ANALYSIS OF RECRUITMENT OF THE SUPERFICIAL AND DEEP SCAPULAR MUSCLES IN PATIENTS WITH CHRONIC SHOULDER OR NECK PAIN, AND IMPLICATIONS FOR REHABILITATION EXERCISES

BIRGIT CASTELEIN

Thesis submitted in fulfillment of the requirements for the degree of Doctor in Health Sciences

Ghent University, 2016

PROMOTOR

Prof. Dr. Ann Cools	Ghent University, Ghent, Belgium

CO-PROMOTOR

Prof. Dr. Barbara Cagnie	Ghent University, Ghent, Belgium

SUPERVISORY BOARD

Prof. Dr. Lieven Danneels	Ghent University, Ghent, Belgium
Prof. Dr. Erik Achten	Ghent University, Ghent, Belgium

EXAMINATION BOARD

Prof. Dr. Lori Michener	University of Southern California, Los Angeles, USA
Prof. Dr. Filip Struyf	University of Antwerp, Antwerp, Belgium
Dr. Katie Bouche	Ghent University Hospital, Ghent, Belgium
Prof. Dr. Damien Van Tiggelen	Ghent University, Ghent, Belgium
Prof. Dr. Jessica Van Oosterwijck	Ghent University, Ghent, Belgium

TABLE OF CONTENTS

GENERAL INTRODUCTION

Chronic shoulder pain and neck pain are among the three most prevalent musculoskeletal disorders in the general population. Shoulder pain affects 22.3% of people, with a significant detrimental impact on health-related quality of life and physical functioning.[51] Neck pain is a common musculoskeletal complaint with a 12-month prevalence of 30-50% in the adult population.[52,53,54] Although examinations of patients with shoulder or neck pain typically focus on impairments of structures in the local region, structures distant from the shoulder and neck are generally recognized to also have an impact on these regions. The central linking structure between the shoulder and neck is the scapula and its surrounding scapular muscular system plays a major role in providing stability and mobility.

The introduction of this dissertation will describe the function of the scapula and its surrounding (both superficial and deeper lying) muscles. In addition, altered scapulothoracic muscle recruitment in relation to shoulder and neck pain will be described. This introduction will mainly focus on scapular function during elevation of the arm. Humeral elevation is a functional movement during which the scapula plays an important role as it has to create a stable base for the glenohumeral joint. Also, an overview of the effect of scapula focused rehabilitation programs, performed in patients with shoulder pain and neck pain, will be given, followed by the current knowledge of scapulothoracic muscle recruitment during exercises, commonly used in those scapular rehabilitation programs. The last part of the introduction will present the aims of this dissertation.

1. The role of the scapula in normal upper limb function

The scapula functions as a bridge between the shoulder complex and the spine and connects the upper limb to the trunk. It articulates with the humerus to form the glenohumeral joint and with the clavicle forming the acromioclavicular (AC) joint. As no actual bony articulation exists between the scapula and the thorax, the scapulothoracic joint is one of the least congruent joints in the body. This allows mobility in many directions including translation movements (protraction/retraction and elevation/depression), and rotational movements (upward/downward rotation, anterior/posterior tilt and internal/external rotation) (Figure 1 and Figure 2).

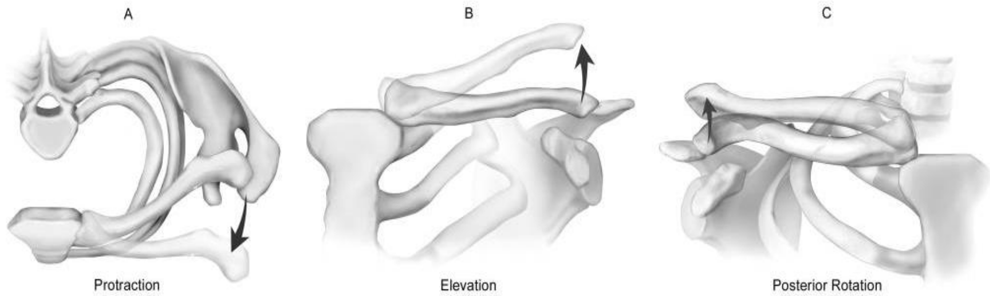


FIGURE 1. Motions of the clavicle: (A) protraction-retraction (superior view right shoulder), with ghosted image representing increased protraction (B) elevation-depression (anterior view right shoulder), with ghosted image representing increased elevation (C) anterior-posterior rotation (lateral view right shoulder) with ghosted image representing posterior rotation. Figure adapted from Ludewig et al.[76]

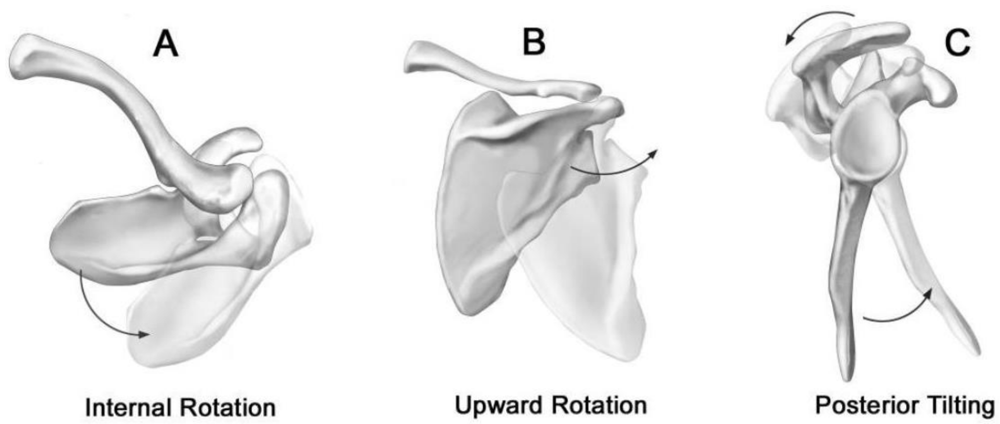


FIGURE 2. Kinematics of the scapula: (A) Internal-External rotation (superior view right shoulder), with ghosted image representing increased internal rotation (B) Upward-Downward Rotation (posterior view right shoulder), with ghosted image representing increased upward rotation, (C) Anterior-Posterior Tilting (lateral view right shoulder), with ghosted image representing increased posterior tilting.
Figure adapted from Ludewig et al.[76]

It is widely recognized that the scapula is important as it has to create a stable base for centering the humeral head and channeling force production during daily activities and sport participation performed with the upper quadrant.

During humeral elevation of the arm, substantial movements at the different shoulder joints are required. The complex scapular movement occurring during elevation of the arm is upward rotation, posterior tilt and either internal or external rotation of the scapula.[10, 76, 85] Upward rotation is seen as the predominant scapulothoracic movement. Also, a movement from an anteriorly to a posteriorly tipped scapular position is demonstrated during humeral elevation.[76] Scapulothoracic internal or external rotation is less consistent during arm elevation, differing in pattern depending on the plane in which the arm is elevated, and on the amount of range of motion (ROM) during elevation.[76] At the end range of elevation some external rotation could occur, although limited data are available.[10, 76, 85] Upward rotation of the scapula occurs approximately linearly throughout humeral elevation, especially beyond 50° of elevation. Posterior tilting and external rotation motions are nonlinear, with the majority of these motions not occurring until after 90° of arm elevation.[86]

Recent investigations have shown that simultaneous movement in the AC and sternoclavicular (SC) joint is necessary for overall scapulothoracic movement. [72, 76, 116, 117, 130] Movements in the SC joint during elevation of the arm are increasing clavicular elevation, posterior axial rotation and retraction. In the AC joint, the scapula is upwardly rotating, posteriorly tilting and internally rotating relative to the clavicle. The relationship between scapulothoracic motion and motion at the SC and AC joints has been termed “coupling”.[130] It is assumed that clavicular elevation and scapular upward rotation are coupled, as well as clavicular posterior rotation and scapular posterior tilting, and clavicular retraction and scapular external rotation.[130]

2. Scapulothoracic muscle recruitment during arm elevation

In view of the limited ligamentous constraints between the scapula and the thoracic wall, the function of the scapula is almost solely dependent on the function of the surrounding muscles. Two different muscle groups attach to the scapula: the scapulohumeral muscles (including rotator cuff muscles, Biceps Brachii, Triceps, and Deltoid muscles) and the scapulothoracic muscles. The scapulothoracic muscle group, which is mainly responsible for scapular movement and dynamic stabilization of the scapula, consists of the Trapezius, Serratus Anterior (SA), Pectoralis Minor (Pm), Levator Scapulae (LS) and Rhomboids (RM) muscles. An optimal interaction between those muscles is needed, providing stability and mobility of the scapula both at rest and during shoulder movements.[87] It is of great importance that the scapula is positioned properly (so that efficient glenohumeral movement can occur) and that all muscles are activated in a coordinated way at the right time and with the right amount of activity.

2.1 Superficial lying scapulothoracic muscles

Two muscle groups are part of the superficial layer of the scapulothoracic muscles: the (three parts of the) Trapezius and the SA. Research has investigated the contributions of these muscles to scapular kinematics during humeral elevation. They have shown that the Upper part of the **Trapezius** (UT) moves the scapula into upward rotation and elevation. As the line of action of the UT is attached to the clavicle, the UT moves the scapula into upward rotation through clavicular elevation (coupled movements).[58] The Middle Trapezius (MT) retracts and externally rotates the scapula. The Lower Trapezius (LT) appears to assist in upward rotation and depression of the scapula.[58] In addition, the inferomedial directed fibres of the LT may also contribute to posterior tilt and external rotation of the scapula. Activation of the LT is also important in the lowering (eccentric) phase of elevation as it eccentrically controls excessive anterior tilt.[27] Furthermore, the LT is assumed to have a more stabilizing function during scapular movement compared to the other 2 parts of the Trapezius.[58] The **SA** muscle consists of different portions each contributing to control the scapula during upper limb tasks. It is suggested that the upper portions of the SA are mainly responsible for protraction, while the main function of the lower portions is to provide upward rotation in conjunction with the UT and LT.[34,110] The lower portions of the **SA** have the largest moment arm for the production of scapular upward rotation and are consequently seen as the prime mover.[64] However, the SA contributes to all components of the normal 3-dimensional scapulothoracic movement as it also posteriorly tilts and externally rotates the scapula during elevation. Moreover, it stabilizes the medial border of the scapula against the thorax during upper limb activities.

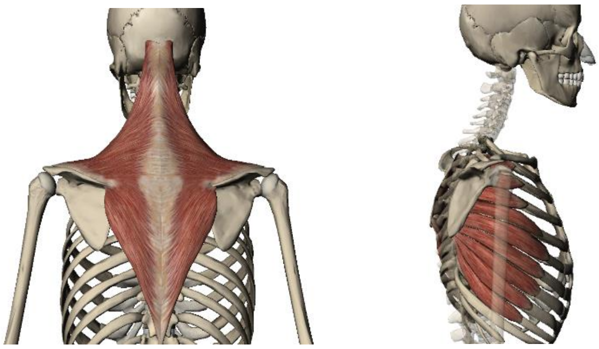


FIGURE 3. Superficial lying scapulothoracic muscles: Trapezius (Posterior view) (Left) and Serratus Anterior (Lateral view) (Right). Figure adapted from Visual Body Human Atlas[137]

In summary, scapular kinematics are determined by the activation of muscle force couples rather than individual activity of one muscle group. As a consequence, a proper firing pattern and recruitment of scapulothoracic muscles is required for normal scapular orientation.[58, 66, 99]

2.2 Deeper lying scapulothoracic muscles

Because there is a lack of electromyographic (EMG) research investigating the contributions of the deeper lying muscles such as the **Pm, LS and RM** to scapular kinematics, little information exists on their activity patterns.

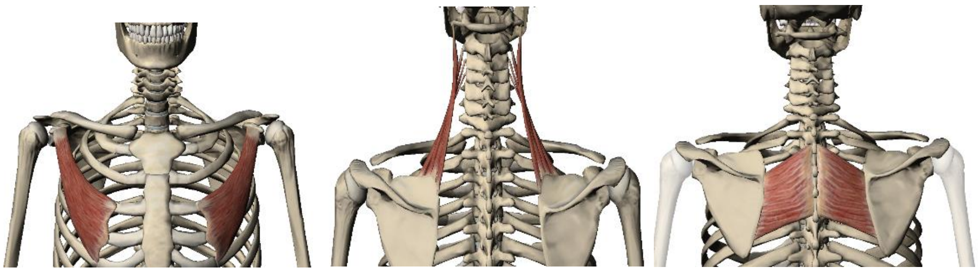


FIGURE 4. Deeper lying scapulothoracic muscles: Pectoralis Minor (Anterior view) (Left), Levator Scapulae (Posterior view) (Middle) and Rhomboid Major (Posterior view) (Right). Figure adapted from visual Body Human Atlas [136]

The **Pm** is the only scapulothoracic muscle that lies entirely on the anterior surface of the thorax also attaching anteriorly (on the coracoid process). Even the SA, which has an anterior attachment on the thorax, inserts posteriorly on the scapula. According to the information from cadaveric dissections, the Pm is believed to move the scapula to protraction, depression and downward rotation.[103] Although the line of pull of the Pm reveals that the Pm is aligned to depress the scapula, the scapula goes into elevation when the Pm is activated to tip the scapula anteriorly (as the scapula lies on the posterior aspect of the thorax). So, the function of the Pm is dependent on the function of other muscles: the Pm elevates the scapula when contracting alone, but contributes to scapular depression with other scapular muscle depressors when preventing anterior tilting of the scapula caused by the pull on the coracoid process.[103] Similarly, inspection of the line of pull of the Pm creates confusion regarding its role in protraction or retraction of the scapula. Despite its medial pull on the coracoid process, the Pm protracts the scapula by causing the scapula to slide anteriorly. The ability of the Pm to protract the scapula makes it a suitable partner with the LS and RM in anatomical force couple for downward rotation of the scapula. The Pm's action of protraction balances the retraction component of the LS and RM, while together they contribute to the scapula's downward rotation.[103]

The **LS** is believed to elevate the scapula and to rotate the scapula downwards.[38] The **RM** functions to stabilize the medial border of the scapula, retracts the scapula and works together with the LS to rotate the scapula downwards.

3. Scapular dyskinesis and its contributing factors

Alterations in scapular position and movement, known as scapular dyskinesis or dysfunction, are often described in literature.[13, 21, 64] Scapular position and control during movement is a critical component for upper limb function. Consequently, scapular dysfunction is often linked to upper quadrant symptoms, such as shoulder pain and neck pain. However, altered scapular position and movements have also been identified in healthy overhead athletes as a sport specific adaptation.[105, 113] There is no consensus about the cause–consequence relationship between scapular dysfunction and shoulder pain or neck pain. Some prospective studies in an athletic population have shown that scapular dysfunction, evaluated in static position[86] or during dynamic movement[17, 62] was a significant contributor to subsequent shoulder pain. In contrast, the study of Myers et al.[98,] who investigated the scapula during dynamic movement, and the study of Struyf et al.[126], who investigated the scapula both in a static and dynamic way, did not found associations between scapular dysfunction and the development of shoulder and neck pain. To date, the cause-consequence relationship in a non-athletic population has not been investigated. Nevertheless, the association between shoulder and neck pain and scapular dysfunction, has extensively been demonstrated.[13, 17, 21, 37, 43, 46, 49, 50, 64, 66, 70, 74, 77, 78, 84, 104, 111, 114, 125, 128, 139]

Several underlying mechanisms have been described that may potentially contribute to scapular dysfunction. These include pain, soft tissue tightness, muscle fatigue, cervical and thoracic posture and changed/suboptimal muscle activation or muscle strength imbalances.[63, 77, 90, 118] These possible contributors will be shortly discussed in the next paragraphs.

One study investigated the influence of **pain** on scapular position and found that scapular alterations (increase in scapular upward rotation at all angles of humeral elevation tested) occurred in response to an acute pain stimulus into the subacromial space.[140] In addition, several other studies have found alterations in scapulothoracic muscle activity in response to experimentally induced pain in the shoulder or neck region.[4, 16, 30, 40, 41, 79, 80, 121] **Soft tissue tightness** has also been linked to scapular dyskinesis, and might be located at the scapulothoracic muscles (Pm, LS and RM) or at the glenohumeral level (stiffness and tightness of posterior shoulder structures, capsule and glenohumeral external rotator muscles). Both deficits can lead to scapular malpositioning. Studies investigating the influence of Pm on scapular positon and dysfunction have mainly focused on the length of the muscle, as it has been hypothesized that adaptive shortening of the Pm is one of the potential mechanisms associated with altered scapular alignment.[77, 129] The Pm is known to downwardly rotate the scapula and to protract and depress the shoulder girdle.[11, 118] As the scapula naturally undergoes upward rotation, posterior tilting and external rotation during elevation of the arm,[31] excessive activation of the Pm may impede the desired scapular movement that is necessary during humeral elevation.[8] Borstad and Ludewig[8] compared scapular kinematics during arm elevation between two groups distinguished by Pm resting length: one group with a relatively short Pm and the other group with a relatively long Pm.[8] The subjects in the relatively short group demonstrated decreased scapular posterior tilting and increased scapular internal rotation during arm elevation. Borstad et al.[7] showed that the amount of internal rotation of the scapula (at rest) was significantly correlated with normalized Pm muscle length. Also, it was shown that the group with the short Pm resting length showed increased scapular internal rotation in the resting position compared with the group of subjects with long Pm resting length. Several clinicians speculate that a forward and downward positioning of the scapula may place Pm antagonist muscles (e.g., LT) in an elongated and weakened position which may contribute to limit the amount and precision of posterior tilting of the scapula during arm elevation.[11, 20, 27, 92] Little investigations have been made regarding the involvement of LS and RM on scapulothoracic malpositioning and dysfunction. However, it is known that tightness and overactivity of both the LS and RM tends to retract, downwardly rotate and elevate the most medial part of the scapula.[6, 118] Consequently, excessive activation or tension in the LS or RM may limit upward rotation that is necessary for normal shoulder function.[6] Therefore, it is believed that high activity of these muscles is not warranted during elevation of the arm. Biomechanical reasoning also indicates that altered activity in the LS may induce detrimental load on the cervical spine.[6, 61, 57] The LS attaches to the upper 4 cervical segments and increased tension may directly induce compressive rotational and shear forces on cervical motion segments. Several studies have examined the effect of **muscle fatigue** on scapular kinematics. A lot of studies found altered scapular kinematics (but variable results) after an upper limb fatigue protocol.[9, 21, 32, 33, 88, 133] Borstad et al.[9] found decreased posterior tilt and increased internal rotation of the scapula during arm elevation after fatiguing the scapular muscles (with a push up plus exercise) in healthy subjects. Maenhout et al.[81] found a significantly more upwardly, externally rotated and posteriorly tilted position at 45° and 60° of abduction after an overhead fatigue protocol. McQuade et al.[88] observed an increased scapular upward rotation and decreased scapulohumeral rhythm after a fatiguing resisted elevation task. In agreement, Ebaugh et al.[32] also reported increased upward and external rotation of the scapula after an elevation fatigue protocol. Chopp et al.[15] showed significantly more posterior tilt and upward rotation (particularly at 90° static elevation) after a fatiguing simulated job task involving arm elevation as well as internal and external rotation. No changes in scapular orientation occurred following a fatiguing internal/external rotation task. Two studies investigated the influence of external rotation fatigue on scapular kinematics.[33, 133] Ebaugh et al.[33] reported less posterior tilt of the scapula in the beginning phase of arm elevation, and increased upward rotation in the mid-ranges of arm elevation. Tsai et al.[133] reported less posterior tilting, external rotation and upward rotation. Contradictory results of all those studies must be seen in light of methodological differences like for example the use of static positions or dynamic elevation for measuring scapular position and criteria used to determine fatigue.[81] In conclusion, following a global fatiguing task, studies have found an increased upward rotation,[15, 32, 81, 88] increased[15, 81] or decreased[9] posterior tilt, and increased internal[9] or external rotation[33, 81]. Following a local fatigue task (external rotation), studies have found less posterior tilt[33, 133], less external rotation[133] and less[33] or more[133] upward rotation.

The effect of upper quadrant **posture** on scapular position and motion has also been investigated.[44, 63] Finley et al.[44] investigated the influence of a slouched posture and reported a significant decrease in posterior tilting and external rotation of the scapula, in comparison with the upright posture. Kebaetse et al.[63] showed that the slouched posture leads to more elevation of the scapula between neutral and 90° of arm abduction and to less upward rotation and less posterior tilt between 90° and maximum abduction, and slightly more internal rotation in all the intervals of abduction. Ludewig and Cook[73] found that a more flexed head position was associated with a decrease in scapular upward rotation and posterior tilting during humeral elevation in the scapular plane. Thigpen et al.[131] showed that individuals with forward head and neck posture showed significantly greater scapular internal rotation, upward rotation and anterior tilt during a flexion task when compared with the ideal posture group. In conclusion, a slouched posture was found to decrease posterior tilt,[44; 63] external rotation[44] and upward rotation[63] and to increase internal rotation[63]. A forward head posture was found to decrease[73] or increase[131] upward rotation, to decrease posterior tilt[73] and increase anterior tilt[131] and to increase internal rotation[131].

Alterations in muscle activation or strength performance (=muscle performance dysfunction) of the scapulothoracic muscles has also been linked to scapular dyskinesis. It is known that the SA functions together with the UT, MT and LT as a force-couple to control the scapular movement.[56, 64, 96] Dysfunction of one of these muscles may compromise normal synergistic force couple relation.[56, 64, 96, 138] Alterations in activation of scapulothoracic muscles, i.e. higher activity of the UT in combination with poor activity of the MT, LT, and SA, has been shown in patients with upper limb symptoms in comparison with healthy controls.[124] The contribution of the muscles in maintaining optimal scapular orientation has been clearly illustrated by studies investigating paralysis of these muscles due to injury to the accessory nerve (Trapezius) or the long thoracic nerve (SA).[83, 115] Trapezius paralysis results in a 'drooping' (depressing) shoulder and scapular downward rotation,[115] whereas SA paralysis is known to result in 'winging' (excessive internal rotation) and downward rotation of the scapula.[83, 115] One study of Laudner et al.[65] investigated the relationship between LT and SA strength and the quantity of scapular upward rotation in professional baseball pitchers and found a moderate to good positive relationship between LT strength and scapular upward rotation at 90 and 120°. In contrast, the relationships between scapular upward rotation and SA strength was poor.

As muscle performance dysfunction plays a major role in the large majority of cases with scapular dysfunction, it is the most common factor investigated in patient populations that are linked to scapular dysfunction. Therefore, this dissertation will discuss muscle performance dysfunction more into detail. Although scapular dysfunction is described to be present in both patients with shoulder and neck pain, the functional demands are different in each group. In the next two paragraphs, scapulothoracic movement and muscle performance problems are described focusing on patients with shoulder pain and on patients with neck pain. Muscle performance problems may be divided into neuromuscular deficits or strength deficits.[19]

4. Scapular dyskinesis and altered muscle recruitment in relation to shoulder and neck pain

4.1 Alterations in scapulothoracic (muscle) function in patients with shoulder pain

Most studies investigating scapulothoracic function in musculoskeletal disorders have focused on patients with shoulder pain. There is a growing body of literature associating abnormal scapulothoracic kinematics, and, to a lesser degree, clavicular kinematics, with many kinds of shoulder pain such as subacromial impingement syndrome (SIS),[37, 49, 66, 68, 74, 84, 85, 139] rotator cuff tendinopathy,[69, 89] rotator cuff tears,[29, 89, 107] shoulder instability,[55, 104, 106, 107, 137, 139] and adhesive capsulitis.[43, 70, 114, 135]

SIS is nowadays described as a group of symptoms, and there is a trend of discontinuing the diagnostic label of SIS. Traditionally, impingement was seen as physical contact between the rotator cuff and the undersurface of the acromion when the arm is elevated.[93, 94] It is known that the acromiohumeral distance is minimal near 90° of elevation.[45] However, recent studies have shown that the rotator cuff has cleared the subacromial space during earlier phases of ROM. It appears that the lateral surface of the greater tuberosity and proximal humeral shaft approximates the acromion at higher angles rather than the tendon footprints or rotator cuff attachment sites. Because the rotator cuff is not attached to the lateral surface of the humerus, the rotator cuff is not compressed between the lateral humeral edge and the acromion at higher angles of elevation. Nowadays, impingement syndrome is rather seen as a "dynamic" condition instead of a "static" anatomical phenomenon. SIS has been considered to be an umbrella of various shoulder conditions.[67] There are many diagnoses that may be associated with SIS, from which rotator cuff pathology, shoulder instability, scapular dysfunction, biceps pathology, superior labrum from anterior to posterior (SLAP) lesions and chronic stiffness of the posterior capsule are most common.[18] Rather a movement-related impairment or a dynamic mechanism (instead of diagnostic label) is associated with impingement syndrome.

Different reviews have been written to summarize the results of studies comparing **scapulothoracic movement** between patients with SIS and healthy controls.[77, 111, 125] A review article from Ludewig and Reynolds[77] identified scapular movement abnormalities in subjects with SIS or rotator cuff disease. Briefly, nine of 11 studies reviewed demonstrated a statistically significant scapular movement deviation in at least 1 movement direction, as compared to healthy control groups. The most frequent findings are reduced upward rotation, reduced posterior tilting and increased internal rotation.[77] Also, Struyf et al.[125] reviewed the knowledge of scapular positioning at rest and scapular movement in different anatomic planes in patients with SIS and asymptomatic subjects. They concluded that during arm elevation, patients with SIS demonstrate decreased upward scapular rotation, decreased posterior tilt, and decreased external rotation. Timmons et al.[132] performed a meta-analysis of published comparative studies to determine the consistent differences in scapular kinematics between subjects with SIS and controls (9 studies). They concluded that overall, the SIS group showed less scapular upward rotation and external rotation, but no differences in scapular posterior tilt. They concluded that subjects with SIS demonstrated altered scapular kinematics, and that these differences are influenced by the plane, level of arm elevation and population. Another systematic review of Ratcliffe et al.[111] summarized research investigating possible differences in scapular orientation between people without shoulder symptoms and people with SIS. The results of this systematic review showed that the findings were inconsistent. Some studies reported patterns of reduced upward rotation, increased anterior tilting and medial rotation of the scapula. In contrast, others reported the opposite, and some identified no difference in motion when compared to asymptomatic controls. A study of Sousa et al.[122] investigated scapular kinematics during arm elevation in individuals with acromioclavicular osteoarthritis (ACO) and in individuals with ACO and rotator cuff disease as compared to controls. At the scapulothoracic joint, the isolated ACO group had greater internal rotation than the control group, and the ACO combined with rotator cuff disease had greater upward rotation than both other groups. It was shown that patients with ACO had altered scapular kinematics, which may represent compensatory responses to reduce pain and facilitate arm motion during arm elevation and lowering.

In general, there is substantial evidence that alterations in scapular kinematics can be identified in patients with SIS in comparison with healthy controls. The most frequent alterations that have been found are reduced upward rotation, reduced posterior tilt and increased internal rotation/decreased external rotation. However, not all reviews show the same deviations and the magnitude of group differences in the different studies have been small.

In the next paragraphs, **muscle performance problems** in patients with SIS will be described. First, knowledge about scapulothoracic muscle strength deficits in patients with SIS will be described, which will be followed by an overview of scapulothoracic muscle activation alterations in patients with SIS.

Some studies have investigated *muscle strength* of the scapulothoracic muscles in patients with SIS and identified strength deficits in these muscles.[22, 23] Cools et al.[22] investigated isokinetic peak force during protraction and retraction movements (at low and high velocity) in overhead athletes with impingement symptoms on the injured and non-injured sides. A lower peak force during isokinetic protraction at high velocity, and a significantly lower protraction/retraction ratio was found on the injured side in comparison with the non-injured side. Cools et al.[23] compared isokinetic muscle performance of the scapular muscles (protraction and retraction, at low and high velocity) between overhead athletes with impingement symptoms and uninjured overhead athletes. They found that overhead athletes with impingement symptoms showed decreased force output/body weight at both velocities in the protractor muscles on the injured side compared with the uninjured side and compared with the control group at high velocity. On both sides, the patient group had significantly lower protraction/retraction ratios than the control group, measured at low velocity. These results confirm that patients with SIS show abnormal muscle strength performance at the scapulothoracic joint.

With regard to *muscle activation*, several authors have demonstrated altered scapulothoracic muscle activity patterns in patients with SIS.[14, 110, 124] A recent systematic review from Struyf et al.[124] summarized all studies that described possible differences in scapulothoracic muscle EMG activity in patients with SIS in comparison with healthy subjects. The results demonstrated that 3 out of 6 articles investigating UT activity showed increased activity, and 3 out of 5 studies investigating LT and SA activity showed decreased LT and SA activity in patients with SIS in comparison with healthy subjects. Sousa et al.[123] compared the scapulothoracic muscle activity during elevation between individuals with isolated ACO, ACO associated with rotator cuff disease, and controls. The ACO with rotator cuff disease group had more UT activity than the isolated ACO and control groups. The isolated ACO group had less SA activity than the control group only in the sagittal plane.

To date, no studies exist that have investigated the scapulothoracic activity of the smaller and less superficial muscles that attach on the scapula (such as the Pm, the LS and RM) in a population with shoulder pain, despite the hypothesized importance of these muscles in shoulder function.[13, 21] Nevertheless, Pm shortness has already been linked to SIS. This muscle has been suggested as a possible contributing mechanism to the kinematic changes found in patients with SIS.[49, 78] Studies comparing competitive overhead sports athletes with and without shoulder pain found a shorter Pm in those reporting shoulder pain.[48, 112, 129]

In conclusion, altered scapulothoracic movement and altered scapulothoracic muscle performance (strength deficit and EMG activity alterations) have been found in patients with SIS in comparison with healthy controls.

4.2 Alterations in scapulothoracic (muscle) function in patients with idiopathic neck pain

Neck pain is a common musculoskeletal complaint with a 12-month prevalence of 30-50% in the adult population.[52] More than 80% can be labeled as idiopathic, indicating that no specific cause can be attributed to the pain. A number of studies have highlighted the importance of the activity of the muscles around the neck region. Most of these studies have focused on the cervical extensors and flexors in patients with neck pain[12, 39, 42, 100, 101] and have indicated altered behavior between different muscle layers and between muscles of the upper and lower cervical regions. Nevertheless, increasing research is indicating to look beyond the cervical muscular system in mechanical neck pain. Some initial evidence exists that the scapula may also be involved in neck pain.[46, 50, 71, 134]

Scapular dysfunction is thought to perpetuate mechanical strain to pain sensitive cervical spine structures because of shared muscle attachments between the scapula and the cervical spine.[6, 102] The uppermost attachments of the scapulothoracic muscles, such as from the Trapezius and the LS, transfer loads from the shoulder girdle to cervical structures. Disturbances in scapular muscle function can induce mechanical loading on the cervical segments and may have implications for the initiation or perpetuation of neck pain.[6]

The first paragraph below will describe some initial evidence of altered scapular orientation and movements in individuals with idiopathic neck pain, and the second paragraph will describe some studies that show an association between impairments in scapulothoracic muscle performance (both strength deficits and neuromuscular deficits) and idiopathic neck pain.

Helgadottir et al.[50] found impairments in scapular movement during arm elevation in patients with neck pain that were similar to those in patients with shoulder pain. A reduced clavicle retraction and scapular upward rotation were observed in patients with neck pain compared with asymptomatic subjects. In addition, some evidence exists that an alteration of the scapular position can result in an immediate change in pain and mobility during provocative movements of the neck.[46, 71, 134] Van Dillen et al.[134] showed that passive elevation of the scapulae resulted in a decrease in symptoms during neck rotation in the majority of patients with neck pain. Likewise, Ha et al.[46] investigated the effects of passive correction of scapular position in patients with neck pain with bilateral scapular downward rotation. It was demonstrated that a passive correction of scapular position resulted in a decrease in neck pain and improved neck rotational ROM and proprioception. In a study of Lluch et al.,[71] the effect of active versus passive scapular correction on pain and pain pressure threshold at the most symptomatic cervical segment was investigated in patients with chronic neck pain. It was shown that only the active scapular correction resulted in a reduction in neck pain and increase in pain pressure threshold.

Some studies have found *weakness* of the scapulothoracic muscles in patients with idiopathic neck pain in comparison with asymptomatic individuals.[108; 109; 119] Petersen et al.[108] showed that individuals with unilateral neck pain were significantly weaker than asymptomatic individuals for the LT , MT and SA strength on the side with neck pain, but not on the pain-free side. Also, within subject differences (between sides) in strength were present in patients with unilateral neck pain for the LT and MT, while in the asymptomatic group no within subject differences for any muscle were found. Shahidi et al.[119] demonstrated significantly reduced MT and RM strength in patients with neck pain in comparison with a control group. Petersen and Wyatt[109] investigated LT muscle strength in patients with unilateral neck pain and found significantly less LT strength on the side of neck pain compared to the contralateral side. In conclusion, studies found weakness in MT,[108, 119] LT,[108] SA[108] and RM[108] in patients with neck pain, in comparison with a healthy control group. Also, reduced LT[108, 109] and reduced MT[108] strength was found on the side of pain in comparison with the pain-free side in patients with neck pain.

In contrast to conditions of shoulder pain such as SIS, few studies have explored the relationship between scapulothoracic muscle recruitment and idiopathic neck pain. Studies investigating *scapulothoracic muscle activation* in patients with idiopathic neck pain have mainly focused on the UT and have shown changes in the behavior of that part of muscle.[39, 59, 60] Few studies have investigated the recruitment of the other parts of the Trapezius and the SA in a population with neck pain. Moreover, the results are not consistent. As part of this dissertation, a systematic review was conducted to review the literature regarding the differences or similarities in scapular muscle activity, measured by EMG, between patients with chronic idiopathic neck pain compared to pain-free controls. We therefore refer to Chapter 3. Based on this systematic literature, it is clear that most studies investigating scapulothoracic muscle activity in patients with idiopathic neck pain have only focused on the UT, indicating the need to investigate other scapulothoracic muscles as well.

In conclusion, initial evidence of altered scapular orientation/movement has been found in patients with idiopathic neck pain. Also, weakness in the scapulothoracic muscles has been found in that population. Studies investigating scapulothoracic muscle activation in patients with idiopathic neck pain have mainly focused on the UT (and have shown changes in the behavior of the UT), indicating the need to investigate other scapulothoracic muscles as well.

5. Outcome of scapula focused rehabilitation programs

A variety of physiotherapeutic treatment modalities have been proposed for the rehabilitation of SIS, as well as idiopathic neck pain. Although the therapist should address all possible deficiencies found on the shoulder girdle/neck level, and on the different levels of the kinetic chain, this dissertation will not describe all aspects of treatment, but will focus solely on scapular aspects of rehabilitation. Figure 4 shows a recently published clinical reasoning algorithm that the clinician may use in the treatment of scapular dysfunction.[36] In the algorithm, it is shown that scapular dysfunction can be attributed to flexibility deficits in the soft tissue surrounding the scapula (left) and/or to altered scapular recruitment patterns or muscle performance (right). In the lower part, the therapeutic strategies are proposed, with a specific rehabilitation approach for each side of the algorithm.

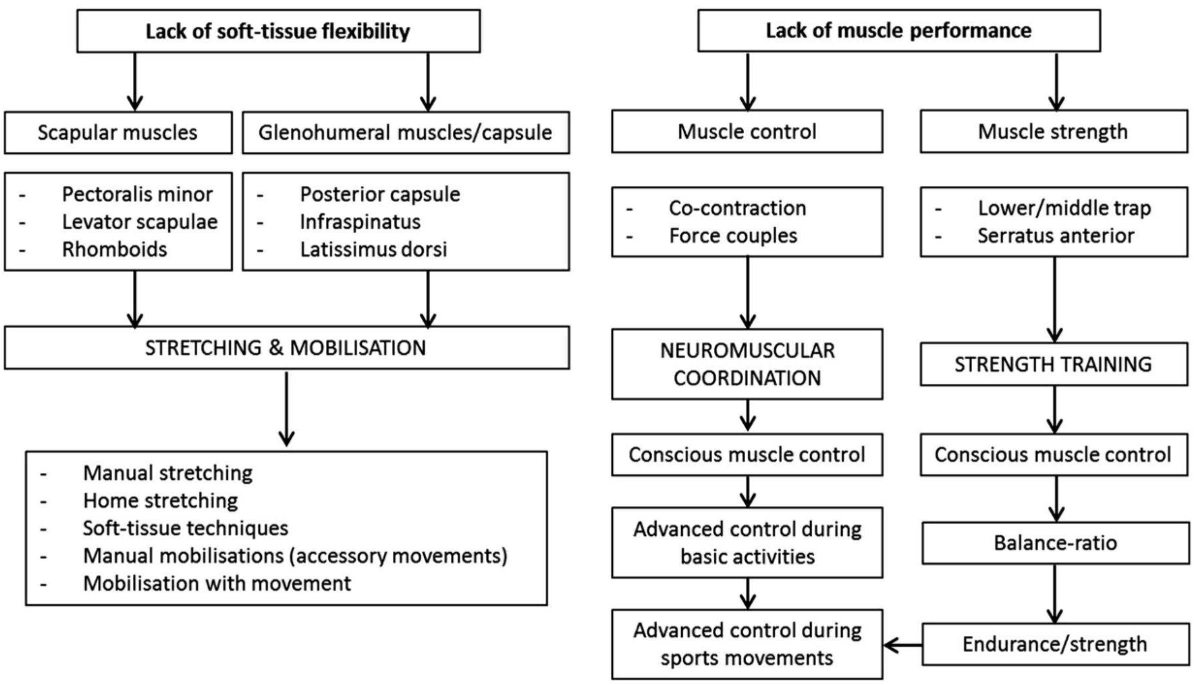


FIGURE 5. Treatment algorithm for scapular dysfunction, adapted from Ellenbecker & Cools[36]

This dissertation will focus on the right part of the algorithm, with specific emphasis on exercises that target appropriate activation patterns in the scapulothoracic muscles. In the following paragraph, studies will be described that investigated the effectiveness of scapulothoracic muscle training in patients with SIS or idiopathic neck pain.

With regard to shoulder pain, four studies have investigated the effectiveness of exercise training of the scapulothoracic muscles in patients with SIS.[5, 26, 91, 97] In addition, Struyf et al.[127] investigated a combination of different scapular interventions (including exercises) in patients with SIS. The results of these different studies will be discussed below.

Baskurt et al.[5] compared the effectiveness between (1) stretching and strengthening exercises and (2) scapular stabilization exercises in patients with SIS. The results showed that pain, ROM, muscle strength, joint position sense, scapular dysfunction and quality of life improved in both groups after treatment. However, the improvements in muscle strength, joint position sense and scapular dysfunction were significantly larger in the group with the scapular stabilization exercises. Moezy et al.[91] investigated the effects of scapular stabilization exercise therapy in comparison with physical therapy in patients with SIS and found that the scapular exercise treatment was superior in decreasing pain, improving scapular protraction, improving head and back posture and increasing shoulder mobility. In a study of De Mey et al.[26] it was shown that a 6-week scapular training method in overhead athletes with SIS showed improved scapular muscle recruitment (decreased Trapezius muscle activation and decreased UT/SA ratio during a similar arm elevation task), and showed significant functional improvement and less pain. Mulligan et al.[97] investigated, as part of their study, the effect of a 4 - week program of scapular stabilization exercises in patients with SIS. After 4 weeks of training the pain score was significantly decreased and the shoulder function significantly improved. Struyf et al.[127] compared the effectiveness of a scapular-focused treatment (including stretching, scapular motor control training and passive manual mobilization) with a control therapy (stretching, muscle friction and eccentric rotator cuff training) in patients with SIS. An important treatment effect in favor of scapular-focused treatment was found in self-reported disability, and also in pain during the Neer, Hawkins and Empty can test. In addition, the scapular focused treatment demonstrated an improvement in self-experienced pain at rest, whereas the control group did not change. As the interventions in the scapular focused group included a combination of different interventions, it is not known if the separated parts of the interventions (i.e. stretching or scapular motor control training or passive manual mobilization) also lead to the same improvements.

With regard to neck pain, Andersen et al.[1] showed that intensive scapular function training with exercises is effective in reducing pain and increasing shoulder elevation strength in adults with chronic non-specific neck/shoulder pain (in comparison with a control group). The study did not compare the scapular training to other active treatments and consequently, does not indicate if scapular function training is more effective than other treatments.

6. Scapulothoracic muscle recruitment during exercises

In general, the above mentioned studies confirm the value of scapular exercises in the treatment of SIS and idiopathic neck pain. However, there is currently no consensus on the best exercise program. In literature, numerous exercises have been prescribed for scapulothoracic muscle training and consequently, exercises included in scapular rehabilitation programs vary widely. The choice for a specific exercise is often based upon the assumed effect on muscle activation, which requires detailed knowledge of exercise-specific activation of muscles in EMG studies. Different researchers have already examined the activation patterns of the scapulothoracic muscles during various exercises that aim to improve scapular muscle recruitment. To date, most studies have investigated the activation of the Trapezius and the SA during different exercises as (1) these muscles are seen as the most important muscles for scapular movement, (2) can be easily investigated with surface EMG (in contrast with the invasive procedure of fine-wire EMG that is needed for the deeper lying scapulothoracic muscles), and are (3) often described to be in dysfunction in both patients with SIS and neck pain.

A lot of different exercises aimed at activating the Trapezius and SA have been described. As the different portions of the Trapezius (UT, MT and LT) are known to have a different function, specific exercises have been described for activation of the different parts of the Trapezius. Table 1 shows which exercises achieved high activation of UT,[24, 28, 35, 95, 120] MT,[2, 28, 35, 95], LT[3, 35, 95, 99, 120] and SA[28, 35, 47, 82, 95, 99, 120].

Upper Trapezius	Middle Trapezius	Lower Trapezius	Serratus Anterior
• Shoulder Shrug • Prone Rowing • Prone Horizontal abduction at 90° and 135° with ER and IR • D1 diagonal pattern flexion • Standing scapular dynamic hug • PNF scapular clock • Military press • 2-hand overhead medicine ball throw • Scaption and abduction below 80°, at 90° and above 120° with ER	• Shoulder Shrug • Prone Rowing • Prone Horizontal abduction at 90° and 135° with ER and IR • Prone Extension • Reverse Fly • Scapular Plane Abduction at 90° and above 120°	• Prone Rowing • Prone Horizontal abduction at 90° and 135° with ER and IR • D2 diagonal PNF pattern flexion and extension • PNF scapular clock • Prone and standing ER at 90° abduction • Standing High Scapular rows • Scapular plane abduction, flexion and abduction below 80° and above 120° with ER.	• Supine scapular protraction • Supine upward scapular punch • IR and ER at 90° abduction • D1 and D2 diagonal pattern flexion and D2 diagonal pattern extension pattern • Standing Scapular Dynamic Hug • PNF scapular depression and protraction movements • Military Press • Empty can • Wall slide • Shoulder flexion, abduction and scaption with external rotation above 120° • Push-up plus

TABLE 1. Exercises with high activity of respectively Upper Trapezius, Middle Trapezius, Lower Trapezius and Serratus Anterior (based on work of Escamilla et al.[38])

*ER (External Rotation), IR (Internal Rotation), D1 (diagonal 1), PNF (Proprioceptive Neuromuscular Facilitation), D2 (diagonal 2)

Some studies also describe exercises to elicit a favorable ratio in different parts of the Trapezius, or between the Trapezius and SA. In case that low activity of the UT is wanted in combination with high activity in LT or MT or SA, exercises with a low UT/LT, UT/MT and UT/SA ratio can be prescribed. For intramuscular Trapezius training, four exercises have been recommended: side lying external rotation, side lying forward flexion, prone horizontal abduction with external rotation and prone extension.[19, 25] Exercises with low UT/SA ratio are elbow push-up/prone bridging, serratus punch supine and serratus punch in closed kinetic chain (bench slide).[75]

Despite the hypothesized importance of the smaller and less superficial muscles that attach to the scapula, very little EMG data are available of the **Pm, LS and RM**, during commonly used rehabilitation exercises. Only one old study (performed in 1992) of Moseley et al.[95] investigated the activity of the deeper lying scapulothoracic muscles during exercises. Hypothetically, excessive activation of the deeper lying muscles (Pm, LS and RM) during scapulothoracic exercises may impede the warranted scapular movement that is necessary during humeral elevation. The main reasons why there is a lack of research data on the EMG activity of these muscles could be that there is an inability to investigate those deeper lying muscles' activity with surface EMG and that there is an absence of standard reference contractions to normalize the data.

Additionally, in the assumption that these muscles may hinder normal scapular movement in case of tightness or hyperactivity, exercise protocols should include exercises that are selected not only based on high activity in the targeted muscle group, but also based on low activity in the muscles that are suggested to be overactive. If this can be achieved, clinicians and researchers may be more able to target specific exercise programs and refine clinical practice guidelines supported by research data.

7. Outline and aims

Based on the available literature it can be concluded that patients with shoulder pain and neck pain have aberrant muscle recruitment in the superficial lying scapulothoracic muscles. However, knowledge of activation patterns of the deeper muscles is lacking. In addition, knowledge of scapulothoracic muscle activity during commonly used rehabilitation exercises is still scarce, in particular with respect to the deeper lying scapulothoracic muscles. Therefore the outline of this dissertation can be divided into two parts:

PART I. To investigate whether superficial and deeper lying scapulothoracic muscle activity is altered in patient populations with shoulder pain and neck pain.

The first aim of this dissertation is to further investigate whether the scapulothoracic muscle is altered activity in patient groups. Most studies have investigated activity with surface EMG and consequently, information about scapulothoracic muscle recruitment is limited to superficial muscle activity. However, insight in muscle activation patterns of the deeper lying muscles is currently lacking, and is therefore investigated in this dissertation.

Since EMG measurements of the deeper lying scapulothoracic muscles have not been extensively described in literature and a protocol of normalization is lacking, the aim of **Chapter 1** is to identify optimal tests in order to normalize the muscle EMG activity in the Pm, LS, and RM, and to optimize the current normalization procedure of the 3 Trapezius parts and SA.

In **Chapter 2**, possible differences in scapulothoracic muscle activity between patients with SIS and healthy subjects during different elevation movements in the scapular plane are described.

In view of the current lack of information regarding scapular muscle dysfunction in relation to neck pain, **Chapter 3** includes a systematic review which summarizes all results from articles that have investigated differences in EMG activity of scapulothoracic muscles between patients with idiopathic neck pain and healthy controls.

Chapter 4 investigates possible differences in scapulothoracic muscle activity between patients with idiopathic neck pain and healthy subjects during different elevation movements in the scapular plane.

PART II. To investigate differences in scapulothoracic muscle activity between during different exercises commonly used in scapular rehabilitation programs, with special focus on the deeper lying muscles.

The second aim is to investigate the differences in scapulothoracic muscle activity between different exercises in healthy subjects. Most studies have investigated activity with surface EMG and consequently, information about the differences in scapulothoracic muscle recruitment between exercises is limited to muscle activity in the superficial muscles. However, the deeper lying muscles are also of importance and are investigated in this dissertation.

In chapters 5, 6 and 7, possible differences in EMG activity of scapulothoracic muscles (including the deeper lying muscles) between several exercises commonly used in scapular rehabilitation programs will be further investigated. Scapulothoracic EMG activity will be measured during elevation exercises in the scapular plane (**Chapter 5**), protraction exercises aimed to activate the SA (**Chapter 6**) and shrugging and retraction exercises (**Chapter 7**).

8. Bibliography

1 Andersen CH, Andersen LL, Zebis MK, Sjogaard G. Effect of scapular function training on chronic pain in the neck/shoulder region: a randomized controlled trial. J Occup Rehabil 2014;24:316-324. 10.1007/s10926-013-9441-1

2 Bagg SD, Forrest WJ. Electromyographic study of the scapular rotators during arm abduction in the scapular plane. Am J Phys Med 1986;65:111-124.

3 Ballantyne BT, O'Hare SJ, Paschall JL, Pavia-Smith MM, Pitz AM, Gillon JF et al. Electromyographic activity of selected shoulder muscles in commonly used therapeutic exercises. Phys Ther 1993;73:668-677; discussion 677-682.

4 Bandholm T, Rasmussen L, Aagaard P, Diederichsen L, Jensen BR. Effects of experimental muscle pain on shoulder-abduction force steadiness and muscle activity in healthy subjects. Eur J Appl Physiol 2008;102:643-650. 10.1007/s00421-007-0642-1

5 Baskurt Z, Baskurt F, Gelecek N, Ozkan MH. The effectiveness of scapular stabilization exercise in the patients with subacromial impingement syndrome. J Back Musculoskelet Rehabil 2011;24:173-179. 10.3233/bmr-2011-0291

6 Behrsin JF, Maguire K. Levator Scapulae Action during Shoulder Movement: A Possible Mechanism for Shoulder Pain of Cervical Origin. Aust J Physiother 1986;32:101-106. 10.1016/s0004-9514(14)60646-2

7 Borstad JD. Resting position variables at the shoulder: evidence to support a posture-impairment association. Phys Ther 2006;86:549-557.

8 Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. J Orthop Sports Phys Ther 2005;35:227-238. 10.2519/jospt.2005.35.4.227

9 Borstad JD, Szucs K, Navalgund A. Scapula kinematic alterations following a modified push-up plus task. Hum Mov Sci 2009;28:738-751. 10.1016/j.humov.2009.05.002

10 Braman JP, Engel SC, Laprade RF, Ludewig PM. In vivo assessment of scapulohumeral rhythm during unconstrained overhead reaching in asymptomatic subjects. J Shoulder Elbow Surg 2009;18:960-967. 10.1016/j.jse.2009.02.001

11 Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. Arthroscopy 2003;19:641-661.

12 Cagnie B, Dolphens M, Peeters I, Achten E, Cambier D, Danneels L. Use of muscle functional magnetic resonance imaging to compare cervical flexor activity between patients with whiplash-associated disorders and people who are healthy. Phys Ther 2010;90:1157-1164. 10.2522/ptj.20090351

13 Cagnie B, Struyf F, Cools A, Castelein B, Danneels L, O'Leary S. The relevance of scapular dysfunction in neck pain: a brief commentary. J Orthop Sports Phys Ther 2014;44:435-439. 10.2519/jospt.2014.5038

14 Chester R, Smith TO, Hooper L, Dixon J. The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: a systematic review of electromyographic studies. BMC Musculoskelet Disord 2010;11:45. 10.1186/1471-2474-11-45

15 Chopp JN, Fischer SL, Dickerson CR. The specificity of fatiguing protocols affects scapular orientation: Implications for subacromial impingement. Clin Biomech (Bristol, Avon) 2011;26:40-45. 10.1016/j.clinbiomech.2010.09.001

16 Christensen SW, Hirata RP, Graven-Nielsen T. The effect of experimental neck pain on pressure pain sensitivity and axioscapular motor control. J Pain 2015;16:367-379. 10.1016/j.jpain.2015.01.008

17 Clarsen B, Bahr R, Andersson SH, Munk R, Myklebust G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. Br J Sports Med 2014;48:1327-1333. 10.1136/bjsports-2014-093702

18 Cools AM, Cambier D, Witvrouw EE. Screening the athlete's shoulder for impingement symptoms: a clinical reasoning algorithm for early detection of shoulder pathology. Br J Sports Med 2008;42:628-635. 10.1136/bjsm.2008.048074

19 Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? Am J Sports Med 2007;35:1744-1751. 10.1177/0363546507303560

20 Cools AM, Johansson FR, Cambier DC, Velde AV, Palmans T, Witvrouw EE. Descriptive profile of scapulothoracic position, strength and flexibility variables in adolescent elite tennis players. Br J Sports Med 2010;44:678-684. 10.1136/bjsm.2009.070128

21 Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. Br J Sports Med 2014;48:692-697. 10.1136/bjsports-2013-092148

22 Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. Br J Sports Med 2004;38:64-68.

23 Cools AM, Witvrouw EE, Mahieu NN, Danneels LA. Isokinetic Scapular Muscle Performance in Overhead Athletes With and Without Impingement Symptoms. J Athl Train 2005;40:104-110.

24 Cordasco FA, Wolfe IN, Wootten ME, Bigliani LU. An electromyographic analysis of the shoulder during a medicine ball rehabilitation program. Am J Sports Med 1996;24:386-392.

25 De Mey K, Cagnie B, Danneels LA, Cools AM, Van de Velde A. Trapezius muscle timing during selected shoulder rehabilitation exercises. J Orthop Sports Phys Ther 2009;39:743-752. 10.2519/jospt.2009.3089

26 De Mey K, Danneels L, Cagnie B, Cools AM. Scapular muscle rehabilitation exercises in overhead athletes with impingement symptoms: effect of a 6-week training program on muscle recruitment and functional outcome. Am J Sports Med 2012;40:1906-1915. 10.1177/0363546512453297

27 de Morais Faria CD, Teixeira-Salmela LF, de Paula Goulart FR, de Souza Moraes GF. Scapular muscular activity with shoulder impingement syndrome during lowering of the arms. Clin J Sport Med 2008;18:130-136. 10.1097/JSM.0b013e318160c05d

28 Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. Am J Sports Med 1999;27:784-791.

29 Deutsch A, Altchek DW, Schwartz E, Otis JC, Warren RF. Radiologic measurement of superior displacement of the humeral head in the impingement syndrome. J Shoulder Elbow Surg 1996;5:186-193.

30 Diederichsen LP, Winther A, Dyhre-Poulsen P, Krogsgaard MR, Norregaard J. The influence of experimentally induced pain on shoulder muscle activity. Exp Brain Res 2009;194:329-337. 10.1007/s00221-008-1701-5

31 Ebaugh DD, McClure PW, Karduna AR. Three-dimensional scapulothoracic motion during active and passive arm elevation. Clin Biomech (Bristol, Avon) 2005;20:700-709. 10.1016/j.clinbiomech.2005.03.008

32 Ebaugh DD, McClure PW, Karduna AR. Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics. J Electromyogr Kinesiol 2006;16:224-235. 10.1016/j.jelekin.2005.06.015

33 Ebaugh DD, McClure PW, Karduna AR. Scapulothoracic and glenohumeral kinematics following an external rotation fatigue protocol. J Orthop Sports Phys Ther 2006;36:557-571. 10.2519/jospt.2006.2189

34 Ekstrom RA, Bifulco KM, Lopau CJ, Andersen CF, Gough JR. Comparing the function of the upper and lower parts of the serratus anterior muscle using surface electromyography. J Orthop Sports Phys Ther 2004;34:235-243. 10.2519/jospt.2004.34.5.235

35 Ekstrom RA, Donatelli RA, Soderberg GL. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. J Orthop Sports Phys Ther 2003;33:247-258. 10.2519/jospt.2003.33.5.247

36 Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. Br J Sports Med 2010;44:319-327. 10.1136/bjsm.2009.058875

37 Endo K, Ikata T, Katoh S, Takeda Y. Radiographic assessment of scapular rotational tilt in chronic shoulder impingement syndrome. J Orthop Sci 2001;6:3-10.

