Journal of Electromyography and Kinesiology 23 (2013) 1158–1165

Contents lists available at SciVerse ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Neuromuscular control of scapula muscles during a voluntary task in subjects with Subacromial Impingement Syndrome. A case-control study

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A R T I C L E I N F O

Article history:
Received 31 August 2012
Received in revised form 24 February 2013
Accepted 29 April 2013

Keywords:
Muscle imbalance
Muscle latency
Shoulder pathology
Scapular stability

A B S T R A C T

Imbalance of neuromuscular activity in the scapula stabilizers in subjects with Subacromial Impingement Syndrome (SIS) is described in restricted tasks and specific populations. Our aim was to compare the scapular muscle activity during a voluntary movement task in a general population with and without SIS ($n = 16$, No-SIS = 15).

Surface electromyography was measured from Serratus anterior (SA) and Trapezius during bilateral arm elevation (no-load, 1 kg, 3 kg). Mean relative muscle activity was calculated for SA and the upper (UT) and lower part of trapezius (LWT), in addition to activation ratio and time to activity onset. In spite of a tendency to higher activity among SIS 0.10–0.30 between-group differences were not significant neither in ratio of muscle activation 0.80–0.98 nor time to activity onset 0.53–0.98.

The hypothesized between-group differences in neuromuscular activity of Trapezius and Serratus was not confirmed. The tendency to a higher relative muscle activity in SIS could be due to a pain-related increase in co-activation or a decrease in maximal activation. The negative findings may display the variation in the specific muscle activation patterns depending on the criteria used to define the population of impingement patients, as well as the methodological procedure being used, and the shoulder movement investigated.

1. Introduction

Subacromial impingement Syndrome (SIS) comprising both shoulder pain and disability is one of the most common shoulder disorders registered in primary care (House and Mooradian, 2010; Ostor et al., 2005). The prevalence of SIS is especially high in overhead sports, as well as in overhead work with high demands for dynamic shoulder stability (Belling Sorensen and Jorgensen, 2000; Cools et al., 2003; van Rijn et al., 2010). SIS is characterized by shoulder pain exacerbated with arm elevation or overhead activities which may be due to a compression of subacromial structures, such as rotator cuff muscle tendons (Fu et al., 1991; Neer, 1972), potentially caused by an inappropriate scapulo-humeral movement (Belling Sorensen and Jorgensen, 2000; Page, 2011). During scapular rotation the serratus anterior (SA) works in coordination with the upper (UT), middle (MT) and lower parts (LT) of the trapezius (Inman et al., 1944; Kibler and McMullen, 2003). A close coupling of SA and LT muscles may counterbalance upper trapezius activity, thereby providing a balanced control of scapular orientation and rotation (Inman et al., 1944). Various parameters have been used previously to describe this activity.

Some authors reported a high mean activity in the UT (Chester et al., 2010; Cools et al., 2004, 2007a; Lin et al., 2006; Ludewig and Cook, 2000) and a low mean activity in SA in subjects with SIS as compared to subjects without SIS (No-SIS) during arm motions in low and high loading conditions (Ellenbecker and Cools, 2010; Lin et al., 2006; Ludewig and Cook, 2000). Further, a higher ratio of relative activation of the UT and the LT (Cools et al., 2007a), and a delay in timing of onset of shoulder muscle activation during standardized tasks is reported for the MT, and the LT muscle, in SIS subjects compared to healthy controls (Cools et al., 2003; Moraes et al., 2008; Wadsworth and Bullock-Saxton, 1997). Moreover, longer latencies of muscle activation in the affected shoulder compared to the non-affected shoulder were found for all three parts of the trapezius muscle and the SA muscle (Moraes et al., 2008).

The current clinical treatment guidelines for patients with SIS are therefore based on the described neuromuscular imbalance and thus they include focus on increasing the activity in the lower

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http://dx.doi.org/10.1016/j.jelekin.2013.04.017

parts of the scapular stabilizing muscles (SA and LT), while decreasing or maintaining the activity of the upper parts of these muscles (UT) (Cools et al., 2008b; Ellenbecker and Cools, 2010).

