotation with varying effort. We included patients with nonspecific NP who did and did not, on clinical inspection, exhibit SDR. We hypothesized that altered axioscapular muscle behavior would only be observed in patients with SDR, and not in those without scapular dysfunction, but both NP groups (with and without SDR) would exhibit altered behavior of NE muscle activity compared to healthy controls. This study stands to enhance understanding of the relevance of SDR for motor control strategies in NP patients that may inform rehabilitation approaches.

2. Methods

2.1. Participants

Sample size calculation was based on a pilot study (10 participants with NP with SDR, 10 with NP with no scapular dysfunction and 10 healthy controls with no scapular dysfunction). Effect sizes ranged from 0.28 to 0.77 with a power of 80% and a significance level of 0.05. The smallest effect size was chosen. The minimum number required was 87 participants (29 per group).

Sixty participants with nonspecific NP (30 with SDR, 30 without scapular dysfunction) and 30 healthy controls without scapular dysfunction, aged between 18-59 years, were recruited. Participants with NP with SDR were recruited from a larger research project of scapular dysfunction in neck pain [7]. Participants with NP without clinical signs of scapular dysfunction and healthy controls were recruited via flyers and posters in local hospitals, physical therapy clinics, community and social networks (e.g., Facebook and Instagram).

Inclusion criteria for both NP groups were chronic nonspecific NP (≥3 months), pain ≥3 on a 0-10 cm Visual Analogue Scale (VAS) and a Neck Disability Index (NDI) score ≥10/100 [19, 20]. The control group had no history of neck pain in the previous year. The SDR for NP participants had to be on the side of neck pain. SDR was identified if the spine of the scapular had a horizontal or infero-lateral inclination and the medial scapular border had an infero-medial inclination [7, 21]. The scapula position was regarded as acceptable in both the NP or control participants if the scapula was judged clinically to be parallel to the spine approximately 2 inches from the midline of the thorax, located between the second and seventh ribs, rotated forward (in the vicinity of 30°), inclined slightly inferiorly-laterally, without any prominence of the scapular angles and borders [5, 21]. An experienced physiotherapist assessed scapular position. Inter-rater reliability of the scapular assessment was conducted in patients with NP (n = 20). The results indicated excellent agreement (%agreement = 90 and kappa coefficient = 0.86). Exclusion criteria for all groups using a self-report questionnaire and a semi-structured interview were histories of head and neck injury or surgery, neurological symptoms (radicular pain, weakness, numbness and tingling), shoulder problems (pain, tenderness on palpation or limitation of active range of motion) and any musculoskeletal or neurological condition that could affect scapular position.

The study was approved by the Institution's ethical review committee (No. AMSEC-62EX-050) and conducted in accordance with the declaration of Helsinki. All participants provided informed consent prior to commencement of the study.

2.2. Electromyography instrumentation and measures

Surface electromyography (sEMG) was used to measure muscle activity of the NE, UT, LT, and SA muscles during isometric shoulder exertions. sEMG signals were sampled at 1,000 Hz and amplified using a differential bioamplifier with a common mode rejection ratio of 85 dB at 60 Hz and input impedance of 200 MΩ (Model FE135 Dual Bio Amp; ADInstruments, Bella Vista, NSW, Australia). The signals were converted to digital data using a 16-bit analog to digital converter in PowerLab 4/35 (Model PL3504; ADInstruments), transferred and filtered using a bandpass filter (10-500 Hz) with LabChart 8.1.5 software (ADInstruments). Bipolar Ag/AgCl surface electrodes (34 x 40 mm Teardrop shape, Ambu® BlueSensor P, Denmark) were placed over the muscle belly with an inter-electrode distance of 2 cm for each target muscle: NE approximately 2 cm from the midline at C4 [22]; UT 2 cm lateral to the midpoint between the spinous process of C7 and the acromion, on the anterior border of the muscle bulk [18]; LT 2/3 on the line from the spine of scapula to the T8 [23]; and SA at rib 6 to 8 vertically along the mid-axillary line [24]. Ground electrodes were placed on the spinous processes of C7 and T1.