38 Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. Sports Med 2009;39:663-685. 10.2165/00007256-200939080-00004

39 Falla D, Bilenkij G, Jull G. Patients with chronic neck pain demonstrate altered patterns of muscle activation during performance of a functional upper limb task. Spine (Phila Pa 1976) 2004;29:1436-1440. 00007632-200407010-00011 [pii]

40 Falla D, Farina D, Dahl M, Graven-Nielsen T. Muscle pain induces task-dependent changes in cervical agonist/antagonist activity. J Appl Physiol 2007;102:601-609.

41 Falla D, Farina D, Graven-Nielsen T. Experimental muscle pain results in reorganization of coordination among trapezius muscle subdivisions during repetitive shoulder flexion. Exp Brain Res 2007;178:385-393.

42 Falla D, Jull G, Hodges PW. Feedforward activity of the cervical flexor muscles during voluntary arm movements is delayed in chronic neck pain. Exp Brain Res 2004;157:43-48. 10.1007/s00221-003-1814-9

43 Fayad F, Roby-Brami A, Yazbeck C, Hanneton S, Lefevre-Colau MM, Gautheron V et al. Three-dimensional scapular kinematics and scapulohumeral rhythm in patients with glenohumeral osteoarthritis or frozen shoulder. J Biomech 2008;41:326-332. 10.1016/j.jbiomech.2007.09.004

44 Finley MA, Lee RY. Effect of sitting posture on 3-dimensional scapular kinematics measured by skin-mounted electromagnetic tracking sensors. Arch Phys Med Rehabil 2003;84:563-568. 10.1053/apmr.2003.50087

45 Giphart JE, van der Meijden OA, Millett PJ. The effects of arm elevation on the 3-dimensional acromiohumeral distance: a biplane fluoroscopy study with normative data. J Shoulder Elbow Surg 2012;21:1593-1600. 10.1016/j.jse.2011.11.023

46 Ha SM, Kwon OY, Yi CH, Jeon HS, Lee WH. Effects of passive correction of scapular position on pain, proprioception, and range of motion in neck-pain patients with bilateral scapular downward-rotation syndrome. Man Ther 2011;16:585-589. 10.1016/j.math.2011.05.011

47 Hardwick DH, Beebe JA, McDonnell MK, Lang CE. A comparison of serratus anterior muscle activation during a wall slide exercise and other traditional exercises. J Orthop Sports Phys Ther 2006;36:903-910. 10.2519/jospt.2006.2306

48 Harrington S, Meisel C, Tate A. A cross-sectional study examining shoulder pain and disability in Division I female swimmers. J Sport Rehabil 2014;23:65-75. 10.1123/jsr.2012-0123

49 Hebert LJ, Moffet H, McFadyen BJ, Dionne CE. Scapular behavior in shoulder impingement syndrome. Arch Phys Med Rehabil 2002;83:60-69.

50 Helgadottir H, Kristjansson E, Mottram S, Karduna AR, Jonsson H, Jr. Altered scapular orientation during arm elevation in patients with insidious onset neck pain and whiplash-associated disorder. JOrthopSports PhysTher 2010;40:784-791. 2497 [pii];10.2519/jospt.2010.3405 [doi]

51 Hill CL, Gill TK, Shanahan EM, Taylor AW. Prevalence and correlates of shoulder pain and stiffness in a population-based study: the North West Adelaide Health Study. International journal of rheumatic diseases 2010;13:215-222. 10.1111/j.1756-185X.2010.01475.x

52 Hogg-Johnson S, van der Velde G, Carroll LJ, Holm LW, Cassidy JD, Guzman J et al. The burden and determinants of neck pain in the general population: results of the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders. Spine (Phila Pa 1976) 2008;33:S39-51. 10.1097/BRS.0b013e31816454c8

53 Hoy D, March L, Woolf A, Blyth F, Brooks P, Smith E et al. The global burden of neck pain: estimates from the global burden of disease 2010 study. Ann Rheum Dis 2014;73:1309-1315. 10.1136/annrheumdis-2013-204431

54 Hoy DG, Protani M, De R, Buchbinder R. The epidemiology of neck pain. Best practice & research Clinical rheumatology 2010;24:783-792. 10.1016/j.berh.2011.01.019

55 Illyes A, Kiss RM. Kinematic and muscle activity characteristics of multidirectional shoulder joint instability during elevation. Knee Surg Sports Traumatol Arthrosc 2006;14:673-685. 10.1007/s00167-005-0012-7

56 Inman VT, Saunders JB, Abbott LC. Observations of the function of the shoulder joint. 1944. Clin Orthop Relat Res 1996:3-12.

57 Janda V. Muscles and motor control in cervicogenic disorders: assessment and management In: Grant R, ed Physical Therapy of the Cervical and Thoracic Spine New York, NY: Churchill Livingstone; 1994: 195-216.

58 Johnson G, Bogduk N, Nowitzke A, House D. Anatomy and actions of the trapezius muscle. Clin Biomech (Bristol, Avon) 1994;9:44-50. 10.1016/0268-0033(94)90057-4

59 Johnston V, Jull G, Darnell R, Jimmieson NL, Souvlis T. Alterations in cervical muscle activity in functional and stressful tasks in female office workers with neck pain. EurJApplPhysiol 2008;103:253-264. 10.1007/s00421-008-0696-8 [doi]

60 Johnston V, Jull G, Souvlis T, Jimmieson NL. Neck movement and muscle activity characteristics in female office workers with neck pain. Spine 2008;33:555-563. 10.1097/BRS.0b013e3181657d0d

61 Karduna AR, McClure PW, Michener LA. Scapular kinematics: effects of altering the Euler angle sequence of rotations. J Biomech 2000;33:1063-1068.

62 Kawasaki T, Yamakawa J, Kaketa T, Kobayashi H, Kaneko K. Does scapular dyskinesis affect top rugby players during a game season? J Shoulder Elbow Surg 2012;21:709-714. 10.1016/j.jse.2011.11.032

63 Kebaetse M, McClure P, Pratt NA. Thoracic position effect on shoulder range of motion, strength, and three-dimensional scapular kinematics. Arch Phys Med Rehabil 1999;80:945-950.

64 Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. J Am Acad Orthop Surg 2003;11:142-151.

65 Laudner KG, Stanek, JM, Meister, K. The relationship of periscapular strength on scapular upward rotation in professional baseball pitchers. J Sport Rehabil 2008; 17:95-105.

66 Laudner KG, Myers JB, Pasquale MR, Bradley JP, Lephart SM. Scapular dysfunction in throwers with pathologic internal impingement. J Orthop Sports Phys Ther 2006;36:485-494. 10.2519/jospt.2006.2146

67 Lewis JS. Rotator cuff tendinopathy/subacromial impingement syndrome: is it time for a new method of assessment? Br J Sports Med 2009;43:259-264. 10.1136/bjsm.2008.052183
68 Lin JJ, Hanten WP, Olson SL, Roddey TS, Soto-Quijano DA, Lim HK et al. Functional activities characteristics of shoulder complex movements: Exploration with a 3-D electromagnetic measurement system. J Rehabil Res Dev 2005;42:199-210.
69 Lin JJ, Hanten WP, Olson SL, Roddey TS, Soto-quijano DA, Lim HK et al. Functional activity characteristics of individuals with shoulder dysfunctions. J Electromyogr Kinesiol 2005;15:576-586. 10.1016/j.jelekin.2005.01.006
70 Lin JJ, Lim HK, Yang JL. Effect of shoulder tightness on glenohumeral translation, scapular kinematics, and scapulohumeral rhythm in subjects with stiff shoulders. J Orthop Res 2006;24:1044-1051. 10.1002/jor.20126
71 Lluch E, Arguisuelas MD, Calvente Quesada O, Martinez Noguera E, Peiro Puchades M, Perez Rodriguez JA et al. Immediate effects of active versus passive scapular correction on pain and pressure pain threshold in patients with chronic neck pain. J Manipulative Physiol Ther 2014;37:660-666. 10.1016/j.jmpt.2014.08.007
72 Ludewig PM, Behrens SA, Meyer SM, Spoden SM, Wilson LA. Three-dimensional clavicular motion during arm elevation: reliability and descriptive data. J Orthop Sports Phys Ther 2004;34:140-149. 10.2519/jospt.2004.34.3.140
73 Ludewig PM, Cook TM. The effect of head position on scapular orientation and muscle activity during shoulder elevation. J Occup Rehabil 1996;6:147-158. 10.1007/bf02110752
74 Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276-291.
75 Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. Am J Sports Med 2004;32:484-493.
76 Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RF. Motion of the shoulder complex during multiplanar humeral elevation. J Bone Joint Surg Am 2009;91:378-389. 10.2106/jbjs.g.01483
77 Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther 2009;39:90-104. 10.2519/jospt.2009.2808
78 Lukasiewicz AC, McClure P, Michener L, Pratt N, Sennett B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. J Orthop Sports Phys Ther 1999;29:574-583; discussion 584-576. 10.2519/jospt.1999.29.10.574
79 Madeleine P, Leclerc F, Arendt-Nielsen L, Ravier P, Farina D. Experimental muscle pain changes the spatial distribution of upper trapezius muscle activity during sustained contraction. Clin Neurophysiol 2006;117:2436-2445.
80 Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L. Shoulder muscle co-ordination during chronic and acute experimental neck-shoulder pain. An occupational pain study. Eur J Appl Physiol Occup Physiol 1999;79:127-140.
81 Maenhout A, Dhooge F, Van Herzeele M, Palmans T, Cools A. Acromiohumeral distance and 3-dimensional scapular position change after overhead muscle fatigue. J Athl Train 2015;50:281-288. 10.4085/1062-6050-49.3.92
82 Malanga GA, Jenp YN, Growney ES, An KN. EMG analysis of shoulder positioning in testing and strengthening the supraspinatus. Med Sci Sports Exerc 1996;28:661-664.
83 Martin RM, Fish DE. Scapular winging: anatomical review, diagnosis, and treatments. Curr Rev Musculoskelet Med 2008;1:1-11. 10.1007/s12178-007-9000-5
84 McClure PW, Michener LA, Karduna AR. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. Phys Ther 2006;86:1075-1090.

85 McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J Shoulder Elbow Surg 2001;10:269-277. 10.1067/mse.2001.112954
86 McKenna L, Straker L, Smith A. Can scapular and humeral head position predict shoulder pain in adolescent swimmers and non-swimmers? J Sports Sci 2012;30:1767-1776. 10.1080/02640414.2012.718092
87 McMahon PJ, Jobe FW, Pink MM, Brault JR, Perry J. Comparative electromyographic analysis of shoulder muscles during planar motions: anterior glenohumeral instability versus normal. J Shoulder Elbow Surg 1996;5:118-123.
88 McQuade KJ, Dawson J, Smidt GL. Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation. J Orthop Sports Phys Ther 1998;28:74-80. 10.2519/jospt.1998.28.2.74
89 Mell AG, LaScalza S, Guffey P, Ray J, Maciejewski M, Carpenter JE et al. Effect of rotator cuff pathology on shoulder rhythm. J Shoulder Elbow Surg 2005;14:58S-64S. 10.1016/j.jse.2004.09.018
90 Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. Clin Biomech (Bristol, Avon) 2003;18:369-379.
91 Moezy A, Sepehrifar S, Solaymani Dodaran M. The effects of scapular stabilization based exercise therapy on pain, posture, flexibility and shoulder mobility in patients with shoulder impingement syndrome: a controlled randomized clinical trial. Med J Islam Repub Iran 2014;28:87.
92 Morais N, Cruz J. The pectoralis minor muscle and shoulder movement-related impairments and pain: Rationale, assessment and management. Phys Ther Sport 2016;17:1-13. 10.1016/j.ptsp.2015.10.003
93 Morrison DS, Frogameni AD, Woodworth P. Non-operative treatment of subacromial impingement syndrome. J Bone Joint Surg Am 1997;79:732-737.
94 Morrison DS, Greenbaum BS, Einhorn A. Shoulder impingement. Orthop Clin North Am 2000;31:285-293.
95 Moseley JB, Jr., Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. Am J Sports Med 1992;20:128-134.
96 Mottram SL. Dynamic stability of the scapula. Man Ther 1997;2:123-131. 10.1054/math.1997.0292
97 Mulligan EP, Huang M, Dickson T, Khazzam M. The effect of axioscapular and rotator cuff exercise training sequence in patients with subacromial impingement syndrome: a randomized crossover trial. Int J Sports Phys Ther 2016;11:94-107.
98 Myers JB, Oyama S, Hibberd EE. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study. J Shoulder Elbow Surg 2013;22:1154-1159. 10.1016/j.jse.2012.12.029
99 Myers JB, Pasquale MR, Laudner KG, Sell TC, Bradley JP, Lephart SM. On-the-Field Resistance-Tubing Exercises for Throwers: An Electromyographic Analysis. J Athl Train 2005;40:15-22.
100 Nederhand MJ, MJ IJ, Hermens HJ, Baten CT, Zilvold G. Cervical muscle dysfunction in the chronic whiplash associated disorder grade II (WAD-II). Spine (Phila Pa 1976) 2000;25:1938-1943.
101 O'Leary S, Cagnie B, Reeve A, Jull G, Elliott JM. Is there altered activity of the extensor muscles in chronic mechanical neck pain? A functional magnetic resonance imaging study. Arch Phys Med Rehabil 2011;92:929-934. 10.1016/j.apmr.2010.12.021
102 O'Leary S, Falla D, Elliott JM, Jull G. Muscle dysfunction in cervical spine pain: implications for assessment and management. J Orthop Sports Phys Ther 2009;39:324-333. 10.2519/jospt.2009.2872

103 Oatis C. Kinesiology: the mechanics and pathomechanics of human movement.: Lippincott: Williams & Wilkins; 2004.
104 Ogston JB, Ludewig PM. Differences in 3-dimensional shoulder kinematics between persons with multidirectional instability and asymptomatic controls. Am J Sports Med 2007;35:1361-1370. 10.1177/0363546507300820
105 Oyama S, Myers JB, Wassinger CA, Daniel Ricci R, Lephart SM. Asymmetric resting scapular posture in healthy overhead athletes. J Athl Train 2008;43:565-570. 10.4085/1062-6050-43.6.565
106 Ozaki J. Glenohumeral movements of the involuntary inferior and multidirectional instability. Clin Orthop Relat Res 1989:107-111.
107 Paletta GA, Jr., Warner JJ, Warren RF, Deutsch A, Altchek DW. Shoulder kinematics with two-plane x-ray evaluation in patients with anterior instability or rotator cuff tearing. J Shoulder Elbow Surg 1997;6:516-527.
108 Petersen SM, Domino NA, Cook CE, Domino NA, Cook CE. Scapulothoracic muscle strength in individuals with neck pain. J Back Musculoskelet Rehabil 2016. 10.3233/bmr-160656
109 Petersen SM, Wyatt SN. Lower trapezius muscle strength in individuals with unilateral neck pain. J Orthop Sports Phys Ther 2011;41:260-265. 10.2519/jospt.2011.3503
110 Phadke V, Camargo P, Ludewig P. Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. Rev Bras Fisioter 2009;13:1-9. 10.1590/s1413-35552009005000012
111 Ratcliffe E, Pickering S, McLean S, Lewis J. Is there a relationship between subacromial impingement syndrome and scapular orientation? A systematic review. Br J Sports Med 2014;48:1251-1256. 10.1136/bjsports-2013-092389
112 Reeser JC, Joy EA, Porucznik CA, Berg RL, Colliver EB, Willick SE. Risk factors for volleyball-related shoulder pain and dysfunction. PM R 2010;2:27-36. 10.1016/j.pmrj.2009.11.010
113 Ribeiro A, Pascoal AG. Resting scapular posture in healthy overhead throwing athletes. Man Ther 2013;18:547-550. 10.1016/j.math.2013.05.010
114 Rundquist PJ. Alterations in scapular kinematics in subjects with idiopathic loss of shoulder range of motion. J Orthop Sports Phys Ther 2007;37:19-25. 10.2519/jospt.2007.2121
115 Safran MR. Nerve injury about the shoulder in athletes, part 2: long thoracic nerve, spinal accessory nerve, burners/stingers, thoracic outlet syndrome. Am J Sports Med 2004;32:1063-1076.
116 Sahara W, Sugamoto K, Murai M, Tanaka H, Yoshikawa H. 3D kinematic analysis of the acromioclavicular joint during arm abduction using vertically open MRI. J Orthop Res 2006;24:1823-1831. 10.1002/jor.20208
117 Sahara W, Sugamoto K, Murai M, Tanaka H, Yoshikawa H. The three-dimensional motions of glenohumeral joint under semi-loaded condition during arm abduction using vertically open MRI. Clin Biomech (Bristol, Avon) 2007;22:304-312. 10.1016/j.clinbiomech.2006.04.012
118 Sahrmann. Diagnosis and treatment of movement impairment syndromes: Elsevier Health Sciences; 2002.
119 Shahidi B, Johnson CL, Curran-Everett D, Maluf KS. Reliability and group differences in quantitative cervicothoracic measures among individuals with and without chronic neck pain. BMC Musculoskelet Disord 2012;13:215. 10.1186/1471-2474-13-215
120 Smith J, Dahm DL, Kaufman KR, Boon AJ, Laskowski ER, Kotajarvi BR et al. Electromyographic activity in the immobilized shoulder girdle musculature during scapulothoracic exercises. Arch Phys Med Rehabil 2006;87:923-927. 10.1016/j.apmr.2006.03.013

121 Sole G, Osborne H, Wassinger C. Electromyographic response of shoulder muscles to acute experimental subacromial pain. Man Ther 2014;19:343-348. 10.1016/j.math.2014.03.001
122 Sousa Cde O, Camargo PR, Ribeiro IL, Reiff RB, Michener LA, Salvini TF. Motion of the shoulder complex in individuals with isolated acromioclavicular osteoarthritis and associated with rotator cuff dysfunction: part 1 - Three-dimensional shoulder kinematics. J Electromyogr Kinesiol 2014;24:520-530. 10.1016/j.jelekin.2014.04.015
123 Sousa Cde O, Michener LA, Ribeiro IL, Reiff RB, Camargo PR, Salvini TF. Motion of the shoulder complex in individuals with isolated acromioclavicular osteoarthritis and associated with rotator cuff dysfunction: part 2 - muscle activity. J Electromyogr Kinesiol 2015;25:77-83. 10.1016/j.jelekin.2014.05.002
124 Struyf F, Cagnie B, Cools A, Baert I, Brempt JV, Struyf P et al. Scapulothoracic muscle activity and recruitment timing in patients with shoulder impingement symptoms and glenohumeral instability. J Electromyogr Kinesiol 2014;24:277-284. 10.1016/j.jelekin.2013.12.002
125 Struyf F, Nijs J, Baeyens JP, Mottram S, Meeusen R. Scapular positioning and movement in unimpaired shoulders, shoulder impingement syndrome, and glenohumeral instability. Scand J Med Sci Sports 2011;21:352-358. 10.1111/j.1600-0838.2010.01274.x
126 Struyf F, Nijs J, Meeus M, Roussel NA, Mottram S, Truijen S et al. Does scapular positioning predict shoulder pain in recreational overhead athletes? Int J Sports Med 2014;35:75-82. 10.1055/s-0033-1343409
127 Struyf F, Nijs J, Mollekens S, Jeurissen I, Truijen S, Mottram S et al. Scapular-focused treatment in patients with shoulder impingement syndrome: a randomized clinical trial. Clin Rheumatol 2013;32:73-85. 10.1007/s10067-012-2093-2
128 Su KP, Johnson MP, Gracely EJ, Karduna AR. Scapular rotation in swimmers with and without impingement syndrome: practice effects. Med Sci Sports Exerc 2004;36:1117-1123.
129 Tate A, Turner GN, Knab SE, Jorgensen C, Strittmatter A, Michener LA. Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. J Athl Train 2012;47:149-158.
130 Teece RM, Lunden JB, Lloyd AS, Kaiser AP, Cieminski CJ, Ludewig PM. Three-dimensional acromioclavicular joint motions during elevation of the arm. J Orthop Sports Phys Ther 2008;38:181-190. 10.2519/jospt.2008.2386
131 Thigpen CA, Padua DA, Michener LA, Guskiewicz K, Giuliani C, Keener JD et al. Head and shoulder posture affect scapular mechanics and muscle activity in overhead tasks. J Electromyogr Kinesiol 2010;20:701-709. 10.1016/j.jelekin.2009.12.003
132 Timmons MK, Thigpen CA, Seitz AL, Karduna AR, Arnold BL, Michener LA. Scapular kinematics and subacromial-impingement syndrome: a meta-analysis. J Sport Rehabil 2012;21:354-370.
133 Tsai NT, McClure PW, Karduna AR. Effects of muscle fatigue on 3-dimensional scapular kinematics. Arch Phys Med Rehabil 2003;84:1000-1005.
134 Van Dillen LR, McDonnell MK, Susco TM, Sahrmann SA. The immediate effect of passive scapular elevation on symptoms with active neck rotation in patients with neck pain. Clin J Pain 2007;23:641-647. 10.1097/AJP.0b013e318125c5b6

135 Vermeulen HM, Stokdijk M, Eilers PH, Meskers CG, Rozing PM, Vliet Vlieland TP. Measurement of three dimensional shoulder movement patterns with an electromagnetic tracking device in patients with a frozen shoulder. Ann Rheum Dis 2002;61:115-120.

136 Visible Body Human Atlas , 3D Muscle Premium 2. In: Argosy Pusblishin, Inc.; 2007-2012.

137 von Eisenhart-Rothe R, Matsen FA, 3rd, Eckstein F, Vogl T, Graichen H. Pathomechanics in atraumatic shoulder instability: scapular positioning correlates with humeral head centering. Clin Orthop Relat Res 2005:82-89.

138 Wadsworth DJ, Bullock-Saxton JE. Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. Int J Sports Med 1997;18:618-624. 10.1055/s-2007-972692

139 Warner JJ, Micheli LJ, Arslanian LE, Kennedy J, Kennedy R. Scapulothoracic motion in normal shoulders and shoulders with glenohumeral instability and impingement syndrome. A study using Moire topographic analysis. Clin Orthop Relat Res 1992:191-199.

140 Wassinger CA, Sole G, Osborne H. Clinical measurement of scapular upward rotation in response to acute subacromial pain. J Orthop Sports Phys Ther 2013;43:199-203. 10.2519/jospt.2013.4276

PART I: SCAPULOTHORACIC MUSCLE RECRUITMENT IN PATIENT POPULATIONS WITH SHOULDER OR NECK PAIN

CHAPTER 1:

OPTIMAL NORMALIZATION TESTS FOR MUSCLE ACTIVATION OF THE LEVATOR SCAPULAE, PECTORALIS MINOR, AND RHOMBOID MAJOR: AN ELECTROMYOGRAPHY STUDY USING MAXIMUM VOLUNTARY ISOMETRIC CONTRACTIONS.

BIRGIT CASTELEIN, PT[1]; BARBARA CAGNIE, PT, PHD[1]; THIERRY PARLEVLIET, MD[2]; LIEVEN DANNEELS, PT, PHD[1]; ANN COOLS, PT, PHD[1]

[1] DEPARTMENT OF REHABILITATION SCIENCES AND PHYSIOTHERAPY, GHENT UNIVERSITY, GHENT, BELGIUM

[2] DEPARTMENT OF PHYSICAL MEDICINE AND ORTHOPAEDIC SURGERY, UNIVERSITY HOSPITAL, GHENT, BELGIUM

ARCHIVES OF PHYSICAL MEDICINE AND REHABILITATION. 2015 OCT; 96(10):1820-7.
(SCI=2.202, Q1)

ABSTRACT

Objective: To identify maximum voluntary isometric contraction (MVIC) test positions for the deeper-lying scapulothoracic muscles (ie, Levator Scapulae, Pectoralis Minor, Rhomboid Major), and to provide a standard set of a limited number of test positions that generate an MVIC in all scapulothoracic muscles.

Design: Cross-sectional Study.

Setting: Physical and rehabilitation medicine department.

Participants: Healthy subjects (N=21).

Interventions: Not applicable.

Main Outcome Measures: Mean peak electromyographic activity from Levator Scapulae, Pectoralis Minor, and Rhomboid Major (investigated with fine-wire electromyography) and from Upper Trapezius, Middle Trapezius, Lower Trapezius, and Serratus Anterior (investigated with surface electromyography) during the performance of 12 different MVICs.

Results: The results indicated that various test positions generated similar high mean electromyographic activity and that no single test generated maximum activity for a specific muscle in all subjects. The results of this study support using a series of test positions for normalization procedures rather than a single exercise to increase the likelihood of recruiting the highest activity in the scapulothoracic muscles.

Conclusions: A standard set of 5 test positions was identified as being sufficient for generating an MVIC of all scapulothoracic muscles: seated T, seated U 135°, prone T-thumbs up, prone V-thumbs up, and supine V-thumbs up. A standard set of test positions for normalization of scapulothoracic electromyographic data that also incorporates the Levator Scapulae, Pectoralis Minor, and Rhomboid Major muscles is one step toward a more comprehensive understanding of normal and abnormal muscle function of these muscles and will help to standardize the presentation of scapulothoracic electromyographic muscle activity.

INTRODUCTION

The most common method to quantify the level of muscle activity is by electromyography. It is generally recognized that normalization of electromyographic data (often expressed as a percentage of a given reference value) is necessary to allow comparisons of muscle activity between muscles, between test sessions, and between and within participants. Different reference values are used, but the use of maximum voluntary isometric contractions (MVICs) has been the most common way to normalize the signals.[1-3]

The primary muscles that cause and control scapular movements are the Trapezius, Serratus Anterior (SA), Levator Scapulae (LS), Pectoralis Minor (Pm), and Rhomboid Major (RM) muscles.[4] Standard normalization references using MVICs for the superficial scapulothoracic muscles (including the Trapezius and SA) have been described by Ekstrom[5] and Boettcher[6] and colleagues. Much research has been performed on the activity of the trapezius and SA during different movements in different population groups. Very little electromyographic data are available on the activity of the smaller and less superficial muscles that attach to the scapula, including the LS, Pm, and RM, despite the hypothesized importance of these muscles in shoulder and neck function.[7,8] The inability to investigate those deeper-lying muscles' activity with surface electromyography and the absence of standard reference contractions to normalize the data could have been the main reasons why there is a lack of research data on the electromyographic activity of these muscles. For the RM, 2 studies[9,10] have investigated the activity during different isometric manual muscle tests. For the LS and Pm, no electromyographic studies seem to have evaluated the activity during isometric manual muscle tests. Studies that nonetheless investigated the muscle activity of the LS[11,12] and Pm[12,13] via fine-wire electromyography did not use standard reference contractions for normalization of the data, but used reference contractions based on anatomic characteristics of the muscles. For example, according to the information from cadaveric dissections, the Pm is believed to move the scapula to protraction, anterior tilt, and downward and internal rotation; the LS is believed to elevate the scapula and to work together with the RM to retract and rotate the scapula downward.[4] However, no electromyographic studies were found that prove that these contractions provide the greatest activation of those muscles. So it still remains unclear which are the most suitable MVIC test positions that target the deeper-lying scapulothoracic muscles. A standard normalization procedure for scapulothoracic electromyographic data that also incorporates the MVICs of the LS, Pm, and RM is needed and could be the first step to enable a more comprehensive understanding of normal and abnormal scapulothoracic muscle function.

Therefore, the purpose of this study was to identify MVIC test positions for the deeper-lying scapulothoracic muscles - that is the LS, Pm, and RM. In addition, we wanted to provide a standard set of a limited number of test positions that are sufficient to produce the highest electromyographic activation of all scapulothoracic muscles.

METHODS

Participants

Twenty-one subjects (10 women, 11 men; age range, 21-55y [mean age, 34y]; mean weight, 67kg; mean height, 174cm) were tested. All subjects were free from current or past shoulder or neck pain and demonstrated full pain-free range of motion of both shoulders. Eighteen subjects were right-handed and 3 were left-handed. Written informed consent was obtained from all participants. The study was approved by the ethics committee of Ghent University Hospital.

Test Procedures

Electromyographic data were collected from 7 scapulothoracic muscles (Upper Trapezius [UT], Middle Trapezius [MT], Lower Trapezius [LT], SA, LS, Pm, RM) on the dominant side of each subject during the performance of 12 different MVICs in randomized order. Each MVIC was repeated 3 times.

Instrumentation

A TeleMyo 2400 G2 Telemetry System (Noraxon USA, Inc) was used to collect the electromyographic data. A combination of surface and intramuscular electrodes was used. Bipolar surface electrodes (Ag/AgCl, Ambu ® Blue Sensor P, Type N-00-S 30x22mm, Ballerup, Denmark) were placed with a 1-cm interelectrode distance over the UT, LT, MT, and SA, according to the instructions of Basmajian and De Luca.[1] Before surface electrode application, the skin surface was shaved, cleaned, and scrubbed with alcohol to reduce impedance (<10kU). Intramuscular paired hook fine-wire electrodes(Carefusion Middleton,WI, USA–wire length 125mm) were used to measure the electromyographic activity of the LS, Pm, and RM. The electrodes were inserted into the muscle belly according to the locations described by Delagi et al[14] using a single-use 25-gauge hypodermic needle. This was done using real-time ultrasound guidance, which has been shown to be an accurate and repeatable method of intramuscular electrode placement.[15] The surface and intramuscular electrodes were looped and taped on the skin to prevent them from being accidentally removed during the experiment and to minimize movement artifacts. The sampling rate was 3000Hz. All raw myoelectric signals were preamplified (overall gain, 1000; common mode rejection ratio, 100dB; <1mV root-mean-square baseline noise).

Test Positions

The 12 different muscle test positions are described in Table 1. Seven tests were performed in the seated position, 3 in prone lying, and 2 in supine lying. Manual pressure was always applied by the same investigator. The investigator held the resistance while the subject exerted a maximal force against it. The contralateral hand of the investigator was used to stabilize the trunk during the different test positions.

	Name	Position*	Description
1	Seated T	Seated	Shoulder abducted to 90° (elbow fully extended) as resistance is applied above the elbow, in a downward direction (to resist abduction)
2	Prone T – thumbs up	Prone	Shoulder horizontally abducted and externally rotated (elbow fully extended) as the examiner applies manual pressure downward (above the elbow) to resist adduction of the scapula and extension of the shoulder
3	Prone V- thumbs up	Prone	Arm raised above head in line with Lower Trapezius muscle fibers (elbow fully extended) as resistance applied above the elbow against further arm raise
4	Seated U 135°	Seated	Shoulder flexed to 135° (elbow fully extended) as resistance is applied above the elbow against further arm raise
5	Kendall levator scapulae/rhomboid	Prone	Arm adducted and slightly extended, scapula adducted and elevated with elbow fully flexed as resistance is applied in the direction of shoulder abduction (with one hand) and in the direction of scapula depression (with the other hand)
6	Elevation scapula	Seated	Scapula elevation as resistance is given over the top of the shoulder in a downward direction (to resist elevation of the scapula)
7	Shoulder abduction/ extension at 90° of abduction	Seated	Arm abducted to 90° in slight extension and slight internal rotation as resistance arm is applied in the direction of adduction and flexion against the posterolateral surface of the upper arm
8	Extension at 30° of abduction	Seated	Shoulder at 30° abduction (elbow fully extended), thumb toward the body; arm extended as resistance applied over the distal forearm (in a forward direction, against extension)
9	Shoulder internal rotation at 90° of abduction	Seated	Shoulder abducted 90° in plane of scapula with neutral humeral rotation and elbow flexed 90°, arm internally rotated as resistance applied at the wrist (in an upward direction, in direction of external rotation)
10	Press up	Seated	Lifting body upwards from a seated position by pressing down through both hands
11	Kendall pectoralis minor	Supine	Scapula protraction as resistance is given in a downward direction on the anterior aspect of the shoulder
12	Supine V- thumbs up	Supine	Arm raised above head in line with pectoralis minor muscle fibers (and elbow fully extended) as resistance applied above elbow. The participant is asked to move the arm to the contralateral hip and the examiner applies manual pressure to counteract that movement.

TABLE 1. Description of MVIC tests, *Seated was without back support

Before data collection, test positions were taught to each subject by the same investigator, and sufficient practice was allowed. When participants reported satisfactory familiarization, three 5-second MVICs were completed for each position, with at least 30 seconds of rest between the different repetitions.[6] There was at least 1.5-minute rest between the different test positions. The participants were asked to reach maximum effort in 1 second, sustain this maximum for 3 seconds, and then relax for the remaining time. The investigator counted the seconds out loud (guided by a metronome). Strong and consistent encouragement from the investigator was given during each MVIC. Subjects were closely monitored to ensure that they did not attempt compensatory movements. If a test was being done incorrectly, it was ceased and repeated. The test positions were performed in a randomized order to avoid systematic effects of fatigue. Two tests (test positions 11 and 12) were not randomized and were always performed at the end, because the supine position of this test did not allow measurement of the activity of the dorsal muscles because of the contact of the electrodes with the examination table. For these 2 test positions, only the Pm activity was of interest.

The rationale behind the choice of the different MVIC test positions was based on former research that has been performed on shoulder muscle MVICs[5,6,9,10,16] and on other studies[12,13] that investigated the deeper-lying scapulothoracic muscles, augmented with results from pilot studies (unpublished).

Signal Processing

The MyoResearch 3.4 Master Edition Software was used for signal processing. The electromyographic signals were filtered with a high-pass Butterworth filter (20Hz). Cardiac artifact reduction was performed, followed by rectification and smoothing (root mean square, window 100ms) of the signals. The average electromyographic value over a window of the peak 2.5 seconds of the 5 seconds during each MVIC trial for each muscle was calculated. The average mean across the 3 trials was used. The electromyographic values for each muscle during each muscle test position were normalized as a percentage of the highest electromyographic value produced by that muscle during the 12 muscle test positions performed by the subject.[5,6] The electromyographic data were therefore expressed as a percentage of the maximum electromyographic amplitude produced by the muscle (%MVIC). For 2 tests (Kendall pectoralis minor and supine V-thumbs up), only the Pm electromyographic activity was extracted, because the activity of the muscles located dorsally was not useful because of friction of the electrodes and leads with the table (supine lying). Similarly, the Pm electromyographic activity during test positions performed in prone lying was not taken into account since it was not useful because of friction of the electrodes and leads with the table (prone lying).

Statistical Analysis

SPSS 22.0 was used for statistical analysis. For each muscle, a linear mixed model (test position as factor) was used to determine whether there were significant differences in electromyographic activity for that muscle between test positions. The residuals of the linear mixed models were checked for normal distribution. A least significant difference pairwise multiple comparison analysis was performed to determine the significance of the differences between pairs of means.

Results

The mean electromyographic activity (%MVIC ± SD) of each muscle during each test position is displayed in Table 2. The test positions that produced significantly higher activity for each muscle were identified and marked (with a single dagger †).

Test Position	UT	MT	LT	SA	LS	Pm	RM
Seated T	86,5 ± 17,7*	55,3 ± 18,9	39,5 ± 18,9	84,4 ± 19,4†	64,4 ± 28,0†	46,8 ± 26,3†	59,8 ± 25,0
Prone T-thumbs up	59,6 ± 19,5	85,3 ± 17,3*	71,6 ± 17,2	16,0 ± 9,2	76,5 ± 26,7*	ND	70,9 ± 26,6†
Prone V-thumbs up	78,3 ± 19,8†	76,1 ± 22,0†	86,7 ± 23,7*	60,3 ± 25,4	68,1 ± 27,7†	ND	74,9 ± 23,7†
Seated U 135°	84,4 ± 18,0†	74,8 ± 22,5†	64,9 ± 24,7	84,5 ± 17,3*	65,7 ± 28,1†	48,6 ± 33,1†	79,7 ± 19,2*
Kendall levator Scapulae/rhomboid	24,9 ± 20,3	27,4 ± 11,4	35,3 ± 22,9	23,5 ± 15,8	59,6 ± 24,4	ND	44,1 ± 26,0
Elevation scapula	60,5 ± 18,9	23,2 ± 13,3	10,2 ± 8,2	35,9 ± 22,2	58,6 ± 21,3	56,4 ± 30,6†	38,6 ± 23,7
Shoulder abduction/extension at 90° of abduction	39,7 ± 20,4	63,0 ± 22,5	62,0 ± 22,0	18,6 ± 11,2	66,9 ± 27,9	34,2 ± 21,3	59,0 ± 21,7
Extension 30° of abduction	14,7 ± 9,0	37,6 ± 13,9	45,8 ± 32,2	27,9 ± 16,4	49,7 ± 23,7	39,4 ± 0,7	56,5 ± 28,9
Shoulder Internal rotation at 90° of abduction	12,7 ± 9,3	20,0 ± 15,0	23,3 ±16,7	22,9 ± 13,1	38,9 ± 19,5	50,9 ± 27,1*	28,1 ± 20,1
Press up	13,1 ± 8,3	17,1 ± 12,8	27,5 ± 11,1	46,3 ± 23,4	9,7 ± 9,4	58,9 ± 32,9*	32,3 ± 21,0
Kendall pectoralis minor	ND	ND	ND	ND	ND	53,5 ± 32,8*	ND
Supine V- thumbs up	ND	ND	ND	ND	ND	64,8 ± 28,0*†	ND

TABLE 2. EMG activity of the each scapulothoracic muscle during each test

NOTE. Values are %MVIC ± SD. No data (ND) indicates no electromyographic activity available for that muscle for that test position because the supine or prone position of this test did not allow measurement of the activity because of the contact of the electrodes of that muscle with the examination table.

Abbreviation: ND, no data

*Highest average electromyographic activity for that muscle.

†No significant difference from muscle test position that elicited highest activity.

Table 3 gives an overview of the different test positions that produced significantly higher activity for each muscle, compared with nonmarked testing positions. Also, the number of subjects in which the muscle test produced maximum electromyographic amplitude was calculated.

Test Position	UT	MT	LT	SA	LS	Pm	RM
Seated T	7✓			9*	3*	0*	
Prone T-thumbs up		9✓			5✓		5*
Prone V-thumbs up	5*	5*	12✓		3*		4*
Seated U 135°	7*	6*		9✓	2*	3*	3✓
Kendall levator scapulae/rhomboid							
Elevation scapula						2*	
Shoulder abduction/extension at 90° of abduction					5*		
Extension at 30° of abduction							
Shoulder Internal rotation at 90° of abduction						2*	
Press Up						5*	
Pectoralis Minor Kendall						3*	
Supine V-thumbs up						5✓	

TABLE 3. An overview of the tests that highly activated the scapulothoracic muscles.

NOTE. The checkmark (✓) indicates the test position that elicited highest electromyographic activity for that muscle. The asterisk (*) indicates a test position that elicited electromyographic activity that is not significantly different from the muscle test that elicited highest activity. Values represent the number of subjects in which the muscle test produced maximum electromyographic amplitude. Empty cells indicate values that were significantly different from muscle test that elicited highest activity for that muscle.

Because various test positions generated a similar high mean electromyographic activity and because no single test generated maximum activity for a specific muscle in all subjects, no single exercise was found that could be deemed as the best exercise for achieving maximal amplitudes of a particular muscle. The results of this study support using a set of test positions rather than a single exercise to increase the likelihood of recruiting the highest activity in the scapulothoracic muscles. It is a better strategy to record from all muscles during different tests rather than determining a specific test for a specific muscle, since the maximum level of activity may be generated from any one of the tests performed. The MVIC for a particular muscle is the maximum level of activation generated across the set of test positions.

Therefore, the following criteria (in a strict order: first criterion 1, if more than 1 test position meets criterion 1, then take criterion 2 into account.) were used to determine an appropriate set of MVICs that have a high likelihood to achieve the highest activation of all scapulothoracic muscles in order to normalize electromyographic data. For each muscle, the test position should (1) produce high mean electromyographic activity, significantly higher than the other test positions; (2) have the highest percentage of subjects achieving maximum activity; and (3) produce the highest mean electromyographic activity. Consequently, based on these criteria, 5 test positions were selected:

(1) seated T (fig 1);

(2) seated U 135 (fig 2);

(3) prone T-thumbs up (fig 3);

(4) prone V-thumbs up (fig 4);

and (5) supine V-thumbs up (fig 5).

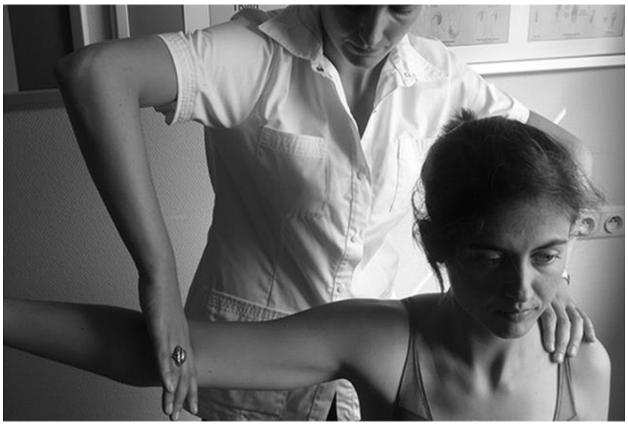


FIGURE 1. Seated T

FIGURE 2. Seated U 135.

FIGURE 3. Prone T-thumbs up.

FIGURE 4. Prone V-thumbs up.

FIGURE 5. Supine V-thumbs up.

DISCUSSION

The aim of this study was to identify MVIC test positions for the deeper-lying scapulothoracic muscles (LS, Pm, RM), and to identify a standard set of a limited number of test positions that generate an MVIC in all scapulothoracic muscles. This is the first study where all deeper-lying muscles are investigated with fine-wire electromyography for their MVIC and where all scapulothoracic muscles are integrally tested for their MVICs. The results indicated that no single exercise elicited the highest activation of a specific muscle in all subjects, thus supporting the use of a set of test positions for normalization purposes, rather than a single exercise. The normalization reference level for each of the scapulothoracic muscles should be taken as the maximum level of activation generated across the set. A standard set of 5 test positions was identified: seated T, seated U 135, prone T-thumbs up, prone V-thumbs up, and supine V-thumbs up.

Overall, for all muscles, a great intersubject variability was observed as to which MVIC elicited the greatest muscular activity. This concern has already been reported in previously published studies investigating MVICs, in the shoulder region[5,6] and other regions.[17-19] Remarkably, greater variability was seen in the electromyographic activity of the muscles measured by fine-wire. As demonstrated previously[3,10] and supported by our results, maximum activity in many shoulder muscles may be generated from various isometric tests in different individuals. Using a set of exercises rather than a single exercise seems to increase the likelihood of producing the highest electromyographic activation of all scapulothoracic muscles. Previous studies[6,9,17,18] have also made recommendations for using a set of tests instead of a single test for a specific muscle. Therefore, similar to the recommendations of Boettcher[6] and Ekstrom,[5] the electromyographic normalization reference value for each of the scapulothoracic muscles would be the maximum electromyographic level generated across the 5 test positions. There is a need to record from all muscles during all tests rather than determining a specific test for a specific muscle, because the maximum level of activity may be generated from any one of the tests performed.

The standard MVIC positions for the UT, MT, LT, and SA, according to the study by Ekstrom,[5] elicited also in the current study the highest electromyographic activity in their respective muscles among the test positions that were examined. The highest UT electromyographic activity was generated during the seated T. This position has been found optimal by other authors too.[5,20] The prone T-thumbs up was the test position that generated the greatest electromyographic activity of the MT, and the prone V-thumbs up for the LT. This is in accordance with other studies.[5,21] For the SA, the highest mean amount of electromyographic activity was generated during the seated U 135, which was similar to the work of Ekstrom.[5] The revelation of this study is that these 4 test positions, previously described as standard test positions for UT, MT, LT, and SA by Ekstrom,[5] are included in our set of 5 test positions. Table 3 shows that these 4 tests highly activate more than 1 shoulder muscle simultaneously. The seated T was the test position that elicited the highest electromyographic activity of 4 muscles (UT, SA, LS, Pm); the prone T-thumbs up, 3 muscles (MT, LS, RM); the prone V- thumbs up, 5 muscles (UT, MT, LT, LS, RM); and the seated U 135°, 6 muscles (UT, MT, SA, LS, Pm, RM). Next to these 4 standard MVIC positions, only 1 extra MVIC position has to be added to generate the highest activity in all 7 scapulothoracic muscles, which reduces the likelihood of fatigue. In future studies, a set of 5 MVIC test positions can be used as a standard to normalize both deeper- and superficial-lying scapulothoracic electromyographic muscle activity.

This study provides some new information about the electromyographic activity of the deeper-lying muscles. Based on anatomic studies, it is generally believed that the LS functions as a retractor, elevator, and downward rotator of the scapula.[16] Our results indicate that the highest electromyographic activity for the LS was during prone T-thumbs up. The electromyographic activity during this test position was not significantly different from 4 other test positions. Surprisingly, it was significantly different from the test positions elevation scapula and Kendall LS/rhomboid, in which the highest LS electromyographic activity was expected. In previously published research,[11] the LS activity was examined during different shoulder movements, and the elevation scapula was indeed used as the 100% reference value. According to the results of this study, it is likely that the LS is more activated by a movement of retraction than of elevation.

The test position that activated the Pm to its highest was with the arm internally rotated and raised above the head (in line with the Pm) and in which resistance was given in the direction in line with the fibers of the Pm muscle. The authors believe that the Pm is then highly activated because it has to pull the scapula anteriorly and inferiorly toward the ribs. Remarkably, this test position did not significantly differ from 6 other test positions that were performed. The position that is often recommended in the literature to highly activate the Pm is protraction of the scapula against resistance (Kendall Pm). Although this protraction test did not show statistical significant differences from the test positions that elicited the highest activity, it showed approximately 11% less activation of the Pm in comparison with the supine V- thumbs up. The Pm seems to be more activated when performing a combination of anterior tilting and protraction, than when solely isolating the protraction movement. No previously published literature exists on MVICs of the Pm to make comparisons.

The test position seated U 135 elicited the highest activity for the RM muscle (not significantly different from activity during prone V-thumbs up and prone T-thumbs up). These results are not in line with previously published research. Smith et al[10] recommended the shoulder abduction/extension at 90 abduction, and Ginn et al[9] recommended the extension at 30 abduction. However, the results of the current study do not support the choice of these test positions, since 2 other exercises produced significantly greater electromyographic activity in the RM than the 2 test positions mentioned above.

The test positions that elicited the highest activity for the deeper-lying muscles measured with fine-wire electromyography, often varied from other positions that have been clinically used.[16] We believe that the test positions used in clinical practice to investigate the strength of a specific muscle (typical with test positions of Kendall[16]) are not the ones that automatically lead to high electromyographic activation. This is especially the case for the fine-wire electromyographic results, since only a single motor unit of that muscle is investigated.

Another striking difference is that for the 3 deeper-lying muscles, the number of subjects in which the test position produced the highest electromyographic amplitude was rather small, while for the superficial-lying muscles, a greater number of subjects were found to have the same position that elicited the highest electromyographic amplitude. Whether this difference is due to the wire versus surface technique or due to the nature of the muscles is unclear. Three other studies investigated MVIC test positions of the deeper-lying shoulder muscles with fine-wire electromyography.[6,9,10] Two studies[6,10] reported no information about the number of subjects in which the muscle test produced the highest electromyographic activity, and 1 study by Ginn[9] reported 1 test position that elicited the highest electromyographic activity for RM for 8 of 14 subjects. Limited research about this topic is available, and future research is necessary to unravel the question of the cause of the low number of subjects having the same test position that elicited the highest electromyographic activity.

Study Limitations

The present results must be viewed in light of the study's limitations. First, we cannot determine whether other test positions would lead to higher electromyographic recordings for some muscles. Second, we do not know whether the results could be influenced by using other electrode types (surface vs fine-wire electromyography). Third, cross-talk might have occurred in our electromyographic signals between superficial and deeper scapulothoracic muscles (such as MT and RM, UT and LS). Nevertheless, all recommended methods have been taken into account to reduce the possibility of cross-talk (small surface electrodes and small interelectrode distance, recommended electrode placement).[1]

CONCLUSION

This is the first study that provides MVICs for the deeper-lying muscles. The results indicated that no single exercise elicited the highest activation for every participant for each muscle, thus supporting the use of an exercise set for normalization purposes to increase the likelihood of recruiting maximal activity in the scapulothoracic muscles. A standard set of 5 test positions was identified as being sufficient for generating an MVIC of all scapulothoracic muscles (UT, MT, LT, SA, LS, Pm, RM): seated T, seated U 135, prone T-thumbs up, prone V-thumbs up, and supine V-thumbs up.

REFERENCES

1 Basmajian JV, De Luca CJ. Muscles alive: their functions revealed by electromyography. Baltimore: William & Wilkins; 1985.
2 Knutson LM, Soderberg GL, Ballantyne BT, Clarke WR. A study of various normalization procedures for within day electromyographic data. J Electromyogr Kinesiol 1994;4:47-59.
3 Burden A. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. J Electromyogr Kinesiol 2010;20:1023-35.
4 Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. Sports Med 2009;39:663-85.
5 Ekstrom RA, Soderberg GL, Donatelli RA. Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis. J Electromyogr Kinesiol 2005;15:418-28.
6 Boettcher CE, Ginn KA, Cathers I. Standard maximum isometric voluntary contraction tests for normalizing shoulder muscle EMG. J Orthop Res 2008;26:1591-7.
7 Cagnie B, Struyf F, Cools A, Castelein B, Danneels L, O'Leary S. The relevance of scapular dysfunction in neck pain: a brief commentary. J Orthop Sports Phys Ther 2014;44:435-9.
8 Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. Br J Sports Med 2014;48:692-7.
9 Ginn KA, Halaki M, Cathers I. Revision of the shoulder normalization tests is required to include rhomboid major and teres major. J Orthop Res 2011;29:1846-9.
10 Smith J, Padgett DJ, Kaufman KR, Harrington SP, An KN, Irby SE. Rhomboid muscle electromyography activity during 3 different manual muscle tests. Arch Phys Med Rehabil 2004;85: 987-92.
11 Behrsin JF, Maguire K. Levator scapulae action during shoulder movement: a possible mechanism for shoulder pain of cervical origin. Aust J Physiother 1986;32:101-6.
12 Moseley JB Jr, Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. Am J Sports Med 1992;20:128-34.
13 Wickham J, Pizzari T, Stansfeld K, Burnside A, Watson L. Quantifying 'normal' shoulder muscle activity during abduction. J Electromyogr Kinesiol 2010;20:212-22.
14 Delagi EF, Iazzetti J, Perpotto A, Morrison D. Anatomical guide for the electromyographer. The limbs and trunk. Spingfield: Charles C. Thomas; 1994.
15 Hodges PW, Kippers V, Richardson CA. Validation of a technique for accurate fine-wire electrode placement into posterior gluteus medius using real-time ultrasound guidance. Electromyogr Clin Neurophysiol 1997;37:39-47.
16 Kendall FP, McCreary EK, Provance PG. Muscles: testing and function. 4th ed. Baltimore: Williams & Wilkins; 1993.
17 Rutherford DJ, Hubley-Kozey CL, Stanish WD. Maximal voluntary isometric contraction exercises: a methodological investigation in moderate knee osteoarthritis. J Electromyogr Kinesiol 2011;21:154-60.
18 Vera-Garcia FJ, Moreside JM, McGill SM. MVC techniques to normalize trunk muscle EMG in healthy women. J Electromyogr Kinesiol 2010;20:10-6.
19 Ng JK, Kippers V, Parnianpour M, Richardson CA. EMG activity normalization for trunk muscles in subjects with and without back pain. Med Sci Sports Exerc 2002;34:1082-6.

20 McLean L, Chislett M, Keith M, Murphy M, Walton P. The effect of head position, electrode site, movement and smoothing window in the determination of a reliable maximum voluntary activation of the upper trapezius muscle. J Electromyogr Kinesiol 2003;13:169-80.

21 Brandell BR, Wilkinson DA. An electromyographic study of manual testing procedures for the trapezius and deltoid muscles. Physiother Can 1991;43:33-9.

CHAPTER 2:

SCAPULOTHORACIC MUSCLE ACTIVITY DURING ELEVATION TASKS MEASURED WITH SURFACE AND FINE WIRE EMG: A COMPARATIVE STUDY BETWEEN PATIENTS WITH SUBACROMIAL IMPINGEMENT SYNDROME AND HEALTHY CONTROLS

BIRGIT CASTELEIN, PT[1]; BARBARA CAGNIE, PT, PHD[1]; THIERRY PARLEVLIET,MD[2]; ANN COOLS, PT, PHD[1]

[1] DEPARTMENT OF REHABILITATION SCIENCES AND PHYSIOTHERAPY, GHENT UNIVERSITY, GHENT, BELGIUM

[2] DEPARTMENT OF PHYSICAL MEDICINE AND ORTHOPAEDIC SURGERY, UNIVERSITY HOSPITAL, GHENT, BELGIUM

MANUAL THERAPY. 2016 JUNE;23:33-9.

(SCI=1.714, Q2)

ABSTRACT

Background: The quality of the scapular movement depends on the coordinated activity of the surrounding scapulothoracic muscles. Besides the well-known changes in Trapezius and Serratus Anterior (SA) activity in patients with subacromial impingement syndrome (SIS), no studies exist that have investigated the activity of the smaller less superficial muscles that attach on the scapula (Pectoralis Minor (Pm), Levator Scapulae (LS) and Rhomboid Major (RM)) in a population with SIS, despite the hypothesized importance of these muscles in shoulder function.

Objectives: To investigate if patients with SIS show differences in deeper and superficial lying scapulothoracic muscle activity in comparison with a healthy control group during arm elevation tasks.

Study Design: Controlled laboratory study

Methods: Activity of the deeper lying (LS, Pm and RM) and superficial lying scapulothoracic muscles (Trapezius and SA) was investigated with fine-wire and surface EMG in 17 subjects with SIS and 20 healthy subjects while performing 3 elevation tasks: scaption, wall slide and elevation with external rotation. Possible differences between the groups were studied with a linear mixed model (factor "group" and "exercise").

Results: For the Pm only, a significant main effect for "Group" was found: during the elevation tasks, the Pm was significantly more active in the SIS group in comparison with the healthy controls.

Conclusion: Patients with SIS show significantly higher Pm activity during elevation tasks in comparison with healthy controls. This study supports the idea of a possible role of the Pm in SIS.