The neuromuscular imbalance has mostly been reported during restricted movement tasks. These include maximum isokinetic strength tasks, i.e. concentric protraction/retraction (Cools et al., 2004), isokinetic arm abduction and external rotation (Cools et al., 2007c) and sudden arm perturbation (Cools et al., 2003). Few studies have included voluntary movements such as arm elevation (Lin et al., 2006; Moraes et al., 2008) and lifting (Ludewig and Cook, 2000) which more closely reflect activities of daily living. Moreover, the included study populations have often been young male overhead athletes (Cools et al., 2003, 2004, 2007a) or mid-aged overhead workers (Ludewig and Cook, 2000). Other risk factors than overhead activities have been found to increase the risk of developing SIS, such as highly repetitive work and forceful exertion in work, awkward postures, and high psychosocial job demands (Frost and Andersen, 1999; van Rijn et al., 2010). However, imbalance of scapular muscle activation has not been studied in a more general SIS population during a voluntary movement task.

Therefore, the aim was to investigate whether the activity of the Trapezius and Serratus muscles is different during a voluntary arm movement task in a general population with SIS compared to a matched population without SIS. In addition, it was of interest to investigate any correlation between the levels of shoulder pain and muscle activity. The hypothesis was that the SIS group compared to the No-SIS group would have a higher muscle activity in the upper part of trapezius compared to the lower part and SA, as well as higher ratios of activation and delayed timing of the onset of activity in the lower trapezius and SA.

2. Materials and methods

2.1. Subjects

A convenience sample of patients and controls, matched on groups by age (20–65 years) and gender, was recruited from physiotherapy clinics and among acquaintances. The population was aimed at matching a general population of SIS-patients, not only working with overhead activities. For the SIS group, the inclusion criteria were at least 30 days with pain/discomfort in the shoulder/neck region within the last year (Juul-Kristensen et al., 2006), but no more than three regions of pain/discomfort in order to exclude generalized musculoskeletal diseases. Furthermore, two or more positive impingement tests based on the Jobe, Neer, Hawkins and Apprehension tests were required (Cools et al., 2008a; Vind et al., 2011). For the healthy control group (No-SIS), the inclusion criteria were less than eight days with pain/discomfort in the shoulder/neck region within the last year, as well as no more than three regions of pain/discomfort elsewhere (Juul-Kristensen et al., 2006), and no positive impingement tests.

Overall exclusion criteria were: history of severe shoulder–neck pathology/trauma, orthopaedic surgery, documented life-threatening diseases, cardiovascular diseases, rheumatoid arthritis, generalized pain, adverse psycho-social conditions or pregnancy, and positive clinical tests for cervical radiculopathy (i.e. Spurling A test, Neck Distraction test, Involved Cervical Rotation test (less than 60°) (Wainner et al., 2003). The inclusion and exclusion criteria were identified by a questionnaire and a detailed interview, validated in previous studies (Andersen et al., 2008; Sandsjo et al., 2006; Sjogaard et al., 2010), as well as a clinical examination of the upper limb and neck performed by a physiotherapist.

A total of 69 subjects volunteered, however, six subjects were excluded during a preliminary telephone interview, based on the overall exclusion criteria. In total, 63 fulfilled the inclusion criteria, 59 accepted to participate in a screenings procedure and of these, 22 subjects were excluded due to the above exclusion criteria or inadequate data collection ($n = 3$), or dropped out due to personal circumstances ($n = 3$). Subjects who, based on the screening procedure, qualified as either a SIS case or a healthy control (No-SIS) ($n = 31$) were invited to participate in the study, comprising 16 subjects with SIS (8 women and 8 men) and 15 No-SIS (8 women and 7 men).

All subjects were informed about the purpose and content of the project and gave informed written consent to participate. The study conformed to the Declaration of Helsinki 2008 (Vollmann and Winau, 1996) and was approved by the Committee on Biomedical Research Ethics for the Region of Southern Denmark, Denmark (Project ID S-20090090). There was no conflict of interest.

2.2. Instrumentation

Bipolar circular surface electromyographical (sEMG) electrodes (10 mm diam, Ambu R Blue Sensor M, Olstykke, Denmark) were placed at the three anatomical subdivisions: UT, MT, and LT of the dominant/involved trapezius muscle and SA during prone lying.