sEMG recordings were made unilaterally on the more painful side in the NP groups and randomly on the dominant or non-dominant side for controls. A reference voluntary contraction for each muscle enabled normalization of EMG amplitude: NE-prone position, head raising 20 mm above the bed [25]; UT-90° shoulder abduction in standing [11]; LT-prone position, arm in approximately 130° shoulder abduction, full elbow extension and thumb up [26]; and SA-sitting, shoulder protraction with 125° shoulder flexion [27]. Each reference contraction was held for 10 seconds and performed 3 times with an interval of 30 seconds between each contraction. The average EMG value was used in analysis.

NE, UT, LT, and SA sEMG activity was recorded during the three isometric exertion tasks in three directions of shoulder movement (30°flexion, 30°abduction, 30°external rotation). sEMG signals were synchronized with the force values recorded with a custom-built load cell.

2.3. Isometric shoulder exertions

A custom-built load cell measured isometric exertions in three 30° shoulder positions: flexion, abduction and external rotation (Fig. 1). Exertion in each direction was performed at three intensities: 20%, 50% and 100% of maximal voluntary contraction (MVC). Positions of 30° were chosen to reflect ranges commonly used in activities of daily living. All measurements were performed unilaterally. Participants sat in an upright position (head/neck and trunk in a neutral position) without support with feet on the floor. The elbow was flexed to 90° with the forearm in a mid-position. The 30° shoulder positions were measured using a universal goniometer. The force application pad was positioned: superior to the anterior elbow crease for flexion; above the lateral humeral epicondyle for abduction; and proximal to the ulnar styloid process for external rotation (Zakharova-Luneva et al., 2012). The non-tested arm rested by the side with the hand placed on the thigh.

The participant's applied force to the application pad was measured by a load cell (HT-Sensor TAL201, Colorado, USA). The load cell signals were amplified (HX711 Amplifier Module, Niwot, CO, USA) and transmitted to a computer. A custom written program (LabView 2014, National Instruments, Austin, TX, USA) was calibrated to convert voltage change to the International System (SI) unit of force in Newtons (N). Real-time visual feedback of force production was displayed to the participant using a bar graph on a computer screen by displaying time-varying force trace relative to the force target for 20% and 50% MVC. Test-retest reliability of unilateral force measured by the custom-built load cell for the three isometric shoulder tasks was conducted in patients with neck pain (n = 20). Intraclass Correlation Coefficients (ICCs) were excellent (0.96-0.99).

2.4. Study procedure

The skin was cleaned with 70% alcohol swabs to minimize skin impedance. sEMG electrodes were attached to the NE, UT, LT, and SA muscles. sEMG normalization tasks were conducted for each muscle. Participants were then set up on the custom-built dynamometry apparatus and completed two familiarization and warm-up trials. Isometric shoulder exertions in 30° flexion, 30° abduction and 30° external rotation were tested in random order to eliminate any order effects. Three repetitions of 100% MVC with 5-second holds were performed first, followed by 3 repetitions at 20% and 50% MVC with 10-second holds. The highest value of the three 100% MVC tasks was used to calculate relative target forces for the 20% and 50% MVC tasks. Participants were instructed to “push as hard as possible” at 100% MVC and to “maintain a constant force level as close as possible to the target” in the 20% and 50% MVC tasks. During the test, participants maintained an upright head and trunk position. Standardized verbal instructions and encouragement were given to all participants. Real-time visual feedback of force production was provided during all isometric tasks. A 30-second rest period was given between each repetition. A 5-minute rest period was provided between each intensity level and each task direction. Participants reported any pain or discomfort during testing on a 0-10 numerical rating scale (NRS). All tests were conducted by an independent examiner who was blinded to the participants’ group status.