INTRODUCTION

The scapula plays an important role in the function of the shoulder. During humeral elevation of the arm, a complex scapular movement of upward rotation, posterior tilt and external rotation is needed to create a stable base for the glenohumeral joint (Kibler and McMullen, 2003). The quality of this scapular movement depends on the coordinated activity of the surrounding superficial (Trapezius and Serratus anterior (SA)) and the deeper lying scapulothoracic muscles, such as Pectoralis minor (Pm), Levator Scapulae (LS) and Rhomboid Major (RM). A lack of activation or excessive activation of scapulothoracic muscles may impede optimal scapular movement. Hypothetically, excessive activation of the deeper lying muscles (Pm, LS and RM) may impede the warranted scapular movement that is necessary during humeral elevation. The LS is believed to elevate the scapula and to work together with the Rhomboids to retract and rotate the scapula downwards (Escamilla et al., 2009). The Pm is believed to move the scapula to protraction, downward rotation, anterior tilt and internal rotation (Oatis, 2004). Normal upward rotation may be influenced by excessive activation or tension in the LS or RM (Behrsin and Maguire, 1986). Also, excessive activation of the Pm muscle may hinder normal posterior scapular tipping that is necessary during humeral elevation (Borstad and Ludewig, 2005). A lack of upward rotation and anterior tilting during elevation of the arm has been related to shoulder impingement syndrome (SIS) (Ludewig and Cook, 2000, Struyf et al., 2011, Timmons et al., 2012). The term shoulder impingement was first introduced by Neer (1972), who described the phenomenon as a mechanical compression of the subacromial structures against the anterior undersurface of the acromion and coracoacromial ligament. In more recent literature, impingement has been described as a group of symptoms rather than a specific diagnosis, and has been considered to be an umbrella of a variety of shoulder conditions (Lewis, 2009). The SIS symptoms are mostly present when the arm is elevated or when overhead activities are performed (Hung et al., 2010, Michener et al., 2004). To date, most studies that have investigated scapulothoracic muscle activity in patients with SIS have focused on the Trapezius and SA (Bandholm et al., 2006, Cools et al., 2007a, Cools et al., 2004, Diederichsen et al., 2009, Lin et al., 2011, Ludewig and Cook, 2000, Moraes et al., 2008, Roy et al., 2008, Santos et al., 2007). No studies exist that investigate the scapulothoracic activity of the smaller and less superficial muscles that attach to the scapula (such as the Pm, the LS and RM) in a population with shoulder pain, despite the hypothesized importance of these muscles in shoulder function (Cagnie et al., 2014, Cools et al., 2014). Information from EMG studies on the activity of the superficial muscles in patients with shoulder pain (Cools et al., 2007b, Ellenbecker and Cools, 2010, Ludewig and Cook, 2000, Reinold et al., 2009) has been a basis for recommendations for the choice of exercises during treatment for patients with shoulder symptoms related to scapulothoracic dysfunction. It is believed that performing exercises which address the appropriate muscles can improve the quality of the scapular movement and restore “normal” movement patterns. Although it is very important to know if patients with impingement symptoms show different activity of the deeper lying muscles, it has never been a topic of investigation. The activity of the deeper lying muscles has been studied by Castelein et al. (2016) during different commonly used rehabilitation exercises (scaption, towel wall slide, elevation with external rotation), showing different muscle activity patterns based on the specific modality of the exercise, however these investigations were performed on healthy subjects without shoulder pain. It would be interesting to know if patients with SIS would show differences during the performance of these elevation tasks, often used in clinical practice (Castelein et al., 2016). Therefore, the objective of this study was to investigate whether the activity of the deeper lying (in particular LS, Pm and RM) and superficial lying muscles is different in a population with SIS compared to a healthy control group during various elevation tasks. This knowledge will aid clinicians in developing more targeted rehabilitation exercises.

MATERIALS AND METHODS

Subjects

Two groups of subjects were recruited: a group with shoulder impingement syndrome (SIS group, n=17) and a matched control group without symptoms (healthy control group, n=20). Subjects were recruited via advertisement from the local community and university. Written informed consent was obtained from all participants. The study was approved by the ethics committee of Ghent University Hospital. SIS was determined by history taking and confirmed by physical examination performed by an experienced musculoskeletal physical therapist. Patients were included in the SIS group if they reported chronic shoulder pain (>1 month during the last year) in the anterior deltoid region of their dominant shoulder and if at least 3 of the following criteria were positive: (1) Positive Neer sign, (2) Positive Hawkins sign, (3) Positive Jobe’s sign, (4) Painful Arc, and (5) Positive Resistance Test against External Rotation (Michener et al. , 2009). Their pain had to have a minimum intensity of 3/10 on the Numeric Rating Scale. Subjects had to be able to perform full ROM of humeral elevation in the scapular plane and this was tested by the investigator before the start of the study. Exclusion criteria were shoulder surgery or dislocation, loss of ROM, positive spurling test, >2 cortisone injections, one cortisone injections within the last month, systemic diseases, current symptoms in the neck region, total rotator cuff rupture and upper limb training or overhead sports > 6h/week.

General design

EMG data was collected from 5 scapulothoracic muscles (Trapezius (UT, MT, LT), SA, LS, Pm, RM) on the dominant side of each subject during the performance of 3 different humeral elevation tasks in the scapular plane (Castelein et al., 2016) : (1) scaption (elevation in the scapular plane), (2) towel wall slide and (3) elevation with external rotation component (with resistance from a Theraband®).

Test Procedure

The experimental session began with a short warm-up procedure with multidirectional shoulder movements, followed by the performance of a set of five the maximum voluntary isometric contractions (MVIC) of the muscles of interest (Castelein et al., 2015), including:

1. "Abduction 90°" (sitting)
2. "Horizontal Abduction with external rotation" (prone lying)
3. "Arm raised above head in line with LT muscle fibers" (prone lying)
4. "Shoulder flexion 135°" (sitting)
5. "Arm raised above head in line with Pm muscle fibers" (supine lying)

MVIC test positions were taught to each subject by the same investigator, and sufficient practice was allowed before real data collection. Manual pressure was always applied by the same investigator and strong and consistent verbal encouragement from the investigator was given during each MVIC to promote maximal effort. All MVICs were performed prior to the different elevation exercises, except for the MVIC "Arm raised above head in line with Pm muscle fibers". This MVIC was always performed at the end (after the exercises) to avoid pressure on the electrodes of the dorsal muscles (due to their contact with the examination table because of the supine position). Each MVIC test position was performed 3 times (each contraction lasted for 5 seconds-controlled by a metronome) with at least 30 seconds rest between the different repetitions. There was a rest period of at least 1.5 minute between the different test positions.

In the second part of the investigation, the subject performed three elevation tasks: (1) elevation in the scapular plane, (2) towel slide against a wall and (3) elevation with external rotation of a Theraband® (Figure 1-3). The tasks were performed in random order (simple randomization: envelopes containing the name of each exercise were shuffled for each participant and this sequence of exercises was allocated to that participant). Before data collection, the subject was given a visual demonstration of each task by the investigator. Each task consisted of an elevation phase of 4s and a lowering phase of 4s. For the task with the Theraband®, 2s were added to induce tension and remove tension on the Theraband® before and after the elevation exercise. Only the influence during the elevation phase of this Theraband® (and not the tension of the glenohumeral external rotation position) on scapulothoracic muscle activity was of interest. A metronome was used to control and standardize the speed of the movement. When the participants were able to perform the proper movement pattern and timing of the exercise, EMG data was collected from five repetitions of each exercise with 5s of rest in between each trial. Between each exercise set, a break of 1,5 minutes was provided. Pain severity was asked during the performance of each of the elevation tasks (0: no pain – 10: worst possible pain).

Figures

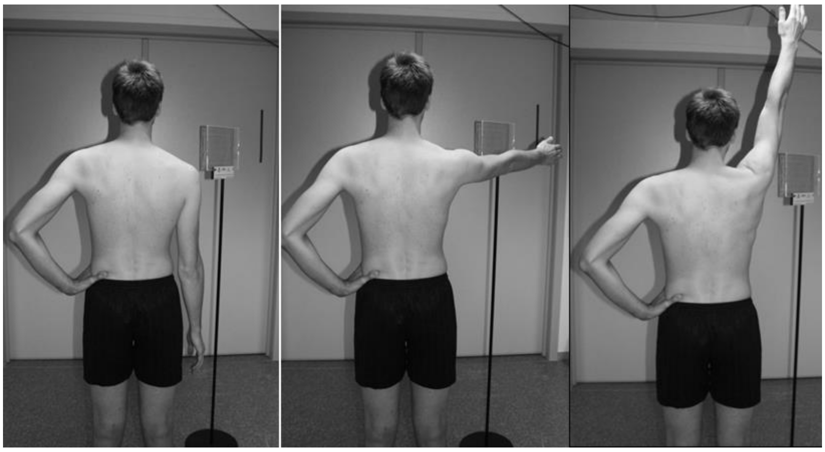


FIGURE 1. Scaption. The subject performed elevation (full range of motion) with the dominant arm (thumb up) in the scapular plane (30°). A pole was used to guide the early phase of elevation in the scapular plane.

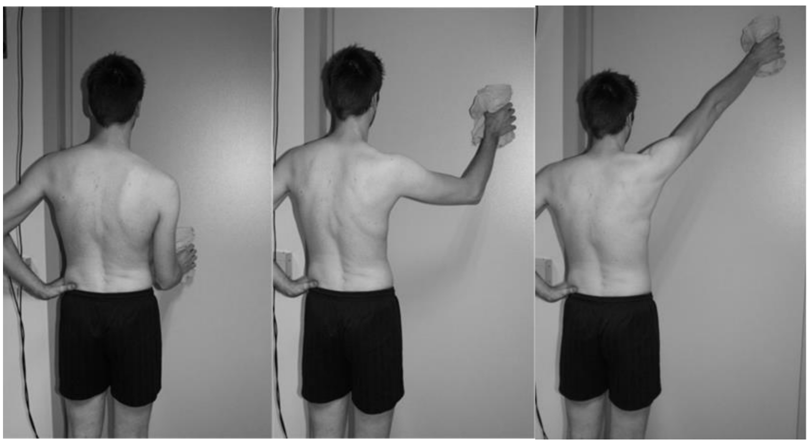


FIGURE 2. Towel Wall Slide. For the starting position, the subject held a towel in the hand and put the hand against the wall with the elbow flexed 90°. The subject moved the towel up by sliding the arm against the wall until elbow was fully extended. This was performed in the scapular plane (30°). The distance between the wall and the subject was determined by the length of the forearm with the elbow in ninety degrees of flexion.

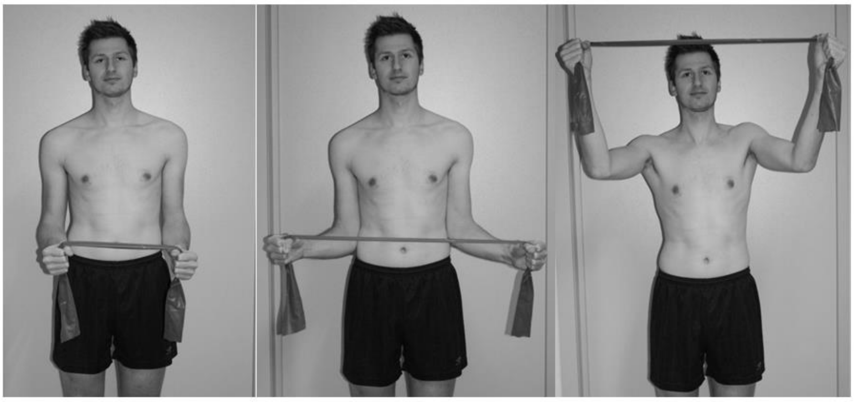


FIGURE 3. Bilateral elevation with external rotation by holding a Theraband®. The subject took the Theraband® (colour red was chosen to give a "medium" resistance) in both hands on two spots that the investigators marked on the Theraband®. The subject flexed the elbows 90° with the shoulder in a neutral position. The Theraband® was then brought to tension with 30° of external rotation in which the wrists remained in the neutral position. From this position an elevation of both arms was carried out up to 90° in the scapular plane while holding the tension of the Theraband®.

Instrumentation

A TeleMyo 2400 G2 Telemetry System (Noraxon Inc., Scottsdale, AZ) was used to collect the EMG data. This study used a combination of surface and intramuscular electrodes. Bipolar circular surface electrodes (Ag/AgCl, Ambu ® Blue Sensor P, Type N-00-S 30x22mm, Ballerup, Denmark) were placed with a 1cm interelectrode distance over the UT, LT and MT, according to the to the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) Project Recommendations (Hermens et al., 1999). Electrodes for the SA were applied longitudinal (on the part where the muscle is most superficial): the first electrode anterior to the Latissimus Dorsi and the second electrode posterior to the Pectoralis Major (caudal from the axilla) (Decker et al. , 1999, Lear and Gross, 1998, Ludewig et al., 2004, Maenhout et al., 2010). A reference electrode was placed over the processus spinosus of C7 vertebrae. Before surface electrode application, the skin surface was shaved, cleaned and scrubbed with alcohol to reduce impedance (<10kOhm). Intramuscular fine-wire electrodes were used to measure the EMG activity of the LS, Pm and the RM. The paired hook fine-wire electrodes (Carefusion Middleton, WI, USA – wire length 125mm, stainless steel, insulated nickel alloy wire, first wire stripped 2mm, second wire insulated for 3mm and then stripped 2mm) were inserted into the muscle belly according to the locations described by Delagi et al.(1994) using a single-use 25-gauge hypodermic needle. This was done using real-time ultrasound guidance, which has been shown to be an accurate and repeatable method of intramuscular electrode placement (Hodges et al., 1997). The surface and intramuscular electrodes were looped and taped on the skin to prevent them from being accidentally removed during the experiment and to minimize movement artifacts. The sampling rate was 3000 Hz. The device had a common mode rejection ratio of 100dB. Gain was set at 1000 (baseline noise <1 µV root-mean-square (RMS)).

Signal Processing and Data Analysis

The Myoresearch 3.4 Master Edition Software Program was used for signal processing. The EMG signals were filtered with a high pass Butterworth filter of 20Hz. Cardiac artifact reduction was performed, followed by full wave rectification and smoothing (root mean square, window 100ms) of the signals. The windows of data were determined based on markers that were manually placed by the investigator during the testing. An average EMG value for each muscle and each participant was calculated for each exercise (average value for the whole movement (concentric plus eccentric phase)). This average value was taken from the 3 intermediate repetitions, because the first and fifth repetitions were not used to control for distortion due to habituation or fatigue. These average EMG data were normalized and expressed as a percentage of their MVIC. For each MVIC, the average EMG value over a window of the peak 2.5 s of the 5s was calculated. The average of the 3 trials was used for normalization (Cools et al., 2007a, De Ridder et al., 2013, Maenhout et al., 2010, Stevens et al., 2007). All five MVIC test positions were analyzed for each muscle (except the Pm activity was not analyzed during prone lying MVIC test positions and the other muscles' activity was not analyzed during supine lying MVIC test positions). The normalization value (100%) was the highest value for that muscle recorded during the 5 MVIC tests.

Statistical analysis

SPSS 22.0 was used for statistical analysis. Means ± standard deviations were calculated for the normalized EMG values (in % of MVIC) of the UT, MT, LT, SA, Pm, LS & RM for each exercise (over the whole movement) and for each group. For each muscle, a linear mixed model with 2 factors was performed: factor "exercise" (3 levels) and factor "group" (2 levels). The residuals of the linear mixed models were checked for normal distribution. Post hoc pairwise comparisons were performed using a Bonferroni correction. Only an interaction effect of "exercise X group" or a main effect of "group" was further interpreted. As we were only interested in the differences between groups, the main effect for the factor "exercise" was not further interpreted. An alpha level of 0.05 was applied to all the data in determining significant differences.

RESULTS

Demographic characteristics of the participants

Thirty-seven female subjects were recruited. The SIS group consisted of 17 participants and the healthy control group of 20 participants. Table 1 shows the demographic characteristics of the participants. There were no significant differences in anthropometric data between the SIS group and the control group (independent sample t-test).

	SIS group (n=17)	**Control group (n=20)**
Height, cm	167.4 ± 6.1	170.1 ± 5.9
Weight, cm	65.7 ± 9.4	62.9 ± 7.1
Age, y	30.1 ± 10.3	28.9 ± 11.5

TABLE 1. Demographic characteristics of the participants. Values are expressed as means ± standard deviation.

Pain intensity reported by the patients with SIS during each of the elevation tasks

The Numeric Rating Score (mean ± SD), reported by the patients with SIS, for pain during "Scaption" was 1,25 ± 1,76, for "Towel wall slide" 1,18 ± 1,40 and for "Elevation with external rotation component" 2,6 ± 1,86.

EMG results

The mean EMG activity of each scapulothoracic muscle for both groups during the "Elevation tasks" is provided in Table 2. No significant "Exercise X Group" interaction was found. For the Pm only, a significant main effect for "Group" (F =5,357 ; p= 0,023) was found. Post hoc analysis revealed that during the elevation tasks, the Pm was significantly more active in the SIS group in comparison with the healthy control group.

Muscle	Population	Scaption	Towel wall slide	Elevation with external rotation	P-value
UT	**Healthy controls**	17,7 ± 5,5	14,2 ± 4,6	12,3 ± 4,1	Exercise X Group NS
	SIS patients	18,7 ± 7,0	14,0 ± 6,5	12,0 ± 8,6	Group NS
	Mean Group Difference (SIS-healthy)	1,00 ± 2,00 (CI:-2,98 / 4,99)	-0,20 ±2,01 (CI:-4,18 / 3,78)	-0,23 ±2,04 (CI:-4,38 / 3,81)	
MT	**Healthy controls**	11,1 ± 4,5	7,4 ± 5,7	21,0 ± 11,9	Exercise X Group NS
	SIS patients	13,9 ± 8,9	7,5 ± 4,8	24,8 ± 11,5	Group NS
	Mean Group Difference (SIS-healthy)	2,86 ± 2,86 (CI:-2,82/ 8,55)	0,10 ± 2,81 (CI:-5,48 / 5,68)	3,81 ± 2,81 (CI:-1,78 / 9,39)	
LT	**Healthy controls**	15,7 ± 5,3	9,1 ± 4,4	29,3 ± 11,6	Exercise X Group NS
	SIS patients	15,6 ± 7,0	8,4 ± 4,7	27,0 ± 11,3	Group NS
	Mean Group Difference (SIS-healthy)	-0,11 ± 2,60 (CI: -5,26 / 5,05)	-0,61 ± 2,60 (CI: -5,77/ 4,55)	-2,29 ± 2,65 (CI: -7,54 / 2,96)	
SA	**Healthy controls**	28,7 ± 14,5	26,8 ± 11,9	20,8 ± 9,0	Exercise X Group NS
	SIS patients	25,7 ± 9,5	25,3 ± 11,0	19,2 ± 5,2	Group NS
	Mean Group Difference (SIS-healthy)	-2,99 ± 3,55 (CI:-10,0 / 4,04)	-1,52 ± 3,55 (CI: -8,55/ 5,51)	-1,62 ± 3,65 (CI: -8,86 / 5,61)	
Pm	**Healthy controls**	9,9 ± 7,6	12,3 ± 9,6	9,0 ± 7,6	Exercise X Group NS
	SIS patients	13,0 ± 8,4	17,5 ± 12,0	12,8 ± 7,5	Group P=0,023*
	Mean Group Difference (SIS-healthy)	3,09 ± 3,00 (CI: -2,86 / 9,04)	5,21 ± 2,95 (CI: -0,65/ 11,1)	3,8 ± 3,2 (CI: -2,35 / 10,0)	*Overall Mean Group difference: -4,04 ± 1,75 CI: 0,577 / 7,503
LS	**Healthy controls**	17,1 ± 11,0	13,7 ± 9,7	22,1 ± 17,4	Exercise X Group NS
	SIS patients	18,1 ± 12,0	13,3 ± 7,2	24,7 ± 17,4	Group NS
	Mean Group Difference (SIS-healthy)	0,99 ± 4,4 (CI: -7,70 / 9,57)	-0,40 ± 4,38 (CI: -9,09 / 8,27)	2,62 ± 4,38 (CI: -6,06 / 11,3)	
RM	**Healthy controls**	26,0 ± 17,8	10,9 ± 4,6	31,3 ± 14,0	Exercise X Group NS
	SIS patients	25,3 ± 14,6	11,0 ± 9,2	31,1 ± 18,4	Group NS
	Mean Group Difference (SIS-healthy)	-0,70 ± 4,67 (CI: -9,97 ± 8,6)	0,07 ± 4,81 (CI: -9,47 / 9,61)	-0,23 ± 4,75 (CI: -9,66 / 9,19)	

TABLE 2. EMG activity (%MVIC ± standard deviation) of each scapulothoracic muscle in each group (healthy controls versus SIS patients) during the various “Elevation Tasks”. The significance level of the p-value is also displayed.

* UT= Upper Trapezius, MT= Middle Trapezius, LT= Lower Trapezius, SA = Serratus Anterior, Pm = Pectoralis Minor, LS = Levator Scapulae, RM = Rhomboid Major, NS = nonsignificant p-value, CI = 95% Confidence Interval for Difference (CI: Lower bound/Upper bound), significant difference if p<0,05

DISCUSSION

The aim of the current study was to investigate if a population with SIS showed differences in deeper and superficial lying scapulothoracic muscle activity in comparison with a healthy control group during different arm elevation tasks. This is the first study that investigated the deeper lying scapulothoracic muscle activity in a population with SIS. The EMG data showed significantly higher Pm activity during all elevation tasks in the population with SIS. For the other deeper lying

(RM and LS) and for the superficial lying scapulothoracic muscles no significant differences were found between the two groups during these specific movement tasks.

This is the first study investigating Pm activity in patients with shoulder pain, so no other data exist to compare our results with. Despite this lack of science based information of Pm activity in patients with shoulder pain, several authors have already suggested the important role of the Pm in shoulder pain. Studies that have suggested the role of Pm in patients with shoulder pain focused on shortening and tension of the Pm (Borstad, 2008, Borstad and Ludewig, 2005, 2006, Muraki et al., 2009). A shortened Pm may have influence on the position of the scapula. As the function of the Pm is to perform scapular protraction, downward rotation and anterior tilting, this muscle is passively lengthened during elevation of the arm as the scapula goes into upward, posterior tilt and external rotation of the scapula (Borstad, 2006, Borstad and Ludewig, 2005, 2006, Muraki et al., 2009). When Pm lacks extensibility, it can lead to a decrease in scapular upward rotation and an increase in scapular anterior tilting and internal rotation (Borstad, 2008, Borstad and Ludewig, 2005, Muraki et al., 2009), which can lead to a reduction of the subacromial space and has been linked to impingement symptoms (Borstad and Ludewig, 2005, Tate et al., 2012). These current results of higher activity of Pm during elevation of the arm in patients with SIS (mean difference with control group: 4,04 ± 1,7 % MVIC, CI [0,577 – 7,50]) might gain insight into the relationship between the Pm and SIS. It is speculated that repetitive overuse of the Pm may result in adaptive shortening and tension and can lead to a malaligned scapula as it pulls the scapula anteriorly. However, the cause-consequence relationship between the activity of Pm and impingement symptoms still remains unclear.

In the current study, no differences were found in LS and RM activity between patients with SIS and healthy controls. No other studies have investigated LS or RM activity in patients with shoulder pain, so no data exist to compare our results with. Hypothetically, overuse of these muscles during elevation could lead to downward rotation/diminished upward rotation of the scapula and a higher risk to impinge the subacromial structures. Nevertheless, the results of this study do not support this hypothesis. Future research should further investigate the role of these muscles in relation to shoulder pain. For superficial muscle activity (Trapezius and SA), no differences were found between the two groups during elevation exercises. Several studies have already investigated the superficial scapulothoracic muscle activity in patients with SIS during elevation exercises (Bandholm et al., 2006, Lin et al., 2011, Ludewig and Cook, 2000, Roy et al., 2008). Our results were similar to the results of Bandholm et al.(2006) and Roy et al.(2008). Bandholm et al.(2006) did not find differences in UT, LT and SA EMG activity between 9 patients with SIS and 9 healthy controls during isometric elevation. Similar, Roy et al.(2008) did not find differences in Trapezius and SA activity between 33 individuals with SIS and 20 healthy individuals while reaching towards targets located at 90° of arm elevation in frontal and scapular plane. In contrast with these results, two other studies (Lin et al., 2011, Ludewig and Cook, 2000) showed differences in scapulothoracic EMG activity between patients with SIS and healthy controls during elevation. Lin et al. (2011) measured the UT, LT and SA activity in 14 overhead athletes with SIS (7 athletes and 7 students) and 7 overhead-playing controls during elevation in the scapular plane. They showed higher UT activity in the 7 SIS overhead athletes in comparison with the controls. Lower LT and SA activity were found in both athletes and students with SIS in comparison with the control group. However, Lin et al. (2011) evaluated overhead athletes, whereas our study excluded overhead athletes (>6h/ week overhead sports), so comparison is rather difficult. Ludewig and Cook (2000) investigated UT, LT and SA activity in 26 overhead workers with SIS and 26 overhead workers without complaints during humeral elevation in the scapular plane under 3 conditions: (1) no load, (2) 2.3 kg load, and (3) 4.6 kg load and in 3 phases of motion (31°-60°, 61°-90° and 91°- 120°). UT EMG activity was higher in patients with SIS, but only during the final 2 phases in the 4.6-kg load condition. LT EMG activity was increased in the group with SIS as compared with the group without SIS in the final 2 phases. The SA muscle demonstrated decreased activity in the group with impingement across all loads and phases. Methodological aspects related to the tasks (plane of elevation, degrees of elevation, load, etc.), different normalization procedures and inclusion criteria of the population could explain these differences across studies.

Some limitations have to be taken into account when interpreting the results of this study. Our EMG data were normalized to data of the MVICs. Discomfort or pain might have interfered with the ability to produce an MVIC. However, for normalization, we used the highest value of EMG activity for that muscle out of a set of 5 MVICs (Castelein et al., 2015). We believe that this set, rather than one MVIC for one muscle limits the role of pain as substantial confounding factor on the EMG results. In addition, discomfort or pain during the performance of the exercises might also have interfered with activity levels and patterns. Nevertheless, relative low levels of pain were reported during the performance of the exercises. Moreover, exercises were randomized to avoid the influence of exacerbation of pain upon the EMG activity. The fact that the sample size, needed for this study, was not calculated a priori is also a limitation of this study. Nevertheless, a post-hoc power calculation analysis (GPower ®) revealed a power of 0.9992285 (with the EMG data from the Pm), which is very good. While this study provided useful information regarding the muscles being activated during various exercises, it did not provide synchronized 3D scapular kinematic analysis with the EMG signal. Investigating scapular movements, along with muscle activity during exercises, would provide additional information. Another limitation of this study is the inter-subject variability of patterns of activity as well as levels of activity that might have occurred during the performance of the different exercises. However, an attempt was made to mimic the clinical situation therefore variation of the tasks without additional feedback equipment were controlled using good explanation, good demonstration and personal feedback. Also, prospective clinical studies are needed to determine whether rehabilitation programs that pay attention to the Pm are more effective than the current standard methods of care.

CONCLUSION

This study supports the idea of a possible role of the Pm in patients with SIS. Significantly higher Pm activity was found in patients with SIS compared to healthy controls during all elevation tasks. For the other scapulothoracic muscles (UT, MT, LT, SA, LS and RM) no significant differences were found between the two groups. The results of this study enhance the insight in scapulothoracic muscle dysfunction.

REFERENCES

Bandholm T, Rasmussen L, Aagaard P, Jensen BR, Diederichsen L. Force steadiness, muscle activity, and maximal muscle strength in subjects with subacromial impingement syndrome. Muscle & nerve. 2006;34:631-9.

Behrsin JF, Maguire K. Levator Scapulae Action during Shoulder Movement: A Possible Mechanism for Shoulder Pain of Cervical Origin. The Australian journal of physiotherapy. 1986;32:101-6.

Borstad JD. Resting position variables at the shoulder: evidence to support a posture-impairment association. Physical therapy. 2006;86:549-57.

Borstad JD. Measurement of pectoralis minor muscle length: validation and clinical application. The Journal of orthopaedic and sports physical therapy. 2008;38:169-74.

Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. The Journal of orthopaedic and sports physical therapy. 2005;35:227-38.

Borstad JD, Ludewig PM. Comparison of three stretches for the pectoralis minor muscle. Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons [et al]. 2006;15:324-30.

Oatis. Kinesiology: the mechanics and pathomechanics of human movement. Lippincott: Williams & Wilkins. . 2004.

Cagnie B, Struyf F, Cools A, Castelein B, Danneels L, O'Leary S. The relevance of scapular dysfunction in neck pain: a brief commentary. The Journal of orthopaedic and sports physical therapy. 2014;44:435-9.

Castelein B, Cagnie B, Parlevliet T, Cools A. Superficial and deep scapulothoracic muscle EMG during different types of elevation exercises in the scapular plane. The Journal of orthopaedic and sports physical therapy. 2016; 46(3): 184-193.

Castelein B, Cagnie B, Parlevliet T, Danneels L, Cools A. Optimal normalization tests for muscle activation of the Levator Scapulae, Pectoralis Minor and Rhomboid Major: an electromyography study using Maximum Voluntary Isometric Contractions. Archives of physical medicine and rehabilitation. 2015; 96(10):1820-7.

Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scandinavian journal of medicine & science in sports. 2007a;17:25-33.

Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B, et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? The American journal of sports medicine. 2007b;35:1744-51.

Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. British journal of sports medicine. 2014;48:692-7.

Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. British journal of sports medicine. 2004;38:64-8.

De Ridder EM, Van Oosterwijck JO, Vleeming A, Vanderstraeten GG, Danneels LA. Posterior muscle chain activity during various extension exercises: an observational study. BMC Musculoskelet Disord. 2013;14:204.

Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. The American journal of sports medicine. 1999;27:784-91.

Delagi EF I J, Perpotto, A., & Morrison, D. . Anatomical guide for the electromyographer. The limbs and Trunck. Spingfield: Charles C Thomas Publisher. 1994.

Diederichsen LP, Norregaard J, Dyhre-Poulsen P, Winther A, Tufekovic G, Bandholm T, et al. The activity pattern of shoulder muscles in subjects with and without subacromial impingement. Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology. 2009;19:789-99.

Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. British journal of sports medicine. 2010;44:319-27.

Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. Sports medicine (Auckland, NZ). 2009;39:663-85.

Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, Rau G, et al. European recommendations for surface electromyography. Roessingh Research and Development1999.

Hodges PW, Kippers V, Richardson CA. Validation of a technique for accurate fine-wire electrode placement into posterior gluteus medius using real-time ultrasound guidance. Electromyography and clinical neurophysiology. 1997;37:39-47.

Hung CJ, Jan MH, Lin YF, Wang TQ, Lin JJ. Scapular kinematics and impairment features for classifying patients with subacromial impingement syndrome. Manual therapy. 2010;15:547-51.

Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. The Journal of the American Academy of Orthopaedic Surgeons. 2003;11:142-51.

Lear LJ, Gross MT. An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. The Journal of orthopaedic and sports physical therapy. 1998;28:146-57.

Lewis JS. Rotator cuff tendinopathy/subacromial impingement syndrome: is it time for a new method of assessment? British journal of sports medicine. 2009;43:259-64.

Lin JJ, Hsieh SC, Cheng WC, Chen WC, Lai Y. Adaptive patterns of movement during arm elevation test in patients with shoulder impingement syndrome. Journal of orthopaedic research : official publication of the Orthopaedic Research Society. 2011;29:653-7.

Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Physical therapy. 2000;80:276-91.

Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. The American journal of sports medicine. 2004;32:484-93.

Maenhout A, Van Praet K, Pizzi L, Van Herzeele M, Cools A. Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity? British journal of sports medicine. 2010;44:1010-5.

Michener LA, Walsworth MK, Burnet EN. Effectiveness of rehabilitation for patients with subacromial impingement syndrome: a systematic review. Journal of hand therapy : official journal of the American Society of Hand Therapists. 2004;17:152-64.

Michener LA, Walsworth MK, Doukas WC, Murphy KP. Reliability and diagnostic accuracy of 5 physical examination tests and combination of tests for subacromial impingement. Archives of physical medicine and rehabilitation. 2009;90:1898-903.

Moraes GF, Faria CD, Teixeira-Salmela LF. Scapular muscle recruitment patterns and isokinetic strength ratios of the shoulder rotator muscles in individuals with and without impingement syndrome. Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons [et al]. 2008;17:48S-53S.

Muraki T, Aoki M, Izumi T, Fujii M, Hidaka E, Miyamoto S. Lengthening of the pectoralis minor muscle during passive shoulder motions and stretching techniques: a cadaveric biomechanical study. Physical therapy. 2009;89:333-41.

Neer CS, 2nd. Anterior acromioplasty for the chronic impingement syndrome in the shoulder. 1972. The Journal of bone and joint surgery American volume. 2005;87:1399.

Reinold MM, Escamilla RF, Wilk KE. Current concepts in the scientific and clinical rationale behind exercises for glenohumeral and scapulothoracic musculature. The Journal of orthopaedic and sports physical therapy. 2009;39:105-17.
Roy JS, Moffet H, McFadyen BJ. Upper limb motor strategies in persons with and without shoulder impingement syndrome across different speeds of movement. Clinical biomechanics (Bristol, Avon). 2008;23:1227-36.
Santos MJ, Belangero WD, Almeida GL. The effect of joint instability on latency and recruitment order of the shoulder muscles. Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology. 2007;17:167-75.
Stevens VK, Vleeming A, Bouche KG, Mahieu NN, Vanderstraeten GG, Danneels LA. Electromyographic activity of trunk and hip muscles during stabilization exercises in four-point kneeling in healthy volunteers. Eur Spine J. 2007;16:711-8.
Struyf F, Nijs J, Baeyens JP, Mottram S, Meeusen R. Scapular positioning and movement in unimpaired shoulders, shoulder impingement syndrome, and glenohumeral instability. Scandinavian journal of medicine & science in sports. 2011;21:352-8.
Tate A, Turner GN, Knab SE, Jorgensen C, Strittmatter A, Michener LA. Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. Journal of athletic training. 2012;47:149-58.
Timmons MK, Thigpen CA, Seitz AL, Karduna AR, Arnold BL, Michener LA. Scapular kinematics and subacromial-impingement syndrome: a meta-analysis. Journal of sport rehabilitation. 2012;21:35470.

CHAPTER 3:

ANALYSIS OF SCAPULAR MUSCLE EMG ACTIVITY IN PATIENTS WITH IDIOPATHIC NECK PAIN: A SYSTEMATIC REVIEW.

BIRGIT CASTELEIN, PT[1]; ANN COOLS, PT, PHD[1]; EMMA BOSTYN, PT[1]; JOLIEN DELEMARRE, PT[1]; TREES LEMAHIEU, PT[1]; BARBARA CAGNIE, PT, PHD[1]

[1] DEPARTMENT OF REHABILITATION SCIENCES AND PHYSIOTHERAPY, GHENT UNIVERSITY, GHENT, BELGIUM

JOURNAL OF ELECTROMYOGRAPHY AND KINESIOLOGY. 2015 APR; 25(2):371-86.

(SCI=1.647, Q2)

ABSTRACT

It is proposed that altered scapular muscle function can contribute to abnormal loading of the cervical spine. However, it is not clear if patients with idiopathic neck pain show altered activity of the scapular muscles. The aim of this paper was to systematically review the literature regarding the differences or similarities in scapular muscle activity, measured by electromyography (= EMG), between patients with chronic idiopathic neck pain compared to pain-free controls. Case-control (neck pain/healthy) studies investigating scapular muscle EMG activity (amplitude, timing and fatigue parameters) were searched in Pubmed and Web of Science. Twenty-five articles were included in the systematic review. During rest and activities below shoulder height, no clear differences in mean Upper Trapezius (= UT) EMG activity exist between patients with idiopathic neck pain and a healthy control group. During overhead activities, no conclusion for scapular EMG amplitude can be drawn as a large variation of results were reported. Adaptation strategies during overhead tasks are not the same between studies. Only one study investigated timing of the scapular muscles and found a delayed onset and shorter duration of the SA during elevation in patients with idiopathic neck pain. For scapular muscle fatigue, no definite conclusions can be made as a wide variation and conflicting results are reported. Further high quality EMG research on scapular muscles (broader than the UT) is necessary to understand/draw conclusions on how scapular muscles react in the presence of idiopathic neck pain.

1. INTRODUCTION

Neck pain is a common complaint with a 12-month prevalence of 30–50% in the adult population (Hogg-Johnson et al., 2008). It is an important source of disability and several underlying mechanisms have been explored. A number of studies has highlighted the importance of the activity of the muscles around the neck/shoulder region. Most of these studies have focused on the cervical extensors and flexors in patients with neck pain (Cagnie et al., 2010; Falla et al., 2004b; Falla et al., 2004c; Nederhand et al., 2000; O'Leary et al., 2011). These studies have indicated that altered behavior between different muscle layers and between muscles of the upper and lower cervical regions may exist in patients with neck pain compared to healthy controls.

However, there is increasing research indicating that there is a broader involvement than only the cervical musculoskeletal system in mechanical neck pain. One muscle group that has gained specific interest is the scapular muscle group. A growing body of evidence supports the theory that the function of the scapula is important in normal neck function, and might be disturbed in patients with neck pain (Cagnie et al., 2014; Cools et al., 2014). The mobility and stability of the scapula is provided by the surrounding scapular muscular system, including Trapezius (with the three different parts: Upper Trapezius (UT), Middle Trapezius (MT), Lower Trapezius (LT), the Serratus Anterior, the Levator Scapulae, the Rhomboidei and the Pectoralis Minor (Kibler et al., 2013). Scapular muscles have the dual role of orientating the scapula while simultaneously transferring loads between the upper limbs and the vertebral column, including the cervical spine (Cools et al., 2014). Disturbances in the function of the scapular muscles can result in an increase of load on the cervical spine, as both the Trapezius and the Levator Scapulae span the cervical spine (Behrsin and Maguire, 1986). Compressive loading of the cervical spine can consequently increase the intradiscal pressure and zygapophyseal joint surface, which could introduce pain. Although a lot of research has already demonstrated alterations in scapular muscle activity in patients with shoulder pain (Cools et al., 2007, 2004; Diederichsen et al., 2009; Lin et al., 2011; Ludewig and Cook, 2000; Roy et al., 2008; Struyf et al., 2014), it is not clear if consistent alterations in muscle function can be identified in the scapular region in patients with neck pain. Moreover, the current body of studies does not enable to delineate if the altered muscle function is a source or a consequence of neck pain.

Different methods exist in order to evaluate muscle function. The most commonly used method by researchers and clinicians is surface electromyography (sEMG). Parameters that can be studied by EMG are amplitude, timing, conduction velocity, fatigability and characteristic frequencies/patterns (Schulte et al., 2006).

As an overview of possible differences or similarities in scapular muscle recruitment between patients with neck pain and healthy control subjects is currently lacking, the aim of this study is to systematically review and summarize the results of scapular muscle EMG activity in patients with chronic mechanical neck pain in comparison with healthy controls without neck pain.

2. METHODS

2.1. Eligibility criteria

The search strategy was based on a combination of key words derived from the PICOS question (patients, intervention, comparison, outcome, study design). These were converted to possible Mesh-terms (between brackets) if available. The articles had to report the results of studies evaluating EMG activity of the scapular muscles (O) in patients with neck pain (P) compared to healthy controls (C). EMG outcome variables concerning amplitude, timing and fatigue were included in this review.

2.2. Information sources and search strategy

Two databases were consulted: Web of Science and MEDLINE database (PubMed). The search strategy was based on a combination of the following Mesh-terms or free-text words: (“Neck Pain” [Mesh] OR “Neck Injuries”[Mesh]) AND (“Electromyography”[Mesh] OR EMG) AND (Trapezius OR “Serratus anterior” OR “Pectoralis Minor” OR “Levator Scapulae” OR Rhomboid OR “Scapular muscles”). The search was developed by the first author. The last search was run on 26/5/2014. In addition, hand-searching was performed by looking to relevant studies that were cited in other studies.

2.3. Study selection

Selection criteria had to be fulfilled to be included in the review (see Table 1).

Inclusion criteria

(1) Concerning patients with neck pain
(2) Concerning following parameters measured by EMG:

Analysis in time domain:

Amplitude analysis: mean amplitude (Root Mean Square (RMS), Average Rectified Value (ARV))

Timing analysis: onset of muscle activity, duration of muscle activity

Analysis in frequency domain:

Spectral analysis: Mean Power Frequency (MPF), Median Power Frequency (MDF)

(3) Concerning at least one of the following scapular muscles: Trapezius (Upper, Middle or Lower Part), Serratus Anterior, Levator Scapulae, Rhomboids, Pectoralis Minor
(4) Comparison between cases and controls
(5) Full text available

Exclusion criteria

(1) Specific pathology (fibromyalgia, cancer, whiplash associated disorders)
(2) Studies concerning treatment outcome
(3) Reviews, systematic reviews or meta-analyses
(4) Articles with high risk of bias (methodological quality below 50%)

TABLE 1. Inclusion and exclusion criteria.

Eligibility assessment was performed independently in a blinded standardized manner by 2 assessors. In the first phase the selection criteria were only applied to the title and abstract. For all possible eligible studies, full texts were retrieved. In the second phase selection was based on the full text articles. If any of the selection criteria were not fulfilled, the article was excluded from the literature review.

2.4 Data items and collection process

Information was collected from each included study which is presented in an evidence table regarding: (1) characteristics of patient group (sample size, gender, pathology), (2) characteristics of control group (sample size, gender), (3) task, (4) results for analysis in time domain (amplitude and timing), (5) results for analysis in frequency domain, (6) detection parameters, (7) processing parameters and (8) information about normalization. The data were extracted independently by two assessors and were compared and merged afterwards. If no agreement could be reached, it was planned a third author would decide.

2.5 Risk of bias in individual studies

All articles were rated on methodological quality using the evidence-based guidelines "Checklist for case-control studies", provided by the Dutch Institute for Healthcare Improvement (CBO) and the Dutch Cochrane Centre. The six items that were scored were: (1) description of the patient and (2) control group, (3) exclusion of selection bias, (4) description of exposure, (5) blinded measurement of exposure and (6) confounding factors (Table 2). The assessment of the methodological quality of the research was executed by two independent assessors (BP.C. and BJ.C). The assessors reached a definitive score during a consensus meeting, resulting in a final quality score. In this review, a quality score of 3/6 or 4/6 was considered as moderate quality, whereas studies scoring 5/6 or 6/6 were qualified as high quality. Articles with a high risk of bias were excluded from the review (methodological quality <50%). Depending on methodological quality and study design, a level of evidence was determined according to the 2005 classification system of the Dutch Institute for Healthcare Improvement CBO (http://www.cbo.nl/Downloads/632/bijlage_A.pdf), independently by the 2 assessors. Finally, a strength of conclusion could be determined, based on the levels of evidence. A strength of conclusion 2 is given when there are at least two independently conducted studies of level B or one study of level A2. A strength of conclusion 3 is given when there is at least one study of level B.

2.6. Summary measures

The primary outcome was the difference in muscle activity (amplitude, timing and frequency parameters) between patients with neck pain and healthy controls.

3. RESULTS

3.1. Study selection

The screening process is presented in Fig.1. First, a total of 288 studies were identified when searching in electronic databases including Pubmed and Web of Science. In addition, 6 articles were found via hand-searching. After deduplication and the two screening phases (title/abstract and full text) 25 studies remained that met the inclusion criteria (Table 1).

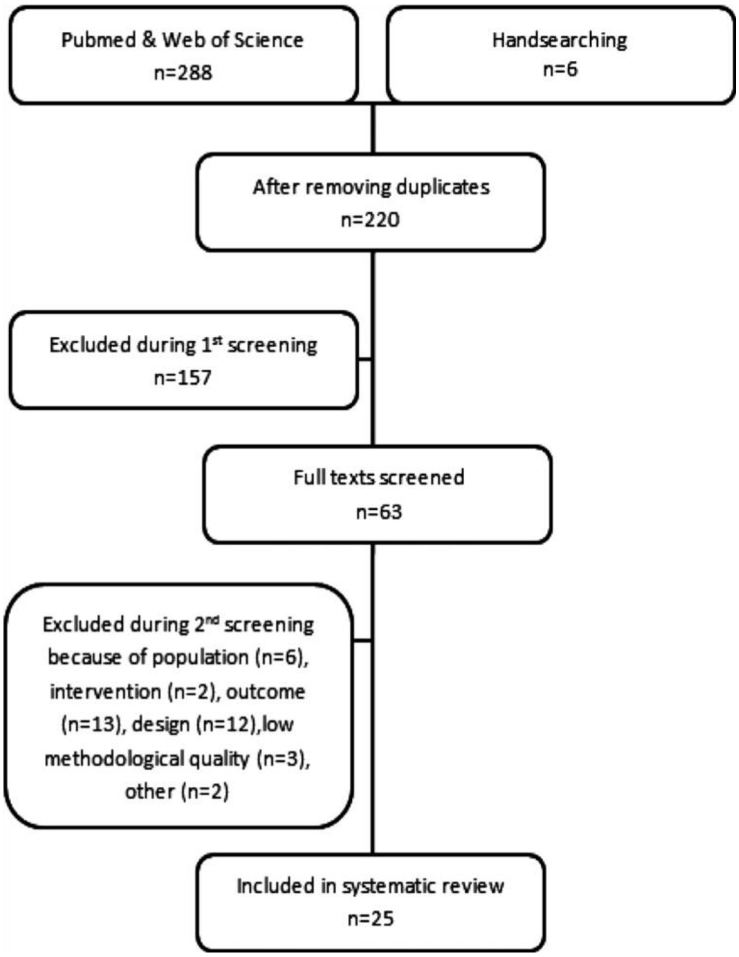


FIGURE 1. Prisma flow diagram of the conducted search.

3.2. Risk of bias and level of evidence

The risk of bias and the level of evidence of the different studies are reported in Table 2. In most cases (93.3% or 140/150 items), the two assessors agreed. During a consensus meeting, the differences were discussed and a definitive score was reached. Most studies lost points on "selection bias" and on "blinding of the study". Only one study (Nilsen et al., 2006) described that the researchers were blinded to the disease status. Others did not describe this, which is understandable given the nature of the assessment (EMG). The assessment of the level of evidence of the included studies (Table 2) showed a 100% agreement between both assessors during the consensus meeting. All studies are situated at level B (=randomized clinical trials of moderate quality or insufficient size or other comparative studies (not-randomized cohort studies, case control studies)). Out of the 25 studies, 23 studies reported results for scapular muscle EMG amplitude, 1 study reported results for scapular muscle EMG timing and 9 studies reported results for scapular muscle EMG fatigue. All 25 studies used surface EMG. Twenty-three studies investigated the EMG activity of the upper part of the Trapezius muscle and 2 studies measured the activity of the three parts of the Trapezius muscle. Not all studies measured the EMG activity during the same tasks. In general, the tasks can be divided into 3 global categories: rest conditions, activities below shoulder height and overhead activities. In addition, the modalities of the tasks differed, including duration, direction, contraction type and specific characteristics of task (analytical or functional). The number of patients varied between 7 and 85. A total of 13 studies investigated only women, whereas 12 studies focused on both men and women.

Studies	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Score	Level of evidence
Andersen et al. (2008)	+	+	+	+		+	5/6	B
Andersen et al. (2014)	+	+	+	+		+	5/6	B
Elcadi et al. (2013)	+	+	+	+		+	5/6	B
Falla et al. (2004a)	+	+		+		+	4/6	B
Falla and Farina (2005)	+	+	+	+		+	5/6	B
Goudy and McLean (2006)	+	+		+		+	5/6	B
Hallman et al. (2011)	+			+		+	3/6	B
Helgadottir et al. (2011)	+	+	+	+		+	5/6	B
Johnston et al. (2008a)	+	+		+		+	4/6	B
Johnston et al. (2008b)	+	+		+		+	4/6	B
Kallenberg et al. (2007)	+	+	+	+		+	5/6	B
Larsson et al. (1999)	+	+		+			3/6	B
Larsson et al. (2000)	+	+	+	+		+	5/6	B
Larsson et al. (2008)	+	+	+	+			4/6	B
Leonard et al. (2010)	+	+	+	+		+	5/6	B
Madeleine et al. (1999)	+	+	+	+		+	5/6	B
Nilsen et al. (2006)	+	+	+	+	+	+	6/6	B
Schulte et al. (2006)	+	+	+	+		+	5/6	B
Sjogaard et al. (2010)	+	+	+	+		+	5/6	B
Sjors et al. (2009)	+	+		+		+	4/6	B
Strom et al. (2009)	+	+	+	+			4/6	B
Takala and Viikari-Juntura (1991)	+	+	+	+		+	5/6	B
Voerman et al. (2007)	+	+	+	+		+	5/6	B
Wegner et al. (2010)	+	+		+		+	4/6	B
Zakharova-Luneva et al. (2012)	+	+		+		+	4/6	B

TABLE 2. Methodological quality of the included studies

+: Agree, : Disagree, Items 1: Are the patients clearly and adequately defined?; 2: Are the controls clearly and adequately defined?; 3: Can selection bias be sufficiently excluded?; 4: Is procedure exposure clearly defined and is the method of assessment to exposure adequate?; 5: Is the exposure blindly recorded for pathology?; 6: Are the most important confounders identified and are they taken into account in the investigation or in the analysis?

3.3. Synthesis of results

The results are reported for each EMG variable separately: EMG muscle amplitude, EMG muscle recruitment timing and EMG muscle fatigue (Table 3).

