SCAPULAR MUSCLE RECRUITMENT DURING SHOULDER IMPINGEMENT REHABILITATION AND INJURY PREVENTION EXERCISES FOR OVERHEAD ATHLETES

KRISTOF DE MEY

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Promotor

Prof. Dr. Ann Cools  Ghent University, Belgium

Co-Promotor

Prof. Dr. Lieven Danneels  Ghent University, Belgium

Process Supervisory Board

Dr. Barbara Cagnie  Ghent University, Belgium

Examination Board

Dr. Kajsa Johansson  Linköping University, Sweden
Prof. Dr. Jan Victor  Ghent University Hospital, Belgium
Dr. Olivier Verborgt  AZ Monica & University Hospital Antwerp, Belgium
Prof. Dr. Nele Mahieu  Ghent University, Belgium
Prof. Dr. Erik Witvrouw  Ghent University, Belgium
Prof. Dr. Ilse De Bourdeaudhuij  Ghent University, Belgium
Prof. Dr. Damien Vantiggelen  Ghent University, Belgium
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To play a wrong note is insignificant, to play without passion is inexcusable.

Ludwig Van Beethoven
Preface
Overhead athletes need full, unrestricted arm function to optimally perform their sport.\textsuperscript{98} Therefore, the shoulders of these athletes require a delicate balance between mobility and stability.\textsuperscript{150} The shoulder joint must be lax enough to allow excessive external rotation but needs sufficient stability to prevent symptomatic humeral head subluxations, a concept known as “the thrower’s paradox”. When compromised, this can lead to pain, injury and decreased athletic performance.\textsuperscript{161}

Impingement symptoms are probably the most common shoulder problem in recreational and competitive overhead athletes, often requiring physiotherapy as a first-line management.\textsuperscript{2,36,45,98} Early literature described impingement as a pathology or a diagnosis, but today impingement is considered to be a cluster of symptoms, rather than a pathology.\textsuperscript{20} Patients complain about shoulder pain during repetitive arm movement, often combined with signs of functional instability. However, a high variety of clinical presentations can be seen. The symptoms frequently occur early in the season, when the athlete’s arm is not conditioned properly.\textsuperscript{162} Injury risk seems to increase with age and has been suggested to be related to the level and volume of play.\textsuperscript{10,66,112,125} The injuries may also arise at the end of the season, as the athlete begins to fatigue, or may have been present over the past couple of seasons, worsening in intensity with each successive year.\textsuperscript{162}

In addition to the existing knowledge on the glenohumeral characteristics in healthy overhead athletes and patients with various pathologic conditions, much knowledge has been gained in the past decade about the role of the scapula during efficient and injury-free playing.\textsuperscript{61,148,154} In normal scapular function, sufficient upward rotation, posterior tilt and external rotation is needed, especially during arm elevation (\textbf{FIGURE 1}).
Altered resting positions and changed kinematics have been observed in those athletes suffering from shoulder impingement symptoms, mainly by retrospective studies.\cite{85,134,137} Deviations in scapular motion in athletes with impingement symptoms can be generally summarized as reduced posterior tilting, reduced upward rotation and increased internal rotation or increased clavicular elevation relative to the thorax.\cite{89,134,137} Kibler et al.\cite{68} defined these scapular position and motion alterations as “scapular dyskinesis”, classified into four categories (FIGURE 2). Generally, these dysfunctions are believed to be linked to disorders in scapular muscle function, which may decrease the quality of functional stability, hence jeopardizing overhead shoulder function.\cite{69}
FIGURE 2: (A) Prominent inferior medial scapular border, classified as type I dyskinesis. (B) Prominent entire medial scapular border, classified as type II dyskinesis. (C) Excessive superior migration of superior medial scapular border, classified as type III dyskinesis. (D) Normal and symmetric scapular motion, classified as type IV. (Adapted from Uhl et al.\textsuperscript{145})

So far, much research has been conducted to clarify the link between scapular dyskinesis and impingement symptoms, focusing on abnormal position and motion, or on aberrant scapular muscle activity.\textsuperscript{19,68,89,101,109,137} With respect to the latter, alterations in the amplitude of electromyographic (EMG) activity and onset timing have been found in subjects with scapular dyskinesis and patients with related impingement symptoms.\textsuperscript{19,109} As a consequence, the importance of scapular muscle training as an essential component of shoulder rehabilitation and prevention training has been emphasized.\textsuperscript{21,38,152}
In the past decade, much attention has been given to rotator cuff muscle strengthening, mainly because (1) their tendons are a frequent site of pathology\textsuperscript{79,128} and (2) because these muscles have the ability to stabilize the glenohumeral joint.\textsuperscript{1,84} Exercises for the deltoid muscles have been limited in patients with impingement because it is believed that these may move the humerus upward, reducing the subacromial space.\textsuperscript{1,158} However, Gagey\textsuperscript{44} concluded the deltoid muscles have a downward oriented force, suggesting that training this muscle might still be appropriate. Indeed, Levy et al.\textsuperscript{78} found that a structured deltoid rehabilitation program is suitable for elderly patients with massive rotator cuff tears. Nevertheless, in athletes with scapular dyskinesis and related impingement symptoms, the general focus is on scapular and rotator cuff exercises.\textsuperscript{64,117} Since the identification of the specific muscle recruitment patterns can help in providing a scientific rationale for their use, the emphasis of this dissertation is on muscle recruitment during scapular muscle exercises relevant in the treatment and prevention of shoulder impingement symptoms in the overhead athlete.
Part I General introduction and aims of the dissertation
1. GENERAL INTRODUCTION

1.1 Scapular muscle function in the asymptomatic overhead athlete

Several researchers have studied scapular muscle function, from which some have measured the amplitude of the scapular muscle activation, while others focused on the timing of the muscles contributing to scapular motion. Generally, the trapezius and serratus anterior (SA) muscles are mostly assessed as they are seen as the greatest contributors to scapular stability and mobility (FIGURE 3). Researchers have focused on the muscle recruitment during both analytical and more functional movement patterns in order to gain more insight into the contributions of the various muscles around the scapula during multiple activities.

FIGURE 3: Anatomical relationship of the trapezius, serratus anterior and rhomboid muscles around the scapula, with the rhomboids just deep to the trapezius. (Adapted from Martin and Fish)

First, some investigators have been studying analytical movements (e.g. flexion and abduction) in order to establish the contributions of the various muscles to the scapular kinematics. The consensus in the literature is that upper trapezius (UT) and SA muscles provide the upward rotary force couple to produce scapular rotation during the early phase of elevation. In addition, it is stated that the middle trapezius (MT) and lower trapezius (LT) do not substantially contribute to scapular posterior tilting torque. Based
on their line of action, it appears that the primary role of these muscles is to generate external rotation of the scapula at the acromioclavicular joint, with the LT having a more stabilizing role. Activation of the LT is also important in the descent of the arm from a position of maximum elevation. This muscle is activated eccentrically to control excessive anterior tilt.\textsuperscript{33} Furthermore, the function of the SA is to stabilize the medial border of the scapula against the thorax, acting as a scapular external rotator. This muscle has the largest moment arm for the production of scapular upward rotation torque. Based on its line of action, it can also contribute substantially to scapular posterior tilting.\textsuperscript{85} Besides knowledge on muscle amplitude levels, researchers also tried to discover the normal pattern of muscle activation, so focusing on the timing of muscle activation during arm elevation.\textsuperscript{19,109} Wadsworth et al.\textsuperscript{153} stated that an initial activation of the UT is normal and is required for optimal scapula contribution to shoulder complex elevation. On the contrary, Wickham et al.\textsuperscript{159} pointed to an early MT activation during elevation. However, little research has been conducted in this area and no consensus regarding normal patterns of muscle activation timing currently exists.

Second, to gain insight into shoulder muscle function during overhead sports, other researchers have been measuring individual muscle contributions to typical movements in particular sports.\textsuperscript{41,59,111} In order to produce the high speed movements specific for each discipline, it appears that high levels of muscle activation are often necessary, as indicated by the EMG signal of the muscle. Peak scapular muscle activity is found high during the arm cocking and arm deceleration phases of baseball pitching, with peak SA activity between 69-106 %maximum voluntary isometric contraction (MVIC), and peak UT, MT and LT activity between 51-78% MVIC.\textsuperscript{41} Moreover, SA activity is found high during the windmill softball pitch, during the tennis serve and forehand motion, forehand and backhand volley and golf swing. During the golf swing, peak UT, MT and LT activity is 42-52% MVIC.\textsuperscript{41} During the normal freestyle stroke in swimming, Pink et al.\textsuperscript{111} found peak activity in the UT and SA during the hand entry phase, while during the pulling phase, the SA maintained high levels of activation. Because the SA is active throughout the entire stroke, with constant activity between 20-45% MVIC which increases at middle pull through and hand exit, it is considered prone to fatigue during swimming. Kibler et al.\textsuperscript{63} also observed timing patterns of muscle activation during the tennis serve motion. They demonstrated that the muscle activation at the shoulder during serving consists of an activation of the UT before the LT in healthy athletes. The SA and UT
were active in the early cocking phase (287 ms and 234 ms before ball impact respectively), while the LT (120 ms) was activated in the late cocking phase just before the acceleration phase. Despite the amount of studies is still limited, the current literature on this topic delivers interesting information to the clinician in terms of scapular muscle recruitment in an asymptomatic population. Possibly, this knowledge may be relevant in the treatment and prevention of patients with shoulder impingement symptoms, since these values may function as a reference value for those active in a progressive shoulder training program.
1.2 Scapular muscle function in the overhead athlete with shoulder impingement symptoms

1.2.1 Shoulder impingement symptoms

Shoulder impingement has been defined as compression, entrapment, or mechanical irritation of the rotator cuff structures and/or long head of the biceps tendon. The injury can occur either beneath the coracoacromial arch (subacromial) or between the undersurface of the rotator cuff and the glenoid or glenoid labrum (internal). There are at least 10 specific diagnoses that may be associated with impingement, from which rotator cuff pathology, shoulder instability, scapular dyskinesis, biceps pathology, superior labrum from anterior to posterior (SLAP) lesions and chronic stiffness of the posterior capsule are most common.

In literature two types of impingement are described: subacromial and internal. Subacromial or external impingement is the mechanical encroachment of the soft tissue (bursa, rotator cuff tendons) in the subacromial space between the humeral head and the acromial arch. Clinically, a “painful arc” is often found during clinical examination. Probably, it is the result of encroachment under the acromion, which particularly takes place between 30° and 60° of glenohumeral abduction. The rotator cuff tendons (m. infraspinatus and m.supraspinatus) can also be impinged between the humeral head and the posteriosuperior rim of the glenoid, referred to as internal impingement. Based on the location of the impingement, anterosuperior and posterosuperior glenoid impingement have been described. However, anteriosuperior glenoid impingement is less common than posterosuperior impingement.

Besides the classification of impingement based on the site of encroachment, impingement is often classified based on the cause of the problem, dividing it into primary versus secondary impingement. In primary impingement, pain and dysfunction is caused by a structural narrowing of the subacromial space, such as acromioclavicular arthropathy, type III acromion, or swelling of the soft tissue in the subacromial space. Other causes may be related to mechanisms of rotator tendinopathy, tendon degeneration or calcifications in the cuff. In secondary impingement, there are no structural obstructions causing the encroachment, but rather functional problems occurring only in specific positions. Secondary impingement may occur in the subacromial space as well as internally in the glenohumeral joint.
et al.\textsuperscript{20} described an algorithm for clinical reasoning in the examination of impingement-related shoulder pain (FIGURE 4). Although it is out of the scope of this dissertation to discuss on the value of each specific test from the clinical examination for athletes with suspected impingement problems, the algorithm provides a practical overview from the different types of impingement where athletes present with in the clinic.\textsuperscript{20}

FIGURE 4: Algorithm for clinical reasoning in the examination of impingement-related shoulder pain (adopted from Cools et al.\textsuperscript{20})

1.2.2 Alterations in scapular muscle function in the overhead athlete with scapular dyskinesis and shoulder impingement symptoms

Several researchers have found alterations in scapular muscle activity in patients with impingement, which have been linked to deviations in the scapular kinematics of these individuals.\textsuperscript{22,24,25,86} They mainly focused on the relative contributions of trapezius and SA muscles, found to stabilize the scapula and induce scapular upward rotation, external rotation and/or posterior tilt to potentially allow the humeral head to clear the acromion during elevation.
Generally, there is some evidence from retrospective research of increased UT activation and reduced SA activation in the same subjects who have demonstrated reduced posterior tilting, increased internal rotation and reduced upward rotation.\textsuperscript{82,86,90,132} According to Ludewig et al.\textsuperscript{85}, excessive activation of the UT can result in excessive clavicular elevation on the thorax and subsequently in excessive anterior tilting through its coupled motion, despite its role as an upward rotator remains debatable. Decreased muscle activity in the LT during concentric isokinetic retraction movements has also been detected, and hence a disturbed balance between UT and LT activity was found.\textsuperscript{25} Furthermore, in a study by Scovazzo et al.\textsuperscript{126}, the SA showed decreased activation through the entire swimming stroke in patients with shoulder pain, which limits the propulsive motion to which the SA can contribute. This could result in impingement due to the inability to upwardly rotate the scapula, usually created by the SA.

Besides dysfunctions in the scapular muscle activation levels, the temporal sequence of recruitment is also found to be deviant in patients with shoulder pain compared to healthy persons. Concerning the different parts of the trapezius muscle, Cools et al.\textsuperscript{24} established timing disorders in the MT and LT in relation to the deltoid muscle activation. They demonstrated significantly delayed MT and LT activation in overhead athletes with shoulder impingement as compared to a control group, in response to an unexpected drop of the arm from an abducted position. Furthermore, in a study by Wadsworth and Bullock-Saxton\textsuperscript{153}, the temporal recruitment pattern of the UT, LT and SA displayed significantly greater variability in competitive freestyle swimmers with shoulder impingement as compared to a control group of swimmers. The study showed a significantly increased timing of muscle activation in swimmers with subacromial impingement, with the greatest delay occurring in the SA. Recently, Phadke and Ludewig\textsuperscript{110} found that subjects with impingement demonstrate significantly earlier activation of the UT while raising the arm when compared to healthy subjects. However, Moraes et al.\textsuperscript{101} could not find differences between subjects with and without impingement symptoms. Nevertheless, the findings of these studies are considered as a basis for selecting exercises and designing protocols for shoulder rehabilitation and injury prevention purposes.\textsuperscript{19,109}
1.2.3 Other factors contributing to scapular dyskinesis

Although scapular muscle dysfunctions in the trapezius and SA play a major role in the large majority of cases with dyskinesis of the scapula, their relevance should be judged with respect to other factors contributing to the observed scapular dyskinesis which can be found during the clinical examination process.

First, it should be kept in mind that other muscles such as the rhomboids, levator scapulae and pectoralis muscles also play an important role in providing the 3-dimensional scapular movement patterns which are necessary to perform certain activities. The rhomboids and levator scapulae assist the trapezius in stabilizing the scapula, particularly with respect to controlling internal and external rotation. On the other hand, these muscles adduct and downwardly rotate the scapula, which may limit upward rotation of the acromion, necessary for normal shoulder function. Therefore, it is believed that the activity in these muscles should remain relatively low in most athletic activities. Additionally, the pectoralis minor assists in producing anterior tilt, internal rotation and protraction when the arm is in lower levels of elevation (60° of abduction). However, as for the rhomboids and levator scapulae, high levels of pectoralis minor activation are generally not regarded as an advantage for efficient shoulder movements. In addition, extrinsic muscles, primarily the pectoralis major and latissimus dorsi, may indirectly affect scapular motions because of their role as prime movers in the glenohumeral joint. However, very little investigations have been made regarding their involvement in subjects with scapular dyskinesis and impingement symptoms, making the need for exercises focusing on these muscles during rehabilitation and injury prevention programs yet to be determined.

Second, muscle inflexibility or soft tissue tightness which can restrict normal scapular motions during arm elevation are other potential mechanisms which should be considered when it comes to the development of scapulothoracic alterations. Limited scapulothoracic and glenohumeral range of motion may have an impact on the scapular function during particular movements patterns. Although inflexibility of the rhomboids, levator scapulae and short head of the biceps, pulling the scapula forward, is often seen in the clinic, only pectoralis minor and posterior shoulder tightness have been investigated in scientific research. Excessive tension in the pectoralis minor possibly resists normal scapular upward rotation, posterior tilt and potentially scapular external rotation that should occur during arm elevation. Indeed, subjects with a relatively shorter pectoralis minor muscle length at rest appear to demonstrate
increased scapular anterior tilting and internal rotation during arm elevation and decreased posterior tilting at higher arm elevation angles (90° and 120°) when compared with subjects with a relatively longer pectoralis minor length at rest. The scapula can also be influenced by glenohumeral motions by placing tension on the glenohumeral capsule and muscles, especially in the presence of glenohumeral internal rotation deficit (GIRD). Consequently, GIRD has been theorized as a potential mechanism for altering scapular kinematics by passively “pulling” the scapula laterally over the thorax, particularly during humeral internal rotation in elevated arm positions. In a study by Borich et al., overhead athletes with a loss of glenohumeral internal rotation of 20% or more as compared to their opposite shoulder, demonstrated increased scapular anterior tilt at end range glenohumeral internal rotation with the arm abducted or flexed to 90°. In another case series study by Wilk et al., baseball pitchers with GIRD were nearly twice as likely to be injured compared to those with normal range of motion (ROM). In addition, Shanley et al. indicated that passive shoulder internal ROM loss of 25° and more was predictive for arm injury in softball and baseball players. Besides limited glenohumeral ROM, slouched sitting, increased thoracic kyphosis, forward head posture and increased age have also been related to unfavourable scapular kinematic alterations. Taken together, these findings suggest that these areas of soft tissue tightness are potential risk factors for scapular dyskinesis associated with shoulder impingement.