A normal standardized procedure for electrode positions was used (Holtermann et al., 2009, 2010) (Fig. 1). All electrodes were placed in line with the fiber directions with an inter electrode distance of 2 cm (Hermens et al., 2000), with reference electrodes at the acromion and the C7 vertebra.

3. Experimental procedure

Pain intensity was evaluated on a 10 cm Visual Analog Scale (VAS) (Wewers and Lowe, 1990) before and after the tests. Surface electromyography (sEMG) was recorded from Trapezius and SA, (dominant arm of the No-SIS subjects) with a total duration of recording for about 1 h per subject.

For normalization of the EMG signals to maximal voluntary EMG (MVE) all subjects initially performed isometric maximal voluntary contractions (MVIC) for each of the three parts of the trapezius muscle and SA. Resting signal level of sEMG data was collected for 30 s in the resting prone lying position. All maximal contractions of the trapezius and SA were performed bilaterally with bilateral resistance, provided proximal to the elbow joints in an externally rotated shoulder position. Three attempts of 5 s duration with verbally encouragement were performed with 1 min rest in between. For the UT MVE, the subject performed an isometric arm elevation in standing with both arms elevated to 90° in the scapular plane. For

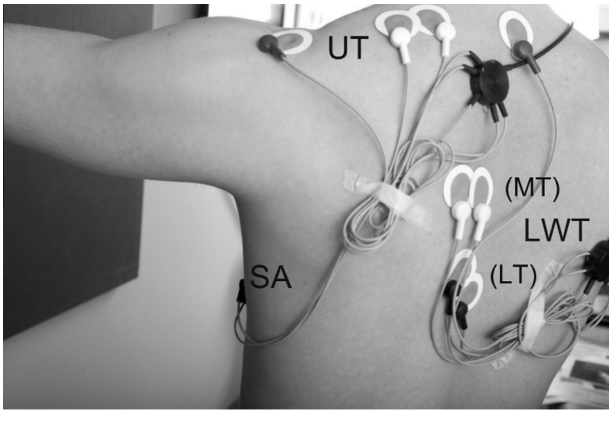


Fig. 1. Electrode placement of SA, UT and LWT.

MT and LT MVE, the subject performed arm abduction in prone lying, with both arms horizontally abducted to 90° and 180° in the scapular plane, while for the SA MVE, the subject performed isometric arm protraction during supine lying with the arms elevated to 90°, with bilateral resistance (Cools et al., 2007b; Ekstrom et al., 2005; Holtermann et al., 2009). The movement task was a shoulder elevation task performed under three conditions: (1) no external load, (2) holding 1 kg load, and (3) holding 3 kg load (Fig. 2). The order of load conditions was not randomized. Arm movements were performed bilaterally with extended elbows in the scapular plane, from 0° to maximum arm elevation (up), followed by lowering (down) to 0° (Ludewig and Cook, 2000). The movements were guided with a metronome, to ensure a similar speed in each task, and the subject was verbally guided. Each trial consisted of 2 s elevation (concentric) and 2 s lowering (eccentric), followed by 4 s pause, with five repetitions per block (loading) condition. There was 1 min pause between each loading condition.

3.1. Data reduction

EMG signals were amplified (gain 400) and analogue band pass filtered with a second order Butterworth filter with cut-off frequencies at 10–400 Hz and were then sampled at 1000 Hz (16 bit CED 1401, Spike2 software, Cambridge Electronic Devices, UK). The EMG amplitude was calculated by root-mean-square (RMS) with a moving window (1 s duration and moving in 100 ms steps) during the maximal EMG recording. Due to activity coherence (pre-analysis) the % MVE of the middle and lower part of trapezius were pooled in the analysis (called LWT).

The onset of muscle activity was defined by visual inspection of the EMG signal (Hodges and Bui, 1996). The time periods for the painful arc, between 60° and 120° part of the 180° swing during concentric and eccentric muscle work (Michener et al., 2009) were 0.7 s long starting 0.7 s after the visually determined onset and from the most elevated point of motion, respectively.