TABLE 3. Evidence table of the included studies

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Andersen et al. (2008)	42 (♀, mean age 44 ± 8yr) Office workers with clinically diagnosed chronic trapezius myalgia	20 (♀, mean age 45 ± 9yr)	Mostly office & computer workers, recruited from workplaces with monotonous work tasks	*Rest prior to the dynamometer tests *Movement tasks: Shoulder isokinetic abduction (15° from the frontal plane) at different speeds: Slow concentric contraction (60°/s) - Fast concentric contraction (180°/s) - Slow eccentric contraction (60°/s-1) - Static contraction (75°)	<u>Amplitude:</u> *Rest: $UT_{NP} = UT_{CON}$ *Movement tasks $UT_{NP} < UT_{CON}$ for slow concentric, slow eccentric & static contraction $UT_{NP} = UT_{CON}$ during fast concentric contraction		- Shielded wires to instrumental differentiation amplifiers - Bandwidth 10-500 Hz - CMRR: >100dB - SR: 1000 Hz - 16 bit A/D-converter	- Filtering using linear EMG envelopes: - Filtering HP: 10Hz - Full Wave Rectification - Filtering LP: 10 Hz (filtering: fourth-order zero phase)	No information
Andersen et al. (2014)	42 (♀, mean age 44 ± 8yr) Office workers with clinically diagnosed chronic trapezius myalgia	20 (♀, mean age 45 ± 9yr)	Mostly office & computer workers, recruited from workplaces with monotonous work tasks	*Movement task: 100 consecutive cycles of 2s isometric MVC's of shoulder elevation followed by 2s relaxation	<u>Amplitude:</u> During rest: $UT_{NP} = UT_{CON}$	MPF: During contractions: $UT_{NP} = UT_{CON}$	- preamplifiers located near the recording site - Shielded wires to instrumental differentiation amplifiers - Bandwidth 10-400Hz - CMRR: >100dB - SR: 1000 Hz - 16-bit A/D converter	- Filtering using linear EMG envelopes - Filtering HP: 10Hz - Full Wave Rectification - Filtering LP: 10 Hz (filtering: fourth-order zero phase) <u>Amplitude:</u> average value of the filtered signal <u>Spectral analysis:</u> PSD(power spectral density) of EMG signals by MPF in epochs of 1000ms Power density spectra: estimated by Welch's averaged, modified periodogram method in which each epoch was divided into eight Hamming windowed sections (50% overlap)	No

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Elcadi et al. (2013)	18 (14♀,4♂,mean age 43,4 ± 10,6yr) Pain or discomfort in the right neck-shoulder-forearm that was associated with their work, ≥ 3 months (20-65j)	17 (matched in sex, mean age 39,00 ±21,11yr)	Office workers (n=10), dental hygienists (n=5) and factory workers (n= 3)	*Movement task: Shoulder isometric elevations with the right arm at different intensities (10,30,50,70 & 100% MVC) (duration 20s with 2 min of rest between each contraction)	<u>Amplitude:</u> $UT_{NP} = UT_{CON}$	MPF: $UT_{NP} = UT_{CON}$	- Amplified (500X) - Bandpass-filtered: Second order Butterworth 10–1000 Hz) - SR: 2086 Hz - 12-bit A/D conversion	<u>Amplitude:</u> RMS (10s window) <u>Spectral analysis:</u> MPF (10s window)	Yes: MVC
Falla et al. (2004)	10 (7♀ ,3♂, mean age 33,6 ± 9,8yr) History of idiopathic neck pain, ≥ 3 months that was associated with cervical joint dysfunction	10 (5♀ ,5♂,mean age 31,4 ± 11,5yr)	No information	*Functional task: Dotting pencil marks in 3 circles in an anticlockwise direction with the right arm (dominant hand),at 88 beat/min (duration 2,5 min) the patients left forearm rested motionless on the table	<u>Amplitude:</u> $UT_{NP} < UT_{CON}$ at 10,60 and 120 seconds in the task for the right arm (not for post-exercise) $UT_{NP} = UT_{CON}$ for left arm at 10,60,120s and post-exercise		- Amplified - Bandwith filter: 10-500 Hz - SR: 1000 Hz	<u>Amplitude:</u> 1sRMS	Yes: Submaximal voluntary contraction (reference contraction: 90° arm abduction sustained for 10 seconds in standing)
Falla & Farina (2005)	19 (♀, mean age 38,1 ± 9,5yr) Chronic neck pain greater than 1 year	9 (♀, mean age 34,8 ± 8,0yr)	No information	*Functional task: Tapping the hands in a cyclic manner between targets positioned mid-thigh and 120° of shoulder flexion, to the beat of a metronome set at 88 beats/min for up to 5 min	<u>Amplitude:</u> $UT_{NP} > UT_{CON}$ for the interval 60-90% of the endurance time (it was divided into 10consecutive non-overlapping intervals, each lasting 10% of the endurance time)	iMNF estimates: $UT_{NP} < UT_{CON}$ for the interval 70-90% of the endurance time	- Amplified - Filtered (-3dB bandwidth, 10–450 Hz) - SR: 2048 Hz - AD conversion: 12bit	<u>Amplitude:</u> ARV (intervals of 250 ms) <u>Spectral analysis:</u> iMNF: (intervals of 250 ms) estimated from the Choi–Williams time-frequency representation	No information
Goudy & McLean (206)	24 (21♀, 3♂,mean age 39,8±8,4yr) Computer workers diagnosed with trapezius myalgia	27 (14♀, 13♂, mean age 37,9±8,3yr)	Computer workers	*Movement task: - Static arm-holding task with arm held in a position of 45° flexion in the scapular plane - Static arm-holding task with arm held in a position of 90° flexion in the scapular plane	<u>Amplitude:</u> Both tasks: $UT_{NP} = UT_{CON}$		- Amplified: input impedance 1 GOhm, CMRR 100 dB at 60 Hz, built in bandpass filter from 10 to 1000 Hz - SR: 2048 Hz.	<u>Amplitude:</u> RMS	Yes: MVC

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Hallman et al. (2011)	23 Trapezius myalgia	22 Matched for age and gender	No information	*Functional task: - Resting Condition - Static hand grip test (HGT) at 30% MVC - Cold pressor task (CPT)	<u>Amplitude:</u> During rest: $UT_{NP} = UT_{CON}$ During HGT & CPT: $UT_{NP} > UT_{CON}$		- SR: 2000Hz - Amplified 1000 times - LP filter: 1000Hz	Off-line: - HP FIR filter: 35Hz <u>Amplitude:</u> RMS	Yes: submaximal voluntary contraction (bilateral arm elevation in frontal plane, abducted to 90° for 15s)
Helgadottir et al. (2011)	22 (20♀,2♂, mean age 35 ± 8yr) patients with insidious onset neck pain (IONP)	23 (18♀, 5♂,mean age 30 ± 8yr matched in height, weight, age, gender and physical activity level)	No information	*Movement task : unilateral arm elevation	<u>Timing:</u> -Onset of muscle activation: Delayed onset SA_{NP} Onset $UT_{NP} = UT_{CON}$ Onset $MT_{NP} = MT_{CON}$ Onset $LT_{NP} = LT_{CON}$ -Duration of muscle activity: Less duration SA_{NP} Duration $UT_{NP} = UT_{CON}$ Duration $MT_{NP} = MT_{CON}$ Duration $LT_{NP} = LT_{CON}$		- Amplifier: input impedance 10 GOhm, CMRR 110dB - SR: 1600 Hz, after going through a BP Filter with cut-off frequency 16Hz and 482 Hz (3dB) - wireless	- HP filtering: 30Hz - Rectification - <u>Muscle Onset</u>: RMS Threshold adjusted at two standard deviations above a resting value > 50 ms - Time of muscle activation: time each muscle maintained that threshold - <u>Duration</u> : dividing the time of muscle activation by the time it took the arm to elevate and descend (between time point 1 and 2).	No

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Johnston et al. (2008)[A]	85 (♀, mean age of "no pain" 43 ± 10,6yr, "mild pain" 43,8 ± 9,4yr and "moderate pain" 45,5 ± 10,3yr) Office workers: Computer users ≥2 years (≥4 hours/day using a visual display monitor) with work-related neck pain, Formed into 3 groups based on the NDI scores (33 "no pain" NDI < 8, 38 "mild pain" NDI 9-29, 14 "moderate pain" NDI < 30)	22 (♀, mean age 37,4 ± 10,4yr) Nonworking women	Office workers: Computer users ≥2 years (≥4 hours/day using a visual display monitor)	*Functional task: -Copy-typing (5min) -Typing with superimposed stress (5min) -Color word stress task (call out the color of the print as quickly and correctly as possible) (5min) UT was measured bilaterally	Amplitude UT workers > UT con UT workers no pain = UT workers mild pain = UT workers moderate pain		- Amplified (Gain = 1,000) - BP Filter: 10-500 Hz - SR: 1000 Hz	Amplitude: 1sRMS	Yes: Submaximal voluntary contractions (reference contraction: bilateral arm abduction at 90° with the elbows straight and palms facing downwards while standing)
Johnston et al. (2008)[B]	85 (♀, mean age of "no pain" 43 ± 10,6yr, "mild pain" 43,8 ± 9,4yr and "moderate pain" 45,5 ± 10,3yr) Office workers: Computer users ≥2 years (≥4 hours/day using a visual display monitor) with work-related neck pain, Formed into 3 groups based on the NDI scores (33 "no pain" NDI < 8, 38 "mild pain" NDI 9-29, 14 "moderate pain" NDI < 30)	22 (♀, mean age 37,4 ± 10,4yr) Nonworking women	Office workers: Computer users ≥2 years (≥4 hours/day using a visual display monitor)	*Functional task: moving a pen with the dominant arm between 3 circles, at 88 beat/min (duration 5 min), the subject's nondominant forearm rested on the desktop motionless	Amplitude: UT workers > UT con for dominant (working) arm UT workers no pain = UT workers mild pain = UT workers moderate pain		- Amplified (Gain = 1,000) - BP Filter: 10-500 Hz - SR: 1000 Hz	Amplitude: 1sRMS	Yes : Submaximal voluntary contractions (reference contraction: bilateral arm abduction at 90° with the elbows straight and palms facing downwards while standing)

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis me Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Kallenberg et al. (2007)	10 (4♀, 6♂, mean age 36,7 ± 9,3yr) Computer work ≥ 20h/week with pain in the neck and/or shoulders, ≥30days/1year	10 (5♀, 5♂, mean age 31 ± 11,7yr) Computer work ≥ 20h/week	Computer workers	*Movement task: Shoulder elevation: stepwise-increased contractions (20,40,60,80,100N: 10s (5x)) and isometric sustained contraction (40N, 15min) followed by stepwise-increased contractions	Amplitude: During step contractions: UTNP = UT CON	MDF: *During step contraction: UTNP: increase and UT CON decrease from the first to the second step contraction *During sustained contraction: UTCON decrease & UTNP stayed constant with time	- Amplified: gain 1000 - Band Pass filter : 10-500 Hz Butterworth filter - Amplifier: input resistance 10^{12}Ohm , CMRR 78 dB, signal to noise ratio 84dB - SR: 4000 Hz - 16bit AD converter	Amplitude: RMS Spectral Analysis: MDF	No info
Larsson et al. (1999)	46 (♀, mean age 42yr) Long-lasting neck pain and work inability (predominantly unilateral pain)	20 (♀, mean age 44yr)	No information : job including elevated arms and lifting, highly repetitive manual work, stress at work, nursing staff, office job	*Movement task: Stepwise increased static elevation of the arms symmetrically in the scapular plane to subsequently 30°,60°, 90° and 135°(load for periods of 1 min each with 1 min of rest in between), repeated with a 1 kg load carried in each hand. Finally, a fatigue test was performed with straight arms elevated at 45° holding a 1kg load in each hand. (=3x10min)	Amplitude: UT NP = UT CON	MPF: UT NP < UT CON	- Pre-amplified and amplified - Filter: upper cut-off frequency : 1000Hz, lower cut-off frequency: 2 and 10Hz - 12 bits AD conversion	- Fast Fourier transform Amplitude: - 0.5s RMS Spectral analysis: - 0.5s MPF (according to Basmajian and DeLuca, 1985)	No information
Larsson et al. (2000)	25 (♀, mean age 47 ± 10yr) Cleaners suffering from chronic trapezius myalgia (>30days last year)	25 (♀, mean age 46 ± 11yr) Cleaners	Cleaners	*Movement task: 150 maximal dynamic shoulder forward flexions using an isokinetic dynamometer		MPFi (mean power frequency initially = mean of mean frequency of contractions 1-3 (Hz)) UTNP = UTCON MPFe (mean frequency endurance level: mean of mean frequency of contractions 101-150 Hz) UTNP = UTCON	- Multi-channel EMG amplifier: CMRR >100dB - 12bits AD conversion - SR: 2kHz - LP filter: 800Hz - HP filter: 16 Hz	Spectral analysis: MPF The power density spectrum was obtained, after applying a Hamming window, using the Fast Fourier Transform (FFT) technique	

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Larsson et al. (2008)	20 (♀, mean age 43,8 ± 9,8yr) Neck- and shoulder pain (current moderate to severe (>4/10) neck and uni- or bilateral shoulder pain >90 days and pain often or almost always last 30 days)(Trapezius myalgia) whose work required highly repetitive work tasks	20 (♀, mean age 45,2 ± 11,3yr)	Work that required highly repetitive work tasks (assembling of car lights and car loudspeakers, packing of food and chocolate and postal sorting)	*Functional task: Working task: During a full 8-hour workday (highly repetitive work), dominant side was recorded	<u>Amplitude:</u> $UT_{NP} = UT_{CON}$		- Digital wireless system - differential high impedance (>10 GOhm) inputs - -50 mV to +35 mV range - Bandwidth: 0–280 Hz - 16 bits A/D conversion - SR: 1000 Hz	<u>Amplitude:</u> RMS -HP Filter: 6th order digital Butterworth filters cutting off frequencies below 15 Hz. - 1 Hz wide 3rd order Butterworth notch filters centred at 50 and 100 Hz	Yes: Submaximal voluntary contraction (two brief (5-6s) static shoulder forward flexions (90°) with 2kg dumbbell)
Leonard et al. (2010)	25 (17♀ ,8♂, mean age 20,7 ± 2yr) Minimum of 2 hours of writing task in their daily activity, pain in neck and shoulder region > 1 month in the past year for which a medical advice was sought and individuals who had complained pain in the past 7 days and also on the day of testing	25 (20♀ ,5♂, mean age 21,0 ± 1,5yr)	Students that performed a minimum of 2 hours of writing task in their daily activity	*Functional task: Writing (30 minutes)	<u>Amplitude:</u> $UT_{NP} > UT_{CON}$		No information	No information	Yes: MVC
Madeleine et al. (1999)	12 (♂, mean age 47,4 ± 1,84 yr) Butchers with neck-shoulder pain, ≥ 3/12 months, with a minimum score of 3/10 VAS while performing daily work	6 (♂, mean age 43,8 ± 2,75yr)	Industrial butchers	*Functional task: Simulation of real-work situations using a knife in the fish and poultry industries (period of 3 minutes recordings = 36 cycles of 5s task) right side was measured	<u>Amplitude:</u> $UT_{NP} = UT_{con}$	MPF: $UT_{NP} >$ UT_{con}	- Pre-amplifiers : gain = 100 - Amplified: 2000 times - BP Filter: 10-400 Hz - SR: 1kHz	<u>Amplitude:</u> RMS <u>Spectral analysis:</u> MPF The power spectrum density of the EMG signal was estimated by using Welch's averaged periodogram method	Yes (30-N cutting force)

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Nilsen et al. (2006)	29 (♀, mean age 41,1 ± 11,3yr) Shoulder/neck pain >3m during last year with local tenderness or triggerpoints	35 (♀, mean age 39,7 ± 12,3yr)	No information	*Functional task: -Uninstructed rest period (5 min) : subject had to find a comfortable position with arms resting on the table in front of them -Mental stressful task (60 min): two choice reaction time test on a monitor – the subject responded by pressing one of two keys ("correct" or "wrong") with the right middle or index finger as quickly and as correct as possible -Recovery period (30 min)	Amplitude: $UT_{NP} = UT_{con}$ (for each part of the task)		- BP filter: 10-1250Hz - A/D conversion - SR: 2kHz	Amplitude: RMS (100ms running time window) Signals were stored with SR = 200Hz	No
Schulte et al. (2006)	7 (♀, mean age 49,4yr) Computer users aged more than 43 years with work-related neck-shoulder pain on the dominant side, ≥ 30 days during last 12 months, all subjects worked at least 20h per week at the computer	9 (♀, mean age 49,9 yr)	Computer users	*Movement task: 6 min sustained isometric shoulder elevation contractions against a force transducer (at 30% MVC), bilaterally	Amplitude: $UT_{NP} < UT_{con}$	MDF: $UT_{NP} = UT_{con}$	- Amplified with a gain of 3,064 - BP Filter (6–500 Hz) - SR: 2,048 Hz - 16-bit A/D converter	Amplitude: RMS - BP Filter (2nd order Butterworth filter (4-500Hz)) Spectral analysis: MDF	Yes: MVC

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Schulte et al. (2006)	7 (♀, mean age 49,4yr) Computer users aged more than 43 years with work-related neck-shoulder pain on the dominant side, ≥ 30 days during last 12 months, all subjects worked at least 20h per week at the computer	9 (♀, mean age 49,9 yr)	Computer users	*Movement task: 6 min sustained isometric shoulder elevation contractions against a force transducer (at 30% MVC), bilaterally	Amplitude: $UT_{NP} < UT_{con}$	MDF: $UT_{NP} = UT_{con}$	- Amplified with a gain of 3,064 - BP Filter (6–500 Hz) - SR: 2,048 Hz - 16-bit A/D converter	Amplitude: RMS - BP Filter (2nd order Butterworth filter (4-500Hz)) Spectral analysis: MDF	Yes: MVC
Sjogaard et al. (2010)	43 (♀, mean age 44 ± 9,8yr) Workers, aged 30-60 years with Trapezius Myalgia, pain or discomfort in the neck/shoulder region for more than 30 days during the previous year, at least once a week, with an intensity of at least 2/10	19 (♀, mean age 44 ± 9,1yr)	Recruited from seven workplaces (two banks, two post office work places, two different national administrative offices, and one industrial production unit) or via advertisements in local newspapers. The work tasks of the participants were typically monotonous and repetitive, e.g. assembly line work or office work with the majority performing computer typing.	*Functional task: -Pegboard task (PEG) (unilateral) (40min) -Stress task with a mouse (STR) = color work conflict task (unilateral same hand) (10min)	Amplitude: For both tasks: $UT_{NP} > UT_{con}$	MPF: For both tasks: $UT_{NP} = UT_{con}$	- Amplified - BP filter (8th order Butterworth filter, 10–400 Hz for EMG) - SR: 1024 Hz.	- HP filter - Full wave Rectification Amplitude: RMS (within windows of 100-ms duration) Spectral Analysis: MPF the power spectral density was calculated in 1-s intervals	Yes: MVC

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Sjörs et al. (2009)	18 (♀, mean age 40,0 ± 6,0yr) Women with chronic trapezius myalgia (MYA) + pain in the trapezius descendens during the last 7 days and > 3m during the last year	30 (♀, mean age 39,9 ± 5,6yr)	No information	*Functional task: -20 min baseline rest -Low-force repetitive work (100min): *2 standardized work stations = Simulated Asssembly (bilateral)(1x) =Fine Finger Dexterity (dominant/most painful side)(2x) *pegboard exercise (dominant/most painful side))(2x) -Trier Social Stress Test (TSST) (20 min) -80 min recovery Measured at the dominant/most painful side	Amplitude: Baseline/uninstructed rest: $UT_{NP} > UT_{con}$ Entire experiment: $UT_{NP} = UT_{CON}$ Trier Social Stress Test: $UT_{NP} = UT_{CON}$		- wireless acquisition - differential high impedance (>10 GOhm) inputs - -50 mV to +35 mV range - 0–280 Hz bandwidth - 16bits AD conversion - SR: 1000 Hz	Amplitude: RMS -HP filter: 6:th order digital Butterworth filters cutting off frequencies below 15Hz - 1 Hz wide 3rd order Butterworth notch filters centred at 50 and 100 Hz	No clear information Reference contractions were applied as covariates in the statistical analysis (the subject performed two brief (5-6 sec) static shoulder forward flexions (90 degrees) with a 2 kg dumbbell)
Strom et al. (2009)	24 (14♀,10♂, mean age 39 ± 6yr) Shoulder/neck pain ≥ 2-3 days/week during the previous 4 weeks, tender points in the corresponding muscle and working more than 80% full time and working on a computer more than 20% of the working time	28 (16♀, 12♂, mean age 33 ± 6yr)	Working more than 80% full time and working on a computer more than 20% of the working time	*Functional task: Computer-based office-work task: correcting typographical errors in a standardized text using the mouse and a word processor as fast and as accurately as possible (90 min)	Amplitude: $UT_{NP} = UT_{con}$		- preamplified 1000x (bandwidth 10–3000 Hz, CMRR > 100 dB, input impedance > 5GOhm, - then amplified twice by an isolation amplifier (first-order BP filter : 10-1000 Hz) - SR: 2000 Hz	Amplitude: 0.1sRMS - resampled 10Hz	Yes : MVC

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Takala & Viikari-Juntura (1991)	10 (♀, mean age 36,5 ± 3,4yr) Female bank cashiers with frequent symptoms in the neck-shoulder region, > 30 days during the past year and symptoms also during the past 7 days	10 (♀,mean age 36,6 ± 3,1yr)	Bank cashiers	*Functional task: Standard work simulation task demanding attention and static holding: subject sat in front of a plate with 9 holes and moved the point of the pin from hole to hole every 5s according to the study instructor's command	<u>Amplitude:</u> $UT_{NP} = UT_{con}$ (for both working arm and resting arm)		- Pre-amplified (bandwidth 10-450 Hz),	<u>Amplitude:</u> 0.2sRMS - LP filtering: 500 Hz - SR = 1000 Hz	Yes: MVC
Voerman et al. (2007)	20 (16♀,4♂, mean age 31,0 ± 7,6yr) Work-related musculo-skeletal disorder (WMSD) with pain in the neck-shoulder region, >30days last year, including the last 7 days and they had to assign their complaints to their computer work	20 (12♀,8♂, mean age 33,6 ± 5,5yr)	Employee population of a large local company in which computer related activities prevailed	*Functional task: -Computer tasks: typing task (10min) bilaterally and clicking mouse stress task (10min) with the dominant side -Reference contraction: arms 90° abducted in the horizontal plane with no additional weight, 15s (4x) bilaterally -Rest measurements in between the tasks (rest before typing task and stress task: 2 min, rest after the tasks: 5 min)	<u>Amplitude:</u> $UT_{NP} = UT_{con}$		- SR: 1024Hz - Filtering: 20-500Hz	<u>Amplitude:</u> RMS	No
Wegner et al. (2010)	18 (11♀, 7♂, mean age 27,2 ± 6,9yr) History of neck pain >3/12 months, NDI-score ≥ 15% + poor scapular posture on the symptomatic side	20 (14♀, 7♂, mean age 24,8 ± 6,6yr)	No information	*Functional task: -Rest condition (10s) -Typing (5min)	<u>Amplitude:</u> *During rest: $UT_{NP} = UT_{CON}$ $MT_{NP} = MT_{CON}$ $LT_{NP} = LT_{CON}$ *During typing: $UT_{NP} = UT_{CON}$ $MT_{NP} > MT_{CON}$ $LT_{NP} < LT_{CON}$		- Amplified (gain = 1000) - Band-width filter 10-500Hz, - SR: 1000 Hz	<u>Amplitude:</u> 1sRMS (1s sliding window	No

Author	Patients	Controls	Nature of work of the subjects	Task	Results Amplitude & Timing Analysis (Time Domain)	Results Spectral Analysis (Frequency Domain)	Detection Amplification Filtering A/D Conversion	Processing	Normali-sation
Zakharova-Luneva et al. (2012)	18 (12♀, 6♂mean age 27,4 ± 7,0yr) History of neck pain >3months, NDI-score ≥ 15/100 + scapular dysfunction on the side of the neck pain	20 (13♀, 7♂mean age 24,9 ±6,7yr)	No information	*Movement tasks: 3 isometric tasks of the shoulder girdle (flexion, abduction and external rotation) at 3 intensities of effort (3x 100% (5s),3x50%(10s) and 3x20%(10s) MVC) using a purpose built dynamometer	Amplitude: UT $_{NP}$ = UT $_{CON}$ for all movement tasks MT $_{NP}$ = MT $_{CON}$ for all movement tasks LT $_{NP}$ > LT $_{CON}$ for abduction and external rotation (not for flexion)		- Amplified (gain = 1000) - BP filter: 10-500 Hz - SR: 1000 Hz	Amplitude: RMS	No

BP = BandPass, CMRR = common mode rejection ratio, CON = Control group, HP = High Pass, LP = Low Pass, MDF = Median Power Frequency, MPF = Mean Power Frequency, NP = Neck Pain group, RMS = Root Mean Square, SR = Sampling Rate, yr = year

3.3.1. EMG muscle amplitude

An overview of the different results for muscle amplitude activity is clustered by the task that was performed (if appropriate, also subdivided into analytical and functional tasks) and was further classified by the muscle part that was measured.

3.3.1.1. During rest.

Seven studies measured the activity of the UT during rest. Six studies (Andersen et al., 2014, 2008; Hallman et al., 2011; Nilsen et al., 2006; Voerman et al., 2007; Wegner et al., 2010) showed consensus and did not find any difference in EMG amplitude between patients with neck pain and healthy controls during rest. In contrast, the study of Sjors et al. (2009) found higher activity in patients with neck pain during rest, in comparison to healthy controls. In addition, Falla et al. (2004a) found no difference in UT amplitude activity between patients with neck pain and healthy controls in the left arms, that rested motionless on the table while the right arm was performing a functional task. The amplitude of MT and LT activity during rest was investigated by Wegner et al. (2010) and they did not find significant differences between patients with neck pain and a healthy control group (see Table 3).

In conclusion, during rest there is moderate evidence that no significant differences in UT amplitude activity exist between patients with neck pain and healthy controls (strength of conclusion 2). Furthermore, reasonable evidence exists that EMG amplitude of the MT and LT does not differ between patients with neck pain and healthy controls during rest (strength of conclusion 3).

3.3.1.2. Activities below shoulder height.

Six studies measured the amplitude of the UT EMG activity during analytical isometric tasks of the shoulder girdle below shoulder height. Schulte et al. (2006) found lower UT activity in patients with neck pain during sustained isometric shoulder girdle elevation (6 min at 30% MVC) against a force transducer. Hallman et al. (2011) found larger UT activity in patients with neck pain during a static hand grip test and Cold Pressor Test. The other studies did not show a difference in amplitude of UT activity during short term (20 s, respectively at 10%, 30%, 50% and 70%) isometric shoulder girdle elevation against a handle connected to a strap attached to a strain gauge dynamometer (Elcadi et al., 2013), during a static arm-holding task (as long as possible) with arm in 45 flexion in the scapular plane (Goudy and McLean, 2006), during step-wise increased contractions (5 force levels, 20, 40, 60, 80 and 100 N, 10 s each) of isometric shoulder elevation (Kallenberg et al., 2007), and during isometric abduction, flexion and external rotation using a purpose built dynamometer (20%, 50%, 100% MVC) (Zakharova-Luneva et al., 2012). Zakharova-Luneva et al. (2012) also investigated the amplitude of MT and LT activity during isometric contractions (abduction, flexion and external rotation) of the shoulder girdle in patients with neck pain, and did not find differences for MT in comparison with a healthy group, but reported higher LT activity in patients with neck pain during isometric abduction and external rotation (but not for flexion) in comparison with the control group.

Eleven studies investigated the amplitude of UT activity during functional (below shoulder height) tasks. Eight studies did not find significant differences in UT activity between patients with neck pain and healthy controls performing functional tasks, i.e. three studies during typing (Johnston et al., 2008a; Voerman et al., 2007; Wegner et al., 2010), two studies during a mouse task (Strom et al., 2009; Voerman et al., 2007), two studies during work or a dynamic work simulation task (Larsson et al., 2008; Madeleine et al., 1999) and one study of Johnston et al. (2008b) where subjects had to move a pen between 3 circles. Three studies (Falla et al., 2004a; Leonard et al., 2010; Sjogaard et al., 2010) found differences in UT amplitude EMG activity between patients with neck pain and healthy controls during dynamic functional tasks. The results, however, were conflicting. Leonard et al. (2010) reported higher UT activity in the neck pain group during writing, Sjogaard et al. (2010) reported higher UT activity in the neck pain group when performing a Pegboard Task, whereas Falla et al. (2004a) reported lower UT activity in the neck pain group when dotting pencil marks in 3 circles.

Six studies measured the amplitude of UT EMG activity during stressful tasks, including pressing one or two keys with their fingers (Nilsen et al., 2006), calling out as fast as possible the color of a print (Johnston et al., 2008a), a Cold Pressor Test (Hallman et al., 2011), the Trier Social Stress Test (Sjors et al., 2009) and a mouse task (Sjogaard et al., 2010; Voerman et al., 2007). Four of the six studies did not find significant differences between the groups (Johnston et al., 2008a; Nilsen et al., 2006; Sjors et al., 2009; Voerman et al., 2007). Hallman et al. (2011) found larger UT activity in patients with neck pain during a Cold Pressor Test. Sjogaard et al. (2010) found also higher UT activity in the neck pain group while Voerman et al. (2007), using a similar task, did not find significant differences between patients with neck pain and healthy controls.

Wegner et al. (2010) investigated the amplitude of the EMG activity of the MT and LT during typing, and found higher MT and LT activity in patients with neck pain.

In conclusion, it seems plausible that there is no difference in amplitude of the UT activity during activities below shoulder height, both for the analytical isometric tasks as for the functional tasks, including the stress tasks (both strength of conclusion 2). For LT, there is some evidence that higher activity is present in patients with neck pain, both during analytical isometric tasks as well as during functional under head tasks (typing) (strength of conclusion 2).

For MT, no consensus can be made as conflicting results are reported (no difference or higher MT activity in patients with neck pain).

3.3.1.3. Overhead activities.

Three studies investigated analytical overhead tasks. Andersen et al. (2008) investigated the amplitude of UT activity during isokinetic abduction movements of the shoulder, and found lower UT activity in patients with neck pain for slow concentric, slow eccentric and static contraction in comparison with healthy controls. During fast concentric contraction, no differences were found between the populations. Larsson et al. (1999) did not find differences in amplitude of UT activity between patients with neck pain and healthy controls during static elevation of the arm in the scapular plane (at 30–60–90–135°). These findings are in accordance with the results from Goudy and McLean (2006) who did not find differences while holding (static) the arm in 90 flexion in the scapular plane (with a maximum of 10 min). Two studies investigated the amplitude of UT activity during a dynamic functional overhead task. Takala and ViikariJuntura (1991) investigated UT activity during an overhead task (subject sat in front of a plate with 9 holes and moved the point of the pin from hole to hole) and did not found differences in amplitude of UT activity between patients with neck pain and healthy subjects. Falla and Farina (2005) found higher UT EMG activity in patients with neck pain during a specific part of the task (for the interval 60–90% of the endurance time while tapping hands between targets positioned at mid-thigh and 120 shoulder flexion). No studies measured the amplitude of MT or LT during overhead activities.

In conclusion, during overhead tasks, no conclusion can be made as conflicting results are reported when comparing UT activity between patients with neck pain and healthy controls (both increased, decreased or no difference).

3.3.2. EMG muscle recruitment timing

Only one study was found that focused on muscle recruitment timing of the scapular muscles in patients with neck pain. Helgadottir et al. (2011) reported a delayed onset and shorter duration of the SA during dynamic unilateral arm elevation (3 s elevation – 3 s lowering) in patients with idiopathic neck pain. No differences were found for onset and duration for the Trapezius muscles between patients with idiopathic neck pain and healthy controls.

In conclusion, there is reasonable evidence that in patients with idiopathic neck pain a delayed onset and shorter duration of the SA during unilateral elevation is seen when comparing with healthy controls (strength of conclusion 3).

3.3.3. EMG muscle fatigue

Nine studies investigated Mean Power Frequency (MPF) or Median Power Frequency (MDF) parameters of the UT between patients with neck pain and healthy controls. Five studies did not find significant differences between patients with neck pain and healthy controls for those parameters during fatiguing tasks (Andersen et al., 2014; Elcadi et al., 2013; Larsson et al., 2000; Schulte et al., 2006; Sjogaard et al., 2010). The four other studies did find statistical significant differences between the two groups, but in general, conflicting results were shown. Larsson et al. (1999) reported significantly lower values of the MPF and suggested an accelerated fatigue development in the most painful muscle of the patients while holding (static) a 1 kg load with straight arms elevated at 45°. In contrast, Madeleine et al. (1999) showed significantly higher values of MPF in butchers with neck pain, compared with pain-free butchers, while performing simulations of real-work situations using a knife. Falla and Farina (2005) showed significant differences in MPF for a part of the task (tapping hands during 5 min): patients with neck pain showed significantly lower values in MPF during the interval 70–90% of the endurance time. Kallenberg et al. (2007) also reported a significant difference between the groups in MDF for a part of the task (isometric sustained shoulder girdle elevation). Kallenberg et al. (2007) concluded that cases showed a less pronounced myoelectric response to the fatiguing task than controls.

No definite conclusion (strength of conclusion 1) can be made for the comparison of muscle EMG fatigue parameters between patients with idiopathic neck pain and healthy controls as a wide variation of tasks and conflicting results are reported.

4. DISCUSSION

The aim of this systematic review was to summarize current evidence regarding scapular muscle EMG activity (amplitude, timing and fatigue) in patients with chronic idiopathic neck pain in comparison with healthy controls.

4.1. Amplitude

Based on the results of this systematic review, there is moderate evidence that there are no systematic significant differences in UT EMG amplitude activity between patients with neck pain and painfree controls, both during rest and during activities below shoulder height. During these tasks, a sustained static activity in the proximal stabilizing muscles is required while (in case of the tasks below shoulder height) small forces are generated in the distal forearm muscles. So the high prevalence of chronic neck pain that is reported during static activities that require sustained postures of the upper limb, is not associated with different mean UT amplitude EMG activity. Hypothetically, this could be explained by relatively low postural UT activity that is required during these tasks (commonly below 5% maximal voluntary electrical (MVE) activation) (Veiersted and Westgaard, 1993) and the fact that large inter-individual variability is associated with EMG data.

When comparing the amplitude of MT and LT EMG activity between patients with neck pain and healthy controls, the results during rest are in line with those found for the UT; there is reasonable evidence that during rest the activity of the MT and LT does not differ between patients with neck pain and healthy controls. Unlike the results of the UT during activities below shoulder height, two studies that investigated MT and LT found differences, although not consistent, between patients with neck pain and healthy controls during these tasks. However, these 2 studies only included patients with neck pain if they showed clinical signs of scapular dysfunction on the side of the neck pain and they compared them with a control group without scapular dysfunction. As a result, it is not clear whether these differences are related to neck pain or to the scapular dysfunction. Further research is necessary to investigate the relationship between scapular orientation and scapular muscle activity in patients with neck pain.

During overhead tasks, conflicting results (both lower activity, higher activity or no differences) are reported when comparing UT EMG amplitude between patients with neck pain and healthy controls. Several hypotheses can be formulated to explain these conflicting results during overhead tasks. The authors believe that the trend of differences in muscle activity in patients with neck pain depends on the characteristics of the task that was performed: different overhead tasks require different degrees (greater or lesser) of shoulder elevation and consequently the UT is subject to greater/lesser loads. This may have consequences for the recruitment (amplitude) of scapular muscles and the size of the possible differences in EMG activity between patients with neck pain and healthy controls. In general, the findings suggest that alterations in scapular muscle mean amplitude activity may be present during upper limb tasks in some individuals with neck pain and that this appears to represent a way to deal with the pain.

4.2. Timing

One study that investigated the timing of the scapular muscles in patients with chronic idiopathic neck pain showed a significantly delayed onset of muscle activation and shorter duration of activity of the SA in the presence of neck pain (Helgadottir et al., 2011). Helgadottir et al. (2011) believe that this can have consequences for the normal synergistic force couple relation between the SA and the Trapezius. Moreover, this result of altered timing activity in patients with neck pain corresponds to what has previously been reported in patients with shoulder disorders (Wadsworth and Bullock-Saxton, 1997) and supports the hypothesis that altered activity of the SA may be a general response to a chronic pain condition in the neck/shoulder region (Kibler and McMullen, 2003). Although this primary result suggests altered timing activity in the SA, more studies on timing of the scapular muscles are necessary to make conclusions.

4.3. Fatigue

Although perceived fatigue of the UT is often reported in patients with neck pain, this systematic review could not make a conclusion on possible differences in scapular EMG fatigue parameters between patients with chronic idiopathic neck pain and healthy subjects.

4.4. General discussion

In general, the absence of clear differences/similarities for the EMG parameters between patients with neck pain and healthy controls is possibly due to the fact that not every subject with neck pain reacts in the same way and to methodological differences between the studies.

Variable patterns in muscle activity in the presence of pain can be found. The relationship between pain and altered muscle activity is complex. Moreover, pain cannot be seen as a continuum as it develops into different stages (discomfort, fatigue, acute, sub-acute, chronic) and it is known that the pain status plays a role in the adaptation mechanisms. Some adaptations in muscle activity occur to various extents in different pain stages (Madeleine, 2010). According to the theory of Hodges and Tucker (2011), and in line with our results, no stereotypical change in muscle activity that is the same in all conditions exists. According to their theory, every individual reacts differently to pain and shows a different muscle recruitment, with a common goal to protect the painful part from further pain or injury. However, although the adaptations to pain show interindividual differences, they have to be taken into account, as these adaptations may have long-term consequences.

Methodological differences between the studies need also to be taken into account when discussing the results of this systematic review. The population of neck pain that was included in this review had idiopathic neck pain. As this is a quite aspecific condition, almost all studies had different inclusion and exclusion criteria for the patient group which has led to a large variety of participants in the different studies. It is hypothesized that subgroups of neck pain patients exist with corresponding different muscle activation patterns. A number of included papers also investigated subjects with a combination of neck and shoulder pain (instead of only neck pain). Nevertheless, the difficulty to differentiate between neck and shoulder pain is generally known, as shoulder pain goes often along with neck pain. In addition, the work that was related to the neck pain differed between the studies. Half of the studies included office workers/computer workers (n = 13), the other half of the studies recruited people with a specific job (n = 3, e.g. butchers, cleaners, assembly work) or a nonspecific job (n = 9). Possibly, the nature of work related to the neck pain may be a factor that could have influenced the results. Sample sizes differed widely (12 of the 25 studies had a population of <20 patients or controls), which may explain why some studies were only able to find a trend, instead of statistical significant differences in EMG activity. EMG activity is known to have large inter-individual variation of muscle activation levels and therefore studies would need larger sample sizes in order to detect differences between the groups.

Moreover, differences in the application of the UT electrodes between studies were also found. Not only the location of the electrodes may influence the EMG signal, but also the interindividual differences in muscle size, thickness of skin and subcutaneous fat can influence the EMG signal. Most studies that investigate EMG amplitude report that normalization of the results is necessary to handle this problem and express their data as a percentage of a reference contraction (e.g. MVC, static shoulder flexion…). Nevertheless, normalized amplitude values can mask group differences (van Dieen et al., 2003). Moreover, reference contractions for normalization also differed between individual studies and some studies did not describe normalization because the authors of these studies believe that the reference contraction itself may also be affected by abnormal motor control. As almost each study has its own normalization procedure or has no normalization procedure, comparison between different studies' results is difficult. Further research should try to make a consensus on the best normalization procedure and implement this in different EMG studies in order to make better comparisons between studies possible which could lead to a better conclusion for EMG studies.

A limitation of this review is that only studies that compared EMG amplitude, timing and fatigue between patients with chronic idiopathic neck pain and pain-free individuals were selected. Possibly, other EMG outcome measures (amplitude distribution probability function, EMG gaps, …) could differ between the two groups. Another limitation of this systematic review is that in 17 out of 25 articles selection bias could not be sufficiently excluded, which could have introduced bias in our results and have weakened the conclusions. Also the fact that the search strategy was performed in only 2 databases (the ones that were available at the University) and that only published data were taken into account is a limitation of this review. Remarkably, most included research studies were carried out in European countries (19 out of 25). One could ask if the results can be generalized to other countries/continents too. It must be admitted that the level of evidence of the studies is limited (level B). However, it was not possible to have a higher level of evidence as all the studies needed to be case-control to fit in the PICO question. Another consequence of the choice for a case-control design is that the direction of the causal relationship between pain and EMG activity cannot be determined by the present study design. The study design could not lead to a decision whether the disturbance of muscle activity is a cause or a consequence of pain. Two studies (Madeleine et al., 2003; Veiersted and Westgaard, 1993) already used a longitudinal design and investigated the relationship between differences in EMG variables of the UT and the development of shoulder and neck pain. Veiersted and Westgaard (1993) showed that a low rate of short muscle rest periods (gaps) significantly entails a higher risk for development of work related musculoskeletal disorders. Madeleine et al. (2003) showed that workers who later developed neck/shoulder complaints showed higher shoulder muscle sEMG activity both prior to and after the start of complaints, compared with workers who remained healthy. More EMG studies with a longitudinal design are needed that investigate the relationship between disturbances in EMG amplitude, timing and fatigue variables and the development of shoulder and neck pain.

Future research is necessary in order to draw definite conclusions regarding possible EMG differences between patients with chronic idiopathic neck pain and healthy subjects. Future research should focus on more high-quality studies (larger sample sizes, less bias). Moreover, other advanced EMG techniques (e.g. high-density surface EMG with higher spatial resolution of the muscle) could be helpful to gain insight in the adaptations of (specific subportions of) muscle activity in the presence of neck pain (Gallina et al., 2013). Scapular EMG data gives important information, but still its interpretation is rather difficult because in most studies no concurrent kinematic analysis of the scapula was performed. Future EMG studies should overcome this limitation of EMG and should try to record kinematic data of the scapula bone in order to better understand the relationship between scapular orientation and muscle activity. Until now, most studies focused on the UT, but also other scapular muscles need to be investigated; including the superficial muscles (via surface EMG: Trapezius and Serratus Anterior) as well as the deeper lying scapular muscles (via fine-wire EMG: Levator Scapulae, Pectoralis Minor & Rhomboidei).

In summary, for EMG amplitude, no clear differences in mean UT EMG activity exist between patients with idiopathic neck pain and healthy subjects during rest and activities below shoulder height. During overhead activities, no conclusion for scapular EMG amplitude can be drawn as a large variation of results were reported. Adaptation strategies during overhead tasks are not the same between studies. Only one study investigated timing of the scapular muscles and found a delayed onset and shorter duration of the SA during elevation in patients with idiopathic neck pain. For scapular muscle fatigue, no definite conclusions can be made as a wide variation as well as conflicting results are reported. Further high quality EMG research on scapular muscles (broader than the UT) is necessary to draw conclusions on how scapular muscles react in the presence of idiopathic neck pain.

REFERENCES

Andersen LL, Nielsen PK, Sogaard K, Andersen CH, Skotte J, Sjogaard G. Torque– EMG–velocity relationship in female workers with chronic neck muscle pain. J Biomech 2008;41:2029–35.

Andersen LL, Andersen CH, Skotte JH, Suetta C, Sogaard K, Saltin B, et al. Highintensity strength training improves function of chronically painful muscles: case-control and RCT studies. BioMed Res Int 2014;2014:187324.

Behrsin JF, Maguire K. Levator scapulae action during shoulder movement: a possible mechanism for shoulder pain of cervical origin. Aust J Physiother 1986;32:101–6.

Cagnie B, Dolphens M, Peeters I, Achten E, Cambier D, Danneels L. Use of muscle functional magnetic resonance imaging to compare cervical flexor activity between patients with whiplash-associated disorders and people who are healthy. Phys Ther 2010;90:1157–64.

Cagnie B, Struyf F, Cools A, Castelein B, Danneels L, O'Leary S. The relevance of scapular dysfunction in neck pain: a brief commentary. J Orthop Sports Phys Ther 2014;44:435–9.

Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction–retraction movement in overhead athletes with impingement symptoms. Br J Sports Med 2004;38:64–8.

Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scand J Med Sci Sports 2007;17:25–33.

Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. Br J Sports Med 2014;48:692–7.

Diederichsen LP, Norregaard J, Dyhre-Poulsen P, Winther A, Tufekovic G, Bandholm T, et al. The activity pattern of shoulder muscles in subjects with and without subacromial impingement. J Electromyo Kinesiol: Off J Int Soc Electrophysiol Kinesiol 2009;19:789–99.

Elcadi GH, Forsman M, Aasa U, Fahlstrom M, Crenshaw AG. Shoulder and forearm oxygenation and myoelectric activity in patients with work-related muscle pain and healthy subjects. Eur J Appl Physiol 2013;113:1103–15.

Falla D, Farina D. Muscle fiber conduction velocity of the upper trapezius muscle during dynamic contraction of the upper limb in patients with chronic neck pain. Pain 2005;116:138–45.

Falla D, Bilenkij G, Jull G. Patients with chronic neck pain demonstrate altered patterns of muscle activation during performance of a functional upper limb task. Spine 2004a;29:1436–40.

Falla D, Jull G, Hodges PW. Feedforward activity of the cervical flexor muscles during voluntary arm movements is delayed in chronic neck pain. Exp Brain Res 2004b;157:43–8.

Falla DL, Jull GA, Hodges PW. Patients with neck pain demonstrate reduced electromyographic activity of the deep cervical flexor muscles during performance of the craniocervical flexion test. Spine 2004c;29:2108–14.

Gallina A, Merletti R, Gazzoni M. Uneven spatial distribution of surface EMG: what does it mean? Eur J Appl Physiol 2013;113:887–94.

Goudy N, McLean L. Using myoelectric signal parameters to distinguish between computer workers with and without trapezius myalgia. Eur J Appl Physiol 2006;97:196–209.

Hallman DM, Lindberg LG, Arnetz BB, Lyskov E. Effects of static contraction and cold stimulation on cardiovascular autonomic indices, trapezius blood flow and muscle activity in chronic neck–shoulder pain. Eur J Appl Physiol 2011;111: 1725–35.

Helgadottir H, Kristjansson E, Einarsson E, Karduna A, Jonsson H. Altered activity of the serratus anterior during unilateral arm elevation in patients with cervical disorders. J Electromyogr Kinesiol 2011;21:947–53.

Hodges PW, Tucker K. Moving differently in pain: a new theory to explain the adaptation to pain. Pain 2011;152:S90–8.

Hogg-Johnson S, van der Velde G, Carroll LJ, Holm LW, Cassidy JD, Guzman J, et al. The burden and determinants of neck pain in the general population: results of the Bone and Joint Decade 2000–2010 Task Force on Neck Pain and its Associated Disorders. Spine (Phila Pa 1976) 2008;33:S39–51.

Johnston V, Jull G, Darnell R, Jimmieson NL, Souvlis T. Alterations in cervical muscle activity in functional and stressful tasks in female office workers with neck pain. Eur J Appl Physiol 2008a;103:253–64.

Johnston V, Jull G, Souvlis T, Jimmieson NL. Neck movement and muscle activity characteristics in female office workers with neck pain. Spine 2008b;33: 555–63.

Kallenberg LA, Schulte E, Disselhorst-Klug C, Hermens HJ. Myoelectric manifestations of fatigue at low contraction levels in subjects with and without chronic pain. J Electromyo Kinesiol: Off J Int Soc Electrophysiol Kinesiol 2007;17:264–74.

Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. J Am Acad Orthop Surg 2003;11:142–51.

Kibler WB, Ludewig PM, McClure PW, Michener LA, Bak K, Sciascia AD. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. Br J Sports Med 2013;47: 877–85.

Larsson R, Oberg PA, Larsson SE. Changes of trapezius muscle blood flow and electromyography in chronic neck pain due to trapezius myalgia. Pain 1999;79:45–50.

Larsson B, Bjork J, Elert J, Gerdle B. Mechanical performance and electromyography during repeated maximal isokinetic shoulder forward flexions in female cleaners with and without myalgia of the trapezius muscle and in healthy controls. Eur J Appl Physiol 2000;83:257–67.

Larsson B, Rosendal L, Kristiansen J, Sjogaard G, Sogaard K, Ghafouri B, et al. Responses of algesic and metabolic substances to 8 h of repetitive manual work in myalgic human trapezius muscle. Pain 2008;140:479–90.

Leonard JH, Kok KS, Ayiesha R, Das S, Roslizawati N, Vikram M, et al. Prolonged writing task: comparison of electromyographic analysis of upper trapezius muscle in subjects with or without neck pain. Clin Ter 2010;161:29–33.

Lin JJ, Hsieh SC, Cheng WC, Chen WC, Lai Y. Adaptive patterns of movement during arm elevation test in patients with shoulder impingement syndrome. J Orthop Res: Off Publ Orthop Res Soc 2011;29:653–7.

Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276–91.

Madeleine P. On functional motor adaptations: from the quantification of motor strategies to the prevention of musculoskeletal disorders in the neck–shoulder region. Acta Physiol (Oxford, England) 2010;199(Suppl. 679):1–46.

Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L. Shoulder muscle co-ordination during chronic and acute experimental neck–shoulder pain. An occupational pain study. Eur J Appl Physiol Occup Physiol 1999;79:127–40.

Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L. The effects of neck–shoulder pain development on sensory–motor interactions among female workers in the poultry and fish industries. A prospective study. Int Arch Occup Environ Health 2003;76:39–49.

Nederhand MJ, Izerman MJ, Hermens HJ, Baten CT, Zilvold G. Cervical muscle dysfunction in the chronic whiplash associated disorder grade II (WAD-II). Spine 2000;25:1938–43.

Nilsen KB, Westgaard RH, Stovner LJ, Helde G, Ro M, Sand TH. Pain induced by lowgrade stress in patients with fibromyalgia and chronic shoulder/neck pain, relation to surface electromyography. Eur J Pain (London, England) 2006;10:615–27.

O'Leary S, Cagnie B, Reeve A, Jull G, Elliott JM. Is there altered activity of the extensor muscles in chronic mechanical neck pain? A functional magnetic resonance imaging study. Arch Phys Med Rehabil 2011;92:929–34.

Roy JS, Moffet H, McFadyen BJ. Upper limb motor strategies in persons with and without shoulder impingement syndrome across different speeds of movement. Clin Biomech (Bristol, Avon) 2008;23:1227–36.

Schulte E, Kallenberg LA, Christensen H, Disselhorst-Klug C, Hermens HJ, Rau G, et al. Comparison of the electromyographic activity in the upper trapezius and biceps brachii muscle in subjects with muscular disorders: a pilot study. Eur J Appl Physiol 2006;96:185–93.

Sjogaard G, Rosendal L, Kristiansen J, Blangsted AK, Skotte J, Larsson B, et al. Muscle oxygenation and glycolysis in females with trapezius myalgia during stress and repetitive work using microdialysis and NIRS. Eur J Appl Physiol 2010;108: 657–69.

Sjors A, Larsson B, Dahlman J, Falkmer T, Gerdle B. Physiological responses to lowforce work and psychosocial stress in women with chronic trapezius myalgia. BMC Musculoskelet Dis 2009;10.

Strom V, Roe C, Knardahl S. Work-induced pain, trapezius blood flux, and muscle activity in workers with chronic shoulder and neck pain. Pain 2009;144: 147–55.

Struyf F, Cagnie B, Cools A, Baert I, Brempt JV, Struyf P, et al. Scapulothoracic muscle activity and recruitment timing in patients with shoulder impingement symptoms and glenohumeral instability. J Electromyo Kinesiol: Off J Int Soc Electrophysiol Kinesiol 2014;24:277–84.

Takala EP, Viikari-Juntura E. Loading of shoulder muscles in a simulated work cycle: comparison between sedentary workers with and without neck–shoulder symptoms. Clin Biomech (Bristol, Avon) 1991;6:145–52.

van Dieen JH, Selen LP, Cholewicki J. Trunk muscle activation in low-back pain patients, an analysis of the literature. J Electromyo Kinesiol: Off J Int Soc Electrophysiol Kinesiol 2003;13:333–51.

Veiersted KB, Westgaard RH. Development of trapezius myalgia among female workers performing light manual work. Scand J Work Environ Health 1993;19: 277–83.

Voerman GE, Vollenbroek-Hutten MM, Hermens HJ. Upper trapezius muscle activation patterns in neck–shoulder pain patients and healthy controls. Eur J Appl Physiol 2007;102:1–9.

Wadsworth DJ, Bullock-Saxton JE. Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. Int J Sports Med 1997;18:618–24.

Wegner S, Jull G, O'Leary S, Johnston V. The effect of a scapular postural correction strategy on trapezius activity in patients with neck pain. Manual Ther 2010;15:562–6.

Zakharova-Luneva E, Jull G, Johnston V, O'Leary S. Altered trapezius muscle behavior in individuals with neck pain and clinical signs of scapular dysfunction. J Manipulative Physiol Ther 2012;35:346–53.

CHAPTER 4:

ARE CHRONIC NECK PAIN, SCAPULAR DYSKINESIS AND ALTERED SCAPULOTHORACIC MUSCLE ACTIVITY INTERRELATED?: A CASE-CONTROL STUDY WITH SURFACE AND FINE-WIRE EMG.

BIRGIT CASTELEIN, PT[1]; ANN COOLS, PT, PHD[1]; THIERRY PARLEVLIET, PT, MD[2]; BARBARA CAGNIE, PT, PHD[1]

[1] DEPARTMENT OF REHABILITATION SCIENCES AND PHYSIOTHERAPY, GHENT UNIVERSITY, GHENT, BELGIUM

[2] DEPARTMENT OF PHYSICAL MEDICINE AND ORTHOPAEDIC SURGERY, UNIVERSITY HOSPITAL, GHENT, BELGIUM

SUBMITTED TO JOURNAL OF ELECTROMYOGRAPHY AND KINESIOLOGY (9/3/2016)

ABSTRACT

Study Design: Controlled laboratory study

Objectives: The function of the scapula is important in normal neck function and might be disturbed in patients with neck pain. The surrounding muscular system is important for the function of the scapula. To date, it is not clear if patients with idiopathic neck pain show altered activity of these scapulothoracic muscles. Therefore, the objective of this study was to investigate differences in deeper and superficial lying scapulothoracic muscle activity between patients which idiopathic neck pain and healthy controls during arm elevation, and to identify the influence of scapular dyskinesis on muscle activity.

Background: Little research is available on scapulothoracic muscle activity in patients with neck pain. Moreover, it is not known if scapular dyskinesis influences the muscle activity.

Methods: Possible scapular dyskinesis was rated with the yes/no method. The deeper lying (Levator Scapulae, Pectoralis Minor(Pm) and Rhomboid major) and superficial lying (Trapezius and Serratus Anterior) scapulothoracic muscles' activity was investigated with fine-wire and surface EMG in 19 female subjects with idiopathic neck pain (age 28,3 ± 10,1 years, average duration neck pain 45,6 ± 36,3 months) and 19 female healthy control subjects (age 29,3 ± 11,7) while performing scaption (elevation in the scapular plane) and wallslide. Possible interactions or differences between subject groups, scapular dyskinesis groups or phases of the task were studied with a linear mixed model.

Results: Higher Pm activity during the wallslide (p=0.024, mean difference 8,8 ± 3,8 % MVIC) was shown in patients with idiopathic neck pain in comparison with healthy controls. For the MT, a significant group*dyskinesis interaction effect was found during elevation which revealed that patients with neck pain and scapular dyskinesis showed lower Middle Trapezius (MT) activity in comparison with healthy controls with scapular dyskinesis (p=0.029, mean difference 5,1 ± 2,2 % MVIC).

Conclusion: In the presence of idiopathic neck pain, higher Pm activity during the wallslide was found. Patients with neck pain and scapular dyskinesis showed lower MT activity in comparison with healthy controls with scapular dyskinesis. Scapular dyskinesis did not have a significant influence on scapulothoracic muscle activity.

INTRODUCTION

Neck pain is an important source of disability and several underlying mechanisms have been explored.[13, 20] Some studies have highlighted the importance of scapulothoracic muscles in the presence of neck pain.[3,8] These scapulothoracic muscles (Trapezius (Upper Trapezius(UT), Middle Trapezius(MT) and Lower Trapezius (LT)), Serratus Anterior(SA), Pectoralis Minor (Pm), Levator Scapulae(LS) and Rhomboids(RM)) are important as they are responsible for transferring loads between the upper limb and the vertebral column, including the cervical spine.[8] Alterations in the scapulothoracic muscle function can perpetuate mechanical strain to pain sensitive cervical spine structures because of shared muscle attachments between the scapula and the cervical spine. The uppermost attachments of the scapulothoracic muscles, such as from the Trapezius and the LS, transfer loads from the shoulder girdle to cervical structures. Disturbances in scapular muscle function can induce mechanical loading on the cervical segments and create or sustain mechanical dysfunction in the cervical spine, and may have implications for the initiation, perpetuation or recurrence of neck pain. Some authors state that the scapulothoracic muscle function might be disturbed in patients with neck pain.[3, 8] A recently published systematic review from Castelein et al.[6] summarized the literature regarding differences or similarities in scapulothoracic muscle activity between patients with chronic idiopathic neck pain and healthy controls, measured by EMG. They found that there were no differences in mean UT EMG activity between patients with idiopathic neck pain and the control group, both during rest and activities below shoulder height. During overhead activities, no conclusion for EMG activity of the scapulothoracic muscles could be drawn as a large variation of results was reported. Moreover, most studies that have investigated scapulothoracic muscle activity in patients with idiopathic neck pain only focused on the UT, while there is a need to investigate other scapulothoracic muscles (including the middle and lower part of the trapezius and the SA) and the deeper lying muscles (LS, Pm and RM).

Humeral elevation is an important and often used upper limb task that requires a complex scapular movement of upward rotation, posterior tilt and external rotation in order to create a stable base for the glenohumeral joint.[22] The quality of this scapular movement depends on the coordinated activity of the surrounding superficial and the deeper lying scapulothoracic muscles. It is currently unclear if patients with idiopathic neck pain show differences during the performance of elevation tasks.[6] Information about possible differences in scapulothoracic muscle activity between patients with neck pain and healthy controls will enhance understanding of the mechanisms associated with idiopathic neck pain. Findings of this study can help to know if evaluation of the scapulothoracic muscles should be an integral component of the management of patients with idiopathic neck pain.

In addition, it is of interest to know if the presence of scapular dyskinesis has a substantial influence on the activation of the different scapulothoracic muscles. Scapular dyskinesis has become an integral component in the evaluation of patients with neck pain as it is thought to perpetuate mechanical strain to pain sensitive cervical spine structures due to shared muscle attachments between the scapula and the cervical spine.[3, 8] However, the significance of scapular dyskinesis is being challenged as it has been shown to be present in asymptomatic people too. Defining muscle activity impairments related to scapular dyskinesis in patients with neck pain can provide foundational knowledge for understanding scapular dyskinesis. Information of this study might be a basis for recommendations for the choice of exercises during treatment for patients with idiopathic neck symptoms related to scapulothoracic dysfunction.

Therefore, the objective of this study was to investigate whether the activity of the superficial (Trapezius and SA) and deeper lying (LS, Pm and RM) muscles is different in a population with idiopathic neck pain compared to a healthy control group during elevation (in open and semi-closed chain). Also, the influence of the presence of scapular dyskinesis on scapulothoracic muscle activity was investigated. It was hypothesized that scapulothoracic muscle activity would differ between the population groups and that scapular dyskinesis would have an influence on scapulothoracic muscle activity.

METHODS

Subjects

Two groups of female subjects were recruited: a group with idiopathic neck pain (neck pain group, n=19) and a matched (age, height, weight) control group without symptoms (healthy control group, n=19). Subjects were recruited via advertisement from the local community and university. Written informed consent was obtained from all participants. The study was approved by the ethics committee of Ghent University Hospital.

Participants were included in the idiopathic neck pain group if they reported chronic neck pain at the side of their dominant arm, for more than 30 days during the last year and with a pain frequency of at least once a week and a pain intensity of minimum 3/10 on the Numeric Rating Scale. The cause of the neck pain had to be unknown (= idiopathic), excluding patients with WAD (whiplash associated disorders), herniated disc, tumors, etc. Other exclusion criteria were: neurological, metabolic or systemic diseases, more than 6h of overhead sports each week and upper limb training in the last 6 months. Healthy candidates were excluded if they reported complaints of current neck or shoulder pain or a history of neck/shoulder pain. In addition, participants were excluded if they had undertaken upper limb training in the last 6 months, if they performed more than 6h of overhead sports per week or if they were known with neurological, metabolic or systemic diseases.

General design

EMG data was collected from 7 scapulothoracic muscles (Trapezius (UT, MT, LT), SA, LS, Pm, RM) on the dominant side of each subject during the performance of (1) scaption (elevation in the scapular plane) and (2) towel wall slide.[4]

Test Procedure

First, the presence or absence of scapular dyskinesis was checked in the subjects. Therefore, a dynamic clinical examination was performed on the basis of the yes/no method.[36] Each examination included observation of the scapular borders (medial and superior borders) during 5 trials of arm elevation in the sagittal and scapular planes.[36] A "yes" means that the clinician states that an abnormal pattern (prominence of medial or superior border or asymmetry/dysrhythmia) of scapular movement is observed. Uhl et al.[36] demonstrated that this method has a sensitivity and positive predictive value of 76% and 74% respectively when compared with the results of a 3-dimensional motion analysis. The inter-rater reliability of the yes/no method yielded a 79% agreement, with a k correlation of 0,41.