2.5. Data management

The sEMG data for each trial were analyzed using custom software written in Matlab (The MathWorks Inc., Natick, MA, USA). Root mean square (RMS) values were calculated within a 100 ms moving window from each signal for time windows of 2 seconds at 100% MVC and for 5 seconds (at steady state) at 20% and 50% MVC. RMS values from the three trials of each isometric task were averaged for all muscles (NE, UT, LT and SA). Average RMS values and each task were normalized against the muscle’s reference value and expressed as a percentage of the reference contraction. To identify the relative activity of the axioscapular muscles, ratios of the UT/LT, UT/SA and LT/SA were calculated for each isometric task [28].

2.6. Statistical analysis

One way analysis of variance (ANOVA) was used to compare demographic data and maximal force exertions between participant groups. Independent t-test was used to determine differences in pain characteristics between the NP groups. As normalized RMS data were not normally distributed, the base-10 logarithm of each normalized RMS value at 20%, 50% and 100% MVC was entered into multivariate analysis of variance (MANOVA) to identify differences between groups for each muscle in each of the three isometric shoulder tasks. A univariate ANOVA with Bonferroni adjustment assessed group differences in the dependent variables identified in the MANOVA. One way ANOVA was used to compare the ratios of UT/LT, UT/SA and LT/SA between groups. Effect size was calculated using partial eta squared (η_p^2) (small=0.02, moderate=0.13 and large=0.26) [29]. All analyses were conducted using IBM SPSS Statistics (Version 17.0). The level of statistical significance was set at $p < 0.05$.

3. Results

3.1. Participants

There were no differences in demographic data between groups (p>0.05, Table 1). Participants in the NP groups had similar characteristics in terms of neck pain duration, pain intensity and neck disability (p>0.05).

3.2. Maximal force exertions

There was no difference in maximal force exertion for each isometric task between the three groups (p>0.05, Table 2). Five participants (16.7%) in the NP group with SDR reported aggravation of neck pain when performing the isometric task at 100% MVC (NRS = 5.5±1.3 for flexion, 6.2±1.3 abduction and 5.3±1.0 external rotation) while it was reported by four (13.3%) in the NP group without scapular dysfunction at 100% MVC (NRS = 5.3±0.6 for flexion, 5.7±1.2 abduction and 5.0±1.4 external rotation). No participant in either NP group reported aggravation of neck pain at 20% and 50% MVC isometric tasks. The control group reported no aggravation of neck pain in any task.

3.3. Activity of axioscapular and neck extensor muscles

Fig. 2 presents the normalized RMS for axioscapular (UT, LT and SA) and NE muscles during the isometric shoulder tasks at different intensities. The NP group with SDR had significantly higher UT activity compared to the other two groups at 20% MVC in 30° shoulder flexion ($p<0.05$; $\eta_p^2=0.14$) and at 20% and 50% MVC in 30° shoulder abduction ($p<0.05$; η_p^2 range from 0.12 to 0.21). There were no between-group differences in UT activity in 30° shoulder external rotation ($p>0.05$). There were no between-group differences in LT and SA muscle activity in all isometric shoulder tasks ($p>0.05$). Both NP groups had significantly greater NE activity than the control group for all isometric shoulder tasks at all intensities (all $p<0.001$; η_p^2 range from 0.26 to 0.63).

3.4. Activation ratios of the axioscapular muscles

Table 3 present the ratio of UT/LT, UT/SA, and LT/SA during isometric shoulder tasks. The UT/LT ratio was significantly higher at 20% MVC in 30° shoulder abduction in the NP group with SDR compared to the other two groups ($p<0.01$; $\eta_p^2=0.14$). The UT/SA ratio was also significantly higher at 20% and 50% MVC in 30° shoulder flexion and at 20% MVC in 30° abduction in the NP group with SDR ($p\leq0.01$; η_p^2 range from 0.11 to 0.22).