Third, some patients have problems which require surgical repair before the dyskinesis can be addressed, such as subjects with scapular muscle detachment, acromioclavicular arthrosis and instability, fractured clavicles, labral injury, rotator cuff disease or glenohumeral instability. In some cases, neurological problems cause the dyskinesis, for example in patients with cervical radiculopathy and long thoracic and spinal accessory nerve injuries. The clinician should take all of these causes into account during the clinical examination process. In addition, he/she should also be cautious in prescribing exercise training in case these factors significantly contribute to the clinical presentation of the athlete.
1.3 Scapular muscle exercises for overhead athletes with scapular dyskinesis and related shoulder impingement symptoms

Since the scapular characteristics are found to be in close relationship with the glenohumeral joint and the rotator cuff, it is generally accepted that scapular training should be part of a comprehensive treatment program for patients with impingement.\textsuperscript{21,38,161} The primary goals of such exercise programs are to elicit optimal levels of muscular activation by using movement patterns and positions that do not create significant subacromial contact. Often, restoration of muscle control and balanced coactivation is a challenge for the clinician. Therefore, a scapular treatment algorithm has been presented in order to help the therapist in the clinical reasoning process, showing exercise training can be relevant in case lack of muscle performance is present (FIGURE 5).\textsuperscript{38}

**Scapular Rehabilitation Algorithm**

**FIGURE 5:** Treatment algorithm for scapular dysfunction (adopted from Ellenbecker and Cools\textsuperscript{38})
Within the scapular treatment algorithm, training conscious muscle control of the scapular muscles is recommended to improve proprioception and to normalize the scapular resting position.\textsuperscript{98} This is done on the basis of the widely recognized presupposition that people should be able to position the scapula at rest and control the scapula during arm movements for optimal upper-limb function in the early stage of scapular treatment.\textsuperscript{103} In order to achieve this goal, the scapular orientation exercise has been described.\textsuperscript{104,157} This exercise can be prescribed as scapular setting in a variety of postures focusing on re-educating the stabilizing muscle parts around the scapula via the implementation of short lever exercises.\textsuperscript{62} Subsequently, the therapist may focus more on muscle control (appropriate co-activation of the scapular force couples) or muscle strength. However, in subjects with shoulder pain, resistance training exercises over the full ROM should be limited and load should be applied with caution.\textsuperscript{93} Instead, scapular cocontraction may be trained by performing specific exercises for scapular muscle control, for example by performing closed kinetic chain (CKC) exercises. Then, the athlete may gradually perform functional diagonals into internal and external rotation with increasing intensity and load, but with accurate scapular control. Because of the observed lack of activity in the MT, LT and SA often combined with excessive use of UT in patients with shoulder pain, exercises which selectively activate the weaker muscle parts with minimal activity in the hyperactive muscles are believed to be an important component in the reduction of the imbalance.\textsuperscript{23,29} After exercise training for muscle balance rehabilitation, in the third stage of scapular muscle treatment, general strengthening, eccentric training and plyometric exercises may be used to increase muscle strength and enhance rapid return to sport.\textsuperscript{21,38,92,108} However, athletes may present with a broad variety of clinical representations, which the clinician should take into account when prescribing appropriate exercises for rehabilitation and injury prevention purposes. In particular, there is a group of athletes experiencing pain but not yet stopped training or contacted a team physician for their complaints, and as a result, do not experience time loss due to their injury.\textsuperscript{7} In those athletes, exercise training may be helpful in order to prevent their injury to become a chronic condition. However, studies focusing on providing exercises for this group of individuals are currently lacking in the literature.
1.3.1 Scapular muscle recruitment during shoulder exercises

Traditionally, the value of an exercise is based on the activation level at which the different muscle parts are activated. In this area of research, EMG studies aiming to acquire more insight into the scapular musculature during shoulder exercises can provide valuable information. Therefore, researchers have examined the muscle activation patterns of various exercises which focus on improving scapular muscle recruitment. Most authors studied the EMG amplitude levels in the scapular muscles during various exercises. From those, some focused on movement learning in an attempt to correct the 3-dimensional movement patterns of the scapula while measuring muscle activation. Others focused on isolated muscle exercises, trying to select those with high activation levels in the stabilizing muscle parts around the scapula thought to facilitate neuromuscular adaptations. \(^{29,42,116}\) (See Appendix for illustration of exercises)

The authors who mainly focused on movement learning point to the value of exercises in which the scapula moves into upward rotation, external rotation and posterior tilt, as these movement patterns are of interest in early stages of rehabilitation. Movement training exercises rather focus on correction of scapular kinematics instead of muscle strengthening purposes. These exercises can initially be done with the arm at the side, placing the scapula in a mid-range position of upward/downward rotation, internal/external rotation and anterior/posterior tilting before progressing to long lever movements. \(^{146}\) For example, Mottram et al. \(^{104}\) demonstrated that it is possible to teach a normal individual consistently to reproduce movements of the scapula into posterior tilt and upward rotation by activating all 3 portions of the trapezius muscle. In some cases, EMG feedback could additionally be used for learning selective activation of the trapezius or SA muscle. \(^{51,52}\) In addition, Oyama et al. \(^{106}\) evaluated scapular kinematics and accompanied muscle activations and found the following exercises to show high scapular stabilizer activation accompanied by desired scapular kinematics: lifting the arm toward the ceiling from a prone position and hold this position while squeezing the shoulder blades together in six different positions (1) 90° abduction and neutral humeral rotation (palm facing floor); (2) 90° abduction and external rotation (thumb pointing toward ceiling); (3) 120° abduction and neutral humeral rotation (palm facing floor); (4) 120° abduction and external rotation (thumb pointing toward ceiling); (5) abducted 45° with 90° of elbow flexion and (6) full extension.
However, most investigators studied isolated shoulder exercises with the attempt to select those exercises characterized by high activation levels in particular muscles, regardless of their scapular kinematics.\textsuperscript{29,42,116} During scapular abduction, UT activity progressively increases from 0° to 60°, remains relatively constant from 60° to 120° and continues to progressively increase from 120° to 180°.\textsuperscript{6} The LT activity tends to be relatively low at angles less than 90° of scapular abduction, abduction and flexion, and then increases exponentially from 90° to 180°.\textsuperscript{42,116} Serratus anterior activity tends to increase in a somewhat linear fashion with arm elevation.\textsuperscript{42,116} An extensive amount of exercises have been attributed to high activation in the UT\textsuperscript{4,28,35,37,54,102,130}, MT\textsuperscript{4,6,35,37,37,54,71,102,165,167}, LT\textsuperscript{4,5,8,16,26,35,37,37,54,70,71,102,102,130,163,165} or SA\textsuperscript{35,37,47,49,70,87,102,105,164} muscles (\textbf{TABLE 1}).
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<td>/</td>
<td>Scapular retraction movement at 130° of shoulder elevation</td>
<td>Scapular protraction and upward scapular punch</td>
</tr>
<tr>
<td>Reverse fly</td>
<td>Reverse fly</td>
<td>Reverse fly</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modified Prone Cobra</td>
<td>Wall-slide</td>
</tr>
<tr>
<td>------------------</td>
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<td>------------</td>
</tr>
<tr>
<td>Front raises</td>
<td></td>
<td>Shoulder extension in 20° or 45° of abduction with the arms externally rotated</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low row, inferior glide, lawnmower and robbery exercise</td>
<td>Low row, inferior glide, lawnmower and robbery exercise</td>
</tr>
</tbody>
</table>

**TABLE 1:** Selected exercises with high UT, MT, LT or SA muscle activation based on EMG research.
For patients with an imbalance in the scapular musculature, some authors have tried to select exercises with low UT/MT\textsuperscript{23}, UT/LT\textsuperscript{3,23,95,155,156} and UT/SA\textsuperscript{23,70,91} ratios (\textbf{TABLE 2}).

<table>
<thead>
<tr>
<th>UT/MT ratio</th>
<th>UT/LT ratio</th>
<th>UT/SA ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>/</td>
<td>Bilateral external rotation at 0°</td>
<td>High row</td>
</tr>
<tr>
<td>/</td>
<td>Prone lying flexion</td>
<td>Standard knee push-up plus</td>
</tr>
<tr>
<td>Side-lying forward flexion</td>
<td>Side-lying forward flexion</td>
<td>Knee push-up plus with homolateral leg extension</td>
</tr>
<tr>
<td>Side-lying external rotation</td>
<td>Side-lying external rotation</td>
<td>Knee push-up plus with a wobble board and homolateral leg extension</td>
</tr>
<tr>
<td>Prone extension</td>
<td>Horizontal abduction with external rotation</td>
<td>One-handed knee push-up plus</td>
</tr>
<tr>
<td>/</td>
<td>One-arm row in a bend position or sitting on a gym equipment</td>
<td>Inferior glide</td>
</tr>
</tbody>
</table>

\textbf{TABLE 2:} Selected exercises with low UT/MT, UT/LT or UT/SA ratios based on EMG research.

In most of these exercises, load is increased by using free weights or elastic resistance. However, an unstable surface is also frequently used with the objective to stimulate the activation level in specific muscle parts, particularly during CKC exercises\textsuperscript{35,75-77,107,113,114,123,142-144}. Researchers investigated the influence of various equipment which provides an unstable surface for CKC training. Some studied push-up exercises on a Swiss ball\textsuperscript{76,123}, while others used a BOSU sports balance trainer\textsuperscript{142} or a wobble board\textsuperscript{91,107}. Overall, researchers found that not all muscles respond with increased muscle activation levels when using an unstable surface\textsuperscript{32,34,76,77}. In some studies, Redcord slings (RS) are used to provide the unstable base of support\textsuperscript{31,53,114}. Although some studies found that this device can be used to effectively treat various musculoskeletal conditions\textsuperscript{147,151}, improve proprioception\textsuperscript{141} and enhance the athlete’s athletic performance\textsuperscript{53,114,121,127,133}, the effect on the individual shoulder muscle activation levels remains undetermined until now. Yet, determining the influence of RS on the shoulder muscle activation may be interesting because this can make clear whether the effectiveness of particular exercises may be caused by altering the muscle...
recruitment due to the use of slings. The results of such studies may also provide data for further research into the relevance of unstable surfaces as a training tool for rehabilitation and injury prevention training purposes in overhead athletes with increased risk for shoulder pain.

In literature, it is believed that the clinician should also work on facilitating correct timing of muscle recruitment. This is based on the assumption that performing shoulder exercises could be beneficial because of alterations in muscle timing patterns. Although muscle timing is found to be changeable with accompanied positive clinical outcomes in patients with patellofemoral pain and low back pain, no research has been conducted establishing exercises which could alter the activation timing of the scapular stabilizing muscle parts in relation to the prime movers at the shoulder. Therefore, determining which exercises activate the scapular stabilizing muscle parts prior to the prime mover activation and then study the effect of those exercises on patients with impingement symptoms by using a prospective study design may be of interest.

1.3.2 The kinetic chain principle in shoulder training

The kinetic chain depicts the body as a linked system of interdependent segments, often working in a proximal-to-distal sequence to impact a desired action at the distal segment. It is the biomechanical system by which the body meets the inherent demands of overhead sport movements. According to the kinetic chain principle, the scapula is an important link between the trunk and arm. Therefore, the scapula must be approached in relation to the other body segments in the kinetic chain. Consequently, integration of shoulder girdle exercises into a more global movement pattern of the entire body has become a treatment goal in shoulder rehabilitation, especially in overhead athletes. In general, research encourages the clinician to start integrating kinetic chain exercises as early as possible in their training program. Kibler et al. proposed to start rehabilitation training with proximal segment control prior to exercises focusing on the scapular musculature. The authors assume this might facilitate scapular retraction. In a recently published article, they described various exercises such as scapular retraction with spinal extension and ipsilateral rotation, sternal lifts, tubing fencing in a lunge position and punches in a
forward or lateral stride.\textsuperscript{62} However, kinetic chain rehabilitation is seen as a spectrum, ranging from dysfunction to full function rather than a step-by-step outline.\textsuperscript{97,138} Sciascia and Cromwell\textsuperscript{124} also provided a theoretical framework for kinetic chain rehabilitation and postulated principles which help assure optimal functioning of the different segments in the kinetic chain: 1) establish proper postural alignment, 2) establish proper motion at all involved segments, 3) facilitate scapular motion via exaggeration of lower extremity/trunk movement, 4) exaggerate scapular retraction in controlling excessive protraction, 5) utilize the closed chain exercise early, and 6) work in multiple planes.

Clinicians often attempt to challenge their patients by performing many analytical exercises with altered bases of support, in an attempt to recruit whole body muscle patterns that interact together to perform active ROM, while stabilizing other areas of the body.\textsuperscript{163} It is believed that these concepts are important to consider in addition to straight-plane, isolated movements of specific muscle groups. Furthermore, integrating kinetic chain components into scapular exercises is seen as a way to increase the activation in particular shoulder muscles. Uhl et al.\textsuperscript{146} found greater activity in the LT when subjects performed an ipsilateral step-up while forwardly flexing the shoulder. They attributed this change in muscle activation level to the engagement of the kinetic chain, as these exercises incorporate hip and trunk extension with shoulder elevation. A similar non-significant increase was found by Smith et al.\textsuperscript{131} when evaluating the incorporation of a step during exercises in healthy subjects. Similarly, Maenhout et al.\textsuperscript{91} investigated the influence of lower extremity position on muscle activity and balance during push-up variations. They revealed increased activity in the SA if the ipsilateral leg was extended, whereas extension of the contralateral leg improved LT activity. So, in their research, they showed that the use of a kinetic chain approach influences scapular muscle activity. However, to date, the amount of information regarding kinetic chain influences on the scapular muscle recruitment is still limited. Gaining further insight into this topic may be of interest because it would elucidate which kinetic chain variations can influence the shoulder muscle recruitment. The results of these studies may then be used to discuss the relevance of increased muscle activation levels in particular muscle parts during certain exercises.
1.3.3 The effect of exercise programs in the treatment and prevention of scapular dyskinesis and related shoulder impingement symptoms

According to recent review articles, exercise training alleviates symptoms in patients with impingement. Kuhn et al. concluded that, although many articles had methodological concerns, the data demonstrate that exercise has statistically and clinically significant effects on pain reduction and improved function, but not on ROM or strength. The current evidence also indicates that therapeutic exercise is more effective in reducing pain and improving function than placebo in both short- and long-term follow-up and more effective than no intervention in short-term follow-up.

Many studies investigated the effect of scapular exercise in relation to glenohumeral training and in combination with other treatment modalities such as manual therapy, corticosteroid injection and radial extracorporeal shockwave therapy. Some authors particularly focused in their research on scapular muscle rehabilitation. In a study by Başkurt et al., adding scapular stabilization exercises proved to be superior to stretching and strengthening exercises alone for increasing scapular muscle strength and decreasing scapular dyskinesis. McClure et al. found no significant kinematic differences after a 6-week exercise program where both scapular kinematics and functional outcome were assessed in subjects with impingement, despite significant improvements in functional status and reductions in pain were also shown. Because improvement in symptoms were found without improvements in scapular kinematics, these authors suggest that improving scapular kinematics may not be the primary mechanism of improving symptoms. They rather supposed that scapular muscle function is of influence. Some evidence can also be found for the effectiveness of corrective movement training, thought to influence the force couples around the scapula in patients with shoulder impingement syndrome. Roy et al. studied the effect of movement training on upper limb shoulder function in patients with shoulder impingement symptoms. They showed that one session of conscious movement training with feedback causes immediate, but temporary effects on motor strategies and upper limb kinematics. They demonstrated significantly decreased EMG activity compared to baseline values immediately after and 24 hours after movement training with feedback. In another study by Roy et al., a 4-week intervention program showed improvements on the Shoulder Pain And Disability Index (SPADI) in 7/8 shoulder impingement patients, although no EMG was recorded in that study. Furthermore, a recent study by
Worsley et al.\textsuperscript{166} demonstrated a 10-week motor control intervention for shoulder impingement can increase function and reduce pain in a case series of 16 adults with symptoms and 16 healthy participants. The researchers found reduced scores on the SPADI in the patients group (10 points). Their study also showed delayed onset and early termination of SA and LT activity pre-intervention when compared with healthy controls, which improved significantly post-intervention. In addition, some evidence for the effect of exercises with high amplitude levels in the scapular stabilizing muscle parts around the scapula can be found. Merolla et al.\textsuperscript{99} studied the effect of the four selected exercises for trapezius muscle balance selected by Cools et al.\textsuperscript{23} and combined them with SA strengthening in a case series of professional volleyball players with scapular dyskinesia. Their results showed decreased pain scores accompanied by increased infraspinatus strength after a 6-month training program. However, the influence of the scapular muscle function was not assessed in that study. Although these studies provide evidence to suggest exercise interventions are able to reduce shoulder impingement symptoms, evidence for changing the muscle function around the scapula is limited, especially in those athletes experiencing pain but not yet stopped training.