The experimental session began with a short warm-up procedure with multidirectional shoulder movements, followed by the performance of a set of five maximum voluntary isometric contractions (MVIC) of the muscles of interest,[5] including:

1. "Abduction 90°" (sitting)
2. "Horizontal Abduction with external rotation" (prone lying)
3. "Arm raised above head in line with LT muscle fibers" (prone lying)
4. "Shoulder flexion 135°" (sitting)
5. "Arm raised above head in line with Pm muscle fibers" (supine lying)

MVIC test positions were taught to each subject by the same investigator, and sufficient practice was allowed before real data collection. Manual pressure was always applied by the same investigator and strong and consistent verbal encouragement from the investigator was given during each MVIC to promote maximal effort. All MVICs were performed prior to the different elevation exercises, except for the MVIC "Arm raised above head in line with Pm muscle fibers". This MVIC was always performed at the end (after the exercises) to avoid pressure on the electrodes of the dorsal muscles (due to their contact with the examination table because of the supine position). Each MVIC test position was performed 3 times (each contraction lasted for 5 seconds-controlled by a metronome) with at least 30 seconds rest between the different repetitions. There was a rest period of at least 1.5 minutes between the different test positions.

In the second part of the investigation, the subject performed the elevation tasks: scaption (Figure 1) and towel wall slide (Figure 2). The exercises were performed in random order (simple randomization: envelopes containing the name of each exercise were shuffled for each participant and this sequence of exercises was allocated to that participant). Before data collection, the subject was given a visual demonstration of each exercise by the investigator. Each exercise consisted of an elevation phase of 4s and a lowering phase of 4s. A metronome was used to control and standardize the speed of the movement. When the participants were able to perform the proper movement pattern and timing of the exercise, EMG data was collected from five repetitions of each exercise with 5s of rest in between each trial. Between each exercise set, a break of 1,5 minutes was provided.

Figures

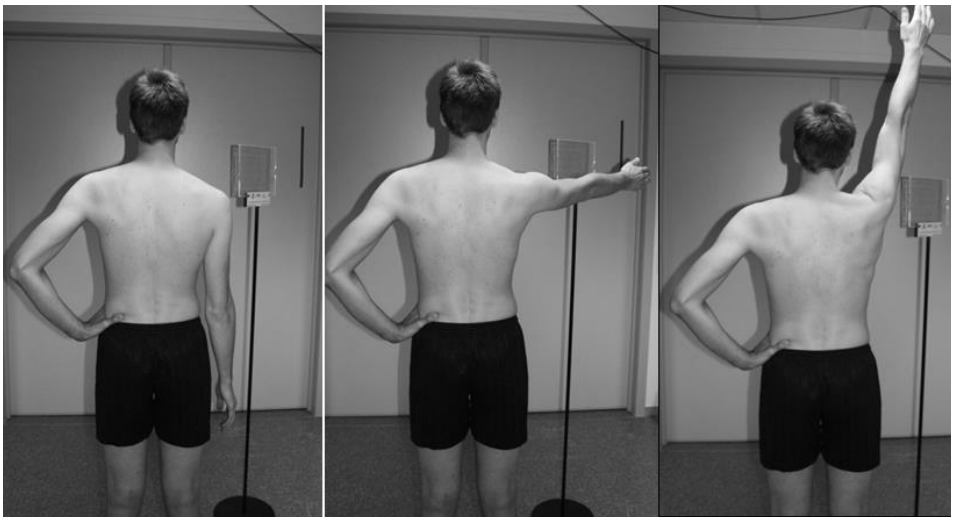


FIGURE 1. Scaption. The subject performed elevation (full range of motion) with the dominant arm (thumb up) in the scapular plane (30°). A pole was used to guide the elevation in the scapular plane.

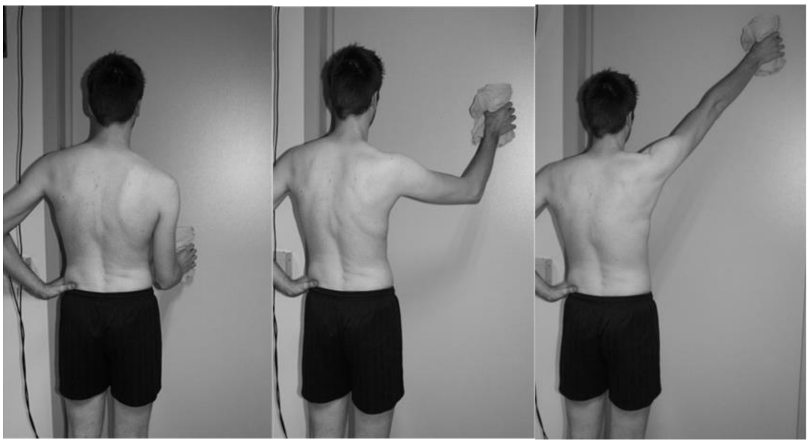


FIGURE 2. Towel Wall Slide. For the starting position, the subject held a towel in the hand and put the hand against the wall with the elbow flexed 90°. The subject moved the towel up by sliding the arm against the wall until elbow was fully extended. This was performed in the scapular plane (30°). The distance between the wall and the subject was determined by the length of the forearm with the elbow in ninety degrees of flexion.

Instrumentation

A TeleMyo 2400 G2 Telemetry System (Noraxon Inc., Scottsdale, AZ) was used to collect the EMG data. This study used a combination of surface and intramuscular electrodes. Bipolar circular surface electrodes (Ag/AgCl, Ambu ® Blue Sensor P, Type N-00-S 30x22mm, Ballerup, Denmark) were placed with a 1cm interelectrode distance over the UT, LT and MT, according to the to the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles)

Project Recommendations.[17] Electrodes for the SA were applied longitudinal (on the part where the muscle is most superficial): the first electrode anterior to the Latissimus Dorsi and the second electrode posterior to the Pectoralis Major (caudal from the axilla).[10, 24, 26, 27] A reference electrode was placed over the processus spinosus of C7 vertebrae. Before surface electrode application, the skin surface was shaved, cleaned and scrubbed with alcohol to reduce impedance (<10kOhm). Intramuscular fine-wire electrodes were used to measure the EMG activity of the LS, Pm and the RM. The paired hook fine-wire electrodes (Carefusion Middleton, WI, USA – wire length 125mm, stainless steel, insulated nickel alloy wire, first wire stripped 2mm, second wire insulated for 3mm and then stripped 2mm) were inserted into the muscle belly, according to the locations described by Delagi et al.[11] using a single-use 25-gauge hypodermic needle. This was done using real-time ultrasound guidance, which has been shown to be an accurate and repeatable method of intramuscular electrode placement.[19] The surface and intramuscular electrodes were looped and taped on the skin to prevent them from being accidentally removed during the experiment and to minimize movement artifacts. The sampling rate was 3000 Hz. The device had a common mode rejection ratio of 100dB. Gain was set at 1000 (baseline noise <1 µV root-mean-square (RMS)).

<u>Signal Processing and Data Analysis</u>

The Myoresearch 3.4 Master Edition Software Program was used for signal processing. The EMG signals were filtered with a high pass Butterworth filter of 20Hz. Cardiac artifact reduction was performed, followed by full wave rectification and smoothing (root mean square, window 100ms) of the signals. The windows of data were determined based on markers that were manually placed by the investigator during the testing. An average EMG value for each muscle and each participant was calculated for each phase of the exercise (4s concentric phase and 4s eccentric phase). This average value was taken from the 3 intermediate repetitions, because the first and fifth repetitions were not used to control for distortion due to habituation or fatigue. These average EMG data were normalized and expressed as a percentage of their MVIC. For each MVIC, the average EMG value over a window of the peak 2,5 s of the 5s was calculated. The average of the 3 trials was used for normalization.[7, 9, 27, 34] All 5 MVIC test positions were analyzed for each muscle (except the Pm activity was not analyzed during prone lying MVIC test positions and the other muscles' activity was not analyzed during supine lying MVIC test positions). The normalization value (100%) was the highest value for that muscle recorded during the 5 MVIC tests.

Statistical analysis

SPSS 22.0 was used for statistical analysis. Possible significant differences in anthropometric data between the neck pain group and the control group were checked with an independent sample t-test. Means ± standard deviations were calculated for the normalized EMG values (in % of MVIC) of the UT, MT, LT, SA, Pm, LS & RM for each exercise and for each group with and without scapular dyskinesis. For each muscle and each exercise, a linear mixed model with 3 factors was performed: factor "group" (2 levels), factor "dyskinesis" (2 levels) and factor "phase" (2 levels). The residuals of the linear mixed models were checked for normal distribution. Post hoc pairwise comparisons were performed using a Bonferroni correction. Only differences between "group" or "dyskinesis" were of interest. An alpha level of 0.05 was applied to all the data in determining significant differences.

RESULTS

Demographic characteristics of the participants

Thirty-eight female subjects were recruited. Table 1 shows the demographic characteristics of the participants. There were no significant differences in anthropometric data between the neck pain group and the control group.

	Neck pain group (n=19)	Control group (n=19)
Age,y	28,3 ± 10,1	29,3 ± 11,7
Height, cm	165,8 ± 5,8	169,4 ± 5,5
Weight, cm	65,4 ± 9,9	62,5 ± 7,1
Scap dysk (yes/no)	9/10	8/11

TABLE 1. Demographic characteristics of the participants. Values are expressed as means ± standard deviation.

EMG results

The mean EMG activity of each scapulothoracic muscle for both groups during the elevation and the towel wallslide is provided in Table 2.

		Scaption		Towel wall slide	
Muscle	**Scapular dyskinesis**	**Healthy Controls**	**Neck pain patients**	**Healthy Controls**	**Neck pain patients**
UT	Yes	17,0 ± 6,0	19,5 ± 7,5	15,2 ± 3,1	16,2 ± 5,0
	No	18,3 ± 5,4	17,8 ± 8,6	12,9 ± 5,1	14,9 ± 11,7
	Total	17,7 ± 5,5	18,6 ± 7,9	13,9 ± 4,4	15,6 ± 9,0
MT	Yes	13,3 ± 4,4	8,2 ± 3,5	9,5 ± 6,7	5,1 ± 2,3
	No	9,7 ± 4,2	11,7 ± 5,9	5,7 ± 4,8	7,0 ± 3,9
	Total	11,2 ± 4,5	10,0 ± 5,1	7,3 ± 5,8	6,1 ± 3,3
LT	Yes	17,5 ± 3,9	19,4 ± 6,6	10,4 ± 4,5	9,1 ± 6,5
	No	14,4 ± 6,1	16,3 ± 9,4	7,7 ± 4,0	12,0 ± 8,5
	Total	15,7 ± 5,4	17,8 ± 8,1	8,8 ± 4,3	10,6 ± 7,5
SA	Yes	31,2 ± 15,9	30,0 ± 8,1	26,8 ± 11,3	26,8 ± 9,6
	No	26,7 ± 14,6	27,8 ± 9,6	27,4 ± 12,8	30,0 ± 17,3
	Total	28,6 ± 14,9	28,8 ± 8,8	27,1 ± 11,9	28,5 ± 13,9
Pm	Yes	6,8 ± 7,4	11,4 ± 9,1	8,8 ± 7,2	28,3 ± 22,2
	No	13,7 ± 7,5	6,4 ± 9,1	14,2 ± 9,5	12,4 ± 17,7
	Total	10,8 ± 8,1	9,2 ± 9,1	12,1 ± 9,0	20,9 ± 15,9
LS	Yes	13,2 ± 6,1	18,1 ± 9,2	15,3 ± 12,8	8,5 ± 6,3
	No	20,6 ± 13,2	18,9 ± 11,9	12,4 ± 7,8	11,4 ± 5,8
	Total	17,5 ± 11,2	18,5 ± 10,4	13,6 ± 10,0	10,1 ± 6,1
RM	Yes	34,4 ± 23,0	23,6 ± 5,0	20,1 ± 26,7	10,9 ± 11,6
	No	21,9 ± 12,9	23,2 ± 14,5	11,7 ± 5,1	15,5 ± 11,5
	Total	26,8 ± 18,0	23,4 ± 10,8	15,0 ± 16,9	13,3 ± 11,5

TABLE 2. EMG activity (%MVIC ± standard deviation) of each scapulothoracic muscle in each group during the various "Elevation Exercises".

* UT= Upper Trapezius, MT= Middle Trapezius, LT= Lower Trapezius, SA = Serratus Anterior, Pm = Pectoralis Minor, LS = Levator Scapulae, RM = Rhomboid Major

Statistical analysis revealed a significant group*scapular dyskinesis interaction effect for the MT activity (p=0,004) during elevation. Post-hoc analysis revealed that the group with neck pain and scapular dyskinesis showed lower MT activity in comparison with the healthy group with scapular dyskinesis (p=0,029, mean difference 5,1 ± 2,2 % MVIC). A significant group effect for the Pm activity during the performance of the towel wall slide (p=0,024) was identified. During the wall slide, it was found that the patients with neck pain showed significantly higher Pm activity in comparison with the healthy control group (p=0,024, mean difference = 8,8 ± 3,8 % MVIC). No other significant main effects or interaction effects were found.

DISCUSSION

The first aim of the current study was to investigate if patients with idiopathic neck pain show differences in deeper and superficial lying scapulothoracic muscle EMG activity in comparison with a healthy control group during different arm elevation tasks. Also possible differences in scapulothoracic muscle activity between the presence or absence of scapular dyskinesis were investigated. Patients with neck pain showed higher Pm activity during the wallslide in comparison with the healthy control group. In addition, it was found that patients with scapular dyskinesis showed lower MT activity in comparison with healthy controls with scapular dyskinesis. The presence of scapular dyskinesis did not have a significant influence on scapulothoracic muscle activity in this study.

Previous studies investigating the differences in scapulothoracic muscle activity between patients with neck pain and healthy subjects during elevation of the arm or overhead activities mainly focused on UT muscle activity.[6] The result of UT EMG activity of the current study is in agreement with the results from Larsson et al.[23], Goudy and McLean [15] and Takala and Viikari-Juntura [35] who did not find differences in UT activity between the patients with idiopathic neck pain and healthy controls during static elevation of the arm in the scapular plane (at 30–60–90–135°),[23] while holding the arm in 90° flexion in the scapular plane[15] or during a dynamic functional overhead task.[35] In contrast, Andersen et al.[1] found lower UT activity during isokinetic shoulder abduction for slow concentric, slow eccentric and static contraction in comparison with healthy controls, while during fast concentric contraction, no differences were found between the populations. Falla and Farina [12] found higher UT EMG activity in patients with neck pain during a specific part of an elevation task (for the interval 60-90% of the endurance time while tapping hands between targets positioned at mid-thigh and 120° shoulder flexion). So in general, conflicting results are found and more research is needed with specific focus on other scapulothoracic muscle activity.

Regarding MT and LT activity, the current study showed no differences in LT activity between patients with neck pain in comparison with healthy controls. Nevertheless, lower MT activity in patients with neck pain and scapular dyskinesis was found in comparison with healthy controls with scapular dyskinesis. To date, no studies measured the MT or LT activity during overhead activities in patients with neck pain.[6] A study of Wegner et al.[37] investigated the amplitude of MT and LT during rest and did not find differences between patients with neck pain and healthy controls. Zakharova-Luneva et al.[38] investigated the amplitude of MT and LT activity during isometric contractions (abduction, flexion and external rotation) of the shoulder girdle in patients with neck pain, and did not find differences for MT in comparison with a healthy group, but reported higher LT activity in patients with neck pain during isometric abduction and external rotation (but not for flexion) in comparison with the control group. Overall, conflicting results are reported and it is difficult to compare the results between studies as the tasks are different. In addition, patient group comparisons were also slightly different from our study as the 2 studies only included patients with neck pain if they showed clinical signs of scapular dysfunction and they compared them with a control group without scapular dysfunction. Dysfunctions of the MT and LT can have implications on scapulothoracic movement as the MT retracts and externally rotates the scapula, and the LT is seen as an important stabilizer which contributes to upward rotation, depression, posterior tilt and external rotation of the scapula.

This study could not find differences in SA EMG activity between patients with neck pain and healthy controls. One other study investigated the SA EMG activity in patients with idiopathic neck pain, but focused on timing of the SA (and not amplitude of the activity), and showed a significantly delayed onset of muscle activation and shorter duration of activity of the SA in the presence of neck pain.[16]

This is the first study investigating **deeper lying scapulothoracic EMG muscle activity** in a population with neck pain, so no other data exist to compare our results with. Hypothetically, overuse of these deeper lying muscles (Pm, LS and RM) could lead to downward rotation of the scapula. In the current study, it was found that patients with neck pain showed higher Pm activity during the towel wall slide in comparison with healthy controls. Higher activity of the Pm can lead to anterior tilt and downward rotation of the scapula, which is not warranted during elevation of the arm. The important role of the Pm in neck pain has already been suggested in different clinical settings, however this study was the first to investigate and confirm this hypothesis. One study of Shahidi et al.[33] already revealed bilateral shortness of the Pm in patients with neck pain compared to healthy individuals. Possibly, repetitive overuse of the Pm may result in adaptive shortening and tension and can lead to a malaligned scapula as described above.

No differences in LS and RM activity were found in this study between patients with idiopathic neck pain and healthy controls. Nevertheless, some authors have already found differences in characteristics of these deeper lying muscles in the presence of neck pain and have suggested a role of these muscles in the presence of neck pain. These differences were found in trigger point presence, tension or shortness of muscles, etc. [14, 30, 32] Future research should further investigate the role of these muscles in relation to neck pain.

This study showed in general that the presence of scapular dyskinesis did not have a statistically significant influence on scapulothoracic muscle EMG: no differences in muscle activity were found between the groups with or without scapular dyskinesis. Two other studies have been performed that already investigated possible differences in scapulothoracic EMG muscle activity between groups with and without scapular dyskinesis, but in a population with shoulder pain.[21, 25] Huang et al.[21] investigated the influence of scapular dyskinesis on scapulothoracic muscle EMG (UT, MT, LT, SA) in participants with unilateral shoulder pain. Scapular dyskinesis was classified in 4 types: pattern 1 (inferior angle prominence), pattern II (medial border prominence), pattern III (excessive/inadequate scapular elevation or upward rotation), pattern IV (normal pattern) or abnormal mixed patterns. Significant differences in EMG activity were only found during the lowering phase: a significant increase in UT activity during the arm-lowering phase was found in participants with pattern II (medial border prominence) and a significant decrease in LT and SA activity was found in participants with combined pattern I and II. It is difficult to compare our results with this study as the population groups and the classification of scapular dyskinesis is different between the two studies. Lopes et al.[25] evaluated scapulothoracic muscle activity (UT, MT, LT, SA) in patients with subacromial impingement syndrome (SIS), with and without visually identified scapular dyskinesis during ascending and descending phases of weighted shoulder flexion. No differences in MT, LT and SA muscle EMG activity were found between patients with and without scapular dyskinesis. Higher UT activity was shown during a short interval (during ascent 30-60° interval) in the SIS group with dyskinesis compared with those without dyskinesis. So both Huang et al.[21] and Lopes et al.[25] found differences in UT activity between groups with and without scapular dyskinesis in a population with shoulder pain. The authors stated that it is possible that subsets of scapular dyskinesis with unique patterns of muscle activity are present. Consequently, future research should include the subsets of scapular dyskinesis and link them to specific muscle activity. Differences in other variables of the scapulothoracic muscles (e.g. muscle timing, muscle activation during different phases of elevation etc.) between patients with and without scapular dyskinesis should be investigated too. Also, larger sample sizes are necessary to unravel the role of scapular dyskinesis on muscle activity.

Some **limitations** have to be taken into account when interpreting the results of this study. Our EMG data were normalized to data of the MVICs. Discomfort or pain might have interfered with the ability to produce an MVIC. However, for normalization, we used the highest value of EMG activity for that muscle out of a set of 5 MVICs. [5] We believe that this set, rather than one MVIC for one muscle limits the role of pain as substantial confounding factor on the EMG results. While this study provided useful information regarding the muscles being activated during various exercises, it did not provide synchronized 3D scapular kinematic analysis with the EMG signal. Investigating scapular movements, along with muscle activity during exercises, would provide additional information. Another limitation of this study is the intersubject variability that might have occurred during the performance of the different tasks. However, attempts were made to control variation, i.e. good explanation, good demonstration and personal feedback. Also, a small number of patients were included in this study and maybe this could have lead to non-significant changes. Nevertheless, other studies using fine-wire EMG on scapulothoracic muscles in a patient population have used similar number of patients.[2, 18, 28, 29, 31] Also, the investigator was not blind for the presence of scapular dyskinesis or neck pain, which might be seen as another limitation of the study. Also, no a priori sample calculation or power analysis was performed on the data. Post-hoc power analysis (GPower®) revealed that our sample size of 38 subjects had enough power to detect differences with effect size 0.50 (power = 0.86).

CONCLUSION

This is the first study investigating deep scapulothoracic muscle EMG activity in patients with idiopathic neck pain. In general, the results higher Pm activity during the wallslide in patients with idiopathic neck pain in comparison with the healthy control group. In addition, it was found that patients with scapular dyskinesis showed lower MT activity in comparison with healthy controls with scapular dyskinesis. The presence of scapular dyskinesis did not have a significant influence on scapulothoracic muscle activity.

REFERENCES

1 Andersen LL, Nielsen PK, Sogaard K, Andersen CH, Skotte J, Sjogaard G. Torque-EMG-velocity relationship in female workers with chronic neck muscle pain. J Biomech 2008;41:2029-2035. 10.1016/j.jbiomech.2008.03.016

2 Barden JM, Balyk R, Raso VJ, Moreau M, Bagnall K. Atypical shoulder muscle activation in multidirectional instability. Clin Neurophysiol 2005;116:1846-1857. 10.1016/j.clinph.2005.04.019

3 Cagnie B, Struyf F, Cools A, Castelein B, Danneels L, O'Leary S. The relevance of scapular dysfunction in neck pain: a brief commentary. J Orthop Sports Phys Ther 2014;44:435-439. 10.2519/jospt.2014.5038

4 Castelein B, Cagnie B, Parlevliet T, Cools A. Superficial and Deep Scapulothoracic Muscle EMG Activity During Different Types of Elevation Exercises in the Scapular Plane. J Orthop Sports Phys Ther 2016:1-26. 10.2519/jospt.2016.5927

5 Castelein B, Cagnie B, Parlevliet T, Danneels L, Cools A. Optimal normalization tests for muscle activation of the Levator Scapulae, Pectoralis Minor and Rhomboid Major: an electromyography study using Maximum Voluntary Isometric Contractions. Arch Phys Med Rehabil 2015. 10.1016/j.apmr.2015.06.004

6 Castelein B, Cools A, Bostyn E, Delemarre J, Lemahieu T, Cagnie B. Analysis of scapular muscle EMG activity in patients with idiopathic neck pain: a systematic review. J Electromyogr Kinesiol 2015;25:371-386. 10.1016/j.jelekin.2015.01.006

7 Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scand J Med Sci Sports 2007;17:25-33. 10.1111/j.1600-0838.2006.00570.x

8 Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. Br J Sports Med 2014;48:692-697. 10.1136/bjsports-2013-092148

9 De Ridder EM, Van Oosterwijck JO, Vleeming A, Vanderstraeten GG, Danneels LA. Posterior muscle chain activity during various extension exercises: an observational study. BMC Musculoskelet Disord 2013;14:204. 10.1186/1471-2474-14-204

10 Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. Am J Sports Med 1999;27:784-791.

11 Delagi EF I J, Perpotto, A., & Morrison, D. Anatomical guide for the electromyographer. The limbs and Trunck. Spingfield: Charles C Thomas Publisher 1994.

12 Falla D, Farina D. Muscle fiber conduction velocity of the upper trapezius muscle during dynamic contraction of the upper limb in patients with chronic neck pain. Pain 2005;116:138-145. 10.1016/j.pain.2005.03.038

13 Fejer R, Kyvik KO, Hartvigsen J. The prevalence of neck pain in the world population: a systematic critical review of the literature. Eur Spine J 2006;15:834-848. 10.1007/s00586-004-0864-4

14 Fernandez-de-las-Penas C, Grobli C, Ortega-Santiago R, Fischer CS, Boesch D, Froidevaux P et al. Referred pain from myofascial trigger points in head, neck, shoulder, and arm muscles reproduces pain symptoms in blue-collar (manual) and white-collar (office) workers. Clin J Pain 2012;28:511-518. 10.1097/AJP.0b013e31823984e2

15 Goudy N, McLean L. Using myoelectric signal parameters to distinguish between computer workers with and without trapezius myalgia. Eur J Appl Physiol 2006;97:196-209. 10.1007/s00421-006-0162-4

16 Helgadottir H, Kristjansson E, Einarsson E, Karduna A, Jonsson H, Jr. Altered activity of the serratus anterior during unilateral arm elevation in patients with cervical disorders. J Electromyogr Kinesiol 2011;21:947-953. 10.1016/j.jelekin.2011.07.007

17 Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, Rau G et al. European recommendations for surface electromyography. Roessingh Research and Development; 1999. (ISBN No. 90-75452-15-2)

18 Hess SA, Richardson C, Darnell R, Friis P, Lisle D, Myers P. Timing of rotator cuff activation during shoulder external rotation in throwers with and without symptoms of pain. J Orthop Sports Phys Ther 2005;35:812-820. 10.2519/jospt.2005.35.12.812

19 Hodges PW, Kippers V, Richardson CA. Validation of a technique for accurate fine-wire electrode placement into posterior gluteus medius using real-time ultrasound guidance. Electromyogr Clin Neurophysiol 1997;37:39-47.

20 Hoy D, March L, Woolf A, Blyth F, Brooks P, Smith E et al. The global burden of neck pain: estimates from the global burden of disease 2010 study. Ann Rheum Dis 2014;73:1309-1315. 10.1136/annrheumdis-2013-204431

21 Huang TS, Ou HL, Huang CY, Lin JJ. Specific kinematics and associated muscle activation in individuals with scapular dyskinesis. J Shoulder Elbow Surg 2015;24:1227-1234. 10.1016/j.jse.2014.12.022

22 Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. J Am Acad Orthop Surg 2003;11:142-151.

23 Larsson R, Oberg PA, Larsson SE. Changes of trapezius muscle blood flow and electromyography in chronic neck pain due to trapezius myalgia. Pain 1999;79:45-50.

24 Lear LJ, Gross MT. An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. J Orthop Sports Phys Ther 1998;28:146-157. 10.2519/jospt.1998.28.3.146

25 Lopes AD, Timmons MK, Grover M, Ciconelli RM, Michener LA. Visual scapular dyskinesis: kinematics and muscle activity alterations in patients with subacromial impingement syndrome. Arch Phys Med Rehabil 2015;96:298-306. 10.1016/j.apmr.2014.09.029

26 Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. The Am J Sports Med 2004;32:484-493.

27 Maenhout A, Van Praet K, Pizzi L, Van Herzeele M, Cools A. Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity? Br J Sports Med 2010;44:1010-1015. 10.1136/bjsm.2009.062810

28 McMahon PJ, Jobe FW, Pink MM, Brault JR, Perry J. Comparative electromyographic analysis of shoulder muscles during planar motions: anterior glenohumeral instability versus normal. J Shoulder Elbow Surg 1996;5:118-123.

29 Morris AD, Kemp GJ, Frostick SP. Shoulder electromyography in multidirectional instability. J Shoulder Elbow Surg 2004;13:24-29. 10.1016/s1058274603002489

30 Munoz-Munoz S, Munoz-Garcia MT, Alburquerque-Sendin F, Arroyo-Morales M, Fernandez-de-las-Penas C. Myofascial trigger points, pain, disability, and sleep quality in individuals with mechanical neck pain. J Manipulative Physiol Ther 2012;35:608-613. 10.1016/j.jmpt.2012.09.003

31 Reddy AS, Mohr KJ, Pink MM, Jobe FW. Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement. J Shoulder Elbow Surg 2000;9:519-523.

32 Sari H, Akarirmak U, Uludag M. Active myofascial trigger points might be more frequent in patients with cervical radiculopathy. Eur J Phys Rehabil Med 2012;48:237-244.

33 Shahidi B, Johnson CL, Curran-Everett D, Maluf KS. Reliability and group differences in quantitative cervicothoracic measures among individuals with and without chronic neck pain. BMC Musculoskelet Disord 2012;13:215. 10.1186/1471-2474-13-215

34 Stevens VK, Vleeming A, Bouche KG, Mahieu NN, Vanderstraeten GG, Danneels LA. Electromyographic activity of trunk and hip muscles during stabilization exercises in four-point kneeling in healthy volunteers. Eur Spine J 2007;16:711-718. 10.1007/s00586-006-0181-1

35 Takala EP, Viikari-Juntura E. Loading of shoulder muscles in a simulated work cycle: comparison between sedentary workers with and without neck-shoulder symptoms. Clin Biomech (Bristol, Avon) 1991;6:145-152. 10.1016/0268-0033(91)90025-l

36 Uhl TL, Kibler WB, Gecewich B, Tripp BL. Evaluation of clinical assessment methods for scapular dyskinesis. Arthroscopy 2009;25:1240-1248. 10.1016/j.arthro.2009.06.007

37 Wegner S, Jull G, O'Leary S, Johnston V. The effect of a scapular postural correction strategy on trapezius activity in patients with neck pain. Man Ther 2010;15:562-566. 10.1016/j.math.2010.06.006

38 Zakharova-Luneva E, Jull G, Johnston V, O'Leary S. Altered trapezius muscle behavior in individuals with neck pain and clinical signs of scapular dysfunction. J Manipulative Physiol Ther 2012;35:346-353. 10.1016/j.jmpt.2012.04.011

PART II: SCAPULOTHORACIC MUSCLE RECRUITMENT DURING DIFFERENT EXERCISES, COMMONLY USED IN SCAPULAR REHABILITATION PROGRAM

CHAPTER 5:

SUPERFICIAL AND DEEP SCAPULOTHORACIC MUSCLE EMG ACTIVITY DURING DIFFERENT TYPES OF ELEVATION EXERCISES IN THE SCAPULAR PLANE

BIRGIT CASTELEIN, PT[1]; BARBARA CAGNIE, PT, PHD[1]; THIERRY PARLEVLIET, MD[2]; ANN COOLS, PT, PHD[1]

[1] DEPARTMENT OF REHABILITATION SCIENCES AND PHYSIOTHERAPY, GHENT UNIVERSITY, GHENT, BELGIUM

[2] DEPARTMENT OF PHYSICAL MEDICINE AND ORTHOPAEDIC SURGERY, UNIVERSITY HOSPITAL, GHENT, BELGIUM

JOURNAL OF ORTHOPAEDIC AND SPORTS PHYSICAL THERAPY; 2016 MARCH; 46(3): 184-93

(SCI=3.011, Q1)

ABSTRACT

Study Design: Controlled laboratory study

Background: In scapular rehabilitation training, exercises that include a humeral elevation component in the scapular plane are commonly implemented. While performing humeral elevation, the scapula plays an important role, as it has to create a stable base for the glenohumeral joint. However, a comparison of both deep and superficial muscle activity of the scapula between different types of elevation exercises is lacking and would be helpful for the clinician in choosing exercises.

Objectives: To evaluate scapulothoracic muscle activity during different types of elevation exercises in the scapular plane.

Methods: Scapulothoracic muscle activity was measured in 21 healthy subjects, using fine-wire electromyography in the levator scapulae, pectoralis minor, and rhomboid major muscles, and surface electromyography in the upper trapezius, middle trapezius, lower trapezius, and serratus anterior muscles. Measurements were conducted while the participants performed the following elevation tasks in the scapular plane: scaption (elevation in the scapular plane), towel wall slide, and elevation with external rotation (Thera-Band). The exercises were performed without and with additional load. Possible differences between the exercises and the load were studied with a linear mixed model.

Results: Performing elevation in the scapular plane with an external-rotation component resulted in higher middle trapezius and lower trapezius activity compared to the scaption and wall slide exercises. The upper trapezius was activated to its highest during scaption. The pectoralis minor and serratus anterior showed the highest activity during the towel wall slide. The towel wall slide activated the retractors to a lesser degree (middle trapezius, lower trapezius, levator scapulae, rhomboid major). Adding load resulted in higher muscle activity in all muscles, with some muscles showing a different activation pattern between the elevation exercises, depending on the load condition.

Conclusion: Scaption activated the upper trapezius to its highest. The addition of an extra external-rotation component may be used when the goal is to activate the lower trapezius and middle trapezius. The towel wall slide exercise was found to increase pectoralis minor activity. Adding load resulted in higher muscle activity. Some muscles showed a different activation pattern between the elevation exercises, depending on the loading condition. The findings of this study give information about which elevation exercises a clinician can choose when the aim is to facilitate specific muscle scapulothoracic activity.

INTRODUCTION

The scapula plays an important role in normal shoulder function, as it has to create a stable base for the glenohumeral joint.[21,39] The scapula has to move in a coordinated relationship with the moving humerus. Therefore, it is almost solely dependent on the function of the surrounding muscles.[17,22,23] The muscles that attach to the scapula can be divided into scapulohumeral and scapulothoracic muscles. The scapulohumeral muscles are dynamic stabilizers of the glenohumeral joint, while the scapulothoracic muscles are necessary for a smooth movement pattern of the scapula. It is generally known that the scapulothoracic muscles, including the trapezius, serratus anterior, levator scapulae, rhomboid major, and pectoralis minor, play a crucial role in providing mobility and stability of the scapula during movements of the humerus.[11] During humeral elevation of the arm, these muscles are challenged, as this elevation causes a complex scapular movement that demands high activity of the scapulothoracic muscles. Any small changes in the pattern of scapulothoracic muscular coordination can produce scapulothoracic movement dysfunction, which can induce aberrant forces on the surrounding regions, including the neck and shoulder, and can lead to the development or perpetuation of pathological conditions.[2,23] It is documented that patients with scapulothoracic dysfunction who perform humeral elevation in the scapular plane show lower electromyographic (EMG) activity of the middle trapezius, lower trapezius, and serratus anterior in comparison with healthy subjects.[25] There is no consensus about upper trapezius activity in patients with scapulothoracic dysfunction, as some authors believe that the upper trapezius is less activated,[28,30,31,36] while others believe that the upper trapezius is activated too much.[8,25,33] Little information exists on the activation pattern of the deeper muscles such as the pectoralis minor, the levator scapulae, and the rhomboid major during humeral elevation in the scapular plane.

It is believed that training with exercises that address the appropriate muscles can improve the quality of this scapular movement.[22] Therefore, exercises that appropriately address the muscles with an elevation component should be implemented. The most efficient plane for the arm-elevation exercises is the scapular plane (30° anteriorly to the frontal plane), as this plane of motion adds stability of the humeral head in the glenoid.[20,27]

Some studies have investigated the activation pattern of the scapulothoracic muscles during commonly used rehabilitation exercises that include an elevation component in the scapular plane.[9,11,12,14,26,34,40] Nonetheless, these studies have only focused on the activity of the superficial scapulothoracic muscles (upper trapezius, middle trapezius, lower trapezius, serratus anterior), and no studies have compared the scapulothoracic muscle activity between different types of rehabilitation exercises with an elevation component. Also, the activity of the deeper-lying muscles is important, as these muscles may also influence the desired scapular movement during humeral elevation. For example, as the pectoralis minor inserts onto the coracoid process, excessive activation of this muscle may impede normal posterior tipping that is necessary during humeral elevation.[5] Likewise, normal upward rotation may be influenced by excessive activation or tension in the levator scapulae or rhomboid major.[2] It is important to know whether different exercises with an elevation component in the scapular plane alter muscle activity in different ways. Different types of exercises with an elevation component in the scapular plane exist, the most common being "scaption." The towel wall slide also includes humeral elevation component in the scapular plane, and is often subjectively reported as being less demanding than scaption. Also, the influence of adding an external rotation component to humeral elevation in the scapular plane is gaining interest in clinical practice.[16]

In scapular rehabilitation, the addition of load is a common way to progress the exercise program to improve muscle function. Therefore, investigation of scapulothoracic muscle activity patterns during both unloaded and loaded conditions is necessary to understand muscle activity requirements as load increases. Although it is expected that increasing resistance during elevation will result in a similar increase in the activity of all scapulothoracic muscles recruited during humeral elevation without load, no evidence is available to confirm this assumption. It is still unknown if increasing load is associated with changes in scapular muscle activity patterns. Knowledge of the impact of load on the scapulothoracic muscles' activity during elevation exercises will aid clinicians in developing more targeted rehabilitation exercises.

Therefore, the first aim of the present study was to compare the EMG activity of 7 key scapulothoracic muscles between different humeral elevation exercises in the scapular plane, in order to recommend the most appropriate exercises during scapulothoracic muscle performance training, and the second aim was to compare scapulothoracic muscle activity patterns during different load conditions.

METHODS

Subjects

Twenty-one subjects (10 female, 11 male; mean age, 32 years; age range, 21-55 years) participated in this study. All subjects were free from current or past shoulder or neck pain and demonstrated full pain-free range of motion of both shoulders. They did not perform overhead sports or upper-limb strength training for more than 6 hours per week. Written informed consent was obtained from all participants. The study was approved by the Ethics Committee of Ghent University Hospital.

General Design

Electromyographic data were collected from 7 scapulothoracic muscles (upper trapezius, middle trapezius, lower trapezius, serratus anterior, levator scapulae, pectoralis minor, rhomboid major) on the dominant side of each subject during the performance of 3 different humeral elevation tasks in the scapular plane, with and without an additional load: scaption (elevation in the scapular plane), towel wall slide, and elevation with an external rotation component (and resistance from a Thera-Band (The Hygenic Corporation, Akron, OH).

Test Procedure

The experimental session began with a short warm-up procedure with multidirectional shoulder movements, followed by the performance of the maximum voluntary isometric contractions (MVICs) of the muscles of interest. A set of 5 different isometric MVIC test positions was completed to allow the EMG data to be normalized.[6] These consisted of the following: (1) abduction at 90° (sitting), (2) horizontal abduction with external rotation (prone lying), (3) arm raised above head in line with lower trapezius muscle fibers (prone lying), (4) shoulder flexion to 135° (sitting), and (5) arm raised above head in line with pectoralis minor muscle fibers (supine lying).

Before data collection, MVIC test positions were taught to each subject by the same investigator, and sufficient practice was allowed. All MVICs were performed prior to the elevation exercises, except for the MVIC of "arm raised above head in line with pectoralis minor muscle fibers”. This MVIC was performed in supine lying and was always performed at the end (after the exercises) to avoid pressure on the electrodes of the dorsal muscles (due to their contact with the examination table in the supine position) until all exercises were performed. Each MVIC test position was performed 3 times (5 seconds each, controlled by a metronome), with at least 30 seconds of rest between the different repetitions. A rest of at least 1.5 minutes between the different test positions was allowed. Manual pressure was always applied by the same investigator, and strong and consistent encouragement from the investigator was given during each MVIC to promote maximal effort.

In the second part of the investigation, the subject performed 3 elevation tasks under 2 conditions: no external load and with an external load. The elevation tasks were elevation in the scapular plane, towel slide against a wall, and elevation with external rotation against a Thera-Band (**FIGURES 1** through **3**). The exercises were performed in random order, with the no-load condition performed first, followed by the load -condition. Before data collection, the subject was given a visual demonstration of each exercise by the investigator. Each exercise consisted of an elevation phase of 4 seconds and a lowering phase of 4 seconds. For the exercise with the Thera-

Band, 2 seconds were added to induce tension and remove tension on the Thera-Band before and after the elevation exercise. This tension (glenohumeral external rotation torque) was not of interest for this study; only the influence of the Thera-Band during the elevation phase of this scapulothoracic muscle activity was of interest.

Figures

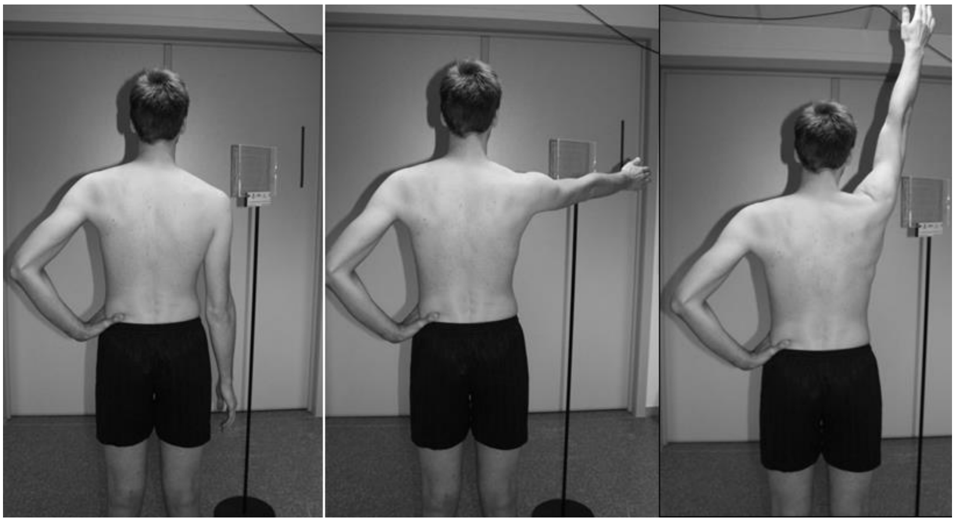


FIGURE 1. Scaption. The subject performed elevation (full range of motion) with the dominant arm (thumbs up) in the scapular plane (30°). A pole was used to guide the elevation in the scapular plane.

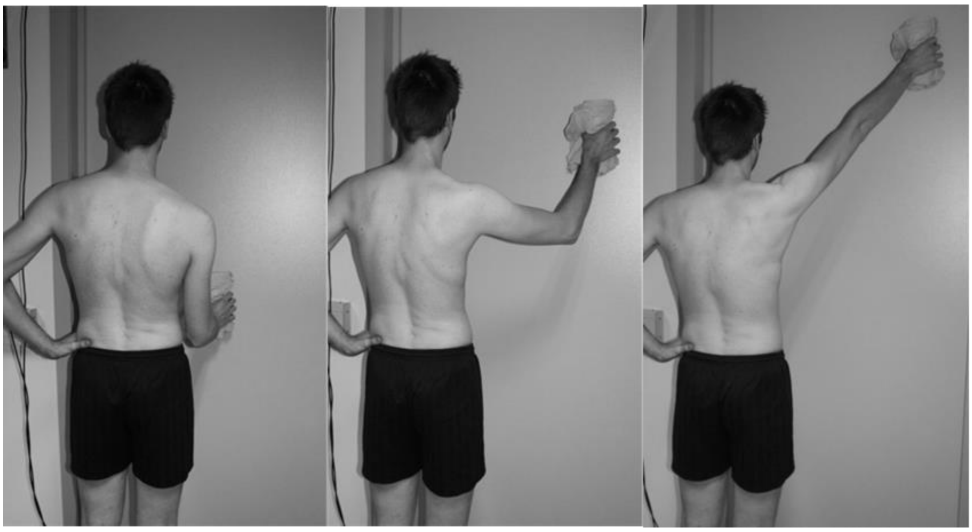


FIGURE 2. Towel Wall Slide. For the starting position, the subject held a towel in the hand and put the hand against the wall with the elbow flexed 90°. The subject moved the towel up by sliding the arm against the wall until elbow was fully extended. This was performed in the scapular plane (30°). The distance between the wall and the subject was determined by the length of the forearm with the elbow in ninety degrees of flexion.

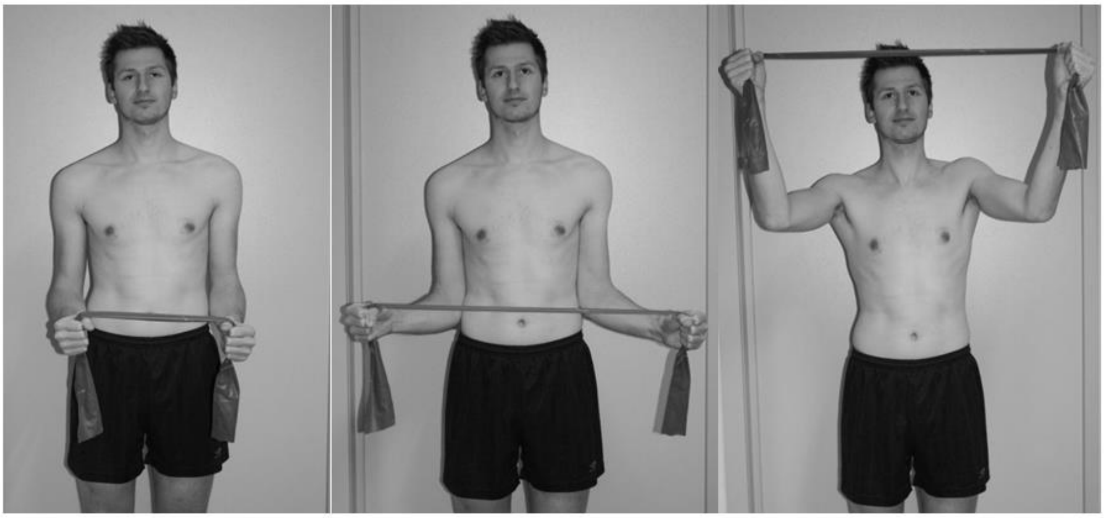


FIGURE 3. Bilateral elevation with external rotation by holding a Theraband®. The subject took the Theraband® (color red) in both hands on two spots that the investigators marked on the Theraband®. The subject flexed the elbows 90° with the shoulder in a neutral position. The Theraband® was then brought to tension with 30° of external rotation in which the wrists remained in the neutral position. From this position an elevation of both arms was carried out up to 90° in the scapular plane while holding the tension of the Theraband®.

A metronome set at 60 beats per minute was used to control and standardize the speed of the movement. When the participants were able to perform the proper movement pattern and timing of the exercise, EMG data were collected from 5 repetitions of each exercise, with 5 seconds of rest between each trial. Between each exercise set, a break of 1.5 minutes was provided. The external load was the same for every exercise. The amount of load of the dumbbell used by the participants was determined in a pilot study (n = 30) to find an external load that achieved a moderate load of ±15 repetition maximum for both male and female subjects divided in categorized according to body weight. For male subjects, the loads assigned to different body-weight classifications were 3 kg, 4 kg, or 5 kg, respectively, for subjects weighing 60 to 69 kg, 70 to 79 kg, and 80 to 89 kg. For female subjects, we could not find differences in the load between different body-weight classifications, so all female subjects were assigned a 2-kg external load.

<u>Instrumentation</u>

A TeleMyo 2400 G2 Telemetry System (Noraxon USA Inc, Scottsdale, AZ) was used to collect the EMG data. A combination of surface and intramuscular electrodes was used. Bipolar circular surface electrodes (Ag/AgCl; Ambu BlueSensor P, type N-00-S; 30 × 22 mm; Ambu A/S, Ballerup, Denmark) were placed with a 1-cm interelectrode distance over the upper trapezius, lower trapezius, middle trapezius, and serratus anterior, according to the instructions of Basmajian and De Luca.[1] A reference electrode was placed over the spinous process of the C7 vertebra. Before surface electrode application, the skin surface was shaved, cleaned, and scrubbed with alcohol to reduce impedance (less than 10 kΩ). Intramuscular fine-wire EMG was used to measure the EMG activity of the levator scapulae, pectoralis minor, and rhomboid major. The paired hook fine-wire electrodes (wire length, 125 mm; stainless steel; insulated nickel alloy wire; first wire stripped 2 mm, second wire insulated for 3 mm and then stripped 2 mm; Becton, Dickinson and Company, Franklin 214 Lakes, NJ) were inserted into the muscle belly (according to the locations described by Perotto and Delagi et al[29]) using a single-use, 25-gauge hypodermic needle. This was done using real-time ultrasound guidance, which has been shown to be an accurate and repeatable method of intramuscular electrode placement.[15] The surface and intramuscular electrodes were looped and taped on the skin to prevent them from being accidentally removed during the experiment and to minimize movement artifacts. The sampling rate was 3000 Hz. The device had a common-mode rejection ratio of 100 dB. Gain was set at 1000 (baseline noise less than 1 μV root-mean-square).

<u>Signal Processing and Data Analysis</u>

The MyoResearch 3.4 Master Edition (Noraxon USA Inc) software program was used for signal processing. The EMG signals were filtered with a high-pass Butterworth filter at 20 Hz. Cardiac artifact reduction was performed, followed by full-wave rectification and smoothing (root-mean-square; window, 100 milliseconds) of the signals. The windows of data were determined based on markers that were manually placed by the investigator during the testing. The EMG data for each muscle and each participant were averaged for each exercise (8 seconds: 4-second concentric phase and 4-second eccentric phase) across the 3 intermediate repetitions of the 5 repetitions completed. The first and fifth repetitions were not used to control for distortion due to habituation or fatigue. These EMG data were normalized and expressed as a percentage of their MVIC. For each MVIC, the average EMG value for the peak 2.5 seconds of the 5 seconds was calculated. The average of the 3 trials was used for normalization. All 5 MVIC test positions were analyzed for each muscle (pectoralis minor activity was not analyzed during prone-lying MVIC test positions, and the activity of other muscles was not analyzed during the supine-lying MVIC test positions). The normalization value (100%) was the highest value for that muscle recorded during the 5 MVIC tests. The same normalization procedures were used for both surface and fine-wire electrodes, as described previously by Wickham et al.[38] and Castelein et al.[7]

<u>Statistical Analysis</u>

SPSS Version 22.0 (IBM Corporation, Armonk, NY) was used for statistical analysis. Trial-to-trial reliability (within-day, intrarater) of the EMG muscle activity was calculated for all scapulothoracic muscles with intraclass correlation coefficients (ICCs; 2-way random, absolute agreement) on the MVIC data of 21 healthy participants from an earlier study by Castelein et al,[6] in which the same methodology was used. Means and standard deviations were calculated for the normalized EMG values (percent MVIC) of the upper trapezius, middle trapezius, lower trapezius, serratus anterior, pectoralis minor, levator scapulae, and rhomboid major for each exercise (with and without the dumbbell). For each muscle, a separate linear mixed model (with random intercept per patient and fixed factors of load, exercise, and exercise by load) was applied to determine if there were significant differences in EMG activity in that muscle between exercises (exercise factor) and between the conditions of load versus no load (load factor). The residuals of the linear mixed models were checked for normal distribution. Post hoc pairwise comparisons were performed using a Bonferroni correction. An alpha level of .05 was applied to all the data in determining significant differences.

RESULTS

Reliability of EMG Data

Table 1 provides trial-to-trial reliability data (ICC, 2-way random, absolute agreement) of muscle activity (both fine-wire and surface EMG) of the scapulothoracic muscles during 3 repetitions of MVICs. Data are from the study by Castelein et al,[6] in which the same methodology was used.

Muscle	Electrodes	Test Position	ICC†
Levator scapulae	Fine wire	Seated T, thumbs up	0.988 (0.975, 0.995)
Rhomboid major	Fine wire	Seated U, 135°	0.971 (0.939, 0.988)
Pectoralis minor	Fine wire	Supine V, thumbs up	0.996 (0.992, 0.999)
Upper trapezius	Surface	Seated T, thumbs up	0.994 (0.987, 0.997)
Middle trapezius	Surface	Prone T, thumbs up	0.964 (0.923, 0.985)
Lower trapezius	Surface	Prone V, thumbs up	0.994 (0.987, 0.997)
Serratus anterior	Surface	Seated U, 135°	0.987 (0.973, 0.994)

TABLE 1. Trial-to-trial Reliability data of scapulothoracic muscle activity during 3 repetitions of Maximum Voluntary Contractions*

Abbreviation: ICC, intraclass correlation coefficient, *Reliability was assessed with a 2-way random ICC (absolute agreement). Data are from Castelein et al.[6], †Values in parentheses are 95% confidence interval

Scapulothoracic Muscle Activity

The mean EMG activity of each scapulothoracic muscle during the different exercises is provided in Table 2, and Figure 4 provides a visualization of these results. To make the data clinically applicable, the results are summarized in Table 3 (without additional load) and Table 4 (with additional load). Due to artifacts, 13 of 882 data points of mean EMG activity were missing (1.5%).

	No Additional Load			Additional Load		
	Scaption	**Wall Slide**	**Elevation Plus External Rotation**	**Scaption**	**Wall Slide**	**Elevation Plus External Rotation**
Upper trapezius	15.9 ± 4.0†	13.6 ± 4.7	12.0 ± 4.0	39.5 ± 10.2†	33.0 ± 10.0	30.9 ± 9.7
Middle trapezius	9.1 ± 4.0	7.3 ± 7.6	19.1 ± 12.2†	26.6 ± 12.9‡	14.6 ± 9.9	25.1 ± 13.7‡
Lower trapezius	12.0 ± 5.6	7.4 ± 4.5	22.5 ± 7.5†	29.2 ± 10.7‡	17.0 ± 7.6	31.0 ± 10.2‡
Serratus anterior	25.1 ± 12.2	26.8 ± 10.3	22.5 ± 11.4	55.2 ± 16.0	53.2 ± 11.9	48.6 ± 15.9
Levator scapulae	17.7 ± 10.5	13.9 ± 13.6	24.7 ± 17.1†	37.1 ± 17.6‡	22.4 ± 15.6	31.2 ± 16.2‡
Pectoralis minor	13.4 ± 6.7	15.7 ± 9.0†	13.7 ± 9.0	28.3 ± 13.5	41.3 ± 27.1†	26.2 ± 15.2
Rhomboid major	21.7 ± 12.9‡	11.6 ± 6.3	33.9 ± 25.0‡	41.1 ± 16.1‡	24.7 ± 9.2	41.2 ± 25.8‡

TABLE 2. Electromyographic Activity of Each Scapulothoracic Muscle During the Different Exercises for Each Load Condition*

*Values are mean ± SD percent MVIC.

†Exercises that show significantly higher activity than the other 2 exercises ($P<.05$).

‡Exercises that show significantly higher activity than the exercise with the lowest value ($P<.05$).

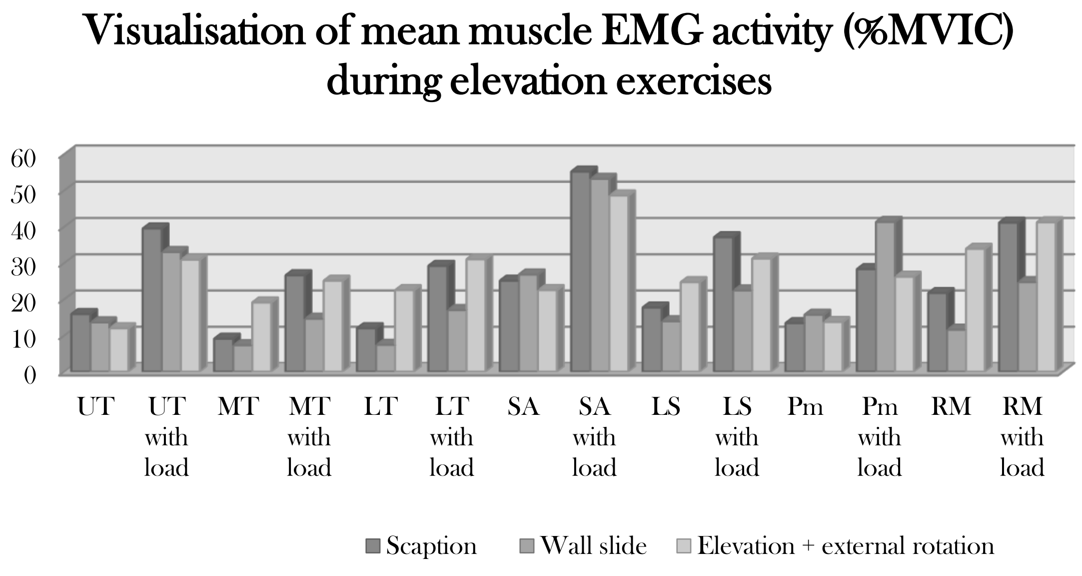


FIGURE 4. Visualization of mean EMG activity (%MVIC) of each scapulothoracic muscle during the different elevation exercises for each load condition. For specific values, see Table 2.