The peak RMS value recorded during MVE was used for EMG normalization (% MVE). Moreover, the analysis of % MVE was based on the mean of trials 2, 3 and 4 under the conditions of no-load, 1 kg, and 3 kg. Normalized muscle activity level (% MVE) of all muscles and activation ratios between UT, LWT and SA were calculated for the periods of painful arc.

Onset difference was given as the time delay between e.g. UT and SA, where a negative value represents initial activity in UT before SA activity, whereas a positive value represent the initial activity in SA.

3.2. Data analysis

The independent *t*-test and Fisheŕs exact test (1-sided) were used to compare subject characteristics between cases (SIS) and controls (No-SIS). For each group means and standard error of the mean were calculated for nine dependent variables in upward and downward arm movement. For each of the three muscles: SA, UT and LWT the dependent variables were relative muscle activity of the muscle parts, activation ratios between the muscles and onset differences within all muscles. A linear mixed model was used to evaluate group differences for each dependent variable with "subject" as random effect and adjusted for "group" (SIS/No-SIS), gender (M/F), load (no-load, 1 kg, 3 kg), age and body mass index (BMI). The interaction effect between group and load was also included in the model. The residuals of the linear mixed models were checked for normal distribution. If data did not follow the Gaussian distribution, they were log-transformed or ranked before analysis but in figures and tables still presented as non-log-transformed means or medians. To specify potential significant main effects Bonferroni post hoc test were preformed subsequently. Significance level was considered to be $p < 0.05$. A Spearman's Rank Order correlation analysis was performed (r_s), to assess the relationship between the pre-test VAS score and relative and ratio muscle activity in SA, UT and LWT for all loading conditions. Furthermore, a correlation was run to determine the interrelatedness between muscles.


Fig. 2. Voluntary movement task (No-load. 1 kg, 3 kg).

Previous results have shown (Ludewig and Cook, 2000) a standard deviation of 40% in Maximal Voluntary Electrical activity (MVE) and a 20% difference (MVE) between the two groups with a sample size of 26 in each group. In the present study a 30% difference was required as a clinical meaningful difference. Based on these data, a power calculation with 80% power and an alpha level of 0.05 revealed a minimal sample size of 14 subjects to be sufficient in each group, however we included a minimum of 15 subjects to be able to account for missing data.

All statistical analyses were performed with the Statistical Package for Social Sciences (PASW), version 18.0.0 (released July 30, 2009).

4. Results

The two groups were similar regarding age and body mass index. As expected a significantly higher level of pre-test pain (VAS) was found for SIS, but there was no significant difference between groups in the change in pain levels from pre to post-test (Table 1).

Results are displayed only for the concentric direction, as timing in this phase was more accurate than for the eccentric phase. However, the eccentric phase was also analyzed and showed similar results. Figures provide the means (SEM) of the EMG variables for the investigated muscles for both groups, except Fig. 5 in which the median and percentiles (without outliers defined as 1.5 to ⩾3 times the interquartile range) are presented instead.

By and large no significant differences between groups were found. Results showed no significant interaction effects (group ∗ - load) for the mean muscle activity for any of the muscle parts, nor any significant main effect of group (UT ($p = 0.30$), LWT ($p = 0.11$), SA ($p = 0.10$)). However, SIS displayed a non-significantly higher relative level of muscle activity in all muscle parts during all

Table 1
Demographic details of subjects.

	Cases (SIS) *n* = 16	Controls (No-SIS) *n* = 15	*P*-value
Sex *n*	8 ♀ 8 ♂	8 ♀ 7 ♂	0.859
Age (years)	41 ± 14	39 ± 12	0.618
BMI	25 ± 3	24 ± 2	0.074
VAS (1–100) (Pre test)	24.3 ± 22	1.8 ± 3	<0.001
VAS diff. (Pre-Post test)	7.8 ± 15	4.6 ± 10	0.485

loading conditions. As expected a significant effect of load was found and post hoc comparison revealed a significantly higher relative activity of all muscle parts in all load/no-load conditions in both the SIS and No-SIS group ($p \leqslant 0.001$) (Fig. 3).