From an injury prevention perspective, Van de Velde et al.\textsuperscript{149} evaluated scapular muscle performance in a population of healthy adolescent swimmers, and compared the pre- and post-test results of a 12-week scapular training program designed for strength or muscle endurance. The authors concluded that both muscle strength and muscle endurance programs improved absolute muscle strength while neither of the programs had a positive effect on scapular muscle endurance. In a more general study by Swanik et al.\textsuperscript{135}, a 6-week functional training program was implemented for swimmers. They found significantly less reported incidences of pain in swimmers who completed the training program compared to a control group. After 6 weeks, participants reported significantly less number of incidences of shoulder pain compared to a control group, despite finding no significant changes in strength. The authors attributed the decreased incidence of shoulder pain to neuromuscular adaptations. They also hypothesized that, although no strength increases were found, the muscles had improved efficiency and were more able to stabilize the scapula and humerus during functional movements, preventing increased contact with the rotator cuff tendons due to a decreased subacromial space width. The study indicates that introducing a prevention program may significantly impact the frequency of shoulder pain, such as impingement.
symptoms. In addition, these studies indicate that further research needs to be conducted to determine the effectiveness of intervention programs on other variables related to pain and muscle function.
2. AIMS OF THE DISSERTATION

In view of the available literature, it is clear that further evaluation of exercise training in the treatment and prevention of impingement in overhead athletes is required. The current knowledge provides a foundation for research in the area of scapular muscle function during analytical and kinetic chain exercises, as well as for studies evaluating the effect of a scapular training program. Hence, the main objectives of this doctoral dissertation are to examine the amplitude level and timing of muscle activity during exercises targeting the scapular muscles in healthy shoulders and in overhead athletes with impingement symptoms and to study the effectiveness of an exercise program. In order to give an answer to various research questions related to this topic, five studies are described.

Part II Muscle recruitment during specific scapular muscle training exercises

<table>
<thead>
<tr>
<th>Study I</th>
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The first aim of this dissertation is to gain insight into the influence of conscious correction of scapular orientation during selected exercises.

Within the scapular treatment algorithm presented by Ellenbecker and Cools\textsuperscript{38}, conscious control of the scapula is indicated as an essential component when training for correction of neuromuscular coordination as well as strength deficits. Placing the scapula into a more neutral position before starting dynamic exercises is considered relevant within this approach. Rehabilitation exercises with low UT/MT and UT/LT ratios have been described to restore scapular imbalance.\textsuperscript{23} However, the exact influences of conscious correction of scapular orientation on the amplitude level and trapezius muscle ratios is currently unclear. Therefore, the first study entitled: “Conscious correction of scapular orientation in overhead athletes performing selected shoulder rehabilitation exercises: what’s the effect on trapezius muscle activation measured by surface electromyography?”
Study II

The second aim is to gain insight into the influence of an unstable surface for CKC exercises, provided by Redcord slings (RS) on the shoulder muscle activation.

During resistance training protocols for overhead athletes, people are encouraged to target the scapular stabilizing muscles while controlling the activation in the prime movers. An unstable surface is frequently used to increase the muscle activation levels around the shoulder, thought to facilitate neuromuscular adaptations. Although RS have been shown to improve proprioception\textsuperscript{141} and enhance the athletic performance\textsuperscript{53,114,121,123,127}, the specific influences of RS on the shoulder muscle function have not yet been investigated. Therefore, a second study was conducted titled: “Shoulder muscle activation levels during 4 closed kinetic chain exercises with and without Redcord slings”.

Study III

The third aim of this dissertation is to investigate which exercises promote early activation of the MT and LT muscle parts in relation to the scapular and glenohumeral prime movers.

Besides dysfunction in the scapular muscle amplitude levels, the temporal sequence of recruitment is found to be altered in patients compared to healthy athletes.\textsuperscript{19,109} However, exercises altering these relative muscle timing properties in the trapezius, and thus correcting normal scapular muscle recruitment are unknown. In particular, exercises with early activation of the stabilizing muscles at the scapulothoracic joint might help to increase the scapular stability, providing a stable platform during glenohumeral movements. However, to date, no studies have been performed in which the timing of scapular muscle activation is examined during particular exercises. Therefore, a study is presented titled: “Trapezius muscle timing during selected shoulder rehabilitation exercises”.
Part III Trapezius muscle activation during scapular retraction exercises in a kinetic chain

Study IV

The fourth aim is to elaborate knowledge on kinetic chain influences on the trapezius muscle activation.

In order to restore trapezius muscle balance, exercises with high LT and low UT activation are of interest. Scapular retraction exercises are thought to be characterized by these trapezius amplitude ratios. In addition, integrating shoulder exercises into a global kinetic chain pattern has been a goal in rehabilitation, partly because it is assumed this increases the activity in particular shoulder muscles. Therefore, we studied: “Kinetic chain influences on upper and lower trapezius muscle activation during eight variations of a scapular retraction exercise in overhead athletes.”

Part IV The effect of scapular muscle rehabilitation exercises in overhead athletes with mild shoulder impingement symptoms

Study V

The fifth aim is to gain insight into the effect of previously selected exercises in a group of overhead athletes with impingement symptoms over time.

In patients with impingement symptoms, reduced MT and LT activation is found with accompanied delays in the temporal recruitment pattern. Literature suggests that exercise training might alter the activation levels and onset timing of the scapular musculature during dynamic activities. However, evidence for the effectiveness of selected exercises is lacking until now, especially in those still active in sports. In the last section, the results of an effect study are presented which is titled: “Scapular muscle rehabilitation exercises in overhead athletes with impingement symptoms: the effect of a 6-week training program on muscle recruitment and functional outcome.”
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34 Part I General introduction and aims of the dissertation


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Part I General introduction and aims of the dissertation


Part I General introduction and aims of the dissertation


Part I General introduction and aims of the dissertation


Part II  Muscle recruitment during specific scapular muscle training exercises
Study I  Conscious correction of scapular orientation in overhead athletes performing selected shoulder rehabilitation exercises: the effect on trapezius muscle activation measured by surface electromyography

Kristof De Mey, PT¹; Lieven Danneels, PT; PhD⁴; Barbara Cagnie, PT, PhD²; Lies Huyghe, PT³; Elien Seyns, PT³; Ann M. Cools, PT, PhD⁴

1 Assistant, Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University Hospital, Ghent, Belgium. 2 Assistant Professor, Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University Hospital, Ghent, Belgium. 3 Student, Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University Hospital, Ghent, Belgium. 4 Professor, Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University Hospital, Ghent, Belgium.

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ABSTRACT

Study design: Controlled laboratory study

Objectives: To assess the effect of conscious correction of scapular orientation on the activation of the 3 sections of the trapezius muscle during shoulder exercises in overhead athletes with scapular dyskinesis.

Background: Previous research has led to the recommendation of 4 exercises for training of the trapezius muscle: prone extension, side-lying external rotation, side-lying forward flexion and prone horizontal abduction with external rotation. However, the extent to which conscious correction of scapular orientation impacts trapezius muscle activation levels during these exercises is unknown.

Methods and Measures: Absolute (upper trapezius [UT], middle trapezius [MT] and lower trapezius [LT] and relative (UT/MT and UT/LT) muscle activation levels were determined with surface electromyography in 30 asymptomatic overhead athletes with scapular dyskinesis during the performance of 4 selected exercises performed with and without conscious correction of scapular orientation. Repeated measures ANOVAs were used to determine if a voluntary scapular orientation correction strategy influenced the activation levels of the different sections of the trapezius during each exercise.

Results: With conscious correction of scapular orientation activation levels of the 3 sections of the trapezius muscle significantly increased during prone extension (mean ± SD difference: UT: 5.9 ± 8.6 %MVIC; MT: 13.8 ± 11.0 %MVIC; LT: 9.8 ± 10.8 %MVIC; P< .05) and side-lying external rotation (UT: 2.2 ± 4.4 %MVIC; MT: 6.7 ± 10.6 %MVIC; LT: 13.3 ± 24.4 %MVIC; P< .05). There was no difference between conditions for side-lying forward flexion and prone horizontal abduction with external rotation. The UT/MT and UT/LT ratios were similar between conditions for all 4 exercises.

Conclusions: Conscious correction of scapular orientation during the prone extension and side-lying external rotation exercise can be used to increase the activation level in the 3 sections of the trapezius in overhead athletes with scapular dyskinesis. Although lack of kinematic data limits the interpretation of the results, this study suggests that conscious correction of scapular orientation can be performed without altering the favorable UT/MT and UT/LT ratios which have been previously reported for these exercises.

Key words: scapula; impingement; physical therapy
INTRODUCTION

Several researchers have found scapular dyskinesis to be associated with chronic shoulder pain in overhead athletes.\(^5, 10, 15, 20\) In addition to scapulothoracic and glenohumeral soft tissue restrictions and the influences of thoracic posture, alterations in scapular muscle recruitment and strength have been found in these individuals when compared to healthy controls.\(^20\) Because scapular orientation and movement can influence function of the glenohumeral joint and the rotator cuff musculature, it is suggested that the scapulothoracic joint requires specific attention during physical therapy treatment, in particular in individuals performing repetitive overhead movements.\(^23\) To help the clinical reasoning process, a scapular treatment algorithm has previously been presented, showing exercise training might be effective when a lack of muscle performance is present.\(^13\)

In the literature, scapular exercise selection is primarily based on 2 different concepts. The first concept is the selection of exercises focused on promoting the normal 3-dimensional movement patterns of the scapula.\(^27, 28\) In general, exercises in which the scapula moves into upward rotation, external rotation, and posterior tilt are of interest.\(^22\) For example, Mottram et al\(^27\) demonstrated the potential to teach healthy individuals to move the scapula into posterior tilt and upward rotation by activating all 3 portions of the trapezius muscle. In addition, Oyama et al\(^28\) showed that various scapular retraction exercises can be beneficial on the basis of their scapular and clavicular kinematics and amounts of muscle activity. There is also evidence for the effectiveness of corrective movement training, thought to influence the force couples around the scapula, in patients with shoulder impingement syndrome.\(^3, 31, 35\)

The second concept is to select exercises focusing on high activation levels in the muscles around the scapula, whether or not they also produce the desired 3-dimensional movement of the scapula.\(^14, 30\) Previous research has shown that the push-up plus, dynamic hug, and wall slide exercises elicit high amounts of serratus anterior muscle activity, with the push-up plus exercise producing minimal upper trapezius activation.\(^8, 16\) In regard to trapezius muscle rehabilitation, Cools et al\(^7\) have identified 4 exercises that demonstrated low upper trapezius/middle trapezius (UT/MT) and upper trapezius/lower trapezius (UT/LT) muscle ratios in healthy individuals: prone extension, side-lying external rotation, side-lying forward flexion and prone horizontal abduction with external rotation (FIGURE 1). Individuals with scapular dyskinesis often show
hyperactivity of the UT with reduced MT and LT muscle activation which is associated with decreased amounts of scapular upward rotation, external rotation, and posterior tilt. These 4 exercises are considered indicated in the rehabilitation of these individuals because they promote high MT and LT muscle activation levels while minimizing UT activation.

**FIGURE 1.** Exercises included in the study: 1) prone extension: starting with the shoulder in 90° of forward flexion, the subject performs extension to neutral position with the shoulder in neutral rotation; 2) side-lying external rotation: 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; 3) side-lying forward flexion: starting with the shoulder along the body, the subject performs 90° forward flexion in the sagittal plane; 4) prone horizontal abduction with external rotation: starting with the shoulders 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.
Within the scapular treatment algorithm, conscious control of the scapula is indicated as an essential component when training for correction of neuromuscular coordination as well as strength deficits (FIGURE 2). Consciously positioning the scapula into a more neutral resting position is considered important within this context. However, it is unclear how conscious correction of scapular orientation affects the activation of the trapezius muscle during various dynamic movements performed under loaded conditions, as during the performance of the 4 previously selected exercises.

**FIGURE 2.** Treatment algorithm for scapular dysfunction suggesting the role of conscious correction of scapular orientation.

Therefore, the purpose of this study was to investigate the influence of conscious correction of scapular orientation on the absolute and relative trapezius muscle activation levels during the performance of the 4 previously selected exercises in overhead athletes with scapular dyskinesis. The results of this study could add
evidence to the fundamental principles of shoulder rehabilitation strategies for individuals with scapular dyskinesis and related shoulder disorders.

METHODS

Subjects

Thirty healthy subjects participated in this study (18 men and 12 women; mean ± SD age, 22 ± 3 years; height, 1.76 ± 0.08 m; weight, 67.1 ± 8.7 kg). All subjects were active in overhead sports, including volleyball, swimming, and badminton at a recreational level. Twenty-nine of the subjects were right handed. Subjects were included if they were between 18 and 30 years old, showed altered scapular resting positions and dyskinesis during dynamic clinical examination on the basis of a yes/no method. A “yes” means that the clinician states that an abnormal pattern of scapular movement (dyskinesis) is observed, which could either be prominence of: the inferior medial scapular angle (Type 1), the entire medial border (Type 2), or the superior border of the scapula (Type 3). Uhl et al demonstrated that this method has a sensitivity and positive predictive value of 76% and 74% respectively when compared with the results of 3-dimensional motion analysis. The subjects also needed to be able to perform the exercises in a pain-free manner. Subjects were excluded if they had shoulder or cervical spine related symptoms, a history of dislocations or shoulder surgery, or if they did not reach full range of motion during shoulder elevation. All subjects gave their written consent to participate. The study was approved by the Ethical Committee of the Ghent University Hospital.

Instrumentation

After shaving and preparation with alcohol to reduce skin impedance (typically ≤ 10 kOhm) bipolar surface EMG electrodes (Blue Sensor – medicotest, Denmark) were placed with a 2 cm inter-electrode distance over the UT, MT, and LT of the dominant shoulder. Electrodes for the UT were placed midway between the spinous process of the seventh cervical vertebra and the posterior tip of the acromion process along the line of the trapezius. The MT electrode was placed midway on a horizontal line between the root of the spine of the scapula and the third thoracic spinous process. The LT electrode was placed obliquely upward and laterally along a line between the
intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process.\textsuperscript{2,7} A reference electrode was placed at the ipsilateral clavicle. To ensure consistency with electrode placement, the same investigator placed all electrodes.\textsuperscript{9} The electrodes were connected to a 16-channel Noraxon Myosystem 2000 electromyographic receiver (Noraxon USA, Inc., Scottsdale, AZ). Correct electrode placement was confirmed by visual inspection of the EMG signals on a computer screen during specific muscle testing. The sampling rate was 1000 Hz. All raw myo-electric signals were preamplified (overall gain=1000, common rate rejection ratio 115dB, Signal to Noise Ratio <1µV RMS baseline noise).

**Testing procedure**

First, verification of EMG signal quality was completed for each muscle by having the subject perform maximal voluntary isometric contractions (MVICs) using manual muscle test positions specific to each muscle. For the UT, resistance was applied to abduction of the arm from a seated position.\textsuperscript{32} The MT was tested in a prone position and resistance was applied to horizontal abduction in external glenohumeral rotation.\textsuperscript{19} The LT was also tested in a prone position with the arm was placed diagonally overhead in line with the fibers of the LT. Resistance was applied against further elevation.\textsuperscript{19} Subjects performed three 5-second MVICs against manual resistance for each muscle. There was a 5-second pause between each MVIC. A metronome was used to control duration of contraction.

Five minutes of rest was provided after MVIC testing. Then, the baseline testing condition, performed without instructions on scapular orientation, consisted of 5 trials for each exercise (concentric phase lasting 3 seconds, metronome controlled). The order of testing for the 4 exercises was randomized. All exercises were performed with hand-held weights and the amount of weight was determined based on gender and body weight (\textbf{TABLE}).\textsuperscript{7} A resting period of 3 seconds was provided between trials. Subjects were allowed to rest for 2 minutes between exercises.
**Male subject weight**

<table>
<thead>
<tr>
<th>Exercise</th>
<th>50-59 kg</th>
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<tbody>
<tr>
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<tr>
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<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
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<tr>
<td>Exercise 3</td>
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<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Exercise 4</td>
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<td>3.0</td>
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**Female subject weight**

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<th>56-64 kg</th>
<th>65-75 kg</th>
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<tbody>
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<td>Exercise 1</td>
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<td>1.5</td>
<td>1.5</td>
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<tr>
<td>Exercise 2</td>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Exercise 3</td>
<td>2.5</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Exercise 4</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

* Exercise 1 = Prone extension;  
  Exercise 2 = Side-lying forward flexion;  
  Exercise 3 = Side-lying external rotation;  
  Exercise 4 = Prone horizontal abduction with external rotation

**TABLE.** Weights (in kilograms) used by the subjects for the 4 exercises

Subsequently, conscious correction of scapular orientation was taught to the subjects in the same manner as it has been described in previous studies. The starting position was determined in each individual by actively positioning the scapula between maximal upward and downward rotation, external and internal rotation, and posterior and anterior tilt. Visual, auditory, and kinaesthetic cues were provided based on the individual’s resting posture when standing and with exercise specific positions (prone or side-lying). For example, for individuals with an anterior tilted scapulae, instructions included “gently bring the tip of your shoulder blade towards your spine”, for those with a downwardly rotated scapula, instructions included “gently lift the top of the shoulder”, while for those with predominantly protracted scapulae, the instructions included to “gently spread the front of your shoulder apart to draw your shoulder blade toward midline”. Drawing the scapula down and in (retraction and depression) was not considered an appropriate command. Substitutions such as retraction with maximum depression, retraction with
elevation, or excessive fixation of the humerus were avoided. The contraction force used to achieve the scapular position had to remain low to ensure low threshold tonic muscle recruitment. The participants practiced the posture exercise until satisfactory correction, as judged by the investigator, was achieved. All participants could correct scapular posture satisfactorily following this intervention.