	Upper Trapezius	Middle Trapezius	Lower Trapezius	Serratus Anterior	Levator Scapulae	Pectoralis Minor	Rhomboid Major
Scaption	[blue]				[orange]		[orange]
Wall Slide						[blue]	
Elevation plus external rotation		[blue]	[blue]		[blue]		[blue]

TABLE 3. Summary of the Findings of the Scapulothoracic Muscle Activity During Elevation Exercises in the Scapular Plane Without Additional Load*

*Blue cells indicate the exercise with the highest activity for that particular muscle, significantly higher activity than exercises with blank cells, and not significantly higher activity than exercises marked with orange cells ($P<.05$). Orange cells indicate the exercise in which the activity for that particular muscle is not significantly different from the exercise with the highest activity, but significantly different from exercise marked with blank cells ($P<.05$). Blank cells indicate the exercise in which the activity for that particular muscle is not significantly different from the activity of the other exercises marked with blank cells, but significantly lower activity than the exercises marked with blue or orange cells ($P<.05$).

	Upper Trapezius	Middle Trapezius	Lower Trapezius	Serratus Anterior	Levator Scapulae	Pectoralis Minor	Rhomboid Major
Scaption	[blue]	[blue]	[orange]		[blue]		[orange]
Wall Slide						[blue]	
Elevation plus external rotation		[orange]	[blue]		[orange]		[blue]

TABLE 4. Summary of the Findings of the Scapulothoracic Muscle Activity During Elevation Exercises in the Scapular Plane With Additional Load*

*Blue cells indicate the exercise with the highest activity for that particular muscle, significantly higher activity than exercises with blank cells, and not significantly higher activity than exercises marked with orange cells ($P<.05$). Orange cells indicate the exercise in which the activity for that particular muscle is not significantly different from the exercise with the highest activity, but significantly different from exercise marked with blank cells ($P<.05$). Blank cells indicate the exercise in which the activity for that particular muscle is not significantly different from the activity of the other exercises marked with blank cells, but significantly lower activity than the exercises marked with blue or orange cells ($P<.05$).

Upper Trapezius, Middle Trapezius, Lower Trapezius, and Serratus Anterior Muscle Activity

For the upper trapezius and serratus anterior, no interaction, but a significant main effect for exercise ($F = 11.23$, $P<.001$; $F = 3.11$, $P = .049$, respectively) and load ($F = 340.98$, $P<.001$; $F = 254.6$, $P<.001$, respectively) was found. Post hoc analysis revealed that during scaption, the upper trapezius was significantly more activated than during the wall slide ($P = .005$) and the elevation with external rotation ($P<.001$). Post hoc analysis did not reveal significant differences in serratus anterior activity between exercises. In the loaded condition, the upper trapezius and serratus anterior muscle activity increased significantly ($P<.001$).

A significant exercise-by-load interaction effect was demonstrated for both the middle trapezius ($F = 8.82$, $P<.001$) and lower trapezius ($F = 6.23$, $P = .003$) activity. If the exercise was performed without additional load, the middle trapezius and lower trapezius generated the most activity during elevation with external rotation in comparison with scaption and the wall slide (both

P<.001). With additional load, the pattern changed, and both scaption and elevation with external rotation showed significantly higher middle trapezius and lower trapezius activity than during the wall slide (both *P*<.001). When comparing load conditions, the middle trapezius and lower trapezius muscle activity was significantly higher in the loaded condition for each exercise (*P*<.007).

<u>Levator Scapulae, Pectoralis Minor, and Rhomboid Major Muscle Activity</u>

For the levator scapulae, a significant exercise-by-load interaction was found (F = 4.42, *P* = .015). Without additional load, elevation with external rotation showed significantly higher levator scapulae activity than the wall slide (*P* = .005). No significant differences for levator scapulae activity were found in the unloaded condition between scaption and the wall slide or scaption and elevation with external rotation. With additional load, both scaption and elevation with external rotation showed significantly higher levator scapulae activity than the wall slide (*P*<.001 and *P* = .028, respectively). When comparing load conditions, the levator scapulae muscle activity was significantly higher (*P*<.013) in the loaded condition for each exercise (except elevation with external rotation: (*P* = .055).

For both the pectoralis minor and rhomboid major, no interaction occurred, but significant main effects for exercise (F = 4.04, *P* = .020; F = 35.31, *P*<.001, respectively) and load (F = 42.87, *P*<.001; F = 31.29, *P*<.001, respectively) were found. Post hoc analysis revealed that for the pectoralis minor, the wall slide showed significantly higher activity than scaption (*P* = .007) and elevation with external rotation (*P* = .002). The rhomboid major activity was significantly higher during scaption and elevation with external rotation in comparison with the wall slide (both *P*<.001). In the loaded condition, pectoralis minor and rhomboid major activity increased significantly (*P*<.001).

DISCUSSION

The primary focus of this study was the activity of the different scapulothoracic muscles during different exercises that included a humeral elevation component in the scapular plane. The main findings were that scapulothoracic muscle activity differed significantly between the different elevation exercises. Adding load resulted in a higher recruitment of all muscles, with some muscles showing a different activation pattern between the elevation exercises, depending on the loading. To the best of our knowledge, this is the first study presenting an overview of and comparing both the superficial and deeper-lying scapulothoracic muscle activity during different exercises with an elevation component in the scapular plane.

Without Additional Load

The upper trapezius showed the lowest activity, whereas the middle trapezius and lower trapezius showed the highest activity, during the elevation exercise that included the external rotation component against elastic resistance. In light of these results, it seems that the exercise of elevation with external rotation is appropriate if the main goal is to activate the middle trapezius and lower trapezius. During this exercise, the intensity of serratus anterior activity was not significantly different from the other exercises performed without load. This result is in accordance with the results of Hardwick et al.[14] who did not find significant differences in serratus anterior activity at different angles between the wall slide and the scaption exercise. These results support recommendations that to add an external-rotation component to a scapular exercise movement to optimize scapulothoracic muscle balance when increased middle trapezius and lower trapezius activity is desired.[16] As mentioned in other studies, the external-rotation component enhances the muscle performance of the posterior stabilizing muscles of the shoulder girdle (middle trapezius, lower trapezius, levator scapulae, and rhomboid major).[10,24] The upper trapezius was activated to its highest during scaption. This is in accordance with results from Escamilla et al.[11] and Hardwick et al.[14] who also reported high upper trapezius activity during elevation. The towel wall slide is often subjectively reported to be less demanding than the other elevation exercises. This study demonstrated that during the performance of the towel wall slide, all muscles that function as retractors of the scapula (middle trapezius, lower trapezius, levator scapulae, and rhomboid major) are activated to a lesser degree than during the other elevation exercises. A study by Hardwick et al.[14] also reported lower activity of the lower trapezius during the performance of the wall slide in comparison with the scaption exercise. Nevertheless, the pectoralis minor showed the highest EMG activity during the towel wall slide. This is possibly caused by the "pushing" movement that is required to keep the towel against the wall. The serratus anterior also showed high activity during the towel wall slide. Apparently, the focus lies more on the protraction than the retraction component during the wall slide, and, consequently, it may be an appropriate exercise if activation of the pectoralis minor and serratus anterior is needed without high activation of the middle trapezius, lower trapezius, rhomboid major, and levator scapulae.

With Additional Load

Holding a dumbbell significantly increased the activity of all scapulothoracic muscles during each exercise. The effect of handheld loads was of interest with regard to possible altered patterns between the exercises with and without additional load. For the upper trapezius, lower trapezius, and rhomboid major, there was no difference in the order of the 3 exercises (from highest activity to lowest activity) between exercises with and without additional load. Nevertheless, the addition of a load was associated with a change in the order of ranking of the exercises for the middle trapezius, serratus anterior, pectoralis minor, and levator scapulae. For the middle trapezius, lower trapezius, and levator scapulae, an interaction of exercise by load was found: adding load, both scaption and elevation with external rotation showed significantly higher middle trapezius, lower trapezius or levator scapulae activity compared to the wall slide; unloaded, the elevation with external rotation resulted in significantly higher activity compared with scaption and the wall slide. Although a shift in ranking order of serratus anterior and pectoralis minor activity was found when adding a load, no significant interaction of exercise by load was found. Overall, these results suggest that adding load may result in higher activity for all muscles, and for some muscles this may have an influence on their relative activity levels between the different elevation exercises.

This study was able to demonstrate significant differences in scapulothoracic muscle activity between different elevation exercises. Nevertheless, when interpreting the results of this study, clinicians should bear in mind that some statistically significant differences are rather small and may have limited clinical significance and relevance. For a clinician, it is a challenge to integrate these scientific results into clinical practice. The former exercises can be used during scapulothoracic rehabilitation (in the case of scapulothoracic strength deficits or muscle imbalances during humeral elevation). A summary of the findings from this research is provided in Table 3 (without additional load) and Table 4 (with additional load) (and gives information about which exercises are the most appropriate when the aim is to facilitate specific muscle recruitment). In other research, the activity of the serratus anterior, middle trapezius, and lower trapezius is often found to be decreased in patients with shoulder pain.[8,33] For the activity of the upper trapezius, there is no consensus: some authors advise reducing the activity of the upper trapezius,[8,25,33] whereas others promote the activity of the upper trapezius as an upward rotator in patients with shoulder and neck pain.[28,30,31,36]

Limitations and Strengths of the Study

The present results must also be viewed within the study limitations. As the investigations were only performed on healthy people, it is not clear if a patient population would show the same amount of muscle activity during these exercises. Therefore, extrapolating these results to a patient population should be undertaken with caution. Nevertheless, previous EMG studies have used similar populations in making recommendations for shoulder exercises.[3,8,27,32] Another limitation of this study is that no concurrent kinematic analysis was performed. Investigating scapular movements, along with muscle activity during exercises, would provide additional information (which muscle causes which movement) that clinicians could use to select exercises based on the needs of the patients. It is also a limitation that we did not normalize the Thera-Band load according to each participant's muscle strength. We used a standardized load (red band), which may represent different muscle effort for different individuals. This might have impacted the muscle activity levels.

This study investigated 7 muscle sites using 2 kinds of electrodes, surface and fine-wire electrodes. In view of this fact, caution should be taken when comparing the results between the different muscles' activity (surface versus fine-wire). There is still a debate in the literature as to whether surface electrodes and fine-wire electrodes measure the same way.[4,13,18,19,35] Nevertheless, other studies have also compared surface EMG results with fine-wire EMG results in the shoulder region.[3,37,38] In our study, the amplifier's bandwidth was wide enough for both intramuscular and surface electrode signals, ensuring that the data from the intramuscular electrodes could be accurately compared to those of the surface electrodes once both had been normalized.[38] The data of this study were normalized by expressing the results as percent MVIC, which enabled comparison between muscles. The differences between muscles' activity must be viewed in percent MVIC.

The strength of this study is that it is the first to map out the activity of all scapulothoracic muscles during different elevation exercises, and especially of the deeper muscles such as the pectoralis minor, levator scapulae, and rhomboid major, which currently lack data about their activity. Future research should also clarify the role of the pectoralis minor, levator scapulae, and rhomboid major in normal and abnormal scapular movement, and their possible role in shoulder and neck pain.

CONCLUSION

This study provides an overview of the activity of both the deep and superficial scapulothoracic muscles during commonly used rehabilitation exercises with a humeral elevation component in the scapular plane. Compared to the scaption movement, the exercise with an extra external rotation component seems to be the best option when the goal is to activate the lower trapezius and middle trapezius. The towel wall slide exercise was found to increase pectoralis minor activity. Adding load resulted in higher relative activity levels of all muscles, with some muscles (middle trapezius, lower trapezius, and levator scapulae) showing a different activation pattern between the elevation exercises, depending on the loading. In the condition without load, the middle trapezius and lower trapezius generated the most activity during elevation with external rotation in comparison with scaption and the wall slide. In the loaded condition, the pattern changed, and both scaption and elevation with external rotation showed significantly higher middle trapezius and lower trapezius activity than during the wall slide. For the levator scapulae, elevation with external rotation showed significantly higher activity than the wall slide without additional load. With additional load, both scaption and elevation with external rotation showed significantly higher levator scapulae activity than the wall slide. The findings of this study give information about which elevation exercises a clinician can choose when the aim is to facilitate specific scapulothoracic muscle activity.

REFERENCES

1. Basmajian JV, De Luca CJ. Muscles Alive: Their Functions Revealed by Electromyography. 5th ed. Baltimore, MD: Williams & Wilkins; 1985.
2. Behrsin JF, Maguire K. Levator scapulae action during shoulder movement: a possible mechanism for shoulder pain of cervical origin. Aust J Physiother. 1986;32:101-106. http://dx.doi.org/10.1016/S0004-9514(14)60646-2
3. Boettcher CE, Cathers I, Ginn KA. The role of shoulder muscles is task specific. J Sci Med Sport. 2010;13:651-656. http://dx.doi.org/10.1016/j.jsams.2010.03.008
4. Bogey RA, Perry J, Bontrager EL, Gronley JK. Comparison of across-subject EMG profiles using surface and multiple indwelling wire electrodes during gait. J Electromyogr Kinesiol. 2000;10:255-259.
5. Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. J Orthop Sports Phys Ther. 2005;35:227-238. http://dx.doi.org/10.2519/jospt.2005.35.4.227
6. Castelein B, Cagnie B, Parlevliet T, Danneels L, Cools A. Optimal normalization tests for muscle activation of the levator scapulae, pectoralis minor, and rhomboid major: an electromyography study using maximum voluntary isometric contractions. Arch Phys Med Rehabil. 2015;96:1820-1827. http://dx.doi.org/10.1016/j.apmr.2015.06.004
7. Castelein B, Cools A, Parlevliet T, Cagnie B. Modifying the shoulder joint position during shrugging and retraction exercises alters the activation of the medial scapular muscles. Man Ther. 2016;21:250-255. http://dx.doi.org/10.1016/j.math.2015.09.005
8. Cools AM, Dewitte V, Lanszweert F, et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? Am J Sports Med. 2007;35:1744-1751. http://dx.doi.org/10.1177/0363546507303560
9. Ekstrom RA, Donatelli RA, Soderberg GL. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. J Orthop Sports PhysTher. 2003;33:247-258. http://dx.doi.org/10.2519/jospt.2003.33.5.247
10. Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. Br J Sports Med. 2010;44:319- 327. http://dx.doi.org/10.1136/bjsm.2009.058875
11. Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. Sports Med. 2009;39:663- 685. http://dx.doi.org/10.2165/00007256-200939080-00004
12. Gaunt BW, McCluskey GM, Uhl TL. An electromyographic evaluation of subdividing active-assistive shoulder elevation exercises. Sports Health. 2010;2:424-432.
13. Giroux B, Lamontagne M. Comparisons between surface electrodes and intramuscular wire electrodes in isometric and dynamic conditions. Electromyogr Clin Neurophysiol. 1990;30:397-405.
14. Hardwick DH, Beebe JA, McDonnell MK, Lang CE. A comparison of serratus anterior muscle activation during a wall slide exercise and other traditional exercises. J Orthop Sports Phys Ther. 2006;36:903-910. http://dx.doi.org/10.2519/jospt.2006.2306 505
15. Hodges PW, Kippers V, Richardson CA. Validation of a technique for accurate fine-wire electrode placement into posterior gluteus medius using real-time ultrasound guidance. Electromyogr Clin Neurophysiol. 1997;37:39-47.
16. Holmgren T, Björnsson Hallgren H, Öberg B, Adolfsson L, Johansson K. Effect of specific exercise strategy on need for surgery in patients with subacromial impingement syndrome: randomised controlled study. BMJ. 2012;344:e787. http://dx.doi.org/10.1136/bmj.e787
17. Inman VT, Saunders JB, Abbott LC. Observations of the function of the shoulder joint. 1944. Clin Orthop Relat Res. 1996:3-12.

18. Jaggi A, Malone AA, Cowan J, Lambert S, Bayley I, Cairns MC. Prospective blinded comparison of surface versus wire electromyographic analysis of muscle recruitment in shoulder instability. Physiother Res Int. 2009;14:17-29. http://dx.doi.org/10.1002/pri.407
19. Johnson VL, Halaki M, Ginn KA. The use of surface electrodes to record infraspinatus activity is not valid at low infraspinatus activation levels. J Electromyogr Kinesiol. 2011;21:112-118. http://dx.doi.org/10.1016/j.jelekin.2010.08.007
20. Johnston TB. The movements of the shoulder-joint: a plea for the use of the 'plane of the scapula' as the plane of reference for movements occurring at the humero-scapular joint. Br J Surg. 1937;25:252-260. http://dx.doi.org/10.1002/bjs.1800259803
21. Kibler WB. The role of the scapula in athletic shoulder function. Am J Sports Med. 1998;26:325-337.
22. Kibler WB, Ludewig PM, McClure PW, Michener LA, Bak K, Sciascia AD. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. Br J Sports Med. 2013;47:877-885. http://dx.doi.org/10.1136/bjsports-2013-092425
23. Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. J Am Acad Orthop Surg. 2003;11:142-151.
24. Kibler WB, Sciascia AD, Uhl TL, Tambay N, Cunningham T. Electromyographic analysis of specific exercises for scapular control in early phases of shoulder rehabilitation. Am J Sports Med. 2008;36:1789-1798. http://dx.doi.org/10.1177/0363546508316281 538
25. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther. 2000;80:276-291.
26. Ludewig PM, Cook TM, Nawoczenski DA. Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. J Orthop Sports Phys Ther. 1996;24:57-65. http://dx.doi.org/10.2519/jospt.1996.24.2.57
27. Moseley JB, Jr., Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. Am J Sports Med. 1992;20:128-134.
28. Mottram SL, Woledge RC, Morrissey D. Motion analysis study of a scapular orientation exercise and subjects' ability to learn the exercise. Man Ther. 2009;14:13-18. http://dx.doi.org/10.1016/j.math.2007.07.008
29. Perotto A, Delagi EF. Anatomical Guide for the Electromyographer: The Limbs and Trunk. 3rd ed. Springfield, IL: Charles C. Thomas; 1994.
30. Pizzari T, Wickham J, Balster S, Ganderton C, Watson L. Modifying a shrug exercise can facilitate the upward rotator muscles of the scapula. Clin Biomech (Bristol, Avon). 2014;29:201-205. http://dx.doi.org/10.1016/j.clinbiomech.2013.11.011
31. Sahrmann SA. Diagnosis and Treatment of Movement Impairment Syndromes. St Louis, MO: Mosby; 2001.
32. Smith J, Padgett DJ, Dahm DL, et al. Electromyographic activity in the immobilized shoulder girdle musculature during contralateral upper limb movements. J Shoulder Elbow Surg. 2004;13:583-588. http://dx.doi.org/10.1016/j.jse.2004.03.010
33. Struyf F, Cagnie B, Cools A, et al. Scapulothoracic muscle activity and recruitment timing in patients with shoulder impingement symptoms and glenohumeral instability. J Electromyogr Kinesiol. 2014;24:277-284. http://dx.doi.org/10.1016/j.jelekin.2013.12.002
34. Szucs KA, Borstad JD. Gender differences between muscle activation and onset timing of the four subdivisions of trapezius during humerothoracic elevation. Hum Mov Sci. 2013;32:1288-1298. http://dx.doi.org/10.1016/j.humov.2013.05.003
35. Waite DL, Brookham RL, Dickerson CR. On the suitability of using surface electrode placements to estimate muscle activity of the rotator cuff as recorded by intramuscular electrodes. J Electromyogr Kinesiol. 2010;20:903-911. http://dx.doi.org/10.1016/j.jelekin.2009.10.003

36. Watson LA, Pizzari T, Balster S. Thoracic outlet syndrome part 2: conservative management of thoracic outlet. Man Ther. 2010;15:305-314. http://dx.doi.org/10.1016/j.math.2010.03.002
37. Wattanaprakornkul D, Cathers I, Halaki M, Ginn KA. The rotator cuff muscles have a direction specific recruitment pattern during shoulder flexion and extension exercises. J Sci Med Sport. 2011;14:376-382. 580 http://dx.doi.org/10.1016/j.jsams.2011.01.001
38. Wickham J, Pizzari T, Stansfeld K, Burnside A, Watson L. Quantifying 'normal' shoulder muscle activity during abduction. J Electromyogr Kinesiol. 2010;20:212- 222. http://dx.doi.org/10.1016/j.jelekin.2009.06.004
39. Wilk KE, Arrigo C. Current concepts in the rehabilitation of the athletic shoulder. J Orthop Sports Phys Ther. 1993;18:365-378. http://dx.doi.org/10.2519/jospt.1993.18.1.365
40. Yoshizaki K, Hamada J, Tamai K, Sahara R, Fujiwara T, Fujimoto T. Analysis of the scapulohumeral rhythm and electromyography of the shoulder muscles during elevation and lowering: comparison of dominant and nondominant shoulders. J Shoulder Elbow Surg. 2009;18:756-763. 591 http://dx.doi.org/10.1016/j.jse.2009.02.021

CHAPTER 6:

SERRATUS ANTERIOR OR PECTORALIS MINOR: WHICH MUSCLE HAS THE UPPER HAND DURING PROTRACTION EXERCISES?

BIRGIT CASTELEIN, PT[1]; BARBARA CAGNIE, PT, PHD[1]; THIERRY PARLEVLIET, MD[2] ; ANN COOLS, PT, PHD[1]

[1] DEPARTMENT OF REHABILITATION SCIENCES AND PHYSIOTHERAPY, GHENT UNIVERSITY, GHENT, BELGIUM

[2] DEPARTMENT OF PHYSICAL MEDICINE AND ORTHOPAEDIC SURGERY, UNIVERSITY HOSPITAL, GHENT, BELGIUM

MANUAL THERAPY; 2016 APRIL; 22:158-64.

(SCI=1.714, Q2)

ABSTRACT

Background: The Serratus Anterior (SA) has a critical role in stabilizing the scapula against the thorax. Research has linked shoulder and neck disorders to impairments in the SA activation. Exercises that target the SA are included in the rehabilitation of shoulder or neck pain and mostly include a protraction component. The Pectoralis Minor (PM) functions as a synergist of the SA. From the literature it is unclear to what extent PM is activated during SA exercises.

Objectives: To determine the activity of SA and PM during different protraction exercises.

Design: Controlled laboratory study.

Method: 26 subjects performed 3 exercises: Modified Push-Up Plus (Wall Version), Modified Knee Push-Up Plus (Floor version) and Serratus Punch. Electromyographic (EMG) data was collected from the SA (surface) and PM (fine-wire EMG).

Results: During the Serratus Punch the SA activity was significantly higher than the PM activity. During the Modified Push-Up Plus exercises (both Wall and Floor version), the SA and PM activity were comparable. The PM showed the highest activity during the Serratus Punch and the Modified Push-Up Plus (Floor), which was significantly higher than during the Modified Push-Up Plus (Wall). The SA showed the highest activity during the Serratus Punch, which was significantly higher than during the Modified Push-Up Plus (Floor) which was in turn significantly higher than the activity during the Modified Push-Up Plus (Wall).

Conclusions: All exercises activated the PM between 15 and 29% Maximum Voluntary Isometric Contraction and the SA between 15 and 43%. The Modified Push-Up Plus exercise against the wall and the floor activated the SA and PM to a similar degree. When maximum activation of the SA with minimal activation of the PM is desired in healthy subjects, the “Serratus punch” seems to be the optimal exercise.

1. INTRODUCTION

Among the muscles attached to the scapula, the Serratus Anterior (SA) muscle has a critical role in stabilizing the scapula against the thorax (Lear and Gross, 1998; Smith et al., 2003). Additionally, SA contributes to all components of the movement of the scapula during elevation of the arm: upward rotation, protraction and external rotation[1] (Lear and Gross, 1998). Research has linked shoulder and neck disorders to impairments in the activation of the SA muscle (weakness, fatigue, timing problems) (Glousman et al., 1988; Scovazzo et al., 1991; Wadsworth and Bullock-Saxton, 1997; Ludewig and Cook, 2000; Helgadottir et al., 2011; Sheard et al., 2012; Larsen et al., 2013). Therefore, various exercises that target the SA are included in the rehabilitation of patients with shoulder or neck pain (Moseley et al., 1992; Andersen et al., 2014; De Mey et al., 2014; Piraua et al., 2014).

Exercises that have been prescribed to predominantly activate the SA mostly include a protraction component. Push-Up exercises are known to be one of the most effective exercises for activating the SA. The Push-Up exercise is a closed kinetic chain exercise performed in a prone position by raising and lowering the body using the arms. Studies showed that the "plus-phase" of the Push-Up exercise shows the highest SA activation as compared with other SA activation exercises (Decker et al., 1999; Ludewig et al., 2004). The "plus-phase" involves posterior translation of the thorax on relatively fixed scapulae, which can be done alone or along with push-ups (Hardwick et al., 2006). Ludewig et al. (2004) suggested that the SA was selectively activated to a greater extent in "Push-Up Plus" than in standard Push-Up exercises. Different modifications on the Push-Up Plus exercises are commonly used in clinical practice: Push-ups can be performed either on the floor ("Floor Push-Up Plus") or against the wall ("Wall Push-Up Plus"), supported on elbow ("Elbow Push-Up Plus"), or hands or feet or knee ("Knee Push-Up Plus"). Alternatively, the "Serratus Punch" (=performing protraction in open kinetic chain) is an exercise that is also often used to activate the SA (Escamilla et al., 2009; Liebenson, 2012).

The Pectoralis Minor (PM) functions as a synergist of the SA. Both the SA and the PM engage in the protraction movement of the scapula. From the literature it is unclear to what extent PM is activated during SA exercises. Apart from the protraction movement, the PM also causes, downward rotation, depression and anterior tilting of the scapula (Oatis, 2004). Overuse of this PM might result in adaptive shortening of the muscle. A shortened PM has been identified as a risk factor that contributes to abnormal scapular positioning (Tate et al., 2012).

[1] Different authors cited in the article use different terminology for same movements: i.e. for scapular rotations: upward (lateral or external)/downward (medial or internal) rotation, anterior/posterior tilt and internal/external rotation. Protraction/retraction and elevation/depression are often described as movements of the clavicle (Helgadottir et al., 2010).

When PM lacks extensibility the scapula is anteriorly tilted and internally rotated (Borstad, 2008), which may lead to the development and perpetuation of upper limb symptoms (rounded shoulder posture, glenohumeral joint dysfunction, subacromial impingement) (Borstad, 2008; Lynch et al., 2010; Wong et al., 2010; Tate et al., 2012; Struyf et al., 2014). Clinical theories (Borstad and Ludewig, 2005; Ludewig and Reynolds, 2009; Cools et al., 2014b) suggest that motor strategy favoring activity in PM over SA is thought to be detrimental. So when performing exercises that include a protraction movement aiming to activate the SA, it is important to know the influence of that exercise on the activation of the PM.

Several studies have investigated SA activity during different SA exercises (Moseley et al., 1992; Decker et al., 1999; Ludewig et al., 2004; Maenhout et al., 2010; De Mey et al., 2014; Park et al., 2014; Piraua et al., 2014). To date, only one study of Moseley et al. (1992) investigated also the Pm activity (and SA activity) during 2 protraction exercises: “Push-Up with hands apart” and “Push-Up with a Plus”. They found these 2 exercises optimal (>50% maximum manual muscle strength test) for both SA and PM, but did not compare muscle activity between muscles or exercises. Moreover, they did not concentrate on the plus-phase, but on the whole exercise. Consequently, EMG investigations are necessary in order to address this current deficit in our knowledge regarding the muscle balance between the SA and PM during exercises that are thought to activate the SA.

Therefore, the purpose of this study was to investigate the EMG activity of the PM and the SA during 3 protraction exercises: (a) the “Modified Push-Up Plus” (Wall Version) (b) the “Modified Knee Push-Up Plus” (Floor Version) and (c) the “Serratus Punch”.

2. METHODS

2.1. Subjects

Twenty-six subjects (15 female, 11 male, mean age 33.3 ± 12.4, ranging from 21 to 56 years old, weight 67.1 ± 9.2 kg, height 174.2 ± 8.2 cm) participated in this study. The choice for the sample size was based on previous research in that area, that investigated differences in SA activity between exercises (Decker et al., 1999; Ludewig et al., 2004; Hardwick et al., 2006; De Mey et al., 2014; Park et al., 2014; Piraua et al., 2014) and that investigated both SA and PM activity (Moseley et al., 1992). Descriptive characteristics of the subject group can be found in Table 1.

	Women	Men	Total
N	15	11	26
Age (years)	31.9 ± 12.8	35.3 ± 12.4	33.3 ± 12.4
Weight (kg)	62.7 ± 7.3	73.2 ± 7.6	67.1 ± 9.2
Height (cm)	169.2 ± 6.2	181.0 ± 4.6	174.2 ± 8.2

Table 1. Descriptive characteristics of the subjects

Data reported as mean ± Standard deviation (SD).

All subjects were free from current or past shoulder or neck pain and demonstrated full pain-free range of motion of both shoulders. They did not perform overhead sports nor upper limb strength training for more than 6 h/ week. Investigation of the in- and exclusion criteria was performed by a clinical expert with several years of experience. Written informed consent was obtained from all participants. The study was approved by the ethics committee of Ghent University Hospital.

2.2. General design

EMG data was collected from the SA and the PM on the dominant side of each subject during the performance of the Modified Push-Up Plus (Wall Version), the Modified Knee Push-Up Plus (Floor version) and the Serratus Punch.

2.3. Test procedure

The experimental session began with a short warm-up procedure with multidirectional shoulder movements, followed by the performance of the maximum voluntary isometric contractions (MVIC) of the muscles of interest. These data are needed for normalization of the EMG signals. A set of different isometric MVIC test positions was completed to allow normalization of the EMG data (Castelein et al., 2015). These consisted of the following:

1. "Abduction 90" (sitting)
2. "Horizontal Abduction with external rotation" (prone lying)
3. "Arm raised above head in line with Lower Trapezius (LT) muscle fibers" (prone lying)
4. "Shoulder flexion 135" (sitting)
5. "Arm raised above head in line with PM muscle fibers" (supine lying)

All MVICs were performed prior to the exercises, except for the MVIC "Arm raised above head in line with PM muscle fibers". This MVIC was performed in supine lying and was always performed at the end (after the exercises) to avoid pressure on the electrodes of the dorsal muscles (due to their contact with the examination table because of the supine position) until all exercises were performed. Each MVIC test position was performed 3 times (each of the contractions lasted for 5 s-controlled by a metronome) with at least 30 s rest between the different repetitions. There was a rest period of at least 1.5 min between the different test positions. Manual pressure was always applied by the same investigator and strong and consistent encouragement from the investigator was given during each MVIC to promote maximal effort. Before data collection, MVIC test positions were taught to each subject by the same investigator, and sufficient practice was allowed.

In the second part of the investigation, the subject performed 5 repetitions of 3 different exercises (Table 2). The exercises were performed randomly. Before data collection, the subject was given a visual demonstration of each exercise by the investigator. Each exercise consisted of a concentric protraction phase of 3 s and an eccentric retraction phase of 3 s. A metronome was used to control and standardize the velocity speed of the movement (60 beeps/ min). When the participants were able to perform the proper movement pattern and timing of the exercise, EMG data were collected from 5 repetitions of each exercise with 5 s of rest in between each trial. Between each exercise set, a break of 1.5 min was provided.

Name	Description of the exercise	Figure
Modified Push-Up Plus (Wall version)	Participant standing in front of the wall, on a distance that is determined by the length of the forearm plus one big step. The hands are placed on the wall on shoulder width with the participants hands pointed to the ceiling The arms are parallel to the floor.The starting position is in maximal scapular retraction. From this position, the patient rolls the shoulders forward (scapular protraction) during 3s and then lowers the body during 3s while allowing the shoulder blades to approximate (scapular retraction). The elbows are in full extension during the whole exercise and the head is kept in-line with the trunk and vertebral column.	
Modified Knee Push-Up Plus (Floor version)	Participant taking place on a bench, with support on knee and hands. The hands are placed on shoulder width with the subjects hands under the acromioclavicular joint. The arms are perpendicular to the floor. The head, trunk and knees are in one line. The starting position is in maximal retraction. From this position, the patient rolls the shoulders forward (scapular protraction) during 3s and then lowers the body while allowing the shoulder blades to approximate (scapular retraction). The elbows are in full extension during the whole exercise and the head is kept in-line with the trunk and vertebral column. During the test, the subject looks at the floor with no cervical rotation, flexion, or extension.	
Serratus Punch	Participant standing with the back to the pulley apparatus (1m), with the shoulder in 90° of forward flexion. The starting position is a scapular retracted position. The participant performs scapular protraction with elbow extended (3s protraction – 3s retraction). The subjects maintains neutral spinal alignment, and does not rotate or lean forward. The contralateral hand is placed at the anterior superior iliac spine for feedback concerning neutral pelvis alignment. *The amount of load of the pulley resistance is determined based on sex and body weight. For female subjects, the dumbbell load is always 2.5kg (independent of the weight of the subject), whereas in male subjects the load is allocated according to the weight of the subject (7kg, 8kg or 10kg for respectively 60-69kg, 70-79kg and 80-89kg).This approach was based on results from a pilot study.	

TABLE 2. Description of the exercises

2.4 Instrumentation

A TeleMyo 2400 G2 Telemetry System (Noraxon Inc., Scottsdale, AZ) was used to collect the EMG data. Bipolar circular surface electrodes (Ag/AgCl, Ambu® Blue Sensor, Medicotest, Type N-00-S 22 mm, Ballerup, Denmark) were used to collect EMG data from the SA. They were placed with a 1 cm interelectrode distance over the SA, according to the to the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) Project Recommendations (Hermens et al., 2000; Cools et al., 2007; De Mey et al., 2009; Maenhout et al., 2010). A reference electrode was placed over the spinous process of C7 vertebrae. Before surface electrode application, the skin surface was shaved, cleaned and scrubbed with alcohol to reduce impedance (<10 kOhm). Intramuscular paired-hook fine-wire electrodes (Carefusion Middleton, WI, USA, wire length 125 mm) were used to measure the EMG activity of the PM. They were inserted into the muscle belly on the midclavicular line to the anterior surface of the third rib (according to the locations described by Delagi et al. (1994) using a single-use 25-gauge hypodermic needle). This was done using real-time ultrasound guidance, which has been shown to be an accurate and repeatable method of intramuscular electrode placement (Hodges et al., 1997). The surface and intramuscular electrodes were looped and taped on the skin to prevent them from being accidentally removed during the experiment and to minimize movement artifacts. The sampling rate was 3000 Hz. All raw myo-electric signals were preamplified (overall gain = 1000, common mode rejection ratio of 100 dB, baseline noise < 1 mV root-mean-square).

2.5. Signal processing and data analysis

The Myoresearch 3.4 Master Edition Software Program was used for signal processing. The EMG signals were filtered with a high pass Butterworth filter of 20 Hz. Cardiac artifact reduction was performed, followed by rectification and smoothing (root mean square, window 100 ms) of the signals. The EMG data for each muscle and each participant was averaged for each exercise across the 3 intermediate repetitions of the 5 repetitions completed. The first and fifth repetitions were not used to control for distortion due to habituation or fatigue. These EMG data were normalized and expressed as a percentage of their MVIC. For each MVIC, the average EMG value was calculated over a window of the peak 2.5 s of the 5 s. The average of the 3 trials was used for normalization. All MVIC test positions were analyzed for each muscle (except the PM activity was not analyzed during prone lying MVIC test positions). The normalization value (100%) was the highest value for that muscle recorded during the MVIC tests.

2.6. Statistical analysis

SPSS 22.0 was used for statistical analysis. Means ± standard deviations were calculated for the normalized EMG values (in % of MVIC). A linear mixed model was applied to determine if there were significant differences in EMG activity between “muscles” (SA, PM) and “exercises” (“Modified Push-Up Plus” (Wall Version), “Modified Knee Push-Up Plus” (Floor Version) and the “Serratus Punch”) and “gender”. The residuals of the linear mixed models were checked for normal distribution. Post-hoc pairwise comparisons were performed using a Bonferroni correction. An alpha level of 0.05 was applied to all the data in determining significant differences.

3. RESULTS

Results of the Linear Mixed Models are shown in Table 3.

Effects	**Significance of corresponding p-value**
Muscle*exercise*phase*gender	Not significant
Exercise*phase*gender	Not significant
Muscle*phase*gender	Not significant
Muscle*exercise*gender	Not significant
Muscle*exercise*phase	Not significant
Muscle*exercise	Significant
Muscle*phase	Significant
Exercise*gender	Not significant
Muscle*gender	Not significant
Phase*gender	Not significant
Exercise*phase	Not significant
Exercise	Significant
Muscle	Significant
Phase	Significant
Gender	Not significant

TABLE 3. Results of statistical analysis of the different main factors and interaction effects. Statistical significance was accepted at $p < 0.05$.

The Linear Mixed Model showed a significant muscle*exercise ($p < 0.002$; F = 7468, df1 = 2, df2 = 261,496) and muscle*phase ($p < 0.001$; F = 31,369, df1 =1, df2 = 260,241) interaction effect. No gender difference was detected for the EMG data. The mean muscle EMG activity for the PM and SA during each exercise (the Serratus Punch, the Modified Push-Up Plus (Wall Version) and the Modified Knee Push-Up Plus (Floor version)) is provided in Fig. 1.

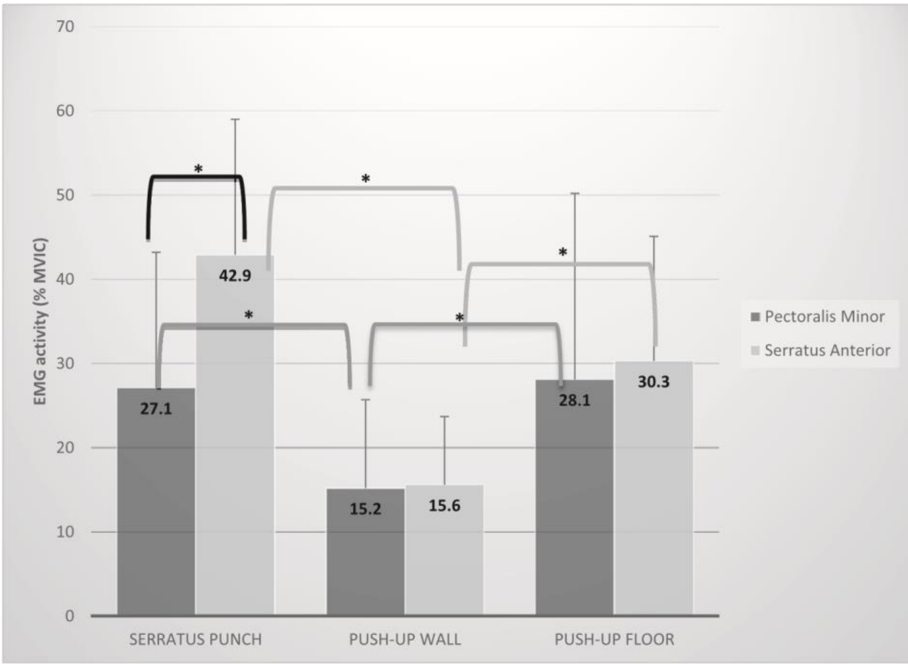


FIGURE 1. EMG activity (%MVIC ± SD) of the Pectoralis Minor and Serratus Anterior during Serratus Punch, Modified Push-Up Plus Wall Version (Push-Up Wall) and Modified Push-Up Plus Floor version (Push-Up Floor), * = $p < 0.05$.

Regarding the muscle*exercise interaction effect, post-hoc tests revealed an increased RMS EMG activity of 15.8% for the SA compared to PM during the Serratus Punch ($p < 0.002$). During the Modified Push-Up Plus (both Wall and Floor version), the amount of SA activity and PM activity were comparable, and did not differ significantly from each other. When comparing the muscle activity between the exercises, the PM showed the highest activity during the Serratus Punch and the Modified Push-Up Plus (Floor version), and this was significantly higher than during the Modified Push-Up Plus (Wall Version) ($p = 0.002$ and $p < 0.001$). The SA showed the highest activity during the Serratus Punch, which was significantly higher than during the Modified Push-Up Plus (Floor Version) ($p < 0.001$) which was in turn significantly higher than the activity during the Modified Push-Up Plus (Wall version) ($p < 0.001$).

Regarding the muscle*phase interaction effect, post-hoc tests showed that during the concentric phase of the protraction exercises, the SA activity was significantly higher than the PM activity ($p < 0.001$). Also, the SA showed significantly higher activity during the concentric phase in comparison with the eccentric phase of the protraction exercises ($p < 0.001$). Mean (±SD) muscle EMG activity of the PM and SA during each phase (concentric and eccentric) of the exercise is provided in Table 4.

	Concentric Phase		Eccentric Phase		Whole Movement	
	Pm activity	**SA activity**	**Pm activity**	**SA activity**	**Pm activity**	**SA activity**
Serratus punch	23.0 ± 13.8	51.5 ± 21.1	29.5 ± 17.3	32.0 ± 13.8	27.1 ± 16.1	42.9 ± 20.2
Modified Push-Up Plus Wall version	13.5 ± 9.7	21.0 ± 10.8	16.8 ± 11.9	10.1 ± 6.8	15.2 ± 10.9	15.2 ± 10.5
Modified Push-Up Plus Floor version	27.9 ± 21.4	39.7 ± 19.6	28.3 ± 24.0	21.0 ± 12.3	28.1 ± 22.5	30.3 ± 18.8

TABLE 4. EMG activity (% MVIC ± SD) of the Pectoralis Minor and Serratus Anterior during each phase (concentric and eccentric) of each exercise.

4. DISCUSSION

Patients with shoulder and neck pain are often recommended to include exercises that focus on SA in their rehabilitation program. From a clinical point of view, it is of interest what the role of the PM is during the performance of these protraction exercises. Exercises that highly activate the SA muscle while minimizing activation in the PM are generally preferred. To our knowledge, this is the first study to compare the muscle activity of the SA and the PM during protraction exercises.

The main finding of the study was that the Serratus Punch exercise seems the best exercise when the aim is to highly activate the SA with minimum activation of the PM. The Modified Push-Up Plus exercises, both in floor and wall version, did activate the PM and the SA to a similar extent. When only focusing on the concentric phase of the exercises, the SA was significantly more activated than the PM in all exercises.

The SA activity during the "Serratus Punch" was found to be the highest of the three exercises. This result is in agreement with previously published research. Cools et al. (2014a) also found that the "Serratus punch" elicited higher activity of the SA in comparison with the "Knee Push-Up Plus". The amount of EMG activity is also in line with the results from Cools et al. (2014a) and Decker et al. (1999). Cools et al. (2014a) found an EMG activity of the SA of 42.7 ± 15.49% MVIC during "Serratus Punch", while our study found an EMG activity of 42.9 ± 16.1% MVIC. For the "Knee Push-Up Plus", our study found an SA EMG activity of 30.3 ± 14.8%MVIC which is in line with the results of Cools et al. (2014a) (37.0 ± 18.12% MVIC) and Decker et al. (1999) (for the protraction phase 42.1 ± 15.4%MVIC and for the retraction phase 35.2 ± 12.7% MVIC). In addition, the "Serratus Punch" was the only exercise in which the activity of the PM was significantly lower than that of the SA, which meets the criteria of good PM/SA ratio.

Despite this good PM/SA ratio (significantly lower PM activity than the SA) it should be noted that the PM is more activated in comparison with the Modified Push-Up Plus wall version (see Fig. 1). Another advantage of the Serratus Punch is that it is performed in a standing position, which is a very functional position, contrary to the positions of the other exercises. The Modified Push-Up Plus wall version showed the lowest PM EMG activity. The Serratus Punch and the Modified Push-Up Plus exercises differ in their performance: the Serratus Punch can be seen as an open kinetic chain exercise, while the Push-Up Plus is a closed kinetic chain exercise. In case of the open kinetic chain, the arm is moving relative to the thorax, which could be one of the reasons why SA is working more in comparison with the PM. This is in contrast with the closed kinetic chain exercises, in which the thorax is moving relative to the arm. In these closed kinetic chain exercises, the SA and PM work to the same extent.

We believe that these results and recommendations can help clinicians in the choice of exercises for scapular rehabilitation. These Push-Up Plus exercises can be used in treatment of scapulothoracic muscle imbalance. Janda describes muscle imbalance as an impaired relationship between muscles prone to facilitation and muscles prone to inhibition (Quesnele, 2011). However, new theories state that imbalance between muscle activity is redistributed within and between muscles, rather than stereotypical inhibition or excitation of muscles (Hodges, 2011). They state that muscle activity can be variable with the objective to "protect" the tissue from further pain or injury. This strategy has short-time benefit, but with potential long-term consequences due to factors as increased load, decreased movement, and decreased variability. The PM and SA are both agonists (for protraction), but also antagonists (SA: upward and external rotation - PM: downward and internal rotation). According to Janda's approach, the PM is part of the tonic system muscles which is prone to tightness or shortness, whereas the SA is part of the phasic system muscle which is prone to weakness or inhibition. Sherrington's law of reciprocal inhibition states that a hypertonic antagonist (PM) muscle may be reflexively inhibiting the agonist (SA) (Sherrington, 1907). Therefore, in the presence of overactive or tight antagonistic muscles, restoring normal muscle tone/activation must first be addressed before attempting to activate a weakened or inhibited muscle. In clinical practice, scapular rehabilitation often starts with stretching of the PM in order to address the adaptive shortening and to reposition the scapula (Ellenbecker and Cools, 2010; Lynch et al., 2010). This is followed by training of the scapular stabilizing muscles. However, sometimes the benefit of these interventions remains unsatisfactory. A possible reason for this recurrence could be that, notwithstanding the fact that the PM is stretched to reposition the scapula, the adaptive shortening of the PM can possibly return because of activation of this muscle during scapular exercises. Overactivation of the PM results in malaligned scapula as it pulls the scapula anteriorly. An anteriorly tipped position of the scapula brings the scapular stabilizing muscles in a lengthened position and this affects their ability to control scapular position at rest as well as during motion (McClure et al., 2012; Tate et al., 2012; Kibler et al., 2013). The nature of this dysfunction impacts on the type of exercise required to restore this stabilizing or supporting role. Therefore it is important to choose the appropriate exercises when the goal is to activate the SA.

Although the exercises did not lead to a high activation of the PM (all protraction exercises activated the PM between 15 and 29% MVIC), we still believe it is recommended to take these results into account when making decisions for rehabilitation. The Push-Up Plus exercises can be used with increasing level of challenge. Since fatigue is a predisposing factor to compensated movement patterns, endurance is more important than absolute strength of the muscles. Endurance of the muscles is increased through repetitive, coordinated exercises at low intensities and high volumes.

Some limitations should be taken into account when interpreting the results of this study. A first limitation of this study is the comparison of surface EMG data from the SA with fine wire EMG data from the PM. Nevertheless, other studies have also compared surface EMG results with fine-wire EMG results in the shoulder region (Boettcher et al., 2010; Wickham et al., 2010; Wattanaprakornkul et al., 2011). Additionally, a difference in workload for the two genders was used in this study for the Serratus Punch exercise. The workload for this exercise was determined based on a pilot study to define the appropriate weight for performing 3 sets of 10 repetitions. This difference in load might influence the motor strategy of men and women although this was not shown in the statistical analysis (Table 3), but the analysis might have been underpowered to identify a possible difference. Nevertheless, a similar approach for determining workload has previously been used in other studies too (Cools et al., 2007, 2014a).

Third, it is a limitation that we did not measure the distance to the wall for each of the participants when performing the Modified Push-Up Plus Wall version. Nevertheless, we believe that the method “the length of the forearm plus one big step” did not lead to differences in shoulder angles between the different participants that would significantly affect the results. Additionally, as we only collected data after the participants had shown ability to perform proper movement and timing of the exercise, it is a limitation that there might have been a difference in how much training each subject received to get this movement and timing correct. Another limitation is the lack of kinematic data during the protraction exercises in our study. It should also be noted that extrapolation of the results to other population groups should be performed with caution.

Furthermore, we should note that although our results show that the Modified Push-Up Plus versions on the floor and on the wall lead to an activation of both the SA and PM in a similar degree, no proof has been given that training with Modified Push-Up Plus exercises effectively leads to overactivity of the PM and to compensation patterns. Some further investigations might be interesting to perform. The influence of other muscles, such as the Pectoralis Major during these protraction exercises could be of interest. The Pectoralis Major is known to be in close relationship with the PM, as it also attaches to the anterior chest wall. As this muscle is also often too active, it might be relevant for future research to investigate the muscle activation during these exercises (Park et al., 2014). The study could also be repeated with a group of patients suffering from shoulder or neck pain. Subsequently, comparing the results of that study with the current investigation could be relevant because this would give more insight into how the pain condition impacts the muscle recruitment during each exercise.

5. CONCLUSION

PM and SA activity were investigated during different exercises that focus on SA activation (Serratus Punch, Modified Push-Up Plus Wall version, Modified Push-Up Plus Floor version). All exercises activated the PM between 15 and 29% MVIC and the SA between 15 and 42%MVIC. The Modified Push-Up Plus exercises against the wall and the floor activated the PM to a similar degree as the SA. When maximum activation of the SA with minimal activation of the PM is desired in healthy subjects, the “Serratus punch” seems to be the optimal exercise.

REFERENCES

Andersen CH, Andersen LL, Zebis MK, Sjogaard G. Effect of scapular function training on chronic pain in the neck/shoulder region: a randomized controlled trial. J Occup Rehabil 2014;24:316-24.

Boettcher CE, Cathers I, Ginn KA. The role of shoulder muscles is task specific. J Sci Med Sport/Sports Med Aust 2010;13:651-6.

Borstad JD. Measurement of pectoralis minor muscle length: validation and clinical application. J Orthop Sports Phys Ther 2008;38:169-74.

Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. J Orthop Sports Phys Ther 2005;35:227-38.

Castelein B, Cagnie B, Parlevliet T, Danneels L, Cools AM. Optimal normalization tests for muscle activation of the levator scapulae, pectoralis minor and rhomboid major: an electromyographic study using maximum voluntary isometric contractions. Arch Phys Med Rehabil 2015;96(10):1820-7. http:// dx.doi.org/10.1016/j.apmr.2015.06.004. Epub 2015 Jun 26.

Cools AM, Borms D, Cottens S, Himpe M, Meersdom S, Cagnie B. Rehabilitation exercises for athletes with biceps disorders and SLAP lesions: a continuum of exercises with increasing loads on the biceps. Am J Sports Med 2014a;42: 1315-22.

Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B, et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? Am J Sports Med 2007;35:1744-51.

Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. Br J Sports Med 2014b;48:692-7.

De Mey K, Cagnie B, Danneels LA, Cools AM, Van de Velde A. Trapezius muscle timing during selected shoulder rehabilitation exercises. J Orthop Sports Phys Ther 2009;39:743-52.

De Mey K, Danneels L, Cagnie B, Borms D, T'Jonck Z, Van Damme E, et al. Shoulder muscle activation levels during four closed kinetic chain exercises with and without Redcord slings. J Strength Cond Res/Natl Strength Cond Assoc 2014;28: 1626-35.

Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. Am J Sports Med 1999;27:784-91.

Delagi E, Perpotto A, Morrison D. Anatomical guide for the electromyographer. The limbs and trunk. Springfield: Charles C Thomas Publisher; 1994.

Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. Br J Sports Med 2010;44: 319-27.

Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. Sports Med Auckl NZ 2009;39:663-85.

Glousman R, Jobe F, Tibone J, Moynes D, Antonelli D, Perry J. Dynamic electromyographic analysis of the throwing shoulder with glenohumeral instability. J Bone Jt Surg Am Vol 1988;70:220-6.

Hardwick DH, Beebe JA, McDonnell MK, Lang CE. A comparison of serratus anterior muscle activation during a wall slide exercise and other traditional exercises. J Orthop Sports Phys Ther 2006;36:903-10.

Helgadottir H, Kristjansson E, Einarsson E, Karduna A, Jonsson Jr H. Altered activity of the serratus anterior during unilateral arm elevation in patients with cervical disorders. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2011;21: 947-53.

Helgadottir H, Kristjansson E, Mottram S, Karduna AR, Jonsson Jr H. Altered scapular orientation during arm elevation in patients with insidious onset neck pain and whiplash-associated disorder. J Orthop Sports Phys Ther 2010;40:784-91.

Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2000;10:361-74.
Hodges PW. Pain and motor control: from the laboratory to rehabilitation. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2011;21:220-8.
Hodges PW, Kippers V, Richardson CA. Validation of a technique for accurate finewire electrode placement into posterior gluteus medius using real-time ultrasound guidance. Electromyogr Clin Neurophysiol 1997;37:39-47.
Jairus Quesnele DC. The assessment and treatment of muscular imbalance : the Janda approach. Man Ther 2011;16:4.
Kibler WB, Ludewig PM, McClure PW, Michener LA, Bak K, Sciascia AD. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. Br J Sports Med 2013;47:877-85.
Larsen CM, Sogaard K, Chreiteh SS, Holtermann A, Juul-Kristensen B. Neuromuscular control of scapula muscles during a voluntary task in subjects with subacromial impingement syndrome. A caseecontrol study. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2013;23:1158-65.
Lear LJ, Gross MT. An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. J Orthop Sports Phys Ther 1998;28: 146-57.
Liebenson C. The serratus punch. J Bodyw Mov Ther 2012;16:268-9.
Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276-91.
Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. Am J Sports Med 2004;32:484-93.
Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther 2009;39:90-104.
Lynch SS, Thigpen CA, Mihalik JP, Prentice WE, Padua D. The effects of an exercise intervention on forward head and rounded shoulder postures in elite swimmers. Br J Sports Med 2010;44:376-81.
Maenhout A, Van Praet K, Pizzi L, Van Herzeele M, Cools A. Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity? Br J Sports Med 2010;44:1010-5.
McClure P, Greenberg E, Kareha S. Evaluation and management of scapular dysfunction. Sports Med Arthrosc Rev 2012;20:39-48.
Moseley Jr JB, Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. Am J Sports Med 1992;20: 128-34.
Oatis CA. Kinesiology: the mechanics and pathomechanics of human movement. Lippincott: Williams & Wilkins; 2004.
Park KM, Cynn HS, Kwon OY, Yi CH, Yoon TL, Lee JH. Comparison of pectoralis major and serratus anterior muscle activities during different push-up plus exercises in subjects with and without scapular winging. J Strength Cond Res/Natl Strength Cond Assoc 2014;28:2546-51.
Piraua AL, Pitangui AC, Silva JP, Pereira dos Passos MH, Alves de Oliveira VM, Batista LS, et al. Electromyographic analysis of the serratus anterior and trapezius muscles during push-ups on stable and unstable bases in subjects with scapular dyskinesis. J Electromyogy Kinesiol Off J Int Soc Electrophysiol Kinesiol 2014;24: 675-81.
Scovazzo ML, Browne A, Pink M, Jobe FW, Kerrigan J. The painful shoulder during freestyle swimming. An electromyographic cinematographic analysis of twelve muscles. Am J Sports Med 1991;19:577-82.