4. Discussion

The study demonstrated altered, albeit selective, axioscapular amplitudes and patterns of muscle activity in participants with NP and SDR. There was significantly higher activity in the UT muscle and activation ratios of the UT/LT and UT/SA in isometric shoulder tasks variously at 20% and 50% MVC in 30º flexion and 30º abduction. The alterations were not observed in the NP and control groups without scapular dysfunction and no differences were observed between group in any task in 30º external rotation. Measurements in arm positions of 30º replicated ranges and positions commonly used in functional activities (e.g., keyboard/devise use, bench work). The notable feature of these results is that the altered axioscapular muscle behavior associated with SDR was demonstrated most consistently in the low force tasks of arm elevation (20% MVC). Differences were not demonstrated in higher force tasks (MVC) in any task. Muscle coordination and motor control strategy is paramount at these lower contraction intensities [30]. These findings have important implications for rehabilitation. They reinforce the need for restoration of motor control of axioscapular muscles at low levels of MVC in patients with SDR, rather than a focus only on high load strengthening exercises [31].

Greater UT activity and UT/LT, UT/SA ratios indicate imbalance and reflect excessive UT muscle activity. Increased UT activity is reported consistently in different upper limb tasks in patients with NP [11, 32]. An optimal interaction between UT, LT and SA muscles is desired to provide stability of the scapula. Increased activation ratios of the UT muscle relative to LT and SA muscles may result in undesired physiologic and biomechanical effects such as changes in muscle-length tension relationships to stabilize the scapula [9, 33]. Several proposals explain the increased UT activity. The levator scapulae, which is synergistic with UT and often shortened and overactive in SDR, may induce a relative increase in UT activity [1]. Increased UT activity may be attributed to impaired deltoid muscle function [34] and relate to compensatory shoulder girdle elevation [9]. Increased UT activity may create a passive mechanism for shoulder stability as SDR tilts the glenoid cavity inferiorly and increases downward pulling tension [1, 35]. Alternatively, increased UT activity in SDR may be a compensatory strategy for reduced UT muscle strength, by increasing motor unit recruitment. LT and SA activity was not influenced by SDR. This was unexpected and the reason unclear at this stage.

Participants with NP demonstrated higher NE activity in all tasks, regardless of scapular dysfunction or not. This is consistent with findings of previous studies [10, 14]. The increased NE activity, as hypothesized, is more likely a factor related to neck pain rather than scapular dysfunction. When the upper limb is loaded, the cervical segments move [36]. Impaired function of the deep cervical extensor muscles (which stabilize/control segmental movement) has been associated with neck pain [37, 38]. The increased NE activity (and UT activity) may be a compensatory strategy for impaired function in the deep extensor muscles. Nevertheless, increased UT and NE activity could increase the loads on the spine. Thus, the potential involvement of both the neck and axioscapular muscles should be considered in assessment and management of patients with NP.

There are some limitations in this study. Interactions of other muscles were not measured (levator scapulae, middle trapezius, rhomboid, pectoralis minor, rotator cuff and deltoid muscles), which might have assisted in explaining our findings. Control of scapular position during the tasks was not assessed. The painful or more painful side of neck pain was tested, and muscle activity may be influenced by hand dominance. Additionally, there was no comparable healthy control group with SDR in the study. Future research should investigate the activation of other scapular and shoulder muscles. Further studies are warranted to assess the effectiveness of exercise programs for the specific disturbances neck and axioscapular muscle activity determined in this study for NP patients with SDR.

5. Conclusion

Greater UT muscle activity and UT/LT and UT/SA ratios were demonstrated in low force isometric shoulder tasks in the NP group with SDR, compared to the NP and healthy control groups without scapular dysfunction. Greater NE activity was observed in both NP groups. The changes in the UT and NE muscle behavior reflect changes in motor control strategies in persons with NP and SDR. Benefits for the patient may be gained if these altered motor strategies are addressed with specific exercise strategies in management.

Conflict of interest statement: The authors declare that there is no conflict of interest regarding the publication of this article.