Once the corrected scapular position could be held for 5 seconds without assistance, the same 4 exercises as done with the baseline condition were repeated again in a randomized order. Subjects were now instructed to perform each exercise starting from the neutral position while maintaining the corrected orientation during the concentric phase of each exercise (3 seconds). When a participant lost the corrected scapular orientation, appropriate verbal cues were provided. Because individuals are typically not able to correct impaired movement patterns over the total range of motion, each exercise was limited to 90°. Also, the analysis of the data was limited to the concentric phase of the exercise because the intervention time was too brief to also learn proper scapular control throughout the isometric and eccentric phases of the movement.

During all measurements, synchronized video recordings were made using a Sony Handycam (DCR-HC 37) to determine when subjects started the exercise movement. All EMG signals were processed with the 98 Myoresearch Software Program® (Noraxon). The raw EMG signals were analog-digital converted (12-bit resolution) at 1000 Hz. After cardiac artifact reduction and rectification and smoothing of the EMG signal with a 100ms Root Mean Square (RMS) moving window to create the linear envelop, the average EMG activation of the UT, MT, and LT was determined over a window of 2 seconds after the start of each exercise and was then normalized according to the MVIC method. This was done by calculating the mean activity of the second, third, and fourth repetition of each exercise. Data for the first and last repetition were not used for further analysis to avoid the influence of learning and fatigue.

**Statistical analysis**

The sample size for this study was based on a minimal relevant difference of 10% in EMG signal amplitude between conditions. Statistical significance was set at 5% with a desired power of 80%.

All statistical analyses were performed with the Statistical Package for the Social Sciences, version 18.0 for Windows (SPSS Inc., Chicago, Illinois). Group means and standard deviations were calculated for the normalized EMG signal amplitude of each
section of the trapezius for each exercise, and for both scapular conditions. Because conscious correction of scapular orientation also might influence the UT/MT and UT/LT muscle activation ratios, making the exercises less or more appropriate in individuals with trapezius muscle imbalance, these were also calculated. Because a Kolmogorov-Smirnov test showed normal distribution of the data, parametric tests were used for statistical analysis.

To determine if the conscious correction of scapular orientation influenced the activation level of the different section of the trapezius during each exercise, 4 separate, 1 for each exercise, 3 by 2 repeated measures ANOVAs were performed. The factor muscle had 3 levels (UT, MT, LT) and the factor scapular orientation had 2 levels (baseline and corrected). Because the influence on the trapezius muscle ratios (UT/MT and UT/LT) was also of interest, 4 separate, 1 for each exercise, 2 by 2 repeated measures ANOVAs were performed. The factor muscle ratio had 2 levels (UT/MT and UT/LT) and the factor scapular orientation had 2 levels (baseline and corrected). A statistical significance of .05 was chosen a priori for these comparisons. For any significant difference, a Bonferroni post hoc test with a .05 α significance level was used for follow-up analysis.

RESULTS

There was a significant muscle by scapular orientation interaction effect for prone extension (F= 5.84; P=.005). Post hoc pair-wise comparisons with Bonferroni correction showed significant significantly (P <.05) higher activation levels for all 3 sections of the trapezius when scapular orientation was performed (mean ± SD differences: UT: 5.9 ± 8.6 %MVIC; MT: 13.8 ± 11.0 % MVIC; LT: 9.8 ± 10.8 %MVIC). The differences in the magnitude of changes among the 3 sections of the trapezius are consistent with the significant interaction.

For the side-lying external rotation exercise, a significant muscle by scapular orientation interaction was also observed (F=3.84; P=.049), with post hoc tests indicating significantly higher activation levels for all sections of the trapezius muscle when conscious correction of scapular orientation was performed (mean ± SD differences: UT: 2.2 ± 4.4 %MVIC; MT: 6.7 ± 10.6 %MVIC; LT: 13.3 ± 24.4 %MVIC). In contrast, with the side-lying forward flexion exercise, there were no significant interaction (F=0.1; P=.82) nor main effect for scapula orientation (F=3.9; p=.057). There were also no
significant interaction and main effects of conscious correction of scapular orientation (F=3.1; P=.63; F=0.1; P=.76 respectively), for the prone horizontal abduction with external rotation exercise (FIGURE 3).

There was no significant muscle ratio by scapular orientation interaction for all 4 exercises (FIGURE 4). During the prone extension exercise, there was also no main effect of muscle ratio or scapular orientation. For both side-lying exercises, there was a main effect for muscle ratio (external rotation F=6.0, P=.02 with a mean difference of 6.0 ± 3.0%; forward flexion F=13.0; P=.001, mean ± SD difference of 20.0 ±6.0%). For
prone horizontal abduction with external rotation, there was a main effect for scapular orientation (F=5.1; P=.03 mean ± SD difference of 16.0 ± 7.0%).

FIGURE 4. Mean (SD) ratio of electromyographic signal amplitude for the 4 exercises performed with and without conscious control of scapular orientation (UT = upper trapezius; MT = middle trapezius; LT = lower trapezius; no significant differences between conditions were found, P>.05)

DISCUSSION

It was hypothesized that conscious correction of scapular orientation would have an influence on the absolute (UT, MT, and LT) and relative (UT/MT and UT/LT) trapezius muscle activation levels during each of the 4 exercises. However, the primary finding of this study was that conscious correction of scapular orientation significantly increased
the absolute muscle activation levels in the 3 sections of the trapezius muscle only for the prone extension and the side-lying external rotation exercise. All exercises showed UT/MT and UT/LT values close to those observed in a previous study, but none of them changed by conscious correction of scapular orientation.

The rationale behind the relevance of conscious correction of scapular orientation is based on improving proprioception, normalizing scapular resting position, and promoting trapezius muscle activation. More specifically, conscious control of the scapular musculature is considered relevant for restoration of neuromuscular coordination as well as strength deficits. In rehabilitation training, the value of an exercise is based on the activation level at which the different muscles are activated. Because overhead athletes with lack of scapular control (scapular dyskinesis) often show lack of muscle activation, exercises promoting high trapezius muscle activation are considered important to facilitate neuromuscular recruitment and better scapular motion. In an attempt to realize these goals, it is often suggested that conscious correction of scapular resting position might help facilitate neuromuscular firing in the different sections of the trapezius, especially the stabilizing MT and LT muscles. Because the scapulothoracic joint almost solely depend upon muscle activity for its functional stability, minor changes induced by conscious correction of scapular orientation can be important in the treatment of overhead athletes with scapular dyskinesis. However, the clinical benefit of conscious correction of scapular orientation during exercise training remains unclear. A 10% difference in muscle activation is considered clinically important in terms of muscle strengthening purposes, but no such value is available in the literature with regard to neuromuscular training.

Various authors have studied both the possibility of humans to selectively activate the different portions of the trapezius as well as the influence of scapular orientation on these recruitment patterns. Holtermann et al showed that the upper and lower sections of the trapezius muscle can be independently activated by voluntary command in a lying position, demonstrating the neuromuscular compartmentalization of this muscle. From a more clinical perspective, Mottram et al studied scapular muscle activation levels and showed optimal scapular posture can be accurately trained in healthy individuals by activating all 3 portions of the trapezius muscle in a seated position. Furthermore, Wegner et al recently demonstrated a significant increase in LT muscle activation during a typing task following conscious correction of scapular
position in patients with neck pain. However, none of these studies investigated the influence of conscious correction of scapular orientation on the trapezius muscle activation levels during particular shoulder exercises. Although Kibler et al.\textsuperscript{21} completed an EMG analysis of specific exercises for scapular control for the early phases of rehabilitation, a specific scapular orientation approach as used in this study has not been previously investigated.\textsuperscript{4, 7}

In this study, the influence of conscious correction of scapular orientation on the trapezius muscle activation levels is demonstrated when applied in overhead athletes performing dynamic shoulder exercises. The results indicate that during prone extension and side-lying external rotation, conscious control of the scapula significantly increases the activation in the 3 sections of the trapezius, suggesting that this approach has the potential to be clinically relevant when used with these 2 exercises. The results are in agreement with those by Mottram et al.\textsuperscript{27} who studied the influence of scapular orientation exercises performed in a seated position without additional arm movements which resulted in increased UT, MT, and LT activation. Conscious correction of scapular orientation did not change the activation of the 3 sections of the trapezius for the side-lying forward flexion and prone horizontal abduction with external rotation exercises, showing that this strategy does not lead to increase recruitment of the trapezius muscle during these 2 exercises. It is noted that prone horizontal abduction with external rotation already produced a high activation level when performed without conscious correction of scapular orientation, which might explain why no statistically significant differences were found between conditions.\textsuperscript{7, 11, 25}

Conscious correction of scapular orientation did not affect UT/MT and UT/LT ratios for all 4 exercises tested in this study.\textsuperscript{7} Because the ratios in this study were close to those reported in the original study by Cools et al.\textsuperscript{7} and were neither decreased or increased with an effort to control scapular position, the basis for which these 4 exercises are considered useful for improving scapular control remain when this strategy is used. These findings also suggest that the presence of scapular dyskinesis has limited influence on the trapezius muscle ratios when compared to a general group of healthy overhead athletes as in the study of Cools et al.\textsuperscript{7} However, in that study, subjects were not screened on the presence or absence of scapular dyskinesis, making it impossible to definitively conclude that scapular dyskinesis does not affect the muscle recruitment during the selected exercises.
Some limitations need to be considered when interpreting the results of this study. First, it must be noted that correction of altered scapular resting positions and impaired overhead movement patterns are 2 separate entities. The present study only investigated the relevance of correcting scapular orientation prior to performing the exercises, suggesting a setting phase is present in the initial phase of arm movement, in which the scapula has little contribution to total shoulder motion. However, no consensus exist on the presence of such a setting phase. In addition, one could question the relevance of the intervention for neuromuscular training purposes and could argue functional upper extremity movement training might be more relevant in altering the function of the force couples around the scapula. Second, we did not monitor other scapulothoracic muscles such as the rhomboids, serratus anterior, and pectoralis minor. Scapular dyskinesis is likely to be the result of a combination of a suboptimal motor control of a variety of scapulothoracic muscles, not only the trapezius. Therefore, the results of this study should not be interpreted isolated from other scapular muscle contributions. Third, it is also suggested that scapular dyskinesis is related to alterations in the timing of scapular muscle activation. Possibly, conscious correction of scapular orientation also has an influence on the trapezius muscle timing during the selected exercises, but this was not monitored in this study. Fourth, a high amount of variability among subjects was found, which could be due to the inclusion of various types of dyskinesis requiring different fine motor control strategies across subjects. This was done because classification of scapular abnormalities by visual observation shows low reliability. Fifth, the use of asymptomatic subjects, despite the presence of scapular dyskinesis, also limits the generalization of the results to patients with shoulder pathology. It remains to be determined how correction of scapular orientation may prevent injuries in overhead athletes and impact symptoms in patients with various shoulder conditions. Therefore, the most appropriate strategy for a specific shoulder condition remains speculative until comparative effectiveness research is performed. Accordingly, the results of this study are to be seen as a first step in the evaluation of the value of conscious correction of scapular orientation in the treatment of shoulder conditions.

On the basis of our research question and our results, we believe further examinations should be performed. First, more studies are needed to define the ability of the subjects to maintain corrected scapular positions during each exercise by measuring multiple
muscle contributions (e.g. serratus anterior) in combination with 3-dimensional movement analysis of the scapula. Second, more studies examining the effect of exercises focusing on high activation levels in the stabilizing muscles of the scapula compared to those focusing on correction of the 3-dimensional movement patterns would give more insight in this topic. It would also be interesting to investigate if changes in muscle activation are also apparent in standing, when the thoracic spine has some axial loading. Third, the long-term effect of scapular orientation and trapezius muscle balance rehabilitation exercises should be investigated by prospective research.

CONCLUSION

This study demonstrated that conscious correction of scapular orientation increases the activation of all 3 sections of the trapezius during the prone extension and side-lying external rotation exercise. In addition, the UT/MT and UT/LT ratios were not changed by the intervention for any of the 4 exercises that were included in the study. These findings suggest that these 4 exercises remain relevant for trapezius muscle balance rehabilitation when conscious scapular orientation is performed. The findings of this study may help physiotherapists in the selection of shoulder rehabilitation exercises in overhead athletes with scapular dyskinesis.
Key points

Findings: During prone extension and side-lying external rotation, conscious correction of scapular orientation promotes higher muscle activation of all 3 sections of the trapezius. It has no significant impact during side-lying forward flexion and prone horizontal abduction with external rotation. Conscious correction of scapular orientation did not change the relative level of activation between the 3 sections of the trapezius.

Implication: Conscious correction of scapular orientation may be a useful component of performing scapular muscle rehabilitation exercises in overhead athletes with scapular dyskinesis, especially for the prone extension and side-lying external rotation exercises.

Caution: This study did not assess the effect of this intervention on scapular orientation and movement during the exercises.

Acknowledgements

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Study II    Shoulder muscle activation levels during 4 closed kinetic chain exercises with and without Redcord slings

Kristof De Mey, PT*; Lieven Danneels, PT, PhD*; Barbara Cagnie, PT, PhD*; Dorien Borms, PT*; Zilke T´Jonck, PT*; Eline Van Damme, PT*. Ann M. Cools, PT, PhD*

*Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University Hospital, Ghent, Belgium.

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ABSTRACT

During resistance training protocols, people are often encouraged to target the scapular stabilizing musculature (middle and lower trapezius and serratus anterior) while minimizing shoulder prime mover activation (upper trapezius and large glenohumeral muscles) in their training regime, especially in overhead athletes. Unstable surfaces are frequently used during closed kinetic chain exercises (CKC) with the objective to encourage specific shoulder muscle recruitment patterns, thought to facilitate neuromuscular adaptations. However, their specific influence on the shoulder muscle activation have rarely been investigated during exercises using Redcord slings (RS). Therefore, a controlled laboratory study was performed on 47 healthy subjects during 4 CKC exercises without and with RS: half push-up, knee push-up, knee prone bridging plus and pull-up. The results were then interpreted with respect to previous research classifying exercises on the basis of their muscle amplitude and ratio levels. The general finding was that not all muscles increased or decreased their activation level when using RS. In addition, the large glenohumeral muscles were highly activated when using RS, especially the pectoralis major during the push-up and knee prone bridging exercise and the posterior deltoid and latissimus dorsi during the pull-up exercise. Five exercises with a low upper trapezius/serratus anterior ratio could be selected: half push-up without and with RS, knee push-up without and with RS and knee prone bridging plus without RS. However, there was not a single exercise that could be selected based on a low upper trapezius/middle trapezius and upper trapezius/lower trapezius ratio. Therefore, RS are only preferred over a stable surface when to goal is to increase the activation in the prime mover muscles of the shoulder.

Key Words: shoulder, sling exercises, surface electromyography
A. INTRODUCTION

Shoulder muscle exercises are often prescribed to restore shoulder function (16), prevent upper extremity injury (42) or enhance the athletic performance (41), especially in overhead athletes. With the objective to select the most appropriate exercises, the muscle recruitment patterns of various shoulder muscles have been studied during both open kinetic chain (OKC) and closed kinetic chain (CKC) exercises (19). While OKC exercises are commonly employed in the training of throwing athletes, they often put considerable stress on the shoulder joint, especially in the “high five” position (23). In contrast, CKC exercises have been shown to stimulate mechanoreceptors and have been found to recruit the stabilizing muscle parts around the shoulder girdle, so contributing to proper shoulder stabilization (20,35,37,43). Research suggests this stimulus can be enlarged by adding an unstable surface, possibly leading to higher levels of muscle activation (5,17). As a result, an unstable surface is often used during shoulder training in an attempt to facilitate neuromuscular adaptations in response to strength training (26,29,38,40,41,45,49-51).

The shoulder complex accounts for a considerable proportion of injuries, both in overhead athletes as in the general resistance training population. In these individuals, specific muscle imbalances have been implicated in the etiology of shoulder disorders such as scapular dyskinesis and shoulder impingement syndrome. In particular, the scapular stabilizing muscle parts have been found to be impaired with respect to the scapular and glenohumeral prime movers (7,30,39). Additionally, athletes often emphasize large muscle groups such as the upper trapezius (UT), pectoralis major (PM), anterior (AD) and posterior deltoid (PD) and latissimus dorsi (LD) in their training regime with the objective to produce gains in strength and hypertrophy, subsequently neglecting the stabilizing muscles such as the middle and lower trapezius (MT, LT) and
serratus anterior (SA). Therefore, exercises to strengthen the MT, LT and SA while avoiding high levels of activation in the large muscle groups (UT, PM, AD, PD, LD) should be incorporated in their training programs.\(^{22,24}\)

Performing exercises on an unstable base of support has been found to increase electromyographic (EMG) activity in specific trunk and leg muscles during squatting movements \(^{2}\), bridging exercises \(^{27,28,34}\) and traditional upper body strength exercises \(^{6,27,28}\). In these studies, differences in the EMG activation of particular shoulder muscles have also been found. A novel training device providing an unstable base of support, Redcord slings (RS), has been described in recent research \(^{10,18,41}\). Some authors found it can be used to effectively treat various musculoskeletal conditions \(^{53,54}\), improve proprioception \(^{48}\) and enhance the athlete’s athletic performance \(^{18,41,44,46,47}\). However, whether RS activate the scapular stabilizing muscle parts while limiting the activation in the larger muscle groups is currently unclear.