Sheard B, Elliott J, Cagnie B, O'Leary S. Evaluating serratus anterior muscle function in neck pain using muscle functional magnetic resonance imaging. J Manip Physiol Ther 2012;35:629-35.

Sherrington CS. Strychnine and reflex inhibition of skeletal muscle. J Physiol 1907;36:185-204.

Smith Jr R, Nyquist-Battie C, Clark M, Rains J. Anatomical characteristics of the upper serratus anterior: cadaverdissection. J Orthop Sports PhysTher 2003;33:449-54.

Struyf F, Meeus M, Fransen E, Roussel N, Jansen N, Truijen S, et al. Interrater and intrarater reliability of the pectoralis minor muscle length measurement in subjects with and without shoulder impingement symptoms. Man Ther 2014;19:294-8.

Tate A, Turner GN, Knab SE, Jorgensen C, Strittmatter A, Michener LA. Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. J Athl Train 2012;47:149-58.

Wadsworth DJ, Bullock-Saxton JE. Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. Int J Sports Med 1997;18:618-24.

Wattanaprakornkul D, Cathers I, Halaki M, Ginn KA. The rotator cuff muscles have a direction specific recruitment pattern during shoulder flexion and extension exercises. J Sci Med Sport/Sports Med Aust 2011;14: 376-82.

Wickham J, Pizzari T, Stansfeld K, Burnside A, Watson L. Quantifying 'normal' shoulder muscle activity during abduction. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2010;20:212-22.

Wong CK, Coleman D, diPersia V, Song J, Wright D. The effects of manual treatment on rounded-shoulder posture, and associated muscle strength. J Bodyw Mov Ther 2010;14:326-33.

Chapter 7:

Modifying the shoulder joint position during shrugging and retraction exercises alters the activation of the medial scapular muscles

Birgit Castelein, PT[1]; Ann Cools, PT, PhD[1]; Thierry Parlevliet, MD[2]; Barbara Cagnie, PT, PhD[1]

[1] Department of rehabilitation sciences and physiotherapy, Ghent University, Ghent, Belgium

[2] Department of physical medicine and orthopaedic surgery, University Hospital, Ghent, Belgium

Manual Therapy. 2016 Feb; 21:250-5
(SCI=1.714, Q2)

ABSTRACT

Background: In patients with shoulder or neck pain, often an imbalance of the activation in the scapular upward and downward rotators is present which can cause abnormalities in coordinated scapular rotation. Shrug exercises are often recommended to activate muscles that produce upward rotation, but little information is available on the activity of the downward rotators during shrugging exercises. The position used for the shrug exercise may affect the relative participation of the medial scapular rotators.

Objectives: To compare muscle activity, using both surface and fine-wire electrodes, of the medial scapular muscles during different shoulder joint positions while performing shrug and retraction exercises.

Design: Controlled laboratory study.

Method: Twenty-six subjects performed 3 different exercises: shrug with the arms at the side while holding a weight ("Shrug"), shrug with arms overhead and retraction with arms overhead. EMG data with surface and fine wire electrodes was collected from the Upper Trapezius (UT), Levator Scapulae (LS), Middle Trapezius (MT), Rhomboid Major (RM) and Lower Trapezius (LT).

Results: The results showed that activity levels of the main medial scapular muscles depend upon the specific shoulder joint position when performing shrug and retraction exercises. High UT activity was found across all exercises, with no significant differences in UT activity between the exercises. The LS and RM activity was significantly lower during "ShrugOverhead" and the RM, MT and LT activity was significantly higher during "RetractionOverhead".

Conclusions: This study has identified that all three exercises elicited similar UT activity. LS and RM activity is decreased with the "ShrugOverhead" exercise. The "RetractionOverhead" was the most effective exercise in activating the medial scapular muscles.

1. INTRODUCTION

The position and motion of the scapula is crucial for normal functioning of the shoulder and neck region (Kibler and McMullen, 2003). Patterned scapular muscle activations are necessary to place the scapula in an optimal position. The Upper Trapezius (UT) moves the scapula into upward rotation and elevation, the function of the Middle Trapezius (MT) is to retract the scapula and the Lower Trapezius (LT) causes upward rotation and depression of the scapula. In addition, the inferomedial directed fibres of the LT may also contribute to posterior tilt and external rotation of the scapula during humeral elevation. The Serratus Anterior is able to protract the scapula and to work with the UT and LT to upwardly rotate the scapula. The Levator Scapulae (LS) is believed to elevate the scapula and to work together with the Rhomboid Major (RM) to retract and rotate the scapula downwards (Escamilla et al., 2009; Castelein et al., 2015). Scapular dyskinesis (known as alterations in static scapular position and loss of dynamic control of scapular motion) and alterations in scapular muscle activation patterns are commonly found in association with shoulder and neck pain conditions (Szeto et al., 2002; Ludewig and Reynolds, 2009; Helgadottir et al., 2010; Kibler and Sciascia, 2010; Helgadottir et al., 2011; Kibler et al., 2012).

Patients with shoulder or neck pain often present with muscle imbalances between the upward rotators (UT and SA) and the downward rotators (LS and RM) of the scapula (Ludewig and Cook, 2000; Sahrmann, 2002; Cools et al., 2004; Ludewig and Reynolds, 2009; Struyf et al., 2014). These changes in muscular balance among the scapular rotators can cause abnormalities in coordinated scapular rotation (Sahrmann, 2002; Cools et al., 2003). Therefore, it is important to integrate exercises in the scapular rehabilitation program that target activation of the scapular muscles, with a focus on the activation of upward rotators while minimizing the activation of the scapular downward rotators (Sahrmann, 2002).

Often the “Shrug”-exercise has been prescribed in scapular rehabilitation programs to facilitate upward rotation of the scapula (Hintermeister et al.,1998; Ekstrom et al., 2003; Pizzari et al., 2014). This exercise is mainly performed in order to correct the drooping shoulder at rest, and during the early stages of elevation. However, Sahrmann (2002) did not find the “Shrug” optimal to emphasize the UT activity and the upward rotation as the “Shrug” was suggested to reinforce the activity of the RM and LS, contributing to the dominance of these scapular downward rotator muscles. Also other authors described that the “Shrug” with the arms by the side may activate the LS rather than UT (Moseley et al., 1992; Smith et al., 2004). So, in order to elicit improved balance among the upward and downward rotators, it may be desirable to modify a shrug exercise. Sahrmann (2002) advises that the “Shrug” should be performed with arms overhead so that the scapula is in upward rotation (“ShrugOverhead”). However, to date, no specific EMG research of the medial scapular muscles has been performed to confirm or reject the hypothesis of Sahrmann (2002) and consequently no evidence exists in order to support these recommendations.

Some studies have investigated EMG activity of scapular muscles during shrug exercises (Moseley et al., 1992; Choi et al., 2015; Pizzari et al., 2014). One study by Moseley et al. (1992) showed that the Shrug was an optimal exercise for the LS (muscle activity >50%MMT). A limitation of the study was that no statistical investigations were made to compare EMG activity between muscles or exercises. Pizzari et al. (2014) investigated the influence of starting a shrug in 30° of glenohumeral abduction (component of slight upward rotation) rather than with the arm by the side, and found that it generated greater Trapezius muscle activity in comparison with the shrug with the arms at the side. The muscle activity of the downward rotators however, such as LS and RM was not investigated in that study. Choi et al. (2015) investigated the EMG activity of the UT, LT and LS with surface electrodes during shrug exercises with different starting positions of shoulder abduction (30-90-150°) in patients with downward rotation positioning of the scapula. While LS muscle activity showed no significant differences, the muscle activity of the scapular upward rotators (UT, LT, and SA) did show significant differences among the shoulder abduction angles during shrug exercises. A limitation of this study was that LS activity was measured with surface EMG electrodes and that possible cross talk could have occurred between the UT and LS. In addition, this study did not investigate RM and MT EMG activity. Overall, there is a lack of research evaluating the activity of the downward rotators, namely the RM and LS during different shoulder joint positions of shrugging and retraction exercises. The main reason for the lack of information on the EMG activity of those muscles may be that they are located too deep to be investigated by surface EMG electrodes (Rudroff, 2008).

Therefore, the purpose of this study was to compare muscle activation levels, using both surface and fine-wire electrodes, of the medial scapular rotators (UT, MT, LT, RM, LS) during 1) the shrug exercise (=shrug with the arms at the side and with a weight), 2) the shrug exercise when arms are elevated, and 3) a retraction exercise while arms are elevated. Understanding variations in the recruitment of all medial scapular muscles (including the downward rotators) during shrug and retraction exercises and the influence of different starting positions may help guide clinicians to select the appropriate exercises for each patient.

2. MATERIALS AND METHODS

2.1 Subjects

Twenty-six subjects (15 female, 11 male, mean age 33.3 ± 12.3 years, ranging from 21 to 56 years old, mean height: 174.7 ± 7.8 cm, mean weight: 67.5 ± 8.9 kg) participated in this study. All subjects were free from current or past shoulder or neck pain and demonstrated full pain-free range of motion of both shoulders. They did not perform overhead sports nor upper limb strength training for more than 6 h/week. Twenty-two subjects were right-handed and 4 were left-handed. Written informed consent was obtained from all participants. The study was approved by the ethics committee of Ghent University Hospital.

2.2 General Design

EMG data was collected from 5 scapulothoracic muscles (UT, MT, LT, LS, RM) on the dominant side of each subject during the performance of the shrug exercise, the shrug exercise started from an overhead position of the arms, and retraction exercise started from an overhead position of the arms.

2.3 Test Procedure

The experimental session began with a short warm-up procedure with multidirectional shoulder movements, followed by the performance of the maximum voluntary isometric contractions (MVIC) of the muscles of interest. This data is needed for normalization of the EMG signals.
A set of 4 MVIC test positions was completed to allow normalization of the EMG data (Castelein et al., 2015). These consisted of the following:

1. “Abduction 90” (sitting)
2. “Horizontal Abduction with external rotation” (prone lying)
3. “Arm raised above head in line with LT muscle fibers” (prone lying)
4. “Shoulder flexion 135” (sitting)

Each MVIC test position was performed 3 times (each of the 3 contractions lasted for 5 s-controlled by a metronome) with at least 30 s rest between the different repetitions. The order of tests was randomized and there was a rest period of at least 1.5 min between the different test positions. Manual pressure was always applied by the same investigator and strong and consistent encouragement from the investigator was given during each MVIC to promote maximal effort. Before data collection, MVIC test positions were taught to each subject by the same investigator. When the participants were able to perform the proper movement pattern and timing of the exercise, EMG data was collected from the MVICs.
In the second part of the investigation, the subject performed three exercises. Fig. 1 shows the description of the different exercises.

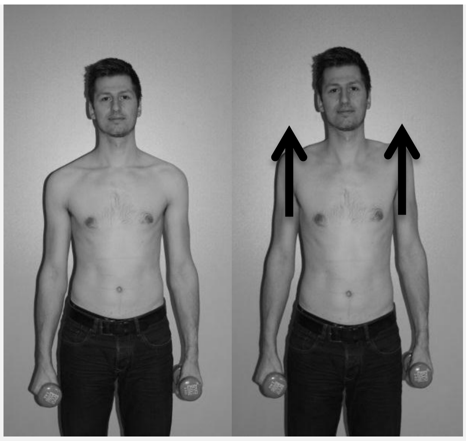
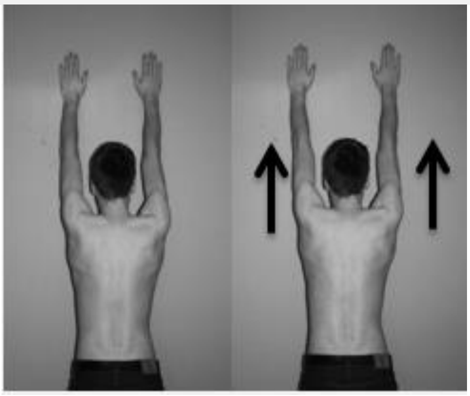
Name	Description of the exercise	Figure
Shrug	Subject standing, holding the dumbbells (5kg) at the side, and elevating the shoulders and returning back to the starting position. (3s elevation – 3s depression).	
ShrugOverhead	Subject standing, placing the arm in overhead position against the wall and performing a shrug movement and returning back to the starting position (3s elevation – 3s depression). (distance to the wall was determined as follow: subjects stood in front of the wall (facing the wall) with the arms besides the body, elbows flexed in 90°, elbow, wrist and fingers in neutral position. The distance to the wall was appropriate when the tips of the fingers were in contact with the wall)	
RetractionOverhead	Subject standing, placing the arm in overhead position against the wall and performing an arm lift (retraction) movement and returning back to the starting position (3s retraction – 3s return). (distance to the wall was determined as follow: subjects stood in front of the wall (facing the wall) with the arms besides the body, elbows flexed in 90°, elbow, wrist and fingers in neutral position. The distance to the wall was appropriate when the tips of the fingers were in contact with the wall)	

FIGURE 1. Description of the exercises

The exercises were performed randomly (simple randomization: envelopes containing the name of each exercise were shuffled for each participant and this sequence of exercises was allocated to that participant). Before data collection, the subject was given a visual demonstration of each exercise by the investigator. Each exercise consisted of a concentric phase of 3s and an eccentric phase of 3s. A metronome was used to control and standardize the velocity speed of the movement (60 beeps/min). When the participants were able to perform the proper movement pattern and timing of the exercise, EMG data was collected from 5 repetitions of each exercise with 5s of rest in between each repetition. Between each exercise set, a break of 1.5 min was provided.

2.4. Instrumentation

A TeleMyo 2400 G2 Telemetry System (Noraxon Inc., Scottsdale, AZ) was used to collect the EMG data. This study used a combination of surface and intramuscular electrodes. Bipolar surface electrodes (Blue Sensor, Medicotest, Ballerup, Denmark) were placed with a 1 cm interelectrode distance over the UT, LT and MT, according to the to the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) Project Recommendations (Hermens et al., 2000; Cools et al., 2007; De Mey et al., 2009; Maenhout et al., 2010). A reference electrode was placed over the spinous process of C7 vertebrae. Before surface electrode application, the skin surface was shaved, cleaned and scrubbed with alcohol to reduce impedance (<10 kOhm). Intramuscular fine-wire electrodes was used to measure the EMG activity of the LS and RM.

The paired hook fine-wire electrodes (Carefusion Middleton, WI, USA - wire length 125 mm) were inserted into the muscle belly (according to the locations described by Perotto et al., 2005) using a single-use 25-gauge hypodermic needle. This was done using realtime ultrasound guidance, which has been shown to be an accurate and repeatable method of intramuscular electrode placement. The surface and intramuscular electrodes were looped and taped on the skin to prevent them from being accidentally removed during the experiment and to minimize movement artifacts. The sampling rate was 3000 Hz. The device had a common mode rejection ratio of 100 dB. Gain was set at 1000 (baseline noise <1 mV root-mean-square (RMS)).

2.5 Signal Processing And Data Analysis

The Myoresearch 3.4 Master Edition Software Program was used for signal processing. The EMG signals were filtered with a high pass Butterworth filter of 20 Hz. Cardiac artifact reduction was performed, followed by rectification and smoothing (root mean square, window 100 ms) of the signals. The EMG data for each muscle and each participant was averaged for each exercise (6s: 3s concentric phase and 3s eccentric phase) across the 3 intermediate repetitions of the 5 repetitions completed. The first and fifth repetitions were not included in the analysis to control for distortion due to habituation or fatigue. These EMG data were normalized and expressed as a percentage of their MVIC. For each MVIC, the average EMG value was calculated over a window of the peak 2.5 s of the 5s. The average of the 3 trials was used for normalization. All MVIC test positions were analyzed for each muscle. The normalization value (100%) was the highest value for that muscle recorded during the MVIC tests.

2.6 Statistical Analysis

SPSS 22.0 was used for statistical analysis. Means ± standard deviations were calculated for the normalized EMG values (in % of MVIC) of the UT, MT, LT, LS and RM for each exercise. Data was checked for differences between male and female subjects. Since there were no gender differences, there was no need for further comparisons. A linear mixed model was applied to determine if there were significant differences in EMG activity between different exercises and different muscles (two factors: "Exercise" and 'Muscle"). The residuals of the linear mixed models were checked for normal distribution. Post hoc pairwise comparisons were performed using a Bonferroni correction. An alpha level of 0.05 was applied to all the data in determining significant differences.

RESULTS

The mean EMG activity of each scapular muscle during the different exercises is provided in Table 1.

	Shrug	**ShrugOverhead**	**RetractionOverhead**
Upper Trapezius	33.8 ± 12.9	25.8 ± 11.9	28.4 ± 12.5
Middle Trapezius	8.1 ± 5.3	6.9 ± 4.6	16.1 ± 11.6
Lower Trapezius	3.4 ± 1.9	7.2 ± 4.5	22.4 ± 8.2
Levator Scapulae	44.0 ± 25.8	19.1 ± 14.1	25.9 ± 22.7
Rhomboid Major	18.8 ± 15.0	10.3 ± 7.3	29.9 ± 15.7

TABLE 1. EMG Activity (%MVIC) of each scapular muscle during the different exercises.

A significant interaction effect for Exercise*Muscle was found ($p < 0.001$). Post-hoc tests revealed that for UT, there were no significant differences between the different exercises. The results revealed that both the MT ($p < 0.047$) and LT ($p < 0.001$) were significantly more activated during "RetractionOverhead" in comparison with "Shrug" and "ShrugOverhead". The LS generated significantly higher activity during "Shrug", in comparison with "RetractionOverhead" and "ShrugOverhead" ($p < 0.001$). The RM generated the most activity during "RetractionOverhead" in comparison with "Shrug" ($p = 0.003$) and "ShrugOverhead" ($p < 0.001$). When comparing different muscles' activity for each exercise, post-hoc tests revealed that during the "Shrug", the LS is significantly more activated than the UT ($p = 0.021$), MT ($p < 0.001$), LT ($p < 0.001$) and RM ($p < 0.001$). The activity of UT during "Shrug" was significantly higher than MT, LT and RM ($p < 0.001$); and the activity of RM during "Shrug" was significantly higher than MT and LT. During "ShrugOverhead", the UT generated significantly higher activity than the MT, LT and RM ($p < 0.001$). Also the LS activity was significantly higher than the MT ($p = 0.003$) and LT ($p = 0.004$) activity during the "ShrugOverhead". During "RetractionOverhead", the MT activity was significantly lower than the UT ($p = 0.002$), LS ($p = 0.032$) and RM ($p = 0.001$) activity.

3. DISCUSSION

The aim of this study was to compare muscle activity levels, using both surface and fine-wire electrodes, of all medial scapular muscles (UT, MT, LT, RM & LS) during three exercises: (1) the shrug exercise with the arms at the side while holding a weight (="Shrug"), (2) the shrug exercise arms are elevated (="ShrugOverhead"), and (3) a retraction exercise while arms are elevated ("RetractionOverhead").

The major finding of this study is that activity levels of the main medial scapular muscles depend upon the specific shoulder joint position while performing the shrug and retraction exercises. This study demonstrates high activity of the UT across all exercises, and shows the lowest activity of the LS and RM during "ShrugOverhead" and the highest activity of the RM, MT and LT during "RetractionOverhead". This is the first study establishing specific scapular muscle activation patterns during these selected scapular exercises, in particular in the deep scapular muscles like RM and LS.

In the literature, the "Shrug" has been prescribed to strengthen the UT (Hintermeister et al.,1998; Ekstrom et al., 2003; Pizzari et al., 2014). In this study, although the numeric data suggest higher activity of UT during the basic shrug exercise, it was found that the amplitude of UT activation was not statistically different among the three different exercises (Shrug - ShrugOverhead - RetractionOverhead). As a consequence, this indicates the capability of all three exercises to activate the UT at a moderate level (between 25 and 33%MVC).

In contrast with the EMG results of the upward rotator (UT), the EMG activity of the downward rotators (LS and RM) does show differences between the exercises. The LS activity during the "ShrugOverhead" (19.1 ± 14.1%MVC) and the "RetractionOverhead" (25.9 ± 22.7%MVC) is significantly lower ($p < 0.001$) in comparison with the "Shrug" (44.0 ± 25.8%MVC). Moreover, the "Shrug" is the only exercise in which the activity of the LS is significantly higher than all other investigated muscles, including the UT ($p = 0.021$). In addition, the RM also shows the lowest activity during the “ShrugOverhead”. So the results of the current study provide evidence of the hypothesis of Sahrmann (2002) that the “ShrugOverhead” should be preferred over the “Shrug”, when the purpose of the exercise is to promote UT activity, with minimal activity in LS and RM. This means that this overhead positions enhances the function of UT to elevate the scapula and to rotate the scapula upwards, as it decreases the activity of LS and RM, that work together to rotate the scapula downwards. This is in line with the suggestions of several other authors to adapt the “Shrug” exercise, with a position of more upward rotation of the scapula in order to minimize the activation of the scapular downward rotators (that are expected to work during the “Shrug”) and enhance the scapular upward rotators (Sahrmann, 2002; Choi et al., 2015; Pizzari et al., 2014). Using anatomical principles, it seems reasonable that if the scapula changes into more upward rotation (in case of “ShrugOverhead”), the line of pull of different muscles changes which causes changes in the length-tension relationships of the muscles assessed. Choi et al. (2015) also investigated LS activity with surface EMG electrodes in shrug exercises with different shoulder abduction angles (30°-90°-150°) in patients with downward rotation positioning of the scapula. In contrast with our results, they did not find significant differences in LS muscle activity among the shoulder abduction angles during the shrug exercises. However, the balance of UT/ LS muscle activity ratio was significantly greater at higher shoulder abduction degrees (90 in comparison with 30), indicating a relatively higher activation of the UT compared to the LS.

The “RetractionOverhead” resulted in the highest activation (ranging from 16 to 30%MVC) of all medial scapular muscles (RM, MT and LT) in comparison with the other exercises, indicating that this exercise is decent for the general activation of the posterior medial scapular shoulder musculature. The MT activity was significantly more activated during a retraction movement (“Retraction 180”) in comparison with an upward rotation movement (“Shrug” and “Shrug180”), which is in line with the known muscle function of the MT, a retractor of the scapula. Remarkably, in this study, the activity of the MT was significantly lower than that of the UT, LS and RM during “RetractionOverhead”. The finding that LS and RM work during “RetractionOverhead” is logical as these muscles work together to retract the scapula. It could be that the other muscles (other than the MT) assist during retraction of the scapula due to the more upward rotation of the scapula in an overhead position. Regarding the LT, it is clinically believed that this muscle has an essential component during upward rotation of the scapula. The LT makes up the crucial lower force couple responsible for control against scapular elevation produced by the LS & UT. A low amount of LT activity was seen during “Shrug” (3.4 ± 1.9%MVC) and “ShrugOverhead” (7.2 ± 4.5%MVC). The exercise “RetractionOverhead” was effective in activating the LT to its highest (22.4 ± 8.2% MVC). The low LT activity during Shrug has also been found in the study from

Pizzari et al. (2014) (3.5 ± 18.4%MVC). Although the "ShrugOverhead" and "RetractionOverhead" have the same starting position, i.e. with the arms elevated which causes an upward rotation of the scapula, the LT is more activated when performing retraction in comparison with when performing shrug. So, besides the role of LT as a muscle that controls the movement of the scapula (Ballantyne et al., 1993), it seems that in an overhead position the fibres of the LT are ideally placed to pull the scapula in retraction. Other studies did also describe maximum activity of the LT when resistance is applied to the arm when raised above the head in line with the LT (in prone position) (Ekstrom et al., 2003).

Interpretation of the results must be viewed within the limitations of the study. It is a limitation that the shrug exercise was performed with weight, while the other exercises were performed without weight. However, this decision was made as these conditions come closest to the way these exercises are performed in clinical practice. This study investigated five muscles using two different kinds of electrodes: surface and fine wire electrodes. EMG activity of the superficial muscles (UT, MT, LT) was investigated with surface electrodes. The fine wire electrodes allowed assessment of the EMG activity of the deeper lying muscles (LS and RM), which is difficult using surface electrodes due to the cross talk from superficial muscle layers. In view of this fact, caution should be taken when comparing the results among the different muscles activity (surface versus fine-wire). It is still under debate whether surface and fine wire electrodes measure the same kind of muscle activity (Giroux and Lamontagne, 1990; Bogey et al., 2000; Jaggi et al., 2009; Waite et al., 2010; Johnson et al., 2011). Nevertheless, other studies have also compared surface EMG results with finewire EMG results in the shoulder region (Boettcher et al., 2010; Wickham et al., 2010; Wattanaprakornkul et al., 2011). In this study, the amplifier's bandwidth was wide enough for both intramuscular and surface electrode signals ensuring that the data from the intramuscular electrodes could be accurately compared to that of the surface electrodes once both had been normalized (Wickham et al., 2010).

While this study provided useful information regarding the muscles being activated during various exercises, they did not document the associated scapular kinematics (3D analysis). Investigating scapular movements, along with muscle activity during exercises, would provide additional information clinicians can use to select exercises based on the needs of the subjects. As this study has been performed on healthy individuals, caution needs to be taken when applying the results of this study to patients. However, the majority of electromyography research on which clinicians currently base rehabilitation programs is from studies of asymptomatic subjects. Clearly, future investigations targeting symptomatic persons performing scapular exercises would advance our understanding of the symptomatic shoulder or neck and potentially facilitate refinement of our rehabilitation programs.

4. CONCLUSION

The exercises Shrug, ShrugOverhead and RetractionOverhead showed varying activity of both superficial and deeper lying medial scapular muscles. This study has identified that all three exercises elicited similar UT activity. The lowest LS and RM activity is best achieved with the ShrugOverhead exercise. The RetractionOverhead was the most effective exercise in activating the medial scapular muscles. These findings provide insights into scapular muscle activation patterns during exercises that involve the medial scapular muscles, in particular in the deep scapular muscles RM and LS.

REFERENCES

Ballantyne BT, O'Hare SJ, Paschall JL, Pavia-Smith MM, Pitz AM, Gillon JF, et al. Electromyographic activity of selected shoulder muscles in commonly used therapeutic exercises. Phys Ther 1993;73:668-77. discussion 77-82.

Boettcher CE, Cathers I, Ginn KA. The role of shoulder muscles is task specific. J Sci Med Sport/Sports Med Aust 2010;13:651-6.

Bogey RA, Perry J, Bontrager EL, Gronley JK. Comparison of across-subject EMG profiles using surface and multiple indwelling wire electrodes during gait. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2000;10:255-9.

Castelein B, Cagnie B, Parlevliet T, Danneels L, Cools A. The optimal normalization tests for muscle activation of the levator scapulae, pectoralis minor and rhomboid major: an EMG study using maximum voluntary isometric contractions. 2015; 96:1820-7.

Choi WJ, Cynn HS, Lee CH, Jeon HS, Lee JH, Jeong HJ, et al. Shrug exercises combined with shoulder abduction improve scapular upward rotator activity and scapular alignment in subjects with scapular downward rotation impairment. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2015:363-70.

Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B, et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? Am J Sports Med 2007;35:1744-51.

Cools AM, Witvrouw EE, Declercq GA, Danneels LA, Cambier DC. Scapular muscle recruitment patterns: trapezius muscle latency with and without impingement symptoms. Am J Sports Med 2003;31:542-9.

Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. Br J Sports Med 2004;38:64-8.

De Mey K, Cagnie B, Danneels LA, Cools AM, Van de Velde A. Trapezius muscle timing during selected shoulder rehabilitation exercises. J Orthop Sports Phys Ther 2009;39:743-52.

Ekstrom RA, Donatelli RA, Soderberg GL. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. J Orthop Sports Phys Ther 2003;33:247-58.

Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. Sports Med Auckl NZ 2009;39:663-85.

Giroux B, Lamontagne M. Comparisons between surface electrodes and intramuscular wire electrodes in isometric and dynamic conditions. Electromyogr Clin Neurophysiol 1990;30:397-405.

Helgadottir H, Kristjansson E, Mottram S, Karduna A, Jonsson Jr H. Altered alignment of the shoulder girdle and cervical spine in patients with insidious onset neck pain and whiplash-associated disorder. J Appl Biomech 2011;27:181-91.

Helgadottir H, Kristjansson E, Mottram S, Karduna AR, Jonsson Jr H. Altered scapular orientation during arm elevation in patients with insidious onset neck pain and whiplash-associated disorder. J Orthop Sports Phys Ther 2010;40:784-91.

Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2000;10:361-74.

Hintermeister RA, Lange GW, Schultheis JM, Bey MJ, Hawkins RJ. Electromyographic activity and applied load during shoulder rehabilitation exercises using elastic resistance. Am J Sports Med 1998;26:210-20.

Jaggi A, Malone AA, Cowan J, Lambert S, Bayley I, Cairns MC. Prospective blinded comparison of surface versus wire electromyographic analysis of muscle recruitmentin shoulder instability. PhysiotherResIntJRes Clin PhysTher2009;14:17-29.

Johnson VL, Halaki M, Ginn KA. The use of surface electrodes to record infraspinatus activity is not valid at low infraspinatus activation levels. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2011;21:112-8.

Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. J Am Acad Orthop Surg 2003;11:142-51.

Kibler WB, Sciascia A. Current concepts: scapular dyskinesis. Br J Sports Med 2010;44:300e5.

Kibler WB, Sciascia A, Wilkes T. Scapular dyskinesis and its relation to shoulder injury. J Am Acad Orthop Surg 2012;20:364-72.

Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276-91.

Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther 2009;39:90-104.

Maenhout A, Van Praet K, Pizzi L, Van Herzeele M, Cools A. Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity? Br J Sports Med 2010;44:1010-5.

Moseley Jr JB, Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. Am J Sports Med 1992;20:128-34.

Pizzari T, Wickham J, Balster S, Ganderton C, Watson L. Modifying a shrug exercise can facilitate the upward rotator muscles of the scapula. Clin Biomech (Bristol, Avon) 2014;29:201-5.

Perotto A, Delagi F, Iazzetti J, Morrison D. Anatomical guide for the electromyographer. The limbs and trunk. Spingfield: Charles C Thomas Publisher; 2005.

Rudroff T. Kinesiological fine wire EMG: a practical introduction to fine wire EMG applications Version 1.0. December 2008.

Sahrmann. Diagnosis and treatment of movement impairment syndromes. Elsevier Health Sciences; 2002.

Smith J, Padgett DJ, Dahm DL, Kaufman KR, Harrington SP, Morrow DA, et al. Electromyographic activity in the immobilized shoulder girdle musculature during contralateral upper limb movements. J Shoulder Elbow Surg 2004;13: 583-8.

Struyf F, Cagnie B, Cools A, Baert I, Brempt JV, Struyf P, et al. Scapulothoracic muscle activity and recruitment timing in patients with shoulder impingement symptoms and glenohumeral instability. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2014;24:277-84.

Szeto GP, Straker L, Raine S. A field comparison of neck and shoulder postures in symptomatic and asymptomatic office workers. Appl Ergon 2002;33:75-84.

Waite DL, Brookham RL, Dickerson CR. On the suitability of using surface electrode placements to estimate muscle activity of the rotator cuff as recorded by intramuscular electrodes. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2010;20:903-11.

Wattanaprakornkul D, Cathers I, Halaki M, Ginn KA. The rotator cuff muscles have a direction specific recruitment pattern during shoulder flexion and extension exercises. J Sci Med Sport/Sports Med Aust 2011;14:376-82.

Wickham J, Pizzari T, Stansfeld K, Burnside A, Watson L. Quantifying 'normal' shoulder muscle activity during abduction. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2010;20:212-22.

GENERAL DISCUSSION

1. Summary and discussion of the results

This dissertation aimed to make a valuable contribution to the field of knowledge of scapulothoracic muscle activity and scapulothoracic muscle training. In order to give an answer to various research questions related to this purpose, we investigated in part 1 the scapulothoracic muscle activity in patients with SIS and in patients with idiopathic neck pain, compared to healthy subjects. In part 2 we explored scapulothoracic muscle recruitment during particular exercises that are widely used and recommended during scapular rehabilitation training.

In general, most research that has investigated scapulothoracic muscle activity in patients and during exercises has focused on the superficial lying scapulothoracic muscles (Trapezius and SA). Very little EMG data are available on the activity of the smaller and less superficial muscles that attach to the scapula, including the Pm, LS and RM, despite the hypothesized importance of these muscles on the position and movement of the scapula.

The inability to investigate those deeper lying muscles' activity with surface EMG and the absence of standard reference contractions to normalize the data could have been the main reasons why there is a lack of research data on the EMG activity of these deeper lying muscles.

Part I: Superficial and deeper lying scapulothoracic muscle activity in patient populations with shoulder pain or neck pain

Chapter 1 of this dissertation describes a study that was performed in order to identify **MVIC test positions that enable normalization** of Pm, LS and RM activity. The overall goal was to identify a limited standard set of test positions that generate an MVIC in all scapulothoracic muscles (including the superficial lying muscles, such as the Trapezius and the SA). This is the first study where all deeper lying muscles were investigated with fine-wire EMG for their MVIC and where all scapulothoracic muscles are integrally tested for their MVICs. Because various test positions generated a similar high mean EMG activity and because no single test generated maximum activity for a specific muscle in all subjects, no single exercise was found that could be deemed as the best exercise for achieving maximal amplitudes of a particular muscle. The results of this study support using a set of test positions rather than a single exercise to increase the likelihood of recruiting the highest activity in the scapulothoracic muscles. It is a better strategy to record from all muscles during different tests rather than determining a specific test for a specific muscle, since the maximum level of activity may be generated from any one of the tests performed. The normalization reference level (MVIC) for each of the scapulothoracic muscles should be taken as the maximum level of activation generated across the set. The following standard set of 5 test positions was identified as being sufficient for generating an MVIC of all scapulothoracic muscles (UT, MT, LT, SA, LS, Pm, RM):

- seated T
- seated U 135°
- prone T-thumbs up
- prone V-thumbs up
- supine V-thumbs up.

Moreover, it was found that the scapulothoracic muscle activity during the performance of these MVICs was reliable with outstanding ICC's (2-way random, absolute agreement, data from 3 repetitions of the different MVICs) ranging from 0,964 to 0,996. This new strategy for normalization should be implemented in further investigations aiming to evaluate scapulothoracic muscle activity. To date, a lot of studies investigating scapulothoracic muscle activity have used one single MVIC test for one specific muscle in order to normalize the muscle activity.[21, 22, 25, 27, 38, 50, 57, 58, 72, 78, 85] Nevertheless, the results of this study recommend that the MVIC for a muscle should be taken as the maximum level of activation across a set of test (rather than determining a specific test for a specific muscle). This recommendation is in line with the recommendations from studies from Boettcher et al.[9] and Ginn et al.[9], who also investigated MVICs for shoulder muscle normalization.

This new standard set of MVICs provides the ability to normalize the deeper lying muscle activity, which allows to interpret the activity of the Pm, LS and RM. This enables comparing scapulothoracic muscle activity between patient groups. This doctoral dissertation aimed to obtain a better insight into possible abnormalities in scapulothoracic muscle activity in patients with **SIS and patients idiopathic neck pain**, as both patient groups have been linked to **scapular dyskinesis**. In **Chapter 2** of this dissertation, the **scapulothoracic muscle activity** of both the deeper lying (Pm, LS and RM) and the superficial lying (Trapezius and SA) muscles was compared between **patients with SIS** and healthy controls during elevation tasks. It was found that during the elevation tasks, the Pm was significantly more active in the SIS group in comparison with the healthy controls. The important role of the Pm in shoulder pain has already been suggested in different clinical and research settings, however this study was the first to investigate and confirm this hypothesis. Studies that have suggested the role of Pm in patients with shoulder pain focused on shortening and tension of the Pm. [11-13, 69] A lack of Pm extensibility during elevation of the arm can lead to a decrease in scapular upward rotation and an increase in scapular anterior tilting and internal rotation,[11-13, 69] which can lead to a reduction of the subacromial space and has been linked to impingement symptoms.[13, 84] These current results of higher Pm activity during elevation of the arm in patients with SIS might gain insight into the relationship between the Pm and SIS. Repetitive overuse of the Pm may result in adaptive shortening and tension and can lead to a malaligned scapula as described above. However, as the study had a cross-sectional design, the cause-consequence relationship between the activity of Pm and SIS symptoms cannot be resolved.

For the other deeper lying (RM and LS) and for the superficial lying scapulothoracic muscles no significant differences were found between the two groups during these elevation tasks. No other studies have investigated LS or RM activity in patients with shoulder pain, so no data exist to compare our results with. Hypothetically, overuse of these muscles during elevation could lead to downward rotation of the scapula and a higher risk to impinge the subacromial structures. Nevertheless, the results of this study do not support this hypothesis. Hypothetically, it could be that impairments of the LS and RM are not associated with an activation problem. Other investigations methods, besides EMG, should try to unravel if dysfunctions of the LS and RM exist. Studies have already demonstrated a higher prevalence of trigger points in the LS in patients with SIS in comparison with healthy controls.[40-42]

Several studies have already investigated the superficial scapulothoracic muscle activity in patients with SIS during elevation exercises and found conflicting results.[5, 52, 53, 75] Our results were similar to the results of Bandholm et al.[5] and Roy et al.[75] who did not find differences in EMG activity of the superficial lying muscles during elevation. Recently, a systematic review of Struyf et al.[81] summarized possible differences in EMG activity of the superficial scapulothoracic muscles in SIS, during different movements (so not only during elevation). Their overall conclusion was that in the SIS-group, the UT muscle activity was increased and the LT and SA muscle activity was decreased. While some studies demonstrate Trapezius and SA dysfunction in the scapulothoracic joint in patients with SIS, our study did not show differences for these muscles activity in patients with SIS. In general, findings are not consistent and this could be due to the presence of several methodological differences between the different studies which makes comparison difficult: differences in the investigated population (overhead athletes, construction workers, etc.), comparisons (side-to-side comparisons versus comparisons between the asymptomatic shoulder of a patient and the healthy shoulder of a control subject), tasks (plane, movement, velocity, ROM, load, etc.), normalization procedures, analysis of the EMG signals etc.

As an overview of possible differences or similarities in scapulothoracic muscle recruitment between patients with idiopathic neck pain and healthy controls was lacking, the aim of **Chapter 3** was to **systematically review** and summarize the results of **scapulothoracic muscle EMG activity** in patients with **chronic idiopathic neck pain** in comparison with healthy controls. It was found that during rest and activities below shoulder height, no clear differences in mean UT EMG activity exist between patients with idiopathic neck pain and a healthy control group. During overhead activities, no conclusion for scapular EMG amplitude can be drawn as a large variation of results were reported. The authors believed that the trend of differences in muscle activity in patients with neck pain depends on the characteristics of the task that was performed: different kind of tasks (in different planes) require different muscle activity. This may have consequences for the recruitment (amplitude) of scapulothoracic muscles and the size of the possible differences in EMG activity between patients with neck pain and healthy controls. In general, the findings suggest that alterations in scapulothoracic muscle mean amplitude activity may be present during upper limb tasks in some individuals with neck pain.

The review mentioned that most studies included have only focused on the UT and that there is a lack of research on other scapulothoracic muscles (such as other parts of the Trapezius and SA). Moreover, no studies exist that that investigate the scapulothoracic activity of the smaller and less superficial muscles that attach to the scapula (such as the Pm, the LS and RM) in a population with neck pain, despite the hypothesized importance of these muscles in scapulothoracic function.[17, 24] In view of the recommendations for future research from this systematic review, **Chapter 4** of this dissertation aimed to investigate the **deeper and superficial lying muscle activity** in patients with **idiopathic neck pain** during elevation. In addition, the influence of the presence of scapular dyskinesis in these patients on scapulothoracic muscle activity was investigated. Higher Pm activity during the wallslide in comparison with the healthy control group. In addition, it was found that patients with scapular dyskinesis showed lower MT activity in comparison with healthy controls with scapular dyskinesis. The presence of scapular dyskinesis did not have a significant influence on scapulothoracic muscle activity in this study.

Other studies investigating the differences in scapulothoracic EMG muscle activity between patients with neck pain and healthy subjects during elevation of the arm or overhead activities mainly focused on UT muscle activity and did not investigate the MT,LT or SA muscles (**Chapter 3**). The result of UT EMG activity of the current study is in agreement with the results from Larsson et al.[49], Goudy and McLean[35] and Takala and Viikari-Juntura[83] who did not find differences in UT activity between the patients with idiopathic neck pain and healthy controls during static elevation of the arm in the scapular plane (at 30-60-90-135°)[49], while holding the arm in 90° flexion in the scapular plane[35] or during a dynamic functional overhead task.[83] In contrast, Andersen et al.[2] found lower UT activity during isokinetic shoulder abduction for slow concentric, slow eccentric and static contraction in comparison with healthy controls, while during fast concentric contraction, no differences were found between the populations. Falla and Farina[32] found higher UT EMG activity in patients with neck pain during a specific part of an elevation task. So in general, conflicting results are found.

Regarding MT and LT activity, the current study showed lower MT activity in patients with neck pain and scapular dyskinesis in comparison with healthy controls with scapular dyskinesis. To date, no studies measured the MT or LT activity during overhead activities in patients with neck pain (Chapter 3). A study of Wegner et al.[89] investigated the amplitude of MT and LT during rest and did not find differences between patients with neck pain and healthy controls. Zakharova-Luneva et al.[92] investigated the amplitude of MT and LT activity during isometric contractions (abduction, flexion and external rotation) of the shoulder girdle in patients with neck pain, and did not find differences for MT in comparison with a healthy group, but reported higher LT activity in patients with neck pain during isometric abduction and external rotation (but not for flexion) in comparison with the control group. Overall, conflicting results are reported and it is difficult to compare the results between studies as the tasks are different. In addition, patient group comparisons were also slightly different from our study as the 2 studies only included patients with neck pain if they showed clinical signs of scapular dysfunction and they compared them with a control group without scapular dysfunction.

Dysfunction of the MT during elevation can have implications on scapulothoracic movement as the MT retracts and externally rotates the scapula. This study could not find differences in SA EMG activity between patients with neck pain and healthy controls. One other study investigated the SA EMG activity in patients with idiopathic neck pain, but focused on timing of the SA (and not amplitude of the activity), and showed a significantly delayed onset of muscle activation and shorter duration of activity of the SA in the presence of neck pain.[37]

This is the first study investigating deeper lying scapulothoracic EMG muscle activity in a population with neck pain, so no other data exist to compare our results with. Hypothetically, overuse of these deeper lying muscles (Pm, LS and RM) could lead to downward rotation of the scapula. In the current study, patients with neck pain showed higher Pm activity during the towel wall slide in comparison with healthy controls. Higher activity of the Pm can lead to anterior tilt and downward rotation of the scapula, which is not warranted during elevation of the arm. The important role of the Pm in neck pain has already been suggested in different clinical settings, however this study was the first to investigate and confirm this hypothesis. Possibly, overuse of the Pm may result in adaptive shortening and tension which can lead to a malaligned scapula. No differences in LS and RM activity were found in this study between patients with idiopathic neck pain and healthy controls. Nevertheless, some authors have already found differences in characteristics of these deeper lying muscles in the presence of neck pain and have suggested a role of these muscles in the presence of neck pain. These differences were found in trigger point presence, tension or shortness of muscles, etc.[33, 68, 77] Future research should further investigate the role of these muscles in relation to neck pain.

In general, the results of this dissertation add a new dimension to the understanding of possible impaired activation of the deeper lying muscles in patients with SIS and idiopathic neck pain. As both Chapter 2 (patients with SIS versus healthy controls) and Chapter 4 (patients with idiopathic neck pain versus healthy controls) investigated the scapulothoracic muscle activity during the same elevation tasks, it is possible to compare the results between studies. By comparing these results, information about the influence of the location of pain itself (shoulder versus neck) on the recruitment of the scapulothoracic muscles during elevation can be achieved. In patients with SIS, it was found that during the elevation tasks, the Pm was significantly more active in the SIS group in comparison with the healthy controls. This was similar to the results of those with neck pain who found higher Pm activity during the towel wallslide in comparison with the healthy control group. This study scientifically confirms the hypothesis of a possible role of the Pm in both patient groups. No differences in LS and RM activity were found in both population groups in comparison with the healthy control group during these elevation tasks. As this is the first study investigating the deeper lying muscle activity, comparisons with other studies are not possible. Regarding the superficial lying muscles, no differences in EMG activity were found between the two patient population groups in comparison with the healthy control group. Our study failed to show the same alterations that have generally been found in patients with SIS: alterations in UT (lower or higher activity), MT (lower activity), LT (lower activity) and SA (lower activity). In the study that compared patients with neck pain with healthy controls it was found that patients with neck pain and scapular dyskinesis showed lower MT activity in comparison with healthy controls with scapular dyskinesis. It was also found that the presence of scapular dyskinesis did not have a significant influence on scapulothoracic muscle activity in this study (idiopathic neck pain versus healthy controls). As we did not investigate the influence of scapular dyskinesis on scapulothoracic muscle recruitment in patients with SIS, we cannot compare these latter results. So, in conclusion, quite similar alterations were found to be present in both patients with SIS (in comparison with healthy controls) and in patients with idiopathic neck pain (in comparison with healthy controls).

Part II: Scapulothoracic muscle activity during different exercises commonly used in scapular rehabilitation programs, with special focus on the deeper lying muscles

Since abnormal scapular position and motion, and altered scapulothoracic muscle activity have been found in populations both with shoulder pain and/or neck pain, it is generally accepted that scapular training should be part of a comprehensive treatment. Different studies confirmed the value of scapular exercises, which aim to restore scapulothoracic muscle function, in the treatment of SIS and idiopathic neck pain.[1, 8, 27, 63, 67, 82]

However, there is currently no consensus about the best exercise program. In literature, numerous exercises have been prescribed for scapulothoracic muscle training. The choice for a specific exercise is often based upon the assumed effect on muscle activation, which requires detailed knowledge of exercise-specific activation of muscles in EMG studies. Different researchers have already examined the activation patterns of the scapulothoracic muscles during various exercises that aim to improve scapulothoracic muscle recruitment. To date, most exercises have been investigated for their activation of the Trapezius and the SA.[23, 28, 30, 36, 57-59, 70, 80] Very little EMG data are available on the activity of the smaller and less superficial muscles that attach to the scapula, including the **Pm, LS and RM**, during different exercises, despite the hypothesized importance of these muscles.

Therefore, in **Part 2 (Chapter 5, 6 and 7)**, different exercises that are often prescribed in scapulothoracic muscle training, were evaluated for their deeper and superficial lying muscle activity. In **Chapter 5**, exercises that include a **humeral elevation** component were investigated: scaption (elevation in the scapular plane), towel wall slide and elevation with external rotation (with Thera-Band). Exercises that include a humeral elevation component in the scapular plane are commonly implemented in scapular training as the scapula plays an important role during humeral elevation in providing a stable base for the glenohumeral joint. The main findings of the study were that scapulothoracic muscle activity differed significantly between the different elevation exercises. The UT showed the lowest activity, whereas the MT and LT showed the highest activity, during the elevation exercise that included the external-rotation component against elastic resistance. In light of these results, it seems that the elevation with external rotation exercise is appropriate if the main goal is to activate the MT and LT. During this exercise, the intensity of SA activity was not significantly different from the other exercises.

UT was activated to its highest during scaption. Pm and SA showed the highest activity during the towel wall slide. In contrast, all muscles that function as retractors of the scapula (MT, LT, LS and RM) are activated to a lesser degree during the towel wall slide than during the other elevation exercises. Adding load resulted in higher muscle activity of all muscles, with some muscles showing a different activation pattern between the elevation exercises pending on the loading.

In **Chapter 6**, **protraction exercises** that are prescribed to train the SA (Modified Push-Up Plus (Wall Version), Modified Knee Push-Up Plus (Floor version) and Serratus Punch) were investigated. SA exercises are often implemented in the rehabilitation program, as it is known that SA is an important stabilizer of the scapula and because research has linked shoulder and neck disorders to impairments in the SA. Exercises that target the SA mostly include a protraction component. It is known that the Pm also engages in the protraction movement of the scapula. However, apart from the protraction movement, the Pm also causes downward rotation, depression and anterior tilting of the scapula.[71] Clinical theories suggest that motor strategies favoring activity in Pm over SA are thought to be detrimental.[13, 24, 55] From a clinical point of view, it is of interest what the role of the Pm is during the performance of these protraction exercises. Exercises that highly activate the SA muscle while minimizing activation in the Pm are generally preferred.

In the study of Chapter 6, the activity of the SA and Pm was investigated during different protraction exercises. All protraction exercises activated the PM between 15 and 29%MVIC and the SA between 15 and 43%MVIC. It was found that during the Serratus Punch the SA activity was significantly higher than the Pm activity. So when maximum activation of the SA with minimal activation of the Pm is desired, the "Serratus punch" seems to be the optimal exercise. During the Modified Push-Up Plus exercises (both Wall and Floor version), the SA and Pm activity were comparable, and not statistically different from each other.

In **Chapter 7**, **shrugging and retraction exercises** were investigated for the activity of the upward and downward rotators of the scapula (UT, LS, MT, RM and LT). It is known that changes in muscular balance among the scapular rotators can cause abnormalities in coordinated scapular rotation.[25, 76] Therefore, it is important to integrate exercises in the scapular rehabilitation program that target activation of the scapular muscles, with a focus on the activation of upward rotators while minimizing the activation of the scapular downward rotators.[76] Often the "Shrug"-exercise has been prescribed in scapular rehabilitation programs to facilitate upward rotation of the scapula, [30, 43, 73] but the activity of the LS and RM, contributing to dominance of the downward rotator muscles, is not known. Three exercises were investigated: shrug with the arms at the side while holding a weight ("Shrug"), shrug with arms overhead ("ShrugOverhead") and retraction with arms overhead ("RetractionOverhead"). The results showed that activity levels of the main medial scapular muscles depend upon the specific shoulder joint position when performing shrug and retraction exercises. High UT activity was found across all exercises, with no significant differences in UT activity between the exercises. LS and RM activity was decreased with the "ShrugOverhead" exercise. The "RetractionOverhead" was the most effective exercise in activating the medial scapular muscles (RM, MT, LT).

2. Clinical implication of the results

The purpose of this paragraph is to place the knowledge of this dissertation into a broader clinical perspective. The presence of alterations in scapulothoracic muscle function has warranted clinicians to consider rehabilitation specifically aimed at the scapular muscles. Several studies have shown the effectiveness of scapular muscle training.[1, 8, 63, 67, 82]

For some muscles, there is agreement in both clinical and research field that these muscles need to be trained such as the MT, LT and SA, and that other muscles such as the Pm need to be inhibited and that their activation should rather be avoided. For the LS and RM, our studies were not able to show dysfunction in these muscles' activity. However, based upon clinical experience, the LS is generally seen as an "overactive" and shortened muscle. With regard to the RM, some clinicians state that this muscle is rather overactive (and leads to downward rotation), while some state this muscle is rather weakened (and leads to abduction of the scapula). Also for the UT there is no consensus: some authors promote the activity of UT, as an upward rotator, while other authors report that the UT is overactive and overused in patients with shoulder and neck pain. In general, no consistent changes in activity are present for each scapulothoracic muscle in patients with SIS and idiopathic neck pain. Specific needs and muscle dysfunctions may vary between patients, and key impairments from subjective and clinical examination should be the basis for an individual specific program. A differentiated approach, based upon specific dysfunctions, is necessary and will be described according each muscle below (focus on UT, focus on SA, focus on MT and LT, focus on whole Trapezius and RM).
As described in the introduction of this dissertation, a patient presenting with scapular muscle dysfunction may have or muscle performance problems, or flexibility problems, or both. Below, an attempt is made to categorize different possible muscle dysfunctions and link them with specific treatment guidelines, by providing the most appropriate exercises (selective activation of the weaker muscle parts, with minimal activity of the hyper/overactive muscles) and stretching or manual therapy techniques. If possible, clinical observable signs of aberrant patterns are added which can be linked to the muscle dysfunction. The recommendations are based upon literature regarding scapular muscle dysfunction and clinical experience, combined with new insights derived from this dissertation. Also, an adapted and updated (with information from this dissertation) clinical treatment algorithm for scapular dysfunction (originally from Ellenbecker and Cools[31]) will be presented.

Focus on Upper Trapezius Muscle

Some authors promote the activity of the UT, as an upward rotator in patients with shoulder and neck pain,[66, 73, 76, 88] while other authors report that the UT is overactive and overused in patients with shoulder and neck pain.[22, 23, 53, 81] Clinical observation of specific aberrant patterns of the scapula can possibly help the clinician in order to choose the best strategy for the UT. Weakness of the UT is often identified in patients with a scapular downward rotation syndrome. In that case an imbalance could exist between the upward and downward rotators of the scapula. Rehabilitation should then focus on strengthening the weak upward rotators, in particular the UT and SA.[76] In addition to the known examples of exercises that have been described to activate the UT, [26, 28, 30, 65, 80] the "overhead shrug" may be beneficial in case that low downward rotator activity (LS and RM) should be obtained, with high activity of UT (Chapter 7). In addition, possible tightness of the LS can be alleviated with stretching of the muscle (flexion, sidebending and rotation to the other side) and triggerpoint therapy (dry needling or manual technique).

In contrast, hyperactivity/overuse of the UT is often recognized by the "shrugging sign" (excessive elevation of the shoulder girdle seen in the early stages of humeral elevation). Huang et al.[44] also found a significant increase in UT activity during the arm-lowering phase in participants with medial border prominence. In case of overuse of the UT, optimizing UT activity should be avoided, and when training other muscles, low UT activity should be achieved during the exercises. In addition to commonly used exercises with low activity in UT, [23, 54] this dissertation showed the "towel wall slide" and the "elevation with external rotation" to be beneficial elevation exercises to train the scapular muscles with significantly lower activity in UT (in comparison with scaption) (Chapter 5). In addition, manual techniques or dry needling of the UT can be performed.[15] Stretching of the UT can be achieved by flexion, sidebending to the other side and rotation to the same side.[60]

Focus on Serratus Anterior Muscle

As the SA has a critical role in stabilizing the scapula against the thorax, a clinical observation sign that is often linked to SA weakness is an internally rotated scapula with a prominent medial border, which is also referred to as scapular winging (or alata), or a prominent inferior border of the scapula as a result of excessive anterior tilting. If the goal is to strengthen the SA, with or without inhibition of UT, a number of exercises can be performed that have been advocated to activate the SA muscle.[28, 30, 36, 59, 65, 70, 80] In our study (Chapter 6) the SA has shown the highest activity during the "serratus punch", which was significantly higher than during the "modified push-up plus (floor)" which was in turn significantly higher than the activity during the "modified push-up plus (wall)".