For activation ratios no differences were demonstrated between the SIS and No-SIS group. No significant interaction effects were observed when comparing group and loading conditions for any of the muscle pairs. In addition, no significant main effects of group (SIS vs. No-SIS) were found (UT/LWT ($p = 0.98$), UT/SA ($p = 0.83$) and LWT/SA ($p = 0.80$)) (Fig. 4). For both groups, the activation ratios of UT/SA and UT/LWT showed a higher relative activation of UT, indicated by a ratio between 1.21 and 1.54, whereas the LWT/SA ratio was ranging from 0.89 to 1.11, indicating similar relative activation.

No differences were found in muscle activity onset when SIS was compared to No-SIS subjects. The interaction effects (group $*$

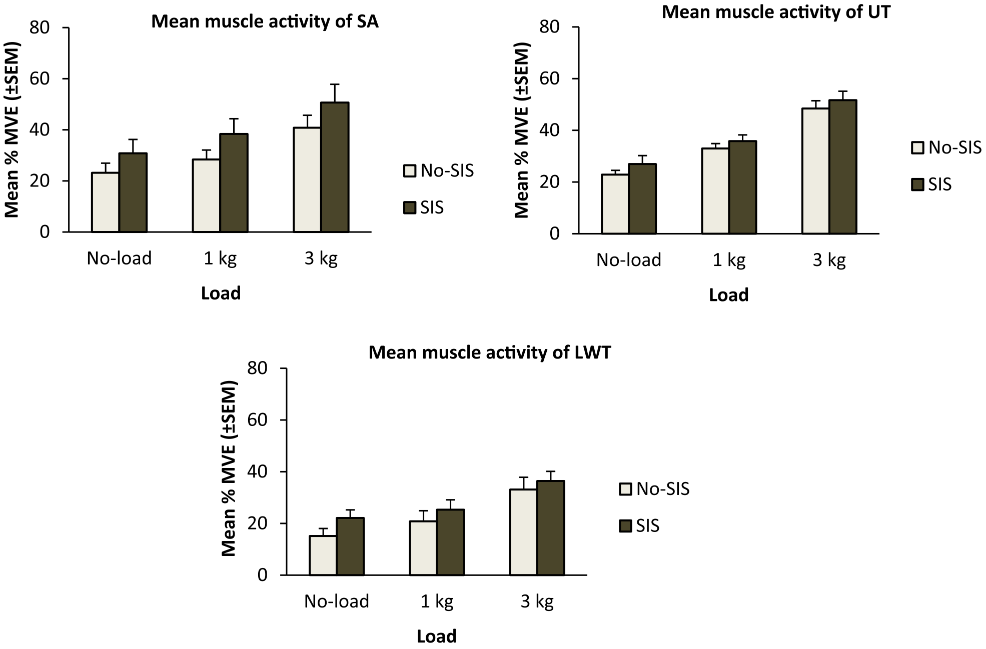


Fig. 3. Muscle activity of Serratus Anterior-(SA), Upper trapezius-(UT) and lower trapezius-(LWT) in *SIS* ($n = 16$) and *no-SIS* ($n = 15$) groups. Muscle activity is expressed as percentage of maximal voluntary EMG for each muscle. Group data are shown as mean % EMG-(SEM) during a voluntary arm movement task with no-load, 1 kg and 3 kg.