Therefore, the main purpose of this study was to examine scapulothoracic and glenohumeral muscle amplitude levels and scapular muscle ratios during 4 selected CKC shoulder exercises without and with RS. Additionally, it was the objective to interpret the results on the basis of previously published categories (amplitude levels and scapular muscle ratios) for clinical relevance determination \(^{8,15}\). These findings could add evidence to the limited body of knowledge on the effect of RS on shoulder muscle function.
B. METHODS

a. Experimental Approach to the Problem

Surface EMG was used to measure muscle activation amplitude levels of scapulothoracic (UT, MT, LT, SA) and glenohumeral (PM, AD, PD, LD) musculature during 4 selected exercises with and without RS: half push-up, knee push-up, knee prone bridging plus and pull-up (Figure 1-4). Exercises requiring extreme levels of core stability were not chosen because some subjects might not have been able to maintain their neutral spinal alignment during each exercise, possibly influencing the results of our investigation (36). During the half push-up, the subject was positioned in a 45° angle above a metal bar. Hands were placed in a pronated position, slightly wider than shoulder width. Then, the subject performed a push-up until the elbows were flexed 90°, to prevent excessive anterior translations in the glenohumeral joint. The same exercise description was given when performing the exercise with the RS, so replacing the metal bar with the slings. During the knee push-up, the subject was positioned in a push-up position on the knees. Feet were elevated and hands were placed slightly wider than the shoulders. Then, a push-up was performed until the elbows were flexed 90°. The same exercise was performed with the RS while gripping the slings 10cm above the ground (10). During the knee prone bridging plus, the subject was positioned while leaning on the elbows with the feet slightly elevated, performing scapular protraction and retraction movements. The same exercise was performed with the RS, elbows positioned 10cm above the ground. During the pull-up exercise, the subject was positioned supine grasping the bar with both hands. While maintaining neutral spinal alignment and maintaining contact with the heels to the floor, the subject performed a pull-up until the elbows were flexed 90°. The same exercise was performed while
grasping the RS. During each exercise, subjects were instructed to maintain neutral spinal alignment.

Figure 1. Half push-up exercise without and with Redcord slings.
Figure 2. Knee push-up exercise without and with Redcord slings.
Figure 3. Knee prone bridging plus exercise without and with Redcord slings.
Figure 4. Pull-up exercise without and with Redcord slings.
a. Subjects

Forty-seven volunteers (26 males, 21 females; mean ± SD age, 22 ± 4.31 years; weight, 69± 8.57 kg; height 176 ± 0.083 cm; body mass index, 22 ± 2.05 kg/m²) were recruited through private physical training practices and fellow students. Participants were included if they were in general good health, had no complaints of shoulder pain or instability in the past 12 months and had no history of orthopedic surgery of the shoulder or surrounding region. Moreover, each subject needed to be able to perform the exercises with proper proximal stability. Some experience with RS was allowed, yet no long term training experience was tolerated to prevent the level of training to be of influence. All subjects gave informed consent for this investigation, which was approved by the Ethical Committee of the Ghent University Hospital.

b. Procedures

For registration of EMG activation, a Noraxon Myosystem 1400 electromyographic receiver (Noraxon USA, Inc., Scottsdale, AZ) was used. In all participants, the dominant side was tested, which was prepared by shaving and cleaning the skin surface to reduce skin impedance (<10kΩ). Bipolar Ag-Cl surface electrodes (Blue sensor; Medicotest, Ølstykke, Denmark) were placed over the tested muscles and a reference electrode was placed over the homolateral clavicle (8,12,14,25,33). The researcher confirmed that the electrodes were correctly placed by inspecting the EMG signals on a computer screen during specific muscle testing. The sampling rate was 1000Hz. All raw myoelectric signals were preamplified (overall gain = 1000, common rate rejection ratio 115 dB, signal-to-noise ratio <1µV root mean square baseline noise). Maximal voluntary isometric contractions (MVIC) were determined for normalization by performing 5 second MVIC’s against manual resistance (9,12,14,33). A metronome was used to control duration of phases and subjects were encouraged by verbal feedback. After
MVIC testing, participants performed the 4 exercises with and without RS: half push-up, knee push-up, knee prone bridging plus, and pull-up. Subjects completed 5 repetitions of each exercise with 5 seconds of intermediate rest while a resting period of 2 minutes was held between exercises. Each exercise consisted of a three second concentric and eccentric phase. During the EMG registration, simultaneous video recordings (Sony Handycam, DCR-HC 37) were made and a metronome was used to control movement speed (60beeps/min). To prevent order biasing, the exercise sequence was randomized. The Myoresearch XP Master Edition 1.07.41 Software Program was used for signal processing. All raw EMG signals were analog/digital converted (12-bit resolution) with a sampling rate of 1000 Hz and after rectification, cardiac artifact reduction and smoothing (Root Mean Square = 100Hz), the results were normalized to the maximal activity measured during the MVIC trials. The EMG data for each muscle and each subject were averaged for each phase across the 3 intermediate repetitions of the 5 completed trials as the first and last repetitions were dismissed for further analysis to avoid the influence of habituation and fatigue. Since the UT/MT, UT/LT and UT/SA ratios were of interest, these were also calculated.

c. Statistical Analyses
SPSS Statistics 19 for Windows (SPSS Science, Chicago, Illinois) was used for statistical analysis and started with a Kolmogorov-Smirnov test, showing normal distribution of the data. Our goal was to determine differences in individual muscle activation patterns and scapular muscle ratios when performing the same exercise with and without RS and not to compare differences between muscle parts or between other exercises. Therefore, only paired T-tests were performed for both normalized means and muscle ratios (UT/MT, UT/LT, UT/SA). Statistical significance was accepted at α=0.05.
C. RESULTS

a. The effect of Redcord slings on shoulder EMG activation

Significantly increased activation in the UT (4.49; p=0.026), LT (5.78; p=0.028), PM (27.16; p=0.005) and PD (9.22; p=0.003) was observed when the half push-up with RS was compared with the normal push-up, while other muscles showed no significant differences. The knee push-up showed no significant differences except for the SA (-15.19; p=0.003) and AD (-13.97, p=0.045) which showed decreased activation levels with RS. For the knee prone bridging plus exercise, significant influences were noted for all muscles with the exception of the UT, LT and LD. In this exercise, the PM (33.91; p=0.001) was the only muscle showing a significantly increased activation level with RS. MT (-5.70; p=0.039), SA (-12.73; p=0.014), AD (-42.82; p=0.0001) and PD (-10.42; p=0.035) significantly decreased their activation level when using RS. During the pull-up, a significantly decreased MT (-9.57; p=0.002) and LT (-7.06; p=0.014) muscle activation was found. On the contrary, AD (10.81; p=0.024) and LD (14.10; p=0.006) showed significantly increased activation levels during this exercise (Table 1-4). The main muscle activation levels of each exercise were also classified into 4 categories based on the study of Digiovine et al. (15): low (<20% MVIC), moderate (20–40% MVIC), high (41–60% MVIC), and very high (>60% MVIC) (Table 5).
## Table 1 & 2. Means and standard deviations for normalized EMG activity of each muscle during the half push-up and knee push-up exercise.

### Half push-up

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Without Redcord</th>
<th>With Redcord</th>
<th>Mean difference</th>
<th>95% confidence interval</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT</td>
<td>9.62±6.47</td>
<td>14.11±9.61</td>
<td>4.49±11.01</td>
<td>0.58 - 8.39</td>
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<tr>
<td>MT</td>
<td>20.78±21.07</td>
<td>18.41±15.05</td>
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<td>-7.62 - 2.89</td>
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<tr>
<td>LT</td>
<td>13.94±12.73</td>
<td>19.73±15.76</td>
<td>5.78±16.40</td>
<td>0.67 - 10.89</td>
<td>.028*</td>
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<tr>
<td>SA</td>
<td>43.56±25.02</td>
<td>38.69±24.94</td>
<td>-4.87±27.43</td>
<td>-13.53 - 3.79</td>
<td>.262</td>
</tr>
<tr>
<td>PM</td>
<td>66.88±39.09</td>
<td>94.04±62.94</td>
<td>27.16±56.30</td>
<td>8.65 - 45.67</td>
<td>.005*</td>
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<tr>
<td>AD</td>
<td>52.86±31.42</td>
<td>55.66±43.23</td>
<td>2.80±33.66</td>
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<td>.597</td>
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<td>PD</td>
<td>20.74±16.49</td>
<td>29.97±24.01</td>
<td>9.22±18.68</td>
<td>3.25 - 15.2</td>
<td>.009*</td>
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<td>LD</td>
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<td>38.72±46.05</td>
<td>8.69±38.12</td>
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<td>.193</td>
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</table>

### Knee push-up

<table>
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<tr>
<th>Muscle</th>
<th>Without Redcord</th>
<th>With Redcord</th>
<th>Mean difference</th>
<th>95% confidence interval</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT</td>
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<td>17.77±31.27</td>
<td>3.59±26.05</td>
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<td>MT</td>
<td>22.81±15.12</td>
<td>18.84±19.08</td>
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<td>LT</td>
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<td>20.79±20.34</td>
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<td>.973</td>
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<td>53.08±29.32</td>
<td>37.89±22.89</td>
<td>-15.19±31.82</td>
<td>-24.75 - 5.63</td>
<td>.008*</td>
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<td>PM</td>
<td>82.88±45.82</td>
<td>90.13±66.64</td>
<td>7.25±68.46</td>
<td>-14.64 - 29.14</td>
<td>.507</td>
</tr>
<tr>
<td>AD</td>
<td>67.07±17.40</td>
<td>53.09±46.39</td>
<td>-13.97±44.79</td>
<td>-27.59 - 0.36</td>
<td>.045*</td>
</tr>
<tr>
<td>PD</td>
<td>26.80±24.31</td>
<td>31.59±28.71</td>
<td>4.78±33</td>
<td>-5.25 - 14.81</td>
<td>.342</td>
</tr>
<tr>
<td>LD</td>
<td>29.61±23.12</td>
<td>27.15±25.01</td>
<td>-2.46±22.87</td>
<td>-10.71 - 5.78</td>
<td>.547</td>
</tr>
</tbody>
</table>
Table 3 & 4. Means and standard deviations for normalized EMG activity of each muscle during the knee prone bridging plus and pull-up exercise.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Without Record</th>
<th>With Record</th>
<th>Mean difference</th>
<th>95% confidence interval</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean difference</td>
<td>lower</td>
<td>upper</td>
</tr>
<tr>
<td>UT</td>
<td>12.8±4.11</td>
<td>1.7±14.91</td>
<td>-11.1±14.851</td>
<td>-11.6±21.84</td>
<td>.549</td>
</tr>
<tr>
<td>MT</td>
<td>23.1±12.72</td>
<td>17.4±20.12</td>
<td>-5.7±16.4</td>
<td>-11.1±11.09</td>
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</tr>
<tr>
<td>LT</td>
<td>20.9±13.46</td>
<td>15.9±14.59</td>
<td>-4.1±13.52</td>
<td>-10.2±2.05</td>
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</tr>
<tr>
<td>SA</td>
<td>57±22.72</td>
<td>46.2±22.79</td>
<td>-12.7±31.63</td>
<td>-22.7±2.74</td>
<td>.014*</td>
</tr>
<tr>
<td>PM</td>
<td>39.0±14.23</td>
<td>27.9±15.12</td>
<td>11.9±14.53</td>
<td>14.7±53.94</td>
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</tr>
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<td>AD</td>
<td>71.3±52.12</td>
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<td>-42.8±48.56</td>
<td>-58.5±27.06</td>
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<td>PD</td>
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<table>
<thead>
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<th>Mean difference</th>
<th>95% confidence interval</th>
<th>P-value</th>
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<td>Mean ± SD</td>
<td>Mean difference</td>
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<td>upper</td>
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<tr>
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Table 5. Classification of mean muscle activation of each exercise based on Digiovine et al. (15), values >60%: very high; 41%-60%: high; 20%-40%: moderate; <20%: low.

<table>
<thead>
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<th>Exercise</th>
<th>Redcord</th>
<th>Category</th>
<th>UT</th>
<th>MT</th>
<th>LT</th>
<th>SA</th>
<th>PM</th>
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<td><strong>Knee prone bridging plus</strong></td>
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</tr>
<tr>
<td><strong>Pull-up</strong></td>
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<td>x</td>
<td>x</td>
<td>x</td>
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</tr>
<tr>
<td></td>
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<td>x</td>
<td>x</td>
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<td>x</td>
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<tr>
<td></td>
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<td>&gt;60</td>
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<td>x</td>
<td>x</td>
<td>x</td>
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</tr>
</tbody>
</table>

b. The effect of Redcord slings on scapular muscle ratios

During the half push-up exercise, a significantly increased UT/MT (38.10; p=0.01) and UT/SA (30.80; p=0.001) ratio was noted when using RS. UT/MT (20.82; p=0.036) and UT/SA (16.13; p=0.015) ratios were also significantly increased during the knee push-up with RS, while the UT/LT (-8.84; p=0.401) ratio did not significantly change. When the knee prone bridging plus was performed with RS, a significant increase could be
observed for the UT/SA (30.78; p=0.031) ratio. During the pull-up, UT/MT (11.61; p=0.014) and UT/LT (15.74; p=0.008) ratios significantly increased, while the UT/SA (-71.95; p=0.015) ratio significantly decreased (Table 6-9). All scapular muscle ratios were also divided into 4 subgroups based on the categories of Cools et al. (8): >100% (poor), 100 to 80% (moderate), 80 to 60% (good), and <60% (excellent) (Table 10).

Table 6 & 7. Scapular muscle ratios during the half push-up and knee push-up exercise without and with Redcord slings.
Table 8 & 9. Scapular muscle ratios during the knee prone bridging and pull-up exercise without and with Redcord slings.

### Knee prone bridging plus

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Without Redcord</th>
<th>With Redcord</th>
<th>Mean difference</th>
<th>95% confidence interval</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT/MT</td>
<td>85.22±64.79</td>
<td>100.75±76.9</td>
<td>15.53±67.66</td>
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<tr>
<td>UT/LT</td>
<td>71.77±43.46</td>
<td>66.48±40.80</td>
<td>5.28±31.66</td>
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<td>33.27±46.42</td>
<td>64.05±126.9</td>
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### Pull-up

<table>
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<th>Ratio</th>
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<th>With Redcord</th>
<th>Mean difference</th>
<th>95% confidence interval</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT/MT</td>
<td>65.05±29.52</td>
<td>76.66±43.63</td>
<td>11.61±29.84</td>
<td>2.43 - 20.79</td>
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<tr>
<td>UT/LT</td>
<td>64.44±30.58</td>
<td>80.19±53.54</td>
<td>15.74±32.34</td>
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<tr>
<td>UT/SA</td>
<td>247.70±221.55</td>
<td>175.75±149.22</td>
<td>-71.95±137.95</td>
<td>-128.90 - 15.01</td>
<td>.015*</td>
</tr>
</tbody>
</table>
## Table 10. Classification of scapular muscle ratios of each exercise based on Cools et al. (8) Values <100%: poor; 100%-80%: moderate; 80%-60%: good; <60%: excellent.

<table>
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<th>Exercise</th>
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<tr>
<td></td>
<td></td>
<td>UT/LT</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>UT/SA</td>
<td>X</td>
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<tr>
<td>With</td>
<td>UT/MT</td>
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<tr>
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<td>UT/LT</td>
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<tr>
<td><strong>Knee push-up</strong></td>
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<td>X</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>UT/LT</td>
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<td></td>
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<td>UT/SA</td>
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<td>With</td>
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<td>UT/SA</td>
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<td></td>
</tr>
<tr>
<td><strong>Knee prone bridging plus</strong></td>
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<td>UT/MT</td>
<td>X</td>
<td></td>
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<tr>
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<tr>
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<td>X</td>
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<td></td>
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<tr>
<td><strong>Pull-up</strong></td>
<td>Without</td>
<td>UT/MT</td>
<td>X</td>
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<tr>
<td></td>
<td></td>
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<td>X</td>
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</table>
DISCUSSION

To our knowledge, the current study is the first to investigate the effect of RS on scapulothoracic and glenohumeral muscle activation during the four selected exercises. The hypothesis of this study was that each muscle part and each scapular muscle ratio would have been altered when comparing the same exercise without and with RS. However, the main finding was that for the same exercise with and without RS, not all muscles respond with an increased or decreased muscle activation level in response to an unstable surface, which is in accordance to the findings of previous research on this topic (11,13,26,29).