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Table 1 Demographic and clinical characteristics of participants

	Controls (n = 30)	Neck pain with no SD (n = 30)	Neck pain with SDR (n = 30)
Age (years)	34.2 ± 7.1	34.8 ± 9.4	38.1 ± 10.1
Gender (n, male/female)	10/20	10/20	10/20
Body mass index (kg/m^2)	21.7 ± 2.6	22.3 ± 3.2	23.2 ± 3.5
Side tested (n, dominance/non-dominance)	20/10	22/8	22/8
Pain duration (months)	-	24.9 ± 12.3	25.0 ± 9.1
Pain intensity (0 - 10 VAS)	-	4.2 ± 0.8	4.2 ± 0.5
Neck disability (% NDI)	-	24.7 ± 10.7	28.9 ± 9.6

Data are presented as mean ± standard deviation unless otherwise indicated.

NDI = neck disability index, VAS = visual analogue scale, SD = scapular dysfunction, SDR = scapular downward rotation

Table 2 Maximal voluntary contraction (MVC) force during isometric shoulder tasks for the neck pain and control groups.

Isometric tasks	Controls	Neck pain with no SD	Neck pain with SDR
30° Flexion (N)	65.2 ± 21.0	66.3 ± 19.4	59.9 ± 14.0
30° Abduction (N)	79.6 ± 27.3	75.0 ± 20.7	72.8 ± 21.7
30° External rotation (N)	46.5 ± 12.2	45.4 ± 12.5	43.1 ± 11.2

Data are presented as mean ± standard deviation.