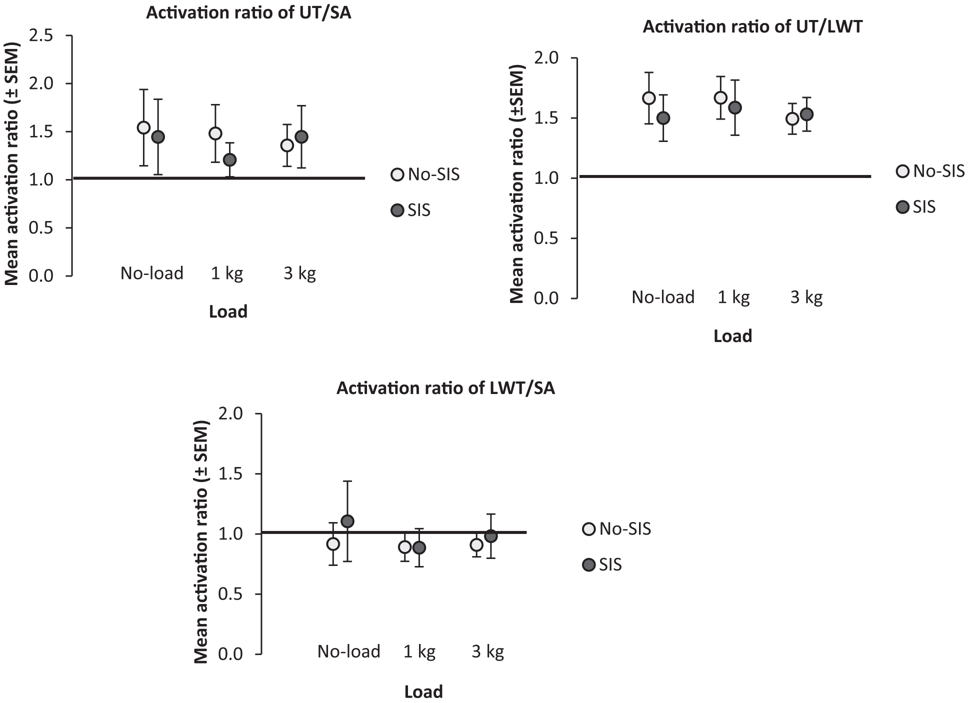


Fig. 4. Activation ratio of muscle activity for Serratus Anterior-(SA)/Upper trapezius-(UT), and UT/lower trapezius-(LWT), as well as LWT/SA in *SIS* ($n = 16$) and *no-SIS* ($n = 15$) groups. Data are shown as mean % EMG-(SEM) during a voluntary arm movement task with no-load, 1 kg and 3 kg.

load) of onset differences between all muscles pairs were non-significant and similar results were observed for the group main effects for all muscle pairs (UT-LWT ($p = 0.98$), UT-SA ($p = 0.78$) and LWT-SA UT ($p = 0.53$)). Load had a significant effect on the differences in onset between UT-LWT and UT-SA ($p \leqslant 0.05$) displayed as delay in activity of LWT and SA, especially in loading condition. The Bonferroni corrected tests showed a significantly larger difference in onset activity for UT-SA at no-load and 3 kg compared to 1 kg in both the SIS and No-SIS group (Fig. 5). For the onset difference between LWT-SA similar onset times were demonstrated.

No significant relationships were observed between VAS pain score and relative muscle activity ($r_s = 0.046–0.313$, $p = 0.092–0.808$), as well as for ratio values ($r_s = -0.064–0.124$, $p = 0.514–0.736$). Significantly positive relationships were observed for the activity between all three muscles ($r_s = 0.385–0.510$, $p = 0.003–0.03$), however non-significantly for no-loading conditions.