Half push-up exercise:
During the half push-up exercise, UT, LT, PM and PD activity increased when using RS. When comparing our results with those of previous studies, Lehman et al. (26) did not observe significant differences when comparing the EMG activation levels of the UT, LT and SA between a push-up performed on a fixed bench and on a Swiss ball. Sandhu et al. (45) neither found differences in the UT and SA muscles when using a Swiss ball during a standard push-up. Tucker et al. (49) found an increased MT activation when performing a standard push-up on a BOSU sports balance trainer. In contrast, we could not find a significant difference in the MT muscle when performing the half push-up exercise. The increased LT activation which was found in our study (5.78% MVIC; p=0.028), was also found in other research in which an unstable base of support was implemented during a standard push-up exercise on one (13) or both (49) hands, although the question arises if these differences are clinically relevant. Concerning the SA muscle, we did not find significant differences. However, the effect of an unstable surface on the SA might differ between the upper and lower parts of this muscle. Park
and Yoo (38) studied the influence of a wobble board during push-up exercises and found that only the lower part of the SA showed increased activation levels. Since we did not distinguish between the two parts of the SA muscle, no conclusions can be made regarding these differences. Concerning the PM muscle, the effect of an unstable surface is not clear. In accordance with Sandhu et al. (45), we found a significantly higher activation level in this muscle (27.16% MVIC; p=0.005), which may be caused by the way shoulder abduction needs to be controlled in case RS are applied. Possibly, the instability induced by RS is higher when compared to other unstable surfaces. Since there is no contact with the floor when using RS, a more unstable condition is created in multiple directions. Indeed, some authors who used unstable surfaces as a Swiss ball, so maintaining contact with the floor, could not observe any difference (29) or even found a decreased PM activation (13) when performing a push-up exercise. Concerning PD muscle activation, we found significantly higher activation when using RS (9.22% MVIC; p=0.003), which is in line with the results of Uhl et al. (52) They suggested that a one-arm push-up, which can be seen as an unstable condition, emphasized PD and infraspinatus muscle activation when compared with a two-handed position. Finally, for AD and LD activation, there was no significant difference. De Oliveira et al. (13) found increased AD activation when studying the influence of a medicine ball. However, a one-hand push-up was performed in their research. In the study of Lehman et al. (29), LD muscle activation was also measured, but the data could not be used because of excessive noise on the EMG signal. Bair et al. (4) neither could find differences for the LD between stable and unstable surfaces in their study including a push-up on a BOSU ball.
Knee push-up exercise:

During the knee push-up, no differences could be found, except for the SA (-15.19% MVIC; p=0.003) and AD (-13.97% MVIC; p=0.045) activation, which significantly decreased. In addition, the trapezius muscle parts were not significantly influenced by the RS. Previous research using other instability devices (Swiss ball, wobble board or Stability trainer) neither could find any differences in these muscle parts (11,32,40,45). The significantly decreased SA activation was also found by Lehman et al. (26) and Maenhout et al. (32). They suggested that a higher position of the hands, placing more weight on lower and less on upper extremities, could lead to the decreased SA activation. Our study (placing the hands 10cm above the floor when using RS) confirms this hypothesis. Nevertheless, some studies did not observe a difference in SA activation, which may be explained by the way the unstable surface is created in these various investigations (11,40,45). In addition, no differences could be found in the glenohumeral muscles, except for the AD, which showed a decreased activation with the use of RS.

Knee prone bridging plus exercise:

During the knee prone bridging plus, the PM (33.91% MVIC; p=0.001) increased while the MT, SA, AD and PD muscle activation decreased. No difference was found between the stable and unstable conditions for the UT and LT muscles, which is in agreement with the result of previous work (26,45). Concerning the SA, our study did not find increased activation levels during this exercise, despite such an increase is often seen during scapular protraction movements, clinically known as the “plus” phase of the exercise (14,31). As previously stated, this is most likely due to influence of body weight (26,32), also explaining Sandhu et al.’s (45) reported lack of statistical significance when a bench was replaced by a Swiss ball during an elbow push up exercise. The
33.91% MVIC increase in PM activation was in accordance with the results of Sandhu et al. (45) who also observed greater PM activation when a stable bench was replaced by a Swiss ball during an elbow push-up exercise, also finding a higher triceps muscle activation. In contrast with our results, Lehman et al. (29) showed no influence on PM activation with the addition of a Swiss ball during a push-up plus exercise with full extension in the elbows, but they also found a dramatic increase in triceps muscle activation. Since the PM is a mono-articular muscle and the triceps is a bi-articular muscle, the PM may have had a smaller role in responding to stability alterations, in contrast to the triceps. In our study, the knee prone bridging plus was performed with the elbows flexed at 90°, possibly reducing the effect of the triceps muscle while increasing the demands of stability in the PM. However, triceps muscle activity was not measured in our study and therefore, these influences remain speculative. Lastly, AD and PD activation significantly decreased when using RS, with the greatest decrease in the AD (-42% MVIC; p=0.0001), for which the reason currently remains undefined.

Pull-up exercise:

During the pull-up exercise, MT and LT activation decreased when using RS, while AD and LD showed increased activation levels. Although our statistical analysis could not provide details regarding statistical differences between muscle parts during the same exercise, MT (68.82% MVIC without and 42.95% MVIC with RS) and LT (69.41% MVIC without and 62.35% MVIC with RS) showed higher activation levels compared to the SA (26.05% MVIC without and 28.37% MVIC with RS) and UT (40.57% MVIC without and 42.95% MVIC with RS) in both conditions. Probably, this is caused by the MT and LT being contributors to the retraction movement of the scapulae which occurs during the elevation of the body in this exercise, whereas lowering the body (protraction), is
Part II  Muscle recruitment during specific scapular muscle training exercises

eccentrically controlled by these muscles, leading to higher activation levels. The significantly higher AD (10.81% MVIC; p=0.024) activation which was found during this exercise, can be explained by the position of the hands, which are placed slightly wider than shoulder width. Under this condition, the AD muscle is at its greatest length and under its greatest tension, especially in combination with a horizontal abduction position (at the end of the concentric phase), probably resulting in higher activation when using RS. LD muscle activation also increased (14.10% MVIC; p=0.006). This muscle contributes to core stabilization and possibly, an unstable surface increases its demand of stability, explaining the significant increase when using slings.

Athletes regularly performing resistance training exercises and overhead athletes with scapular dyskinesis are recommended to include exercises to strengthen the MT, LT and SA muscle parts while avoiding high levels of activation in the large muscle groups in their training regime (21,23). In general, higher activation levels are preferred with the intend to induce larger strength gains in particular muscle groups. Therefore, analyzing the extent to which a muscle is recruited to perform a certain activity can help trainers and physical therapists to select the most appropriate exercises in a particular case. In general, researchers propose that the threshold value for muscle strength gains during exercise require EMG activation greater than 50-60% (1,3). Consequently, normalized EMG values in the “high” and “very high” category are considered relevant for strength training purposes. During both stable push-up exercises, the SA muscle showed high activation levels. However, the activation in the SA muscle decreased to a moderate level when using RS. In addition, the two push-up exercises without and with RS, and the knee prone bridging plus exercise with RS showed high activation in the PM. During the pull-up exercise, regardless of surface type, high to very high activation was found
for the MT, LT, PD and LD. With RS, MT and LT activation significantly decreased, but the amount of muscle activation remained “high”. AD muscle activation was also found high under both conditions during this exercise. In addition, the pull-up with RS showed the highest UT activation of all exercises. However, since athletes often present with increased UT activation as part of their strength imbalance, this might not be the preferred exercise in athletes presenting with scapular dyskinesis or impingement syndrome. Finally, all exercises showed high to very high AD muscle activation, with the exception of the knee prone bridging plus with RS.

From an injury prevention perspective, it is particularly interesting to select exercises for restoration of scapular muscle balance. Five exercises showed a low UT/SA ratio: half push-up with and without RS, knee push-up with and without RS and knee prone bridging plus without RS. There was not a single exercise that could be selected based on a low UT/MT and UT/LT ratio. Furthermore, the results demonstrated that for all ratios and all exercises tested, RS were not preferred over a stable condition, except for the UT/LT ratio during the knee push-up exercise. However, no statistical difference could be found for the UT/LT ratio between both conditions.

Some limitations should be taken into account when interpreting the results of this study. First, the results of this trial only provide evidence for the influence of RS during the selected exercises. The results do not imply that RS influence the specific recruitment patterns of the shoulder musculature in a similar way during other exercises than the ones studied. It does neither provide the necessary information to comment on the effectiveness of those exercises. Second, it should be noted that extrapolation of the results to athletes with shoulder pain should be performed with caution. For example,
Tucker et al. (49) found that, during closed chain exercises, the MT differs in overhead athletes with a history of secondary shoulder impingement compared with those who lack this history. Probably, the influence of RS on the shoulder muscle activation is also dependent on the athlete’s current level of symptoms when performing closed chain exercises. Third, the individual degree of difficulty during each exercise was not taken into account in our study. In contrast, Huang et al. (18) made an individual progression in the level of difficulty, which was determined by the subject’s ability to execute the exercise comfortably and correctly. Although we selected exercises on the basis of their limited need for proximal stability, with all subjects receiving constant feedback, this may be the major limitation from a clinical point of view.

Based on the results of our study, some further investigations might be interesting to perform. First, the influence of RS on the activation levels of other muscles, such as those of the rotator cuff, could be of interest. Since these muscles act as the main glenohumeral stabilizers, investigating their muscle activation levels and study the influence of various unstable conditions during closed kinetic chain exercises might be relevant. Second, the study could be repeated with a group of athletes suffering from shoulder dysfunction like scapular dyskinesis and/or impingement syndrome. Subsequently, comparing the results of that study with the current investigation could be relevant because this would give more insight into how these aspects impact the shoulder muscle recruitment during each exercise. Third, a randomized controlled trial could be performed to study the effect of exercises with RS in athletes suffering from mild impingement symptoms. Finally, another point of interest would be to examine the effect of an individual progression in degree of difficulty during the exercises and to
accompany the EMG measurements by a synchronized kinematic evaluation while using the full Redcord workstation.

**PRACTICAL APPLICATIONS**

Athletes involved in resistance training in general and overhead athletes in particular are recommended to include strengthening exercises for the scapular stabilizing muscles while minimizing the activation in the larger muscles around the shoulder. CKC exercises on an unstable surface are frequently used for proper strengthening of the shoulder, often while using RS. Therefore, knowing how RS influence the activation levels in particular shoulder muscles, especially the MT, LT and SA, is of interest. The current study investigated 4 CKC exercises with and without RS and found that the influence of RS on the shoulder muscle function is muscle and exercise dependent. Five exercises could be effective when the goal is to strengthen the SA while minimizing the activation in the UT: half push-up without and with RS, knee push-up without and with RS and knee prone bridging plus without RS. However, the use of RS is not preferred over a stable surface when the goal is to strengthen the MT and LT while minimizing the activation in the scapular and glenohumeral prime movers. Therefore, clinicians should be aware that using RS does not necessarily imply higher activation will be obtained in the muscles responsible for scapular stabilization. However, within a general strengthening training program, RS may be of additional value.
ACKNOWLEDGEMENTS

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REFERENCES


Part II Muscle recruitment during specific scapular muscle training exercises


Study III  Trapezius muscle timing during selected shoulder rehabilitation exercises

Kristof De Mey, PT*; Barbara Cagnie, PT, PhD*; Annemie Van de Velde, PT*; Lieven Danneels, PT, PhD*; Ann M. Cools, PT, PhD*

*Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University Hospital, Ghent, Belgium


Impact factor: 2.482
ABSTRACT

Study Design: Controlled laboratory study

Objectives: To examine the timing of the trapezius muscle in relation to the posterior deltoid (PD) muscle and in relation to one another during selected shoulder exercises (1: prone extension; 2: forward flexion in side lying; 3: external rotation in side lying and 4: prone horizontal abduction with external rotation).

Background: Deficiencies in trapezius muscle recruitment have been identified in patients with shoulder pain. Alterations in the trapezius muscle activation level and timing have been identified in previous research. Scapular muscle exercises in which the middle trapezius (MT) and lower trapezius (LT) showed optimal activity with minimal upper trapezius muscle (UT) participation have been recently identified. However, it is currently unknown if these exercises also promote early activation of the scapular stabilizing musculature.

Methods and Measures: The intermuscular and intramuscular timing of muscle activation (based on an activation level of greater than 10% MVIC beyond basic activity) of the 3 portions of the trapezius muscle during 4 exercises were examined by surface EMG in 30 healthy subjects on the dominant side (14 males, 16 females). One sample T tests were used to determine which portions of the trapezius muscle were activated significantly earlier or later than the PD (intermuscular timing). An ANOVA for repeated measures (3 levels) was used for each exercise to determine possible timing differences among the 3 portions of the trapezius muscle (intramuscular timing).

Results:
Intermuscular and intramuscular differences in timing of the portions of the trapezius muscle were found. Concerning the intermuscular timing, the UT was activated significantly later than the PD (p<.01) and the MT was activated significantly earlier than the PD (p<.01) during the prone extension exercise. During the horizontal abduction with external rotation exercise, the MT (p<.01) and the LT (p=.01) were activated significantly earlier than the PD. During prone extension, side lying external rotation, and prone horizontal abduction with external rotation, significant differences were found between the UT and MT, between the UT and LT but not between the MT and LT. In these exercises the MT and LT were activated significantly earlier than the UT. During forward flexion in side lying, no significant differences were found between the trapezius muscle parts.
**Conclusions:** With the exception of the LT during prone extension, the prone extension exercise and the prone horizontal abduction with external rotation exercise promote early activation of the MT and LT in relation to the scapular and glenohumeral prime mover. Taken into account the limited generalizability of the results due to a narrow age range and healthy subjects, these exercises are potentially promising for the treatment of intermuscular and intramuscular timing disorders of the trapezius muscle.

**Key Words:** shoulder; scapula; rehabilitation exercises; trapezius muscle timing
INTRODUCTION
Shoulder pathology in general and impingement in particular are probably the most common injuries in competitive and recreational overhead athletes.\textsuperscript{1, 47} Although the etiology is considered to be multifactorial, recent literature extensively discusses the possible scapulothoracic contribution to glenohumeral pathology.\textsuperscript{28, 30, 59, 61, 64} More specifically, various authors suggest that shoulder injuries may be linked to abnormalities in scapular position and movement.\textsuperscript{20, 39, 45, 53, 69} Some authors focus on global muscle strength weakness and others emphasize relative muscle strength imbalance in the scapulothoracic muscles.\textsuperscript{7, 11, 12, 19, 41} Furthermore, muscle recruitment patterns of the scapular muscles are examined in overhead athletes with and without shoulder pain.\textsuperscript{9-11, 24, 29, 40, 46, 58, 60, 68} In general, these parameters provide a basis for selecting exercises and designing protocols for shoulder rehabilitation and injury prevention purposes.

In patients, deficiencies in muscle recruitment of the different portions of the trapezius muscle have been identified. Although no general consensus exists, several authors describe the middle trapezius (MT) and lower trapezius (LT) as showing less activation during dynamic activities in patients with glenohumeral instability or impingement compared to healthy individuals.\textsuperscript{7, 11, 19, 39, 46, 48, 58} Because scapular stability is crucial for optimal shoulder function and the MT and LT are considered to be the major stabilizers at the scapulothoracic joint, these deficiencies might compromise normal shoulder function and increase the risk for impingement and instability.\textsuperscript{26, 28, 37, 38} Based on this assumption, Cools et al.\textsuperscript{8} recently investigated which exercises show high MT and LT activation with minimal upper trapezius (UT) participation (low UT/MT or UT/LT ratio). This was done to establish which exercises should be prescribed to restore the scapular muscle balance and increase scapular stability. On the basis of this research, 4 exercises were selected: prone extension, forward flexion in side lying, external rotation in side lying and prone horizontal abduction with external rotation (FIGURE 1).
FIGURE 1. Exercises studied: (1) prone extension; (2) forward flexion in side lying; (3) external rotation in side lying; (4) prone horizontal abduction with external rotation.

In addition to dysfunctions in the scapular muscle activation level, the temporal sequence of recruitment is also found to be abnormal in patients with shoulder pain compared to healthy persons. Finally, it is generally accepted in literature that an association between scapulothoracic dysfunction and glenohumeral complaints exists. More specifically, it is described that athletes with shoulder impingement symptoms display significantly increased variability and larger delays in the timing of trapezius muscle recruitment. In regard to the different portions of the trapezius muscle, Cools et al. established timing disorders in the MT and LT in relation to deltoid muscle activation. The temporal sequence of recruitment is assumed to be another important factor influencing the coordinative scapular motion with humeral elevation. More specifically, it is postulated that an early activation of stabilizing muscles at the proximal scapulothoracic joint in relation to prime-mover activation at the glenohumeral joint is important for maintaining proper scapulothoracic stability throughout glenohumeral movement. Moreover, the scapulothoracic joint almost solely depends upon muscle...
activity for its functional stability.\textsuperscript{43} Consequently, the results of these studies suggest the importance of restoring scapular muscle timing patterns in patients with shoulder pain. Because muscle timing is found to be changeable\textsuperscript{14,66} and, to date, little is known about which exercises could be efficacious at the shoulder by promoting early activation of the MT and LT muscle parts in relation to the scapular and glenohumeral prime movers, the current study examines the timing of the 3 portions of the trapezius muscle during the 4 above-mentioned exercises.\textsuperscript{8,13,66} Hence, two research questions were proposed: (1) in which of the 4 exercises are the different portions of the trapezius muscle active before the posterior deltoid (PD) muscle (intermuscular timing) and (2) in which exercises are the MT and LT active before the UT (intramuscular timing). We hypothesize that (1) differences in timing between the portions of the trapezius muscle and the glenohumeral prime mover (PD) would be found and (2) the exercises would show an activation sequence in which differences in timing between UT, MT and LT will be found. In case the MT and LT show muscle activation prior to the UT and PD, these exercises would be useful for restoring intermuscular and intramuscular scapular timing disorders.