Huang et al.[44] has shown evidence for a significant decrease in SA and LT activity in participants with combined medial border and inferior angle prominence (combined pattern scapular dyskinesis I and II). So, in the presence of this combined pattern, SA and LT training should be combined (see next paragraph for exercises who activate the LT).

Prominence of the medial border or the inferior angle of the scapula is often also clinically linked to overactivity or shortness of the Pm. In that case, exercises with a low Pm/SA should be preferred. The exercise that is known to have a good Pm/SA ratio is the "serratus punch"(Chapter 6). Nevertheless, despite this good Pm/SA ratio, it should be noted that the Pm is more activated in comparison with the "modified push-up plus (wall)". Sometimes, restoring normal muscle tone of the antagonist (i.e. Pm) should first be addressed before attempting to activate a weakened or inhibited muscle (i.e. SA). Several stretches of the Pm have been described such as the unilateral corner stretch, sitting manual stretch, supine manual stretch, scapular retraction and posterior tilting while the shoulder is in neutral or small elevation and slight external rotation, direct pressure on the coracoid process, open book stretch etc.[6, 14, 51, 56, 69, 87, 91]

Focus on Middle Trapezius and Lower Trapezius

Weakness of the MT and LT are often present in patients with scapular dyskinesis, particular in those patients presenting with increased anterior tilt and protraction. A number of exercises have been described to train the MT [3, 28, 30, 65] and LT [4, 30, 65, 70, 80]. Also, exercises with low UT and high MT and LT (UT/MT and UT/LT ratio) are described.[23] If both MT and LT have to be trained in combination with low Pm and UT activity, "elevation with external rotation" can be recommended (Chapter 5). This exercise is also known to have the highest RM and LS activity in comparison with the other elevation exercises, whereas the SA activity was similar. Also, "retractionoverhead" is known to be an effective exercise in activating the MT, LT and RM (Chapter 7).

Focus on whole Trapezius and Rhomboid

The studies from this dissertation did not add new information to the body of exercises that activate the whole Trapezius muscle.[28, 65] Regarding the RM, the exercise "elevation with external rotation" elicits high activity of the RM, while the "towel wall slide" is known to elicit low RM activity (Chapter 5).

Below, an adapted and updated (with information from this dissertation) clinical treatment algorithm for scapular dysfunction can be found (originally from Ellenbecker & Cools[31]) (See Figure 1).

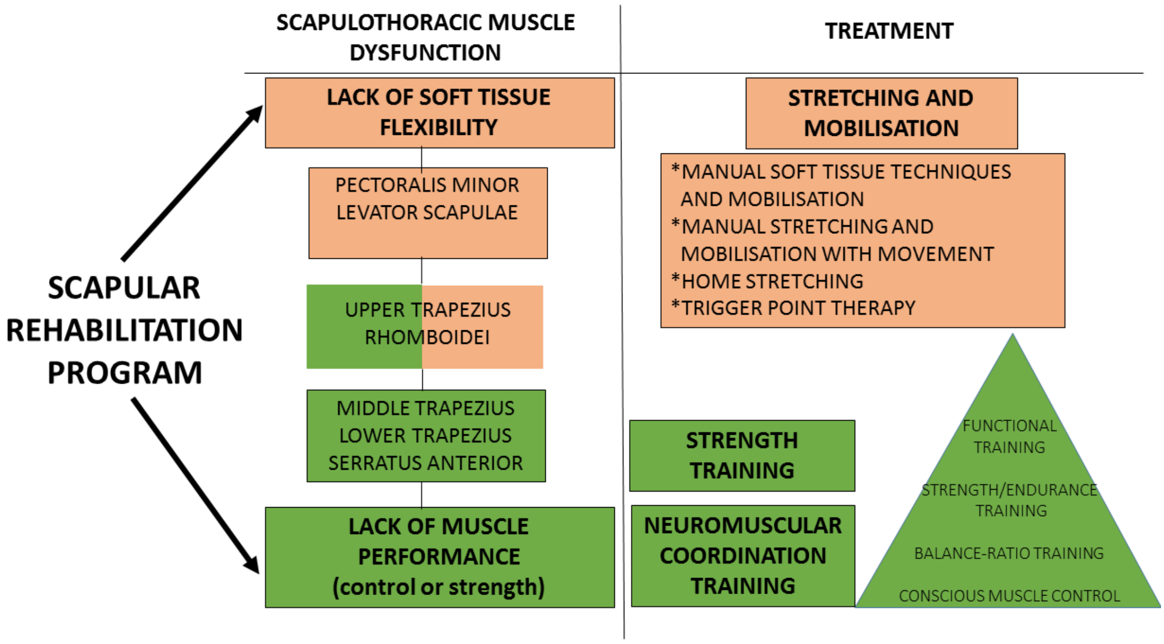


FIGURE 1. Updated treatment algorithm for scapular dysfunction (originally from Ellenbecker & Cools[31]) In scapular rehabilitation, two pathways can be followed: Red Pathway (management of lack of soft tissue flexibility, with presentation of most common muscles in which inflexibility occurs (LEFT-red), and accompanying treatment suggestions (RIGHT-red)) or Green Pathway (management of lack of muscle performance, with presentation of most common muscles in which control or strength problems occur (LEFT-green), and accompanying treatment suggestions (RIGHT-green)).

Also, an overview of different exercises for different muscle balance ratios is provided in the Appendix. (Appendix 1) Exercises are recommended for following muscle ratios:

- high UT/low LS activity
- high SA/low UT activity
- high LT/low Pm activity
- high SA/low Pm activity
- high MT/low UT activity
- high LT/low UT activity

3. Strengths and limitations

To allow appropriate interpretation of the results of the studies included in this dissertation, several strengths and limitations must be taken into account. They will be discussed within the following paragraphs.

A strength of this dissertation is the **consistency of the methodology** over the different studies. In each study, a telemetry system was used which allows easy investigation of muscle activity without cables or wires who can possibly restrain the range of motion. Also, in each study surface electrodes were used to record muscle activity for the UT, MT, LT and SA, while fine-wire electrodes allowed assessment of activity of the Pm, LS and RM. The same normalization method (which was developed by the authors in Chapter 1) and the same signal processing was used. This enables comparisons across studies more easy.

A known disadvantage of the EMG method is that **cross-talk** might have occurred in our EMG signals between superficial and deeper lying scapulothoracic muscles (such as MT and RM, UT and LS). Nevertheless, all recommended methods have been taken into account to reduce the possibility of cross-talk (small surface electrodes and small interelectrode distance, recommended electrode placement). Also, is still under debate whether surface and fine wire electrodes measure the same kind of muscle activity. [10, 34, 45, 46, 86] In our studies, the amplifier's bandwidth was wide enough for both fine wire and surface electrode signals ensuring that the data from the fine wire electrodes could be accurately compared to that of the surface electrodes once both had been normalized.[90]

A big strength of this dissertation is that it is the first to map out the activity of **the deeper lying muscles**. Despite the widespread use of scapulothoracic exercises in clinical settings, knowledge about the activation of the deeper lying muscles during various exercises was lacking. This dissertation will be a first step in implementing the information of the deeper lying muscles in scapular muscle training. Although it is a strength that the deeper lying muscles were investigated, the use of fine-wire EMG techniques is time consuming and the invasive procedure limits easy recruitment of participants for the studies. These drawbacks have limited the possibility to examine large sample sizes. Moreover, although subjects did not report pain by the insertion of the fine-wire EMG electrodes, it might be possible that the presence of these electrodes might have influenced the scapulothoracic recruitment. In our studies, relatively small sample sizes were investigated. In addition with the known large inter-individual variation of muscle activation levels, this could explain why some studies were not able to find significant differences between the population groups. So caution should be taken when interpreting the conclusions. Although the sample sizes used in our study were the same as in other studies (investigating shoulder muscles with fine wire EMG),[7, 39, 48, 61, 64, 74] studies need larger sample sizes in order to detect differences between the groups. Also, studies need to clearly define their patients and control groups, and avoid selection bias in the inclusion of their subject groups. Moreover, future studies should use standardized normalization procedures in order to make better comparisons between studies possible which could lead to a better conclusion for EMG studies.

Another limitation of this dissertation is that only the variable "**average muscle amplitude**" has been investigated. Analyses on different intervals of the movement could have given more information about possible differences in scapulothoracic muscle activity between the groups. In addition, also other EMG variables, such as timing, conduction velocity, fatigability and characteristic frequencies/patterns, could have given additional valuable information.[79]

It should be noted that the studies which examined muscle activity during different rehabilitation exercises were performed on healthy subjects and that therefore the results cannot be translated to patient population. Also, the conclusions on patient data only account for SIS and idiopathic neck patients, and **cannot be generalized** to all shoulder or neck patients (larger groups) or subgroups of SIS and idiopathic neck pain patients. The patients included in the studies were only characterized by their general symptoms and possible underlying mechanisms or causes were not taken into account. However, it could be possible that subgroups of patients show specific muscle recruitment patterns. In line with this comment, it is a limitation of the study in Chapter 2 that the presence or absence of scapular dyskinesis was not taken into account. It is not yet fully clear if people with scapular dyskinesis activate their muscles in another way compared to those without dyskinesis. Nevertheless, the choice of our patient groups in the studies (SIS and neck pain) can also be regarded as a strength as these patients have earlier been associated with altered scapular dysfunction. Moreover, it has already been shown that scapular exercise training is effective in these populations. [1, 8, 27, 63, 67, 82]

Another limitation of this dissertation is that the causal relationship cannot be determined by the present study design. No decision could be made whether the disturbance of muscle activity is a cause or a consequence of pain. More EMG studies with a longitudinal design are needed that investigate the relationship between disturbances in EMG and the development of shoulder and neck pain.

4. Considerations for future research

Based on the results of the different studies performed in this dissertation, some new research questions arise for further topics of investigations in this area.

This dissertation recommends specific exercises in order to activate specific muscles, based upon the EMG research of the deeper and superficial lying muscle activity during these exercises. However, future research should unravel if performing these exercises really leads to higher activation or strength of some muscles, or a change in activation or ratio of the scapulothoracic muscles. The efficacy of these exercises in treating dysfunctions must be investigated. Although this dissertation investigated the acute influence of the exercises on the recruitment of the scapulothoracic muscles, no proof has been given that training with these exercises effectively leads to a change in activation, so it would be interesting to study the effect of a training program on the recruitment of the scapulothoracic muscles. Both acute and chronic training effects need to be examined in patient populations (such as neck and shoulder pain) or healthy pain free patients with scapular dysfunction.

Future studies should also investigate scapulothoracic muscle activity in different subgroups of patient groups. Possibly, identification of relevant patient subgroups might lead to more specific treatment approach. Subgroups of patients can exist based upon a dominant dysfunction pattern (myofascial, articular, muscle control or strength). Research should unravel if a treatment in subgroups according to a specific dysfunction pattern (or a combination of different dysfunction patterns) is superior in comparison with standard physiotherapy for a general group.

Although only a few studies investigated the activity of the deeper lying scapulothoracic muscles in this dissertation, we believe that these studies give a valuable addition to the knowledge of scapulothoracic muscle activity. Nevertheless, we believe that more research is necessary in order to draw definite conclusions regarding possible EMG differences of the deeper lying muscle activity. Future investigations should also focus on more high-quality studies with larger sample sizes. Moreover, the influence of the deeper lying muscles on the scapula should be further investigated, maybe with other parameters such as stiffness, trigger point presence, etc.

In this dissertation, the muscle activity of the exercises was investigated in a healthy population. Consequently, the new insights regarding the recruitment patterns of the scapulothoracic muscles during exercises only accounts for the healthy population. Extrapolating these results to a patient population should be undertaken with caution. Nevertheless, previous EMG studies have used similar healthy populations in making recommendations for shoulder exercises. However, future research should aim to investigate if a patient population would show the same amount of muscle activity during exercises. Therefore, future investigations targeting symptomatic persons performing scapular exercises would potentially facilitate refinement of our rehabilitation programs. Future research should also investigate more functional and kinetic chain exercises (which tend to incorporate other body segments in shoulder exercises), which is different from the rather analytical exercises investigated in our studies.

Although EMG data give important information, its interpretation remains rather difficult because no concurrent kinematic analysis of the scapula was performed. Future EMG studies should overcome this limitation of EMG and should try to record 3D-kinematic data of the scapula in order to better understand the relationship between scapular orientation and muscle activity. Linking muscle function and kinematic alterations can possibly gain insight into the effectiveness of some exercises.

In this dissertation, muscle activity was measured with EMG, as to date EMG has been widely considered as an essential and reliable technique to measure muscle activation patterns. However, the technique of EMG has also disadvantages. Recently mfMRI has been proposed as a novel technique to accurately map activity of deeper and superficial lying muscles simultaneously.[16, 47, 62] In contrast to EMG which measures real time electric changes in muscle activity, mfMRI is a post-exercise evaluation technique which maps the exercise induced metabolic changes in recently activated muscles.[16, 29, 47] This highlights that both techniques should be seen as complementary.[29] So, in the future, muscle activation around the scapula should also be investigated with mfMRI. In the Appendix of this dissertation, some results are presented from some preliminary studies we have performed with mfMRI. The first mfMRI study investigated the influence of induced shoulder muscle pain on activation of the rotator cuff and scapulothoracic muscles during elevation of the arm (Appendix 2). The second mfMRI study compared rotator cuff and scapulothoracic muscle activation during elevation of the arm between patients with idiopathic neck pain and healthy subjects (Appendix 3).

5. Bibliography

1 Andersen CH, Andersen LL, Zebis MK, Sjogaard G. Effect of scapular function training on chronic pain in the neck/shoulder region: a randomized controlled trial. J Occup Rehabil 2014;24:316-324. 10.1007/s10926-013-9441-1

2 Andersen LL, Nielsen PK, Sogaard K, Andersen CH, Skotte J, Sjogaard G. Torque-EMG-velocity relationship in female workers with chronic neck muscle pain. J Biomech 2008;41:2029-2035. 10.1016/j.jbiomech.2008.03.016

3 Bagg SD, Forrest WJ. Electromyographic study of the scapular rotators during arm abduction in the scapular plane. Am J Phys Med 1986;65:111-124.

4 Ballantyne BT, O'Hare SJ, Paschall JL, Pavia-Smith MM, Pitz AM, Gillon JF et al. Electromyographic activity of selected shoulder muscles in commonly used therapeutic exercises. Phys Ther 1993;73:668-677; discussion 677-682.

5 Bandholm T, Rasmussen L, Aagaard P, Jensen BR, Diederichsen L. Force steadiness, muscle activity, and maximal muscle strength in subjects with subacromial impingement syndrome. Muscle Nerve 2006;34:631-639. 10.1002/mus.20636

6 Bang MD, Deyle GD. Comparison of supervised exercise with and without manual physical therapy for patients with shoulder impingement syndrome. J Orthop Sports Phys Ther 2000;30:126-137. 10.2519/jospt.2000.30.3.126

7 Barden JM, Balyk R, Raso VJ, Moreau M, Bagnall K. Atypical shoulder muscle activation in multidirectional instability. Clin Neurophysiol 2005;116:1846-1857. 10.1016/j.clinph.2005.04.019

8 Baskurt Z, Baskurt F, Gelecek N, Ozkan MH. The effectiveness of scapular stabilization exercise in the patients with subacromial impingement syndrome. J Back Musculoskelet Rehabil 2011;24:173-179. 10.3233/bmr-2011-0291

9 Boettcher CE, Ginn KA, Cathers I. Standard maximum isometric voluntary contraction tests for normalizing shoulder muscle EMG. J Orthop Res 2008;26:1591-1597. 10.1002/jor.20675

10 Bogey RA, Perry J, Bontrager EL, Gronley JK. Comparison of across-subject EMG profiles using surface and multiple indwelling wire electrodes during gait. J Electromyogr Kinesiol 2000;10:255-259.

11 Borstad JD. Resting position variables at the shoulder: evidence to support a posture-impairment association. Phys Ther 2006;86:549-557.

12 Borstad JD. Measurement of pectoralis minor muscle length: validation and clinical application. J Orthop Sports Phys Ther 2008;38:169-174. 10.2519/jospt.2008.2723

13 Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. J Orthop Sports Phys Ther 2005;35:227-238. 10.2519/jospt.2005.35.4.227

14 Borstad JD, Ludewig PM. Comparison of three stretches for the pectoralis minor muscle. J Shoulder Elbow Surg 2006;15:324-330. 10.1016/j.jse.2005.08.011

15 Cagnie B, Castelein B, Pollie F, Steelant L, Verhoeyen H, Cools A. Evidence for the Use of Ischemic Compression and Dry Needling in the Management of Trigger Points of the Upper Trapezius in Patients with Neck Pain: A Systematic Review. Am J Phys Med Rehabil 2015;94:573-583. 10.1097/phm.0000000000000266

16 Cagnie B, Elliott JM, O'Leary S, D'Hooge R, Dickx N, Danneels LA. Muscle functional MRI as an imaging tool to evaluate muscle activity. J Orthop Sports Phys Ther 2011;41:896-903. 10.2519/jospt.2011.3586

17 Cagnie B, Struyf F, Cools A, Castelein B, Danneels L, O'Leary S. The relevance of scapular dysfunction in neck pain: a brief commentary. J Orthop Sports Phys Ther 2014;44:435-439. 10.2519/jospt.2014.5038

18 Castelein B, Cagnie B, Parlevliet T, Cools A. Serratus anterior or pectoralis minor: Which muscle has the upper hand during protraction exercises? Man Ther 2015. 10.1016/j.math.2015.12.002

19 Castelein B, Cagnie B, Parlevliet T, Cools A. Superficial and Deep Scapulothoracic Muscle EMG Activity During Different Types of Elevation Exercises in the Scapular Plane. J Orthop Sports Phys Ther 2016:1-26. 10.2519/jospt.2016.5927

20 Castelein B, Cools A, Parlevliet T, Cagnie B. Modifying the shoulder joint position during shrugging and retraction exercises alters the activation of the medial scapular muscles. Man Ther 2016;21:250-255. 10.1016/j.math.2015.09.005

21 Choi WJ, Cynn HS, Lee CH, Jeon HS, Lee JH, Jeong HJ et al. Shrug exercises combined with shoulder abduction improve scapular upward rotator activity and scapular alignment in subjects with scapular downward rotation impairment. J Electromyogr Kinesiol 2015;25:363-370.

22 Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scand J Med Sci Sports 2007;17:25-33. 10.1111/j.1600-0838.2006.00570.x

23 Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? Am J Sports Med 2007;35:1744-1751. 10.1177/0363546507303560

24 Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. Br J Sports Med 2014;48:692-697. 10.1136/bjsports-2013-092148

25 Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. Br J Sports Med 2004;38:64-68.

26 Cordasco FA, Wolfe IN, Wootten ME, Bigliani LU. An electromyographic analysis of the shoulder during a medicine ball rehabilitation program. Am J Sports Med 1996;24:386-392.

27 De Mey K, Danneels L, Cagnie B, Cools AM. Scapular muscle rehabilitation exercises in overhead athletes with impingement symptoms: effect of a 6-week training program on muscle recruitment and functional outcome. Am J Sports Med 2012;40:1906-1915. 10.1177/0363546512453297

28 Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. Am J Sports Med 1999;27:784-791.

29 Dickx N, D'Hooge R, Cagnie B, Deschepper E, Verstraete K, Danneels L. Magnetic resonance imaging and electromyography to measure lumbar back muscle activity. Spine (Phila Pa 1976) 2010;35:E836-842. 10.1097/BRS.0b013e3181d79f02

30 Ekstrom RA, Donatelli RA, Soderberg GL. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. J Orthop Sports Phys Ther 2003;33:247-258. 10.2519/jospt.2003.33.5.247

31 Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. Br J Sports Med 2010;44:319-327. 10.1136/bjsm.2009.058875

32 Falla D, Farina D. Muscle fiber conduction velocity of the upper trapezius muscle during dynamic contraction of the upper limb in patients with chronic neck pain. Pain 2005;116:138-145. 10.1016/j.pain.2005.03.038

33 Fernandez-de-las-Penas C, Grobli C, Ortega-Santiago R, Fischer CS, Boesch D, Froidevaux P et al. Referred pain from myofascial trigger points in head, neck, shoulder, and arm muscles reproduces pain symptoms in blue-collar (manual) and white-collar (office) workers. Clin J Pain 2012;28:511-518. 10.1097/AJP.0b013e31823984e2

34 Giroux B, Lamontagne M. Comparisons between surface electrodes and intramuscular wire electrodes in isometric and dynamic conditions. Electromyogr Clin Neurophysiol 1990;30:397-405.

35 Goudy N, McLean L. Using myoelectric signal parameters to distinguish between computer workers with and without trapezius myalgia. Eur J Appl Physiol 2006;97:196-209. 10.1007/s00421-006-0162-4

36 Hardwick DH, Beebe JA, McDonnell MK, Lang CE. A comparison of serratus anterior muscle activation during a wall slide exercise and other traditional exercises. J Orthop Sports Phys Ther 2006;36:903-910. 10.2519/jospt.2006.2306

37 Helgadottir H, Kristjansson E, Einarsson E, Karduna A, Jonsson H, Jr. Altered activity of the serratus anterior during unilateral arm elevation in patients with cervical disorders. J Electromyogr Kinesiol 2011;21:947-953. 10.1016/j.jelekin.2011.07.007

38 Herrington L, Waterman R, Smith L. Electromyographic analysis of shoulder muscles during press-up variations and progressions. J Electromyogr Kinesiol 2015;25:100-106.

39 Hess SA, Richardson C, Darnell R, Friis P, Lisle D, Myers P. Timing of rotator cuff activation during shoulder external rotation in throwers with and without symptoms of pain. J Orthop Sports Phys Ther 2005;35:812-820. 10.2519/jospt.2005.35.12.812

40 Hidalgo-Lozano A, Fernandez-de-las-Penas C, Alonso-Blanco C, Ge HY, Arendt-Nielsen L, Arroyo-Morales M. Muscle trigger points and pressure pain hyperalgesia in the shoulder muscles in patients with unilateral shoulder impingement: a blinded, controlled study. Exp Brain Res 2010;202:915-925. 10.1007/s00221-010-2196-4

41 Hidalgo-Lozano A, Fernandez-de-las-Penas C, Calderon-Soto C, Domingo-Camara A, Madeleine P, Arroyo-Morales M. Elite swimmers with and without unilateral shoulder pain: mechanical hyperalgesia and active/latent muscle trigger points in neck-shoulder muscles. Scand J Med Sci Sports 2013;23:66-73. 10.1111/j.1600-0838.2011.01331.x

42 Hidalgo-Lozano A, Fernandez-de-las-Penas C, Diaz-Rodriguez L, Gonzalez-Iglesias J, Palacios-Cena D, Arroyo-Morales M. Changes in pain and pressure pain sensitivity after manual treatment of active trigger points in patients with unilateral shoulder impingement: a case series. J Bodyw Mov Ther 2011;15:399-404. 10.1016/j.jbmt.2010.12.003

43 Hintermeister RA, Lange GW, Schultheis JM, Bey MJ, Hawkins RJ. Electromyographic activity and applied load during shoulder rehabilitation exercises using elastic resistance. Am J Sports Med 1998;26:210-220.

44 Huang TS, Ou HL, Huang CY, Lin JJ. Specific kinematics and associated muscle activation in individuals with scapular dyskinesis. J Shoulder Elbow Surg 2015;24:1227-1234. 10.1016/j.jse.2014.12.022

45 Jaggi A, Malone AA, Cowan J, Lambert S, Bayley I, Cairns MC. Prospective blinded comparison of surface versus wire electromyographic analysis of muscle recruitment in shoulder instability. Physiother Res Int 2009;14:17-29. 10.1002/pri.407

46 Johnson VL, Halaki M, Ginn KA. The use of surface electrodes to record infraspinatus activity is not valid at low infraspinatus activation levels. J Electromyogr Kinesiol 2011;21:112-118. 10.1016/j.jelekin.2010.08.007

47 Kinugasa R, Kawakami Y, Fukunaga T. Quantitative assessment of skeletal muscle activation using muscle functional MRI. Magn Reson Imaging 2006;24:639-644. 10.1016/j.mri.2006.01.002

48 Kronberg M, Brostrom LA, Nemeth G. Differences in shoulder muscle activity between patients with generalized joint laxity and normal controls. Clin Orthop Relat Res 1991:181-192.

49 Larsson R, Oberg PA, Larsson SE. Changes of trapezius muscle blood flow and electromyography in chronic neck pain due to trapezius myalgia. Pain 1999;79:45-50.
50 Lee JH, Cynn HS, Choi WJ, Jeong HJ, Yoon TL. Various shrug exercises can change scapular kinematics and scapular rotator muscle activities in subjects with scapular downward rotation syndrome. Hum Mov Sci 2016;45.
51 Lee TS, Kilbreath SL, Refshauge KM, Pendlebury SC, Beith JM, Lee MJ. Pectoral stretching program for women undergoing radiotherapy for breast cancer. Breast Cancer Res Treat 2007;102:313-321. 10.1007/s10549-006-9339-0
52 Lin JJ, Hsieh SC, Cheng WC, Chen WC, Lai Y. Adaptive patterns of movement during arm elevation test in patients with shoulder impingement syndrome. J Orthop Res 2011;29:653-657. 10.1002/jor.21300
53 Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276-291.
54 Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. Am J Sports Med 2004;32:484-493.
55 Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther 2009;39:90-104. 10.2519/jospt.2009.2808
56 Lynch SS, Thigpen CA, Mihalik JP, Prentice WE, Padua D. The effects of an exercise intervention on forward head and rounded shoulder postures in elite swimmers. Br J Sports Med 2010;44:376-381. 10.1136/bjsm.2009.066837
57 Maenhout A, Benzoor M, Werin M, Cools A. Scapular muscle activity in a variety of plyometric exercises. J Electromyogr Kinesiol 2016;27:39-45. 10.1016/j.jelekin.2016.01.003
58 Maenhout A, Van Praet K, Pizzi L, Van Herzeele M, Cools A. Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity? Br J Sports Med 2010;44:1010-1015. 10.1136/bjsm.2009.062810
59 Malanga GA, Jenp YN, Growney ES, An KN. EMG analysis of shoulder positioning in testing and strengthening the supraspinatus. Med Sci Sports Exerc 1996;28:661-664.
60 Martin-Pintado Zugasti A, Rodriguez-Fernandez AL, Garcia-Muro F, Lopez-Lopez A, Mayoral O, Mesa-Jimenez J et al. Effects of spray and stretch on postneedling soreness and sensitivity after dry needling of a latent myofascial trigger point. Arch Phys Med Rehabil 2014;95:1925-1932 e1921. 10.1016/j.apmr.2014.05.021
61 McMahon PJ, Jobe FW, Pink MM, Brault JR, Perry J. Comparative electromyographic analysis of shoulder muscles during planar motions: anterior glenohumeral instability versus normal. J Shoulder Elbow Surg 1996;5:118-123.
62 Meyer RA, Prior BM. Functional magnetic resonance imaging of muscle. Exerc Sport Sci Rev 2000;28:89-92.
63 Moezy A, Sepehrifar S, Solaymani Dodaran M. The effects of scapular stabilization based exercise therapy on pain, posture, flexibility and shoulder mobility in patients with shoulder impingement syndrome: a controlled randomized clinical trial. Med J Islam Repub Iran 2014;28:87.
64 Morris AD, Kemp GJ, Frostick SP. Shoulder electromyography in multidirectional instability. J Shoulder Elbow Surg 2004;13:24-29. 10.1016/s1058274603002489
65 Moseley JB, Jr., Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. Am J Sports Med 1992;20:128-134.
66 Mottram SL, Woledge RC, Morrissey D. Motion analysis study of a scapular orientation exercise and subjects' ability to learn the exercise. Man Ther 2009;14:13-18. 10.1016/j.math.2007.07.008

67 Mulligan EP, Huang M, Dickson T, Khazzam M. The effect of axioscapular and rotator cuff exercise training sequence in pateints with subacromial impingement syndrome: a randomized crossover trial. International journal of sports physical therapy 2016;11:94-107.

68 Munoz-Munoz S, Munoz-Garcia MT, Alburquerque-Sendin F, Arroyo-Morales M, Fernandez-de-las-Penas C. Myofascial trigger points, pain, disability, and sleep quality in individuals with mechanical neck pain. J Manipulative Physiol Ther 2012;35:608-613. 10.1016/j.jmpt.2012.09.003

69 Muraki T, Aoki M, Izumi T, Fujii M, Hidaka E, Miyamoto S. Lengthening of the pectoralis minor muscle during passive shoulder motions and stretching techniques: a cadaveric biomechanical study. Phys Ther 2009;89:333-341. 10.2522/ptj.20080248

70 Myers JB, Pasquale MR, Laudner KG, Sell TC, Bradley JP, Lephart SM. On-the-Field Resistance-Tubing Exercises for Throwers: An Electromyographic Analysis. J Athl Train 2005;40:15-22.

71 Oatis C. Kinesiology: the mechanics and pathomechanics of human movement.: Lippincott: Williams & Wilkins; 2004.

72 Oyama S, Myers JB, Wassinger CA, Lephart SM. Three-dimensional scapular and clavicular kinematics and scapular muscle activity during retraction exercises. J Orthop Sports Phys Ther 2010;40:169-179.

73 Pizzari T, Wickham J, Balster S, Ganderton C, Watson L. Modifying a shrug exercise can facilitate the upward rotator muscles of the scapula. Clin Biomech (Bristol, Avon) 2014;29:201-205. 10.1016/j.clinbiomech.2013.11.011

74 Reddy AS, Mohr KJ, Pink MM, Jobe FW. Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement. J Shoulder Elbow Surg 2000;9:519-523.

75 Roy JS, Moffet H, McFadyen BJ. Upper limb motor strategies in persons with and without shoulder impingement syndrome across different speeds of movement. Clin Biomech (Bristol, Avon) 2008;23:1227-1236. 10.1016/j.clinbiomech.2008.07.009

76 Sahrmann. Diagnosis and treatment of movement impairment syndromes: Elsevier Health Sciences; 2002.

77 Sari H, Akarirmak U, Uludag M. Active myofascial trigger points might be more frequent in patients with cervical radiculopathy. Eur J Phys Rehabil Med 2012;48:237-244.

78 Schachter AK, McHugh MP, Tyler TF, Kreminic IJ, Orishimo KF, Johnson C et al. Electromyographic activity of selected scapular stabilizers during glenohumeral internal and external rotation contractions. J Shoulder Elbow Surg 2010;19:884-890.

79 Schulte E, Kallenberg LA, Christensen H, Disselhorst-Klug C, Hermens HJ, Rau G et al. Comparison of the electromyographic activity in the upper trapezius and biceps brachii muscle in subjects with muscular disorders: a pilot study. Eur J Appl Physiol 2006;96:185-193. 10.1007/s00421-004-1291-2

80 Smith J, Dahm DL, Kaufman KR, Boon AJ, Laskowski ER, Kotajarvi BR et al. Electromyographic activity in the immobilized shoulder girdle musculature during scapulothoracic exercises. Arch Phys Med Rehabil 2006;87:923-927. 10.1016/j.apmr.2006.03.013

81 Struyf F, Cagnie B, Cools A, Baert I, Brempt JV, Struyf P et al. Scapulothoracic muscle activity and recruitment timing in patients with shoulder impingement symptoms and glenohumeral instability. J Electromyogr Kinesiol 2014;24:277-284. 10.1016/j.jelekin.2013.12.002

82 Struyf F, Nijs J, Mollekens S, Jeurissen I, Truijen S, Mottram S et al. Scapular-focused treatment in patients with shoulder impingement syndrome: a randomized clinical trial. Clin Rheumatol 2013;32:73-85. 10.1007/s10067-012-2093-2

83 Takala EP, Viikari-Juntura E. Loading of shoulder muscles in a simulated work cycle: comparison between sedentary workers with and without neck-shoulder symptoms. Clin Biomech (Bristol, Avon) 1991;6:145-152. 10.1016/0268-0033(91)90025-l
84 Tate A, Turner GN, Knab SE, Jorgensen C, Strittmatter A, Michener LA. Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. J Athl Train 2012;47:149-158.
85 Tucker WS, Armstrong CW, Gribble PA, Timmons MK, Yeasting RA. Scapular muscle activity in overhead athletes with symptoms of secondary shoulder impingement during closed chain exercises. Arch Phys Med Rehabil 2010;91:550-556.
86 Waite DL, Brookham RL, Dickerson CR. On the suitability of using surface electrode placements to estimate muscle activity of the rotator cuff as recorded by intramuscular electrodes. J Electromyogr Kinesiol 2010;20:903-911. 10.1016/j.jelekin.2009.10.003
87 Wang CH, McClure P, Pratt NE, Nobilini R. Stretching and strengthening exercises: their effect on three-dimensional scapular kinematics. Arch Phys Med Rehabil 1999;80:923-929.
88 Watson LA, Pizzari T, Balster S. Thoracic outlet syndrome part 2: conservative management of thoracic outlet. Man Ther 2010;15:305-314. 10.1016/j.math.2010.03.002
89 Wegner S, Jull G, O'Leary S, Johnston V. The effect of a scapular postural correction strategy on trapezius activity in patients with neck pain. Man Ther 2010;15:562-566. 10.1016/j.math.2010.06.006
90 Wickham J, Pizzari T, Stansfeld K, Burnside A, Watson L. Quantifying 'normal' shoulder muscle activity during abduction. J Electromyogr Kinesiol 2010;20:212-222. 10.1016/j.jelekin.2009.06.004
91 Wong CK, Coleman D, diPersia V, Song J, Wright D. The effects of manual treatment on rounded-shoulder posture, and associated muscle strength. J Bodyw Mov Ther 2010;14:326-333. 10.1016/j.jbmt.2009.05.001
92 Zakharova-Luneva E, Jull G, Johnston V, O'Leary S. Altered trapezius muscle behavior in individuals with neck pain and clinical signs of scapular dysfunction. J Manipulative Physiol Ther 2012;35:346-353. 10.1016/j.jmpt.2012.04.011

SUMMARY

The scapula, which functions as a bridge between the shoulder complex and the spine, is almost solely dependent on the function of the surrounding muscles for its stability and mobility. The Trapezius and the Serratus Anterior work together as 'a force couple' which is considered necessary for optimal scapular movement. The Pectoralis Minor, Levator Scapulae and Rhomboids can also influence the scapular position and motion. Small changes in the pattern of scapulothoracic muscle coordination can produce scapular dysfunction, which is often linked to upper quadrant symptoms. The results of this dissertation added a new dimension to the understanding of possible impaired activation of the superficial and deeper lying scapulothoracic muscles in patients with shoulder impingement syndrome and in patients with idiopathic neck pain.

This study confirmed the hypothesis of a possible role of the Pectoralis Minor in both patients with shoulder impingement symptoms and neck pain. Excessive activation of the Pectoralis Minor, which downwardly rotates, anteriorly tilts and internally rotates the scapula, may impede the desired movement of the scapula that is necessary during elevation. Also, decreased Middle Trapezius activity in the presence of scapular dyskinesis, was found in patients with idiopathic neck pain. This dissertation could not show altered activity of the Levator Scapulae and the Rhomboid Major in neither groups. It is generally known from earlier research that patients with shoulder impingement symptoms show alterations in Upper Trapezius, Middle Trapezius, Lower Trapezius and Serratus Anterior activity. However, our study failed to show these same alterations. In general, comparison between studies is however difficult as the EMG results may vary dependent on the task, the population, normalization procedures etc.

Although there is no consensus if consistent alterations exist in patients with shoulder impingement symptoms or in patients with idiopathic neck pain, studies have shown that scapulothoracic muscle training is effective in these populations. Given the amount of exercises that are available, it is crucial to define optimal exercises pending on the individual presentation of the patient. The best exercises for patients with an altered pattern in scapulothoracic muscles (muscle imbalance or strength deficit) are often based upon selective activation of the weaker muscle parts, while minimizing the activity of the hyperactive muscles. A thorough understanding of the deeper lying muscle activity in exercises that are widely used in clinical settings is provided by this dissertation and is imperative for selecting the most appropriate rehabilitation exercise. Elevation exercises in the scapular plane, protraction exercises and shrugging and retraction exercises were investigated for their deeper (and superficial lying) muscle activation. In general, the results showed that the deeper lying muscles were active during these exercises and that their activity differed according to the specific performance of the exercises.

These new insights will hopefully assist trainers and therapists in optimizing training and treatment programs by selecting the most appropriate exercise and in refining clinical practice guidelines supported by research data.

NEDERLANDSE SAMENVATTING

Het schouderblad fungeert als een brug tussen de schouder en de wervelkolom, en is voor zijn stabiliteit en mobiliteit bijna uitsluitend afhankelijk van de functie van de omliggende spieren. De Trapezius en de Serratus Anterior werken samen als een "krachtenkoppel", wat nodig wordt geacht voor een optimale beweging van het schouderblad. De Pectoralis Minor, Levator Scapulae en Rhomboidei kunnen ook een invloed hebben op de scapulaire positie en beweging. Kleine veranderingen in het coördinatie-patroon van deze scapulothoracale spieren kunnen zorgen voor een dysfunctie van het schouderblad (=scapulaire dysfunctie), wat vaak gelinkt wordt aan symptomen in het bovenste kwadrant. De resultaten van dit proefschrift geven meer inzicht in het begrijpen van mogelijke afwijkende activiteit van oppervlakkige en dieper gelegen scapulothoracale spieren bij patiënten met schouder impingement symptomen en bij patiënten met idiopathische nekpijn.

De resultaten van dit proefschrift bevestigen de hypothese van een mogelijke rol van de Pectoralis Minor bij zowel patiënten met impingement symptomen als patiënten met nekpijn. Overmatige activiteit van de Pectoralis Minor, een spier die zorgt voor neerwaartse rotatie, anterieure tilt en interne rotatie van het schouderblad, kan de gewenste beweging van het schouderblad, die nodig is tijdens elevatie van de arm, belemmeren. Ook gedaalde activiteit van de middelste bundel van de Trapezius in de aanwezigheid van scapulaire dyskinesie, werd aangetoond bij patiënten met idiopathische nekpijn. Dit proefschrift kon in geen van beide groepen een afwijkende activiteit aantonen in de Levator Scapulae en de Rhomboid Major. Het is algemeen geweten van eerder onderzoek dat er veranderingen in Trapezius (bovenste, middenste en onderste bundel) en in Serratus Anterior activiteit voorkomen bij patiënten met schouder impingement symptomen. Over het algemeen is het moeilijk om studies onderling te vergelijken omdat EMG resultaten kunnen variëren afhankelijk van de taak, de bestudeerde populatie, de normalizatieprocedures, enz.

Hoewel er geen consensus bestaat over het feit of er al dan niet consistente afwijkende patronen in scapulothoracale spieractiviteit zouden bestaan bij patiënten met impingement of patiënten met idiopathische nekpijn, hebben studies aangetoond dat training van de scapulothoracale spieren wel effectief is bij deze populaties. Gezien de hoeveelheid oefeningen die beschikbaar zijn, is het cruciaal dat enkel oefeningen gekozen worden die optimaal zijn volgens de individuele presentatie van de patiënt. De beste oefeningen voor patiënten met een veranderd patroon in de scapulothoracale spieren (spieronevenwicht of krachtstekort) worden vaak geselecteerd op basis van selectieve activatie van de zwakkere spieren, in combinatie met minimale activiteit van de hyperactieve spieren. Dit proefschrift geeft een beter inzicht in de activiteit van de dieper gelegen spieren tijdens oefeningen die vaak worden gebruikt in klinische setting. Dit is onontbeerlijk voor het selecteren van de meest gepaste oefening. De spieractiviteit van de dieper gelegen (en oppervlakkig gelegen) spieren werd onderzocht tijdens verschillende elevatie-oefeningen in het scapulair vlak, tijdens protractie oefeningen en tijdens shrugging en retractie oefeningen. Uit de resultaten bleek dat de dieper gelegen spieren actief waren tijdens deze oefeningen en dat de spieractiviteit verschilde naargelang de specifieke uitvoering van de oefeningen. Deze nieuwe inzichten zullen hopelijk trainers en therapeuten helpen bij het optimaliseren van training en behandelprogramma's door het selecteren van de meest geschikte oefening en het verfijnen van de klinische richtlijnen, ondersteund door onderzoeksdata.

APPENDICES

Appendix 1

GOAL	EXERCISE DESCRIPTION

High UT
Low LS

ShrugOverhead[20]

Subject standing, placing the arm in overhead position against the wall and performing a shrug movement and returning back to the starting position.

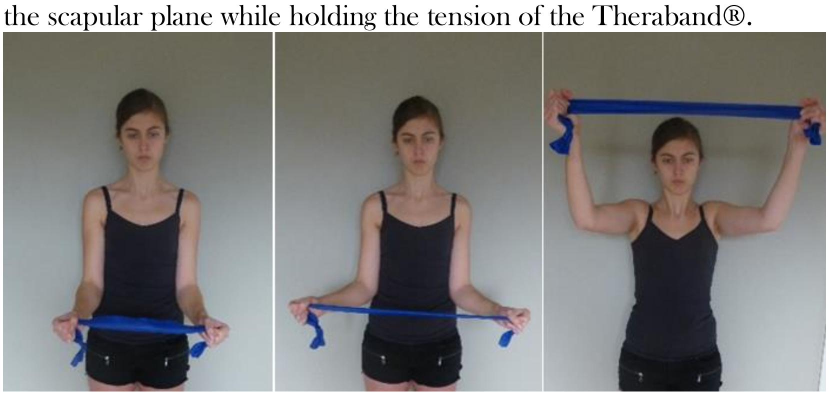
High SA
Low UT

Towel Wall Slide[19]

For the starting position, the subject holds a towel in the hand and puts the hand against the wall with the elbow flexed 90°. The subject moves the towel up by sliding the arm against the wall until elbow is fully extended. This is performed in the scapular plane (30°).

Bilateral Elevation with External Rotation by holding a Theraband®[19]

The subject takes the Theraband® in both hands and flexes the elbows 90° with the shoulder in a neutral position. The Theraband® is then brought to tension with 30° of external rotation in which the wrists remain in the neutral position. From this position an elevation of both arms is carried out up to 90° in the scapular plane while holding the tension of the Theraband®.

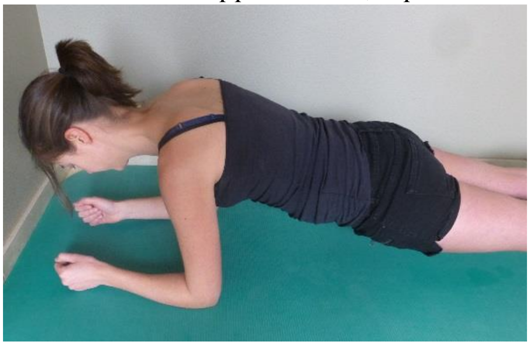


GOAL | **EXERCISE DESCRIPTION**

High SA
Low UT

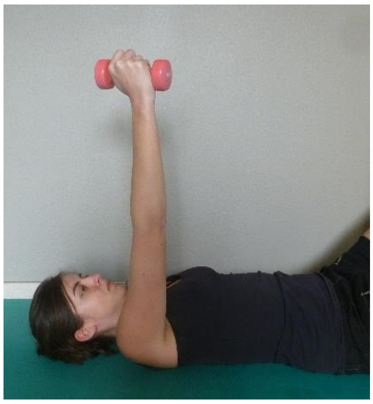

<u>**Elbow Push-Up/Prone Bridging**</u>[54]

The elbows are flexed 90° and placed on shoulder width. The arms are perpendicular to the floor. The head, trunk and knees are in one line. The starting position is in retraction. From this position, the subject rolls the shoulders forward (scapular protraction) and then lowers the body while allowing the shoulder blades to approximate (scapular retraction).

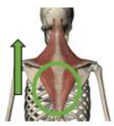


<u>**Serratus Punch Supine**</u>[54]

Subject supine, with the arm flexed in 90°. The subject performs scapular protraction with elbow extended (direction towards the ceiling).

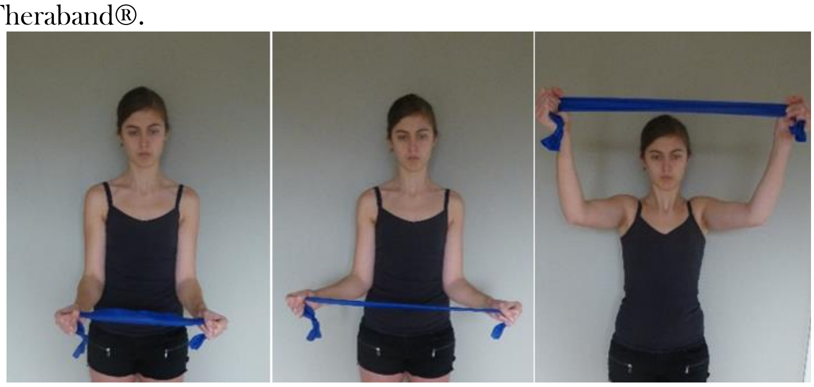


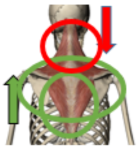
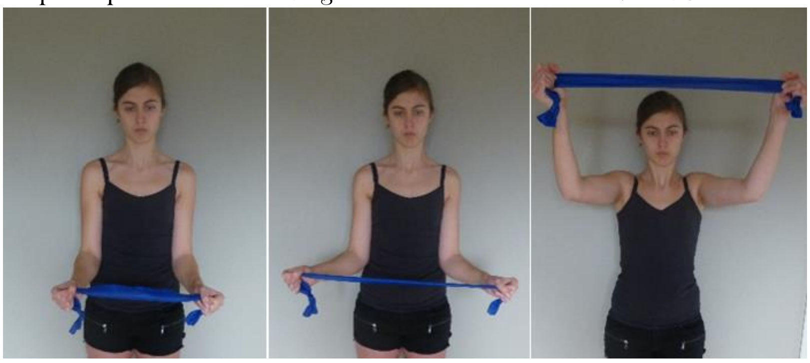
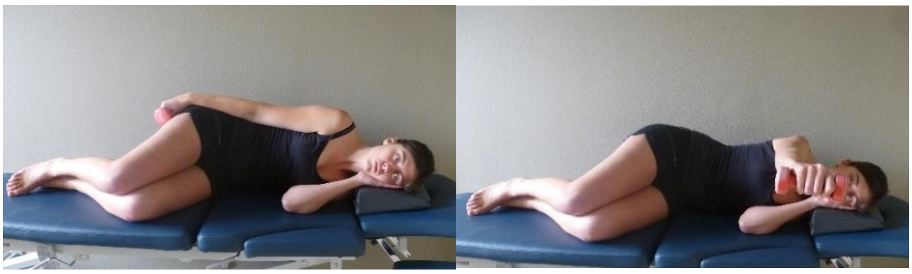
High LT
Low Pm




<u>**Bilateral Elevation with External Rotation by holding a Theraband®**</u>[19]

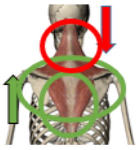
The subject takes the Theraband ® in both hands and flexes the elbows 90° with the shoulder in a neutral position. The Theraband® is then brought to tension with 30° of external rotation in which the wrists remain in the neutral position. From this position an elevation of both arms is carried out up to 90° in the scapular plane while holding the tension of the Theraband®.



GOAL	EXERCISE DESCRIPTION
High SA **Low Pm**	**<u>Serratus Punc</u>**[18] Subject standing with the back to the pulley device, with the shoulder in 90 of forward flexion. The starting position is a scapular retracted position. The participant performs scapular protraction with elbow extended. The subjects maintains neutral spinal alignment, and does not rotate or lean forward. 
High **MT or LT** **Low UT** 	**<u>Bilateral Elevation with External Rotation by holding a Theraband®</u>**[19] The subject takes the Theraband ® in both hands and flexes the elbows 90° with the shoulder in a neutral position. The Theraband® is then brought to tension with 30° of external rotation in which the wrists remain in the neutral position. From this position an elevation of both arms is carried out up to 90° in the scapular plane while holding the tension of the Theraband®.  **<u>Side-lying Forward Flexion</u>**[23] Starting with the shoulder along the body, the subject performs 90° forward flexion in the sagittal plane. 

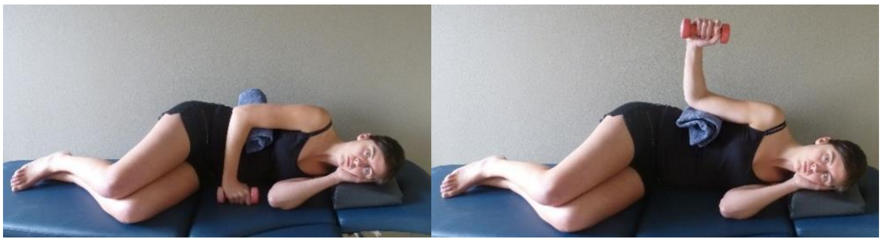
GOAL | **EXERCISE DESCRIPTION**

High
MT or LT
Low UT



<u>Side-Lying External Rotation</u>[23]

Starting with the shoulder in neutral position and the elbow flexed 90°, the subject performs external rotation of the shoulder with a towel between the elbow and trunk to avoid compensatory movements.



<u>Prone Horizontal Abduction with External Rotation</u>[23]

Starting with the shoulder resting in 90° forward flexion, the subject performs horizontal abduction to a horizontal position, with external rotation of the shoulder at the end of the movement.

<u>Prone Extension</u>[23]

Starting with the shoulder in 90° of forward flexion, the subject performs extension to neutral position with the shoulder in neutral rotation.

Appendix 2

THE INFLUENCE OF INDUCED SHOULDER MUSCLE PAIN ON ROTATOR CUFF AND SCAPULOTHORACIC MUSCLE ACTIVITY DURING ELEVATION OF THE ARM EVALUATED BY MUSCLE FUNCTIONAL MAGNETIC RESONANCE IMAGING

BIRGIT CASTELEIN, PT[1]; BARBARA CAGNIE, PT, PHD[1]; THIERRY PARLEVLIET, MD[2]; ANN COOLS, PT, PHD[1]

[1] DEPARTMENT OF REHABILITATION SCIENCES AND PHYSIOTHERAPY, GHENT UNIVERSITY, GHENT, BELGIUM

[2] DEPARTMENT OF PHYSICAL MEDICINE AND ORTHOPAEDIC SURGERY, UNIVERSITY HOSPITAL, GHENT, BELGIUM

REVISION SUBMITTED TO JOURNAL OF ELBOW AND SHOULDER SURGERY.

ABSTRACT

Background: Altered recruitment of rotator cuff and scapulothoracic muscles has been identified in patients with Subacromial Impingement Syndrome (SIS). However, to date, the cause consequence relationship between pain and altered muscle recruitment has not been fully unraveled.

Methods: The effect of experimental shoulder pain (by injection of hypertonic saline in the supraspinatus(SS)) on the activity of SS, Infraspinatus(IS), Subscapularis, Trapezius and Serratus Anterior activity was investigated during the performance of an elevation task by use of muscle functional MRI in 25 healthy individuals. Measurements were taken at 4 levels (C6-C7,T2-T3,T3-T4,T6-T7) at rest and after the elevation task performed without and with experimental shoulder pain.

Results: During elevation of the arm, experimental induced pain caused a significant activity reduction, expressed as reduction in T2 shift of the IS (p=0,029). No significant changes in T2 shift values were found for the other rotator cuff muscles, nor the scapulothoracic muscles.

Conclusions: This study demonstrates that acute experimental shoulder pain has an inhibitory impact on the activity of the IS during elevation of the arm. Acute experimental shoulder pain did not seem to influence the scapulothoracic muscle activity significantly. The findings suggest that rotator cuff muscle function (IS) should be a consideration in the early management of patients with shoulder pain. Worsening of pain symptoms should be avoided on the basis of the harmful effect of the inhibition of the IS.

Level of evidence: Basic Science, Experimental Pain Study

Appendix 3

COMPARISON OF ROTATOR CUFF AND SCAPULOTHORACIC MUSCLE ACTIVATION DURING ELEVATION OF THE ARM BETWEEN PATIENTS WITH NECK PAIN AND HEALTHY SUBJECTS: A MUSCLE FUNCTIONAL MRI STUDY

BIRGIT CASTELEIN, PT[1]; ANN COOLS, PT, PHD[1]; LIEVEN DANNEELS, PT, PHD[1]; BARBARA CAGNIE, PT, PHD[1]

[1] DEPARTMENT OF REHABILITATION SCIENCES AND PHYSIOTHERAPY, GHENT UNIVERSITY, GHENT, BELGIUM

MANUSCRIPT IN PREPARATION

ABSTRACT

Objective: To examine differences between patients with idiopathic neck pain and healthy subjects in muscle activation of the rotator cuff and scapulothoracic muscles when performing elevation in the scapular plane, with the technique of mfMRI.

Design: Case-control study

Setting: Physical and rehabilitation medicine department

Participants: Patients with idiopathic neck pain (n=24) and a matched control group without symptoms (n=23).

Interventions: Muscle activation (estimated by T2 shift) of the Supraspinatus (SS), Infraspinatus (IS), Subscapularis (SUB), Trapezius and Serratus Anterior (SA) during the performance of an elevation task was investigated by use of muscle functional MRI in a group with neck pain and a healthy control group. mfMRI measurements were taken at 4 levels (C6-C7,T2-T3,T3-T4,T6-T7) at rest and after the elevation task.

Main Outcome Measure(s): T2 shift of the different muscles

Results: During elevation of the arm, there was a significant activity reduction in the Middle Trapezius and IS in the group with idiopathic neck pain (respectively: p = 0,018 and p = 0,011). For the other muscles, no significant differences were found between the group with idiopathic neck pain and the healthy control group.

Conclusions: This study is the first to investigate differences on rotator cuff as well as scapulothoracic muscle activity with mfMRI between patients with neck pain and healthy subjects. This study demonstrates that patients with idiopathic neck pain showed a decreased IS and MT activity (seen as decreased T2 shift) during elevation of the arm.

LIST OF ABBREVIATIONS

AC	Acromioclavicular
ARV	Average Rectified Value
BP	BandPass
CI	Confidence Interval
CMMR	Common Mode Rejection Ratio
CON	Control group
EMG	Electromyography
EMG	Electromyographic
HP	High Pass
ICC	Intraclass Correlation Coefficient
LP	Low Pass
LS	Levator Scapulae
LT	Lower Trapezius
mfMRI	muscle functional Magnetic Resonance Imaging
MPF	Mean Power Frequency
MT	Middle Trapezius
MVIC	Maximum Voluntary Isometric Contraction
NP	Neck Pain
PICOS	Patient Intervention Comparison Outcome Study design
PM	Pectoralis Minor
RM	Rhomboid Major
RMS	Root Mean Square
ROM	Range of Motion
SC	Sternoclavicular
SD	Standard Deviation
SIS	Shoulder Impingement Syndrome
SR	Sampling Rate
Yr	Year