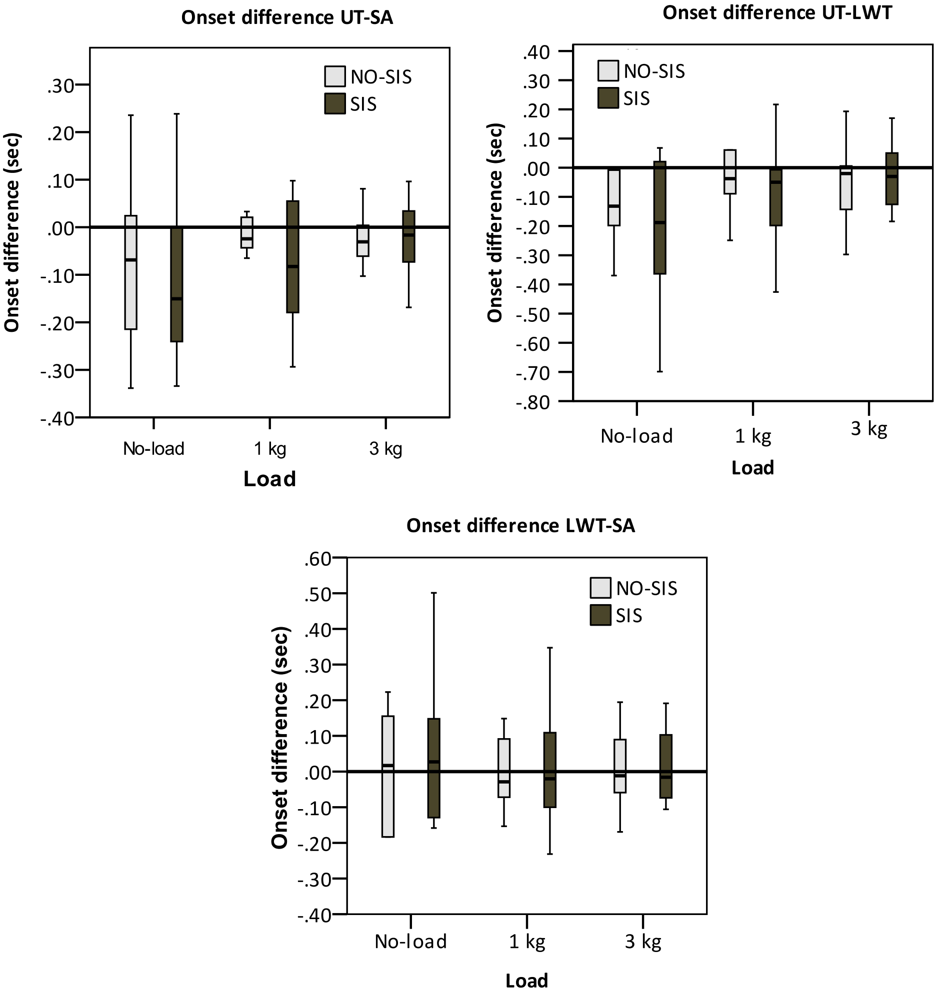
5. Discussion

The hypotheses of differences regarding magnitude of muscle activation, ratio of activation or timing of shoulder muscle activation onset between the SIS and No-SIS group was not confirmed in this general population of impingement patients. However, SIS displayed a general, non-significant trend to higher level of mean muscle activity compared to No-SIS in all muscles (SA, UT, LWT) and during all loading conditions. The results of the current study, will mainly be discussed in relation to choice of populations and tasks of other studies.

5.1. Magnitude of muscle activity

The previously reported pattern of decreased muscle activity of SA and increased activity of UT in studies of overhead athletes and workers with SIS was not found for the current general population.

Other studies also reported no significant differences in SA activity (de Morais Faria et al., 2008; Finley et al., 2005). Most of these studies reported a trend towards a decreased SA EMG activity for the patient group (Chester et al., 2010), whereas our results show an increase in muscle activity. An increased SA-activity could be due to pain related increase in co-activation, as opposed to a pain related decrease in activation. This may be due to various methodological procedures or variety in the studied tasks such as, as concentric/eccentric arm elevation, wheelchair transfer and isometric abduction with/without hand held or isokinetic load applied in the different studies. Furthermore various inclusion criteria for the patient population. While the increased UT activity in SIS is in line with previous studies (Ludewig and Cook, 2000; Cools


Onset difference UT-SA

Onset difference UT-LWT

Onset difference LWT-SA

Fig. 5. Difference of muscle activity onset between Upper trapezius-(UT)-Serratus Anterior-(SA), UT-lower trapezius-(LWT), and LWT-SA in *SIS* ($n = 14$) and *no-SIS* ($n = 13$) (missing = 4) groups. Data are shown as median 25th and 75th percentiles and whiskers representing the highest and lowest values during a voluntary arm movement task with no-load, 1 kg and 3 kg. Outliers (1.5–$\geqslant$3 times the interquartile range) are not displayed.

et al., 2007a) only one earlier study has reported increased LT activity (Ludewig and Cook, 2000). Also the latter study emphasized that mechanisms of shoulder impingement may differ in relation to different subject samples depending on previous exposure.

5.2. Activation ratios

The similar activation ratios in SIS versus No-SIS subjects in our study did not support previous findings of a SIS related unbalanced activation ratio of the scapular muscles. The varying results may be due to different tests (maximal versus sub-maximal tasks), as well as different movement tasks (restricted versus voluntary) across studies. Different performance strategies in voluntary movement tasks may result in larger intra- and inter-individual variations. An altered muscle activation therefore, might not be a dominant feature characterizing SIS patients.