**METHODS**

**Subjects**

The data were obtained from a group of 30 healthy volunteers (14 males, 16 females. mean ± SD age, 24 ±2.8 years; body weight 66.1 ±14.2 kg; height 172.9 ±7.8 cm; body mass index 22.0 ± 0.0 kg/m\(^2\)). Subjects were recruited from the student population and in the local metropolitan area. Twenty-five were right handed and 5 were left-handed. The dominant shoulder was tested in all subjects. Subjects were included if they were between 20 and 30 years old and able to perform the exercises in a pain-free range of motion. Subjects were excluded if they had a history of dislocation of the shoulder, shoulder surgery, current symptoms related to the cervical spine or documented structural injuries to the shoulder complex.\textsuperscript{10} Subjects participating in competitive overhead sports or performing high level upper extremity strength training on a regular base were also excluded. Inclusion and exclusion criteria were assessed with a questionnaire. All subjects gave their written informed consent to participate in this study, which was approved by the Ethical Committee of Ghent University.
Orientation
On the day of testing each subject received a brief screening examination, signed the
informed consent, and was oriented to the testing protocol. All testing was performed on
the dominant shoulder, defined as the arm used to throw a ball. The protocol was
sequenced as follows: warm up, electrode placement, practice and familiarization,
maximum voluntary isometric contraction (MVIC) testing and exercise testing.

Electrode positioning
After a warm-up procedure (shoulder movements in all directions and push ups against
the wall), the skin was shaved and prepared with alcohol in order to reduce skin
impedance (typically $\leq 10$ kOhm). Bipolar surface electrodes (Blue Sensor; Medicotest,
Ølstykke, Denmark) were then placed with a 2-cm interelectrode distance over the
upper, middle and lower portion of the trapezius and the PD. The PD was chosen in our
study as the glenohumeral prime mover because this is the muscle part identified as
being highly active during the exercises selected, except for the forward flexion in side
lying exercise. Electrodes for the UT were placed midway between the spinous
process of the seventh cervical vertebra and the posterior tip of the acromion process
along the line of the trapezius. The MT electrodes were placed midway on a horizontal
line between the root of the spine of the scapula and the third thoracic spinous process.
The LT electrodes were placed obliquely upward and laterally along a line between the
intersection of the spine of the scapula with the vertebral border of the scapula and the
seventh thoracic spinous process. The PD electrodes were placed in the middle of the
muscle belly on the midline between the deltoid tuberositas and the posterior part of the
acromion. A reference electrode was placed over the ipsilateral clavicle. To ensure
consistency with electrode placement, the same investigator placed all electrodes.
Correct electrode placement was confirmed by visual inspection of the EMG signals on
a computer screen during specific muscle testing. Each set of bipolar recording
electrodes from each of the 4 muscles was connected to a Noraxon Myosystem 2000
electromyographic receiver (Noraxon USA, Inc, Scottsdale, AZ). The sampling rate was
1000Hz. All raw myo-electric signals were preamplified (overall gain=1000, common
rate rejection ratio 115dB, signal-to-noise ratio, $<1\mu$V RMS baseline noise, and filtered
to produce a bandwidth of 10-1000Hz).
Maximum voluntary isometric contraction (MVIC)
First, the resting level of the electrical activity of each muscle was recorded. Then, verification of EMG signal quality was completed for each muscle by having the subject perform maximal isometric contractions in manual muscle test positions specific to each muscle of interest. For the UT, resistance was applied to abduction of the arm from a seated position. The MT was tested in a prone position and resistance was applied to horizontal abduction in external glenohumeral rotation. For LT testing, performed in a prone position, the arm was placed diagonally overhead in line with the lower fibers of the trapezius. Resistance was applied against further elevation. For PD testing, the patient was placed in a seated position, with the arms in a neutral position. Resistance was applied against glenohumeral extension. Subjects performed three 5-second maximum voluntary isometric contractions against manual resistance by the investigator. A 5-second pause occurred between muscle contractions. A metronome was used to control duration of contraction. Before the MVIC recordings, subjects were instructed to contract as forcefully as possible and to reach maximal force as rapidly as possible. After rectification, ECG reduction and smoothing, the peak average EMG value over a window of 1 second was calculated for each trial. Further calculations were performed with the mean of the repeated trials as a normalization value (100%).

Exercise description
After MVIC testing, there was a 5-minute rest period for each subject. Then each subject performed a series of 4 randomized dumbbell exercises. The exercises were selected based on previous research and are presented in TABLE 1 & FIGURE 1. Before data collection, the exercises were demonstrated by a member of the research team. Then the subject performed the exercises without resistance for familiarization purposes, receiving corrective feedback as needed. Subjects completed 5 trials of each exercise. Three seconds were provided between. Subjects were allowed to rest for 2 minutes between exercises. During each exercise, verbal encouragement and, if necessary, performance corrections were given by the same examiner. Because our aim was to investigate muscle latency times at the beginning of the exercise, only the concentric phase of each exercise was used for further analysis. All exercises were performed from a free weight resting position to ensure minimal basic resting level on the EMG recording. The amount of weight used by the subjects was determined based on gender and body weight (TABLE 2 & 3).
Exercise Description

Exercise 1: prone extension The subject is prone with the shoulders resting in 90° forward flexion. From this position the subject performs bilateral extension to neutral position with the shoulder in neutral rotational. The subject is in side lying position, with the shoulder in neutral.

Exercise 2: forward flexion in side lying The subject performs 90° unilateral forward flexion in a sagittal plane.

Exercise 3: external rotation in side lying The subject is side lying with the shoulder in neutral position and the elbow flexed 90°. From this position the subject performs 90° external rotation of the shoulder with a towel between the elbow and trunk to avoid compensatory movements.

Exercise 4: prone horizontal abduction with external rotation The subject is prone with the shoulders resting in 90° forward flexion. From this position the subject performs bilateral horizontal abduction with an additional external rotation of the shoulder at the end of the movement.

**TABLE 1.** Exercises studied on inter- and intramuscular trapezius timing.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Subject weight</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Exercise 1*</td>
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<tr>
<td>Exercise 2*</td>
<td>2.5</td>
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<tr>
<td>Exercise 3*</td>
<td>2.5</td>
</tr>
<tr>
<td>Exercise 4*</td>
<td>1.5</td>
</tr>
</tbody>
</table>

* Exercise 1 = Prone extension  
  Exercise 2 = Forward flexion in side lying  
  Exercise 3 = External rotation in side lying  
  Exercise 4 = Prone horizontal abduction with external rotation

**TABLE 2.** Dumbbell weights (in kilograms) applied to the male subjects for the 4 exercises
PART II  Muscle recruitment during specific scapular muscle training exercises

<table>
<thead>
<tr>
<th>Exercise</th>
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<tr>
<td></td>
<td>50-55 kg</td>
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<tr>
<td>Exercise 4*</td>
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</table>

* Exercise 1 = Prone extension
  Exercise 2 = Forward flexion in side lying
  Exercise 3 = External rotation in side lying
  Exercise 4 = Prone horizontal abduction with external rotation

**TABLE 3.** Dumbbell weights (in kilograms) applied to the female subjects for the 4 exercises

Data analysis
All raw EMG signals were analog/digital converted (12-bit resolution) at 1000 Hz. After rectification, ECG reduction and smoothing, the resting level was determined for each exercise and for the four muscle parts of interest (UT, MT, LT and PD). Then, the muscle activation of the different muscle parts was calculated. The muscle signal was considered a contraction if it exceeded the trigger level of 10% of the maximal voluntary contraction beyond basic activity during the concentric phase of the exercise.\(^9, 10, 57\) A lower level, often used in determination of muscle timing activation was not chosen because it was suggested that this was too low to investigate the differences in muscle timing between different muscles. The same muscle activation level (>10% MVIC) was used as in previous research to enhance the consistency between studies.\(^9\) The point in time at which the muscle activity reached this EMG activity level was determined. Then, these moments in time were averaged for each muscle and each exercise across the 3 intermediate repetitions of the 5 completed repetitions.

Statistical analysis
Because the specific topic of interest in this study was to investigate the intermuscular and intramuscular trapezius muscle timing, the relative activation of the UT, MT and LT in relation to the PD was first determined. This was done by subtracting the timing activation values of the PD from the UT, MT and LT respectively. Negative values reflect muscle activity of the UT, MT and LT before the PD. Positive values reflect muscle activity of the UT, MT and LT after the PD. Means (in milliseconds) and
standard deviations were calculated for the 3 muscle timing values for each exercise. Because all data were normally distributed with equal variances, parametric tests were used for statistical analysis.

First of all, a 1-sample \(t\) test (2-tailed) was used to determine which mean relative latency times were significantly different from 0. This was done to determine which muscle parts were activated significantly earlier or later than the PD. These results represent the intermuscular differences in timing from PD. The forward flexion in side lying exercise was not included for this analysis since no appropriate deltoid data were available for this movement. Thus, 9 separate 1-sample \(t\) tests without correction were done for the intermuscular comparison.

Second, an analysis of variance (ANOVA) for repeated measures was used for each exercise to determine possible timing differences among the 3 portions of the trapezius muscle, thus representing intramuscular variation in timing. The “within-subjects” factor for the ANOVA was the portions of the trapezius muscle (3 levels). Post hoc analysis was performed using a Bonferroni procedure in case a significant difference was found with analysis of variance (\(\alpha = .05\)). All statistical analyses were performed with the Statistical Package for the Social Sciences, version 15.0 (SPSS Inc., Chicago, IL).

**RESULTS**

Intermuscular timing: trapezius muscle parts versus posterior deltoid

For intermuscular differences in timing, the 1-sample \(t\) test showed significant differences in mean relative latency times for one or more portions of the trapezius during each exercise (\(P<.05\)). During the prone extension exercise, the UT was activated significantly later than the PD (\(df = 29, t = 2.871\)), and the MT was activated significantly earlier than the PD (\(df = 29, t = -3.760\)). During side-lying external rotation the UT was activated significantly later than the PD (\(df = 29, t = 4.624\)). During the horizontal abduction with external rotation exercise, the MT (\(df = 29, t = -5.010\)) and the LT (\(df = 29, t = -2.637\)) were activated significantly earlier than the PD. Results of the calculations of the intermuscular differences in timing are summarized in TABLE 4. A schematic representation of the relative trapezius muscle timing in relation to the PD muscle is presented in FIGURE 2.
TABLE 4. Results for the One sample T test of the mean relative latency times different than zero reflecting intermuscular differences in timing. Standard deviation of the timing of muscle activation of UT, MT and LT in relation to PD is presented. (Mean in milliseconds) (N=30)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>UT</th>
<th>MT</th>
<th>LT</th>
</tr>
</thead>
<tbody>
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<td>518.74</td>
<td>989.78</td>
<td>.01</td>
</tr>
<tr>
<td><em>Exercise 3</em></td>
<td>515.89</td>
<td>611.14</td>
<td>&lt;.01</td>
</tr>
<tr>
<td><em>Exercise 4</em></td>
<td>58.90</td>
<td>585.50</td>
<td>.57</td>
</tr>
</tbody>
</table>

* Exercise 1 = Prone extension  
Exercise 3 = External rotation in side lying  
Exercise 4 = Prone horizontal abduction with external rotation
FIGURE 2. Schematic representation of the activation timing of the upper (UT), middle (MT), and lower (LT) portions of the trapezius relative to the timing of the posterior deltoid (PD). The vertical 0 line represents activation of the PD. Values less than 0 reflect muscle activation before the PD. Values greater than 0 reflect muscle activation after the PD. Data are means and standard deviations of the timing of muscle activation for the UT, MT, and LT in relation to the PD. *Indicates significant differences in muscle timing in relation to PD. Data in milliseconds (n=30).
**Intramuscular timing: comparison between upper, middle and lower trapezius**

Because the temporal recruitment within the trapezius muscle was also of interest, differences between the portions of the muscle were calculated. The ANOVA revealed significant differences (P < .05), representing intramuscular differences in timing. Post hoc comparisons between trapezius muscle parts showed significant intramuscular differences in 3 of the 4 exercises studied. During prone extension (df = 2, F = 15.238), side lying external rotation (df = 2, F = 15.809), and prone horizontal abduction with external rotation (df = 2, F = 8.016), significant differences were found between the UT and MT, between the UT and LT but not between the MT and LT. So, in these exercises the MT and LT were activated significantly earlier than the UT, without significant difference between MT and LT. During forward flexion in side lying, no significant differences were found between the portions of the trapezius (df = 2, F = 0.838). Detailed results of the calculations of the intramuscular differences in timing are summarized in **TABLE 5**.
### Table 5.

Results for the post hoc analysis (Bonferroni) for each exercise reflecting intramuscular differences in timing. (Mean in milliseconds)  
(N=30)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Trapezius muscle parts</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>UT-MT</td>
<td>UT-LT</td>
<td>MT-LT</td>
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<tr>
<td></td>
<td>Mean difference</td>
<td>P value</td>
<td>Mean difference</td>
<td>P value</td>
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<tr>
<td>Exercise 1*</td>
<td>815.40</td>
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<td>666.78</td>
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<td>= 1.00</td>
<td>-28.5</td>
<td>= 1.00</td>
<td>-66.18</td>
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<tr>
<td>Exercise 3*</td>
<td>503.31</td>
<td>&lt; .01</td>
<td>511.26</td>
<td>&lt; .01</td>
<td>7.94</td>
</tr>
<tr>
<td>Exercise 4*</td>
<td>301.52</td>
<td>&lt; .01</td>
<td>421.74</td>
<td>&lt; .01</td>
<td>120.22</td>
</tr>
</tbody>
</table>

* Exercise 1 = Prone extension  
   Exercise 2 = Forward flexion in side lying  
   Exercise 3 = External rotation in side lying  
   Exercise 4 = Prone horizontal abduction with external rotation
DISCUSSION

Scapular muscle training is an essential part of progressive shoulder rehabilitation and injury prevention exercise programs.\textsuperscript{6, 23} Because the identification of the specific muscle recruitment patterns of exercises helps to provide a scientific rationale for their use, various researchers investigated the activation patterns of the shoulder muscles during different types of exercises.\textsuperscript{2, 5, 8, 17, 25, 32, 41, 48, 51, 52, 63} However, one important measure of the muscular coordination in the scapular muscles has rarely been studied: the timing of the temporal recruitment pattern during physical therapy shoulder exercises. Our study investigated this during four frequently used exercises.

The results of this study largely confirm our hypotheses. The intermuscular timing analysis showed that the MT and LT were activated before the PD in three of the four exercises (prone extension, forward flexion in side lying and prone horizontal abduction with external rotation), supporting our first hypothesis. Furthermore, intramuscular timing analysis showed that in three exercises (prone extension, external rotation in side lying and prone horizontal abduction with external rotation), the MT and LT were activated prior to the UT, supporting our second hypothesis. In conclusion, with the exception of the LT during prone extension, the prone extension exercise and the prone horizontal abduction with external rotation exercise showed activation of the stabilizing parts of the trapezius muscle prior to the scapular and glenohumeral prime mover (UT and PD).

Previous work from our laboratory and other research groups showed that the prone extension exercise is characterized by high activity of the MT with minimal UT activation.\textsuperscript{8, 50} The current study shows that the MT is also recruited first during this movement. Furthermore, the intramuscular analysis revealed no significant difference in timing between the MT and LT. The second exercise selected, horizontal abduction with external rotation, showed similar results. This exercise has previously been found to show high infraspinatus activity and was recently selected as an adequate scapulothoracic exercise based on a low UT/LT ratio.\textsuperscript{8, 65} Kinney et al.\textsuperscript{35} found that the middle and lower trapezius muscle show the greatest amount of activation at 90° and 125° of abduction during this movement in healthy individuals. Our study confirms the hypothesis that differences in muscle timing activation among muscle parts can be found during this exercise. The MT and LT showed earlier activation than the UT (intramuscular timing) and the PD (intermuscular timing) in this movement performed at
90° abduction. In addition, as well as for the prone extension exercise, the timing of muscle activation between the MT and LT was similar.

In general, shoulder training is frequently performed to restore upper extremity function or to prevent shoulder injury. To achieve these goals, a multitude of exercises are used in clinical practice. Traditionally, the value of an exercise is based on the activation level at which the different muscle parts are activated.\(^5\), \(^8\), \(^23\), \(^52\), \(^65\) However, performing shoulder exercises could also be beneficial because of alterations in muscle timing patterns.\(^10\) More specifically, it has been postulated that the timing of muscle activation of the scapular muscles is an important factor in the relationship between the dynamic muscular actions and the scapular kinematics.\(^9\), \(^10\), \(^18\) Consequently, an early activation of stabilizing muscles at the scapulothoracic joint could help to increase the scapular stability in order to provide a stable platform during glenohumeral movements.\(^28\) Furthermore, it is stated that the stabilizing action of the scapular muscles is essential for an adequate performance of the rotator cuff during upper limb elevation.\(^15\) If the scapular muscles better stabilize and synchronize scapular movements, this could increase the capacity of the rotator cuff to stabilize the glenohumeral joint. To our knowledge, muscle timing sequences of the 3 portions of the trapezius muscle during the above mentioned exercises have not yet been the topic of investigation. Therefore, the results of this study are to be seen as a first step in the evaluation of the clinical importance of performing exercises with initial MT and LT activation for various goals.

From a critical point of view, one could also question the relevance of performing these exercises with the objective to change muscle timing. Although an early activation of the trapezius stabilizing muscle parts seems favorable on a neuromuscular level, biomechanical studies demonstrating the advantage during functional activities are lacking. Furthermore, it remains to be determined if voluntary shoulder movement training is an appropriate method to improve the delayed trapezius muscle timing found as a reflex mediated timing disorder. In our study, we examined the timing of the muscle during a volitional arm movement, whereas in previous research a response to free falling of the arm was examined.\(^10\) Nevertheless, altered muscle timing and accompanied positive clinical outcomes after specific training programs have already been found in patients with patellofemoral pain and low back pain.\(^13\), \(^14\), \(^66\), \(^67\) Hence, it is
not unlikely that the efficacy of shoulder muscle training is also related to changes in the timing of the action of the portions of the trapezius.

Some methodological issues require special attention in interpreting our results. First, it must be taken into account that the age range of the subjects was narrow, and that this limits the generalizability of the results. The reason why young healthy shoulders were selected in our investigation was because the aim of our study was to define the normal muscle timing of the trapezius muscle parts during the selected exercises. However, it must be stressed that the use of healthy young subjects is a limitation to our study. Therefore, muscle timing patterns should be emphasized in future research in overhead athletes and patients with shoulder dysfunction or pain by using a population-based epidemiologic sampling strategy.

Second, some exercise-related factors should be taken into consideration. For example, the amount of weight used by the subjects might have influenced the recruitment order during the different movements. Several reasons motivated the use of low weights in our study. Relatively low loads are generally recommended in training done with the objective to restore scapular neuromuscular function, fatigue was maximally avoided and the same individualization method for load determination was used as in our previous study. However, it should be noted that higher loads are frequently used in overhead athlete rehabilitation and that this could influence the recruitment order of the muscles.

Third, the initiation of the movement itself was not accompanied by a synchronized kinematic evaluation. Although vital limitations accompany these experiments (eg, skin displacements), it would give additional information on the relationship between scapular kinematics and neuromuscular parameters such as the magnitude and timing of muscle activation. To date, little is known about the influence of altered scapular recruitment patterns on shoulder biomechanics and patient symptoms. Future studies should evaluate this in view of appropriate selection of exercises for shoulder rehabilitative and preventive purposes. Nevertheless, the starting position, movement direction and ROM was standardized in our study and the muscle timing was determined with maximum accuracy.

The use of surface EMG during dynamic contractions has been a topic of discussion in literature regarding skin displacement, movement artefacts, influences of contraction
modalities on the EMG signals, and normalization methods.\textsuperscript{16, 21} Considerable effort was made to minimize the effects of crosstalk. Adjacent bipolar electrode pairs were generally spaced more than 2 cm from each other by the same investigator and recommendations for muscle specific electrode placements were followed.\textsuperscript{3, 70}

Second, our results showed high standard deviation values, reflecting high individual variability in muscle timing of the muscles studied. High variability in muscle timing of shoulder muscles has also been found by other researchers.\textsuperscript{10, 29, 49, 57, 68} Several reasons could explain this finding. For example, large inter-individual differences in selective motor innervations of each subdivision of the trapezius muscle by the cranial and spinal accessory nerve are described based on anatomical research.\textsuperscript{33, 34, 54} Different innervational supply to a muscle could possibly influence the motor output to the different portions of the trapezius. Also, the sensitivity of the testing procedure used to determine muscle timing is to be considered. In the literature, different methods are used to determine the timing of muscle activity and multiple influencing factors are also described.\textsuperscript{9, 57, 62, 66} Although the actual rise time of the EMG signal may be altered by the processing used, the same standardized procedure was utilized as in our previous research to ensure maximum comparability between studies.\textsuperscript{9}

Some limitations should be mentioned from a clinical point of view. During functional activities as arm abduction in the scapular plane, Wadsworth et al.\textsuperscript{68} stated that an initial activation of the UT is normal and is required for optimal scapula contribution to shoulder complex elevation. During sport-specific movements (e.g., serving in tennis), a general proximal-to-distal activation pattern has been found. Yet, it is recently demonstrated that the muscle activation at the shoulder during these movements also consists of an activation of the UT before the LT in healthy athletes.\textsuperscript{29} Because rehabilitation and conditioning programs should be designed with the activation sequences found in the sport-specific movements, one could focus on an activation pattern opposite to that postulated in this study. However, Kibler et al.\textsuperscript{32} stated recently that exercises with initial UT activation should merely be performed in later phases of rehabilitation. Therefore, we propose our exercises to be performed in early stages of rehabilitation with the objective to promote early activation of the scapular stabilizing musculature. This investigation presents data on relative scapular muscle timing for several exercises and theorizes regarding preferential exercise selection. Ultimately, the choice of the most appropriate exercise for a patient-specific condition remains
Muscle recruitment during specific scapular muscle training exercises

theoretical until comparative effectiveness research is presented in the literature. It should be noted that the function of the scapular muscles during functional activities is characterized by a synergistic action of muscles to produce 3-dimensional movements of the scapulothoracic joint. Because they do not work in isolation, it remains to be determined to which extent isolated training targeting the stabilizing trapezius muscle parts can change the muscle activation timing during functional activities as throwing. The rationale to assume that this could be possible is based on the finding that the UT, MT and LT muscle parts participate in different ways within the force couples controlling scapulothoracic movement, and on previous research identifying that the timing of muscle activation can be changed by physical therapy treatment. However, to date, it is still not clear whether temporal changes in scapular muscle activation can be induced by shoulder training. The possibility exists that altered muscle timing activation patterns are carried over to the exercise. This could diminish its clinical effectiveness in individuals with dysfunction or patients with shoulder pain. The results of this study should also consider serratus anterior muscle function and not interpreted isolated from other scapular muscles. Finally, the exercises studied are all traditional exercises performed in a lying position (prone or side lying), while integration of shoulder movements in a kinetic chain is promoted strongly in recent literature. Therefore, we propose our exercises to be performed prior to more complex exercises performed in more functional positions.

On the basis of our research question and our results, we believe further examinations should be performed. First, more research should be done on the trapezius muscle timing characteristics in healthy and injured athletes under various conditions. Both muscle reaction times and muscle recruitment patterns during voluntary shoulder movements should be studied. Second, it should be investigated which, if any, biomechanical advantages are associated with an early activation of the MT and LT. Third, little is known about the muscle recruitment patterns during other exercises and during sports-specific movements. More knowledge in this area may benefit many aspects of athletic training and sport-specific rehabilitation. Fourth, the short- and long-term effects of trapezius muscle training on the timing of the different muscle parts should be determined by prospective research in view of an effective injury rehabilitation or preventive shoulder training program.
CONCLUSION
Our results suggest that, with the exception of the LT during prone extension, the prone extension exercise and the prone horizontal abduction with external rotation exercise promote early activation of the MT and LT in relation to the scapular (UT) and glenohumeral prime mover (PD). Taking the limited generalizability of results into account, these exercises are potentially useful in the treatment of trapezius muscle timing disorders. Further prospective research in both overhead athletes and patients with shoulder pain is mandatory to substantiate this assumption.
KEY POINTS

Findings
With the exception of the LT during prone extension, the prone extension and the prone horizontal abduction with external rotation exercise promote early activation of the stabilizing portions of the trapezius muscle (MT and LT) in young healthy subjects.

Implication
These findings help to inform decision making with regard to exercise prescription for shoulder rehabilitation. Because previous studies have shown that the MT and LT had delayed activation in subjects with shoulder impingement symptoms, performing these exercises may be potentially useful in the treatment of timing alterations of the trapezius muscle.

Caution
Generalization of the results is limited because of the narrow age range and healthy subjects tested in this study. This study does not provide data on effectiveness of these exercises in rehabilitation for those with shoulder pain.

ACKNOWLEDGEMENTS

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Part III Trapezius muscle activation during scapular retraction exercises in a kinetic chain
Study IV  Kinetic chain influences on upper and lower trapezius muscle activation during eight variations of a scapular retraction exercise in overhead athletes

Kristof De Mey, PT*; Lieven Danneels, PT, PhD*; Barbara Cagne, PT, PhD*; Lotte Vanden Bosch Lotte**, PT; Johan Flier, PT**; Ann M. Cools, PT, PhD*

*Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University Hospital, Ghent, Belgium; **Private practice, The Netherlands


Impact factor: 3.034
Abstract

Objectives: To describe and compare the activation levels of the upper and lower trapezius muscle and study the influence of trunk and lower extremity position or movement during eight variations of a scapular retraction exercise.

Design: Descriptive study. Exercise performance was standardized and individualized based on height, age and body weight.

Method: Individual muscle activation was captured by surface electromyography in thirty young healthy overhead athletes. Exercises were performed in front of a pulley apparatus.

Results: The mean values for upper trapezius and lower trapezius were 6.59% and 15.93% of maximum voluntary isometric contractions respectively. Main effects were found for “exercise” (F=2.60; p=0.037) and “muscle part” (F=25.44; p<0.001) in an ANOVA for repeated measures model showing higher lower trapezius muscle activation compared to the upper trapezius across exercises. A unipodal squat position on the contralateral leg increased trapezius muscle activation by 3.93% maximum voluntary isometric contraction (p=0.019) compared to the conventional seated performance of the exercise. No differences between phases were found and no exercise activated a particular muscle part (upper trapezius or lower trapezius) to a greater extent in comparison with other exercises since no two-way interactions were found with p<0.05.

Conclusions: All exercise variations may be useful in the early phases of scapular rehabilitation training because of their favourable trapezius muscle balance activation. Standing in a squat position on the contralateral leg can be prescribed in order to stimulate trapezius muscle recruitment. However, future comparative effectiveness studies are needed to identify the long-term training benefits of these exercises.
**Key words:** scapula; trapezius; exercises; electromyography; kinetic chain
Introduction

Scapular dyskinesis and related shoulder impingement syndrome are common conditions, particularly in overhead athletes.\(^1\) Although various muscles contribute to the three-dimensional movements around the shoulder, a lack of activity in the lower trapezius (LT) has been observed in these people, often in combination with an excessive upper trapezius (UT) activation.\(^2\) This might contribute to excessive clavicle elevation on the thorax coupled with increased anterior tilt at the scapulothoracic joint which causes the rotator cuff to impinge during elevation.\(^3\) The UT and LT muscles play different roles around the scapula during dynamic activities. Whereas the UT does not appear to have a line of action for being a substantive upward rotator in healthy persons, the LT assists in producing scapulothoracic upward rotation.\(^4\) Furthermore, evidence indicates that the LT acts as a stabilizer at the scapulothoracic joint.\(^4\) Consequently, scapular muscle exercises characterized by high LT and low UT muscle activation are of interest in the rehabilitation of patients with secondary impingement.

Training the activation and strength of selective muscle parts is the most common clinical approach in the management of musculoskeletal disorders. Depending on different stages of rehabilitation, various exercises might improve scapular muscle performance. In general, rowing and scapular retraction exercises have been found to enhance scapular muscle performance because of their preferential trapezius muscle activation.\(^5\)\(^-\)\(^7\) In addition, the scapular retracted position has been found to reduce symptoms and increase muscle performance in patients with impingement symptoms.\(^8\),\(^9\)

Recent guidelines have pointed to the value of integrating shoulder girdle exercises into a global functional kinetic chain for multiple reasons.\(^10\),\(^11\) In general, these recommendations are based on the principle of sport specificity emphasizing the core
Part III Trapezius muscle activation during scapular retraction exercises in a kinetic chain

as the center of the body during upper extremity training. Furthermore, it is assumed to increase the activity in particular shoulder muscles compared to more artificially stabilized positions such as the prone, side-lying or seated position. Maenhout et al. have recently investigated the influence of the position of the lower extremity on scapular muscle activity and balance during closed kinetic chain push-up variations. In their research, they discovered that contralateral leg extension stimulates LT activity during a knee push up plus exercise. However, the influence of proximal body segments during scapular retraction exercises integrating the trunk and lower extremity has not yet been investigated. Therefore, the purpose of this study was to analyze UT and LT muscle activation levels in an overhead athletic population during eight variations of a high scapular retraction movement. It was hypothesized that differences between UT and LT muscle activation would be found in all exercises and that the kinetic chain, influenced by lower extremity position or movement, would have an effect on these activation levels.

Methods

The data were obtained from a group of 30 healthy overhead athletes (17 male, 13 female), including volleyball and tennis players, and swimmers (mean ± SD age, 20 ±3.5 years; mean ± SD weight 69.4 ±10.5 kg; mean ±SD body height 179 ±0.11 cm; mean ± SD BMI 22 ±0.02). The participants were recruited from the student population in the local metropolitan area. Twenty-seven were right-handed and 3 were left-handed, and it was the dominant shoulder that was tested. Athletes were included if they were between 18 and 30 years old and were able to perform the exercises correctly. People were excluded if they had a history of glenohumeral instability, shoulder surgery, or if they currently exhibited symptoms related to the spine or structural injuries to the
shoulder complex. Athletes engaged in an upper limb strength training program for more than 5 hours per week were also excluded in order to avoid interference from specific adaptations. Inclusion and exclusion criteria were assessed by means of a questionnaire. All participants gave their written informed consent to participate in this study, which was approved by the Ethical Committee of Ghent University Hospital.

After the athletes had completed a warm-up consisting of shoulder movements in all directions and push ups against the wall, the skin was shaved and prepared with alcohol in order to reduce skin impedance (typically ≤ 10 kOhm). Bipolar surface electrodes (Blue Sensor – Medicotest, Denmark) were then placed with a 2 cm inter-electrode distance over the UT and LT muscle parts of the dominant shoulder. Electrodes for the UT were attached midway between the spinous process of the seventh cervical vertebra and the posterior tip of the acromion process along the line of the trapezius. The LT electrode was placed obliquely upward and laterally along a line between the intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process. A reference electrode was placed over the clavicle of the dominant shoulder. To ensure consistency with electrode placement, all electrodes were put into position by one researcher. Each set of bipolar recording electrodes from the eight muscles was connected to a Noraxon Myosystem 1400 electromyographic receiver (Noraxon USA, Inc., Scottsdale, AZ). The sampling rate was 1000Hz and all raw myo-electric signals were preamplified (overall gain=500, common mode rejection ratio 115dB, signal to noise ratio <1µV RMS baseline noise).

First, the resting level of the electrical activity of each muscle was recorded. Then, maximum voluntary isometric contraction (MVIC) was determined in manual muscle test
positions that were specific to both muscles of interest. For the UT, resistance was applied to abduction of the arm from a seated position. For LT testing in a prone position, the arm was placed diagonally overhead in line with the lower fibers of the trapezius and resistance was applied against further elevation. Participants performed three 5-s MVICs against manual resistance by the researcher. A 5-second pause occurred between muscle contractions. A metronome was used to control the duration of the contractions. After rectification, electrocardiogram reduction and smoothing, the average electromyographic (EMG) value over a window of 2 seconds was calculated for each trial. Further calculations were performed with the mean of the repeated trials as a normalization value (100%).

After MVIC testing, there was a 5-minute resting period for each participant. Then, each person conducted a series of eight scapular retraction exercises in a randomized order in front of a pulley apparatus. The exercises are presented in Table 1 and Figures 1 and 2. All angles were verified using a goniometer. All exercises were performed at 1 m in front of the pulley apparatus. The height was adjusted to be at head level of each participant depending on the participant’s posture. Participants carried out the retraction movement starting from a scapular protracted position. Each exercise was performed until the elbow was positioned at the lateral side of the trunk. The athletes were instructed to maintain neutral spinal alignment. A neutral grip was applied during each exercise. The contralateral hand was placed at the anterior superior iliac spine for feedback concerning neutral pelvis alignment. Before data collection, the exercises were demonstrated by one of the researchers. Then, the participant first carried out the exercises without resistance in order to become familiar with the exercise, receiving corrective feedback as needed. Five trials of each exercise were completed. Between
trials, a relative resting period of 3 s was provided. The participants were allowed to rest for two min between exercises. Each exercise was executed in three phases (concentric, isometric and eccentric), each lasting 3 s. A metronome was used to control the duration of the phases. During each exercise, the same examiner encouraged the participants verbally and, if necessary, corrected their performance. During EMG measurement, synchronized video recordings were made with a Sony Handycam (DCR-HC 37) to control duration of phases. Subjects were divided into genders, age and into three subgroups based on their weight for resistance determination. (Table2). Within each subject, the same load was used for all postures.

<table>
<thead>
<tr>
<th>High scapular retraction exercise</th>
<th>Variation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Sitting Trunk supported and feet positioned on the ground</td>
<td>Variation Description</td>
<td></td>
</tr>