N = Newtons, SD = scapular dysfunction, SDR = scapular downward rotation

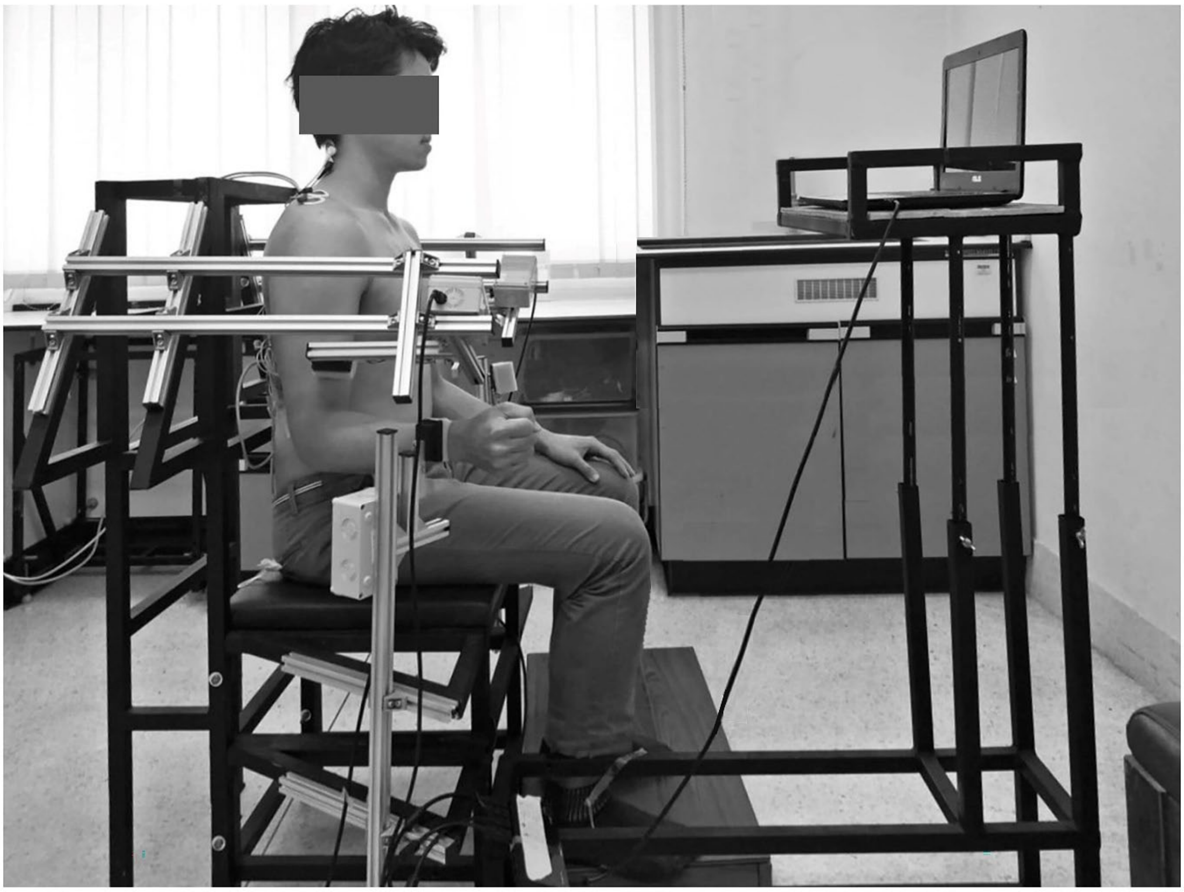

Fig. 1. Experimental setup.

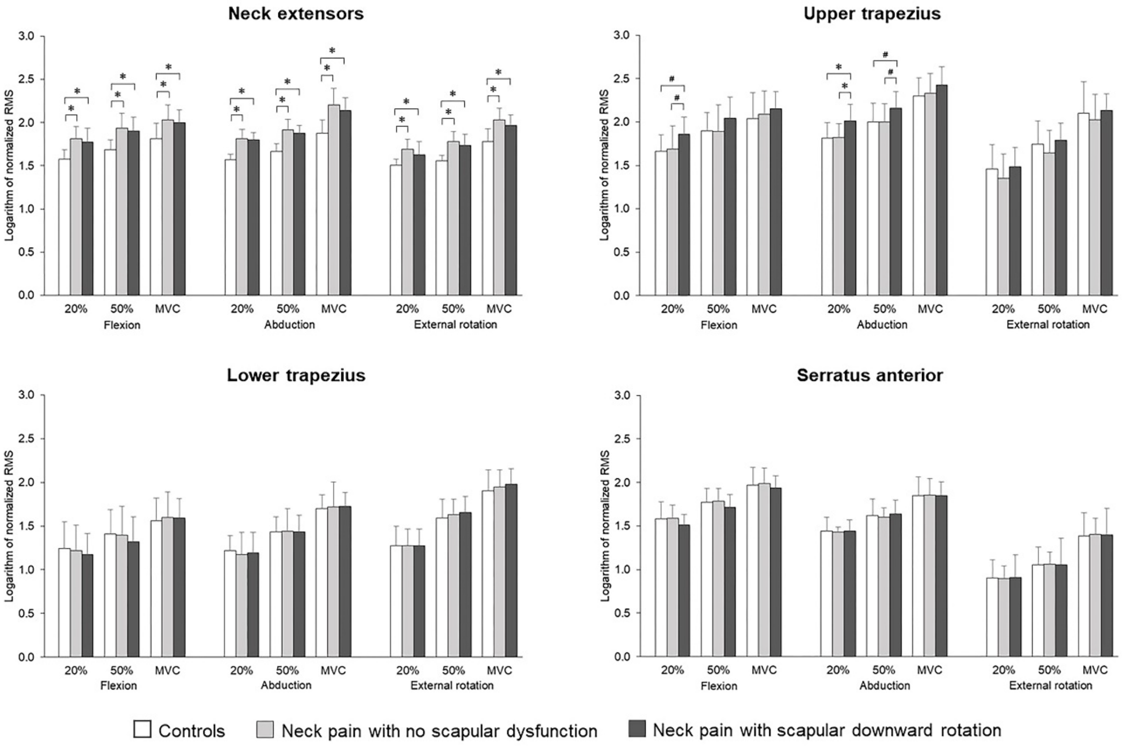

Fig. 2. The normalized RMS values (mean and standard deviation) for the axioscapular (upper trapezius, lower trapezius and serratus anterior) and neck extensors muscles during isometric shoulder tasks (30°flexion, 30°abduction and 30°external rotation) at different intensities (20%, 50% and 100% MVC) in the neck pain with scapular downward rotation, neck pain with no scapular dysfunction and control groups. * $p<0.001$, $^{\#}p<0.05$.