5.3. Onset differences

The onset differences between UT-LWT and UT-SA displayed a minor but non-significant delay in activity of LWT and SA, especially in no-loading conditions. These findings relate to our study hypotheses, but no significant group differences were observed. The similar onset times for SIS and No-SIS are in agreement with (Moraes et al., 2008), but in contrast with other studies (Cools et al., 2003; Wadsworth and Bullock-Saxton, 1997). Again, the different testing conditions may be the explanation. Negative results always deserve careful consideration of the size of a clinically relevant difference, and whether the study has the power to detect such a difference. In the present study the non-significant findings and the variation in estimates of both the activation ratios and the onset differences probably also reflect the range of patients included, with a standardized set of clinical test for SIS commonly used in the examination of shoulder patients.

5.4. Interplay between serratus and lower trapezius muscles

The general synergistic activation and simultaneous onset of LWT and SA, suggest a functional relationship with equal activity distribution independent of load. This close functional relationship is consistent with the classical paper from Inman et al. (1944), who proposed that the Serratus anterior and the lower trapezius muscle constitute the ‘‘lower scapular rotary force couple’’ during upward rotation (Inman et al., 1944). The lack of an obvious difference between SIS and No-SIS in this functional coupling of LWT and SA activity, may question the relevance of using the imbalance in muscle activation, as found previously in studies of overhead workers and athletes, as a basic premise for treatment in the more general population of SIS patients.

5.5. Study implications

It is an open question whether a uniform neuromuscular activity pattern exists across different SIS populations and testing procedures. According to (Hodges, 2011) musculoskeletal pain conditions may not induce a stereotypical change in muscles that is the same in all conditions. Perhaps pain redistributes activity between regions within or between muscles in an individual- and task-specific manner, although with a common goal to protect the painful part from further pain or injury.

Our results question, whether exercises decreasing activity in the upper part of trapezius and increasing the activity of the SA and the lower part of trapezius should be preferred in rehabilitation. It appears to be difficult to generalize the results to the general population with SIS. Presumably, a more individual and task-specific approach should be considered. In this aspect, we agree with Ludewig and Cook, 2000 on the statement, that ‘‘different impingement sites may relate to unique kinematic abnormalities, making it more difficult to ascertain overall group differences between subjects with shoulder impingement and subjects without shoulder impairment’’. Future longitudinal studies are recommended to examine whether muscle activity pattern is influenced by development of SIS and/or reduction of symptoms, to guide more specifically treatment strategies in rehabilitation of SIS.

5.6. Strength and limitations of the study

The strength of the study is the strict inclusion criteria in accordance to a clinical decision algorithm intended to obtain the highest clinical between group contrast between SIS and No-SIS. However, even with the current criteria for SIS, pain on the testing day was relatively low for SIS, decreasing between-group contrasts. SIS was a mixed patient population regarding work place exposure since they were recruited among those seeking treatment for SIS in physiotherapy clinics. This may have decreased between-group contrasts, compared to previous studies with more homogeneous exposures, e.g. overhead work or sports. Another limitation is the rather small sample size which could increase possibility of a type II error. In addition the lack of kinematic measures to standardize the range of motion represents a limitation of the procedure.

A further strength of the study is the standardized procedures of electrode placement and normalization of the electromyography signal, commonly used in similar studies within this area.

6. Conclusion

The hypothesized differences regarding muscle activation, ratio of activation and shoulder muscle activation onset between SIS patients and controls were not confirmed. However, SIS displayed non-significantly tendency to higher level of mean muscle activity in all muscles (UT, LWT, SA) compared to No-SIS during all loading conditions. The higher relative muscle activity in SIS subjects could be due to a pain related increased co-activation or decreased maximal activation. The negative findings may display the variation in the specific muscle activation patterns depending on the criteria used to define the population of impingement patients, as well as the methodological procedure being used, and the shoulder movement investigated.

Acknowledgements

This study was supported by the National Research Fund for Health and Disease, the Research Fund for the Region of Southern Denmark, the Arthritis Research Association and the Danish Physiotherapy Research Foundation. The authors are grateful to Dr. Janet Taylor for assistance in structuring the manuscript and comments on the English language and to Dr. Eleanor Boyle for her statistical advice.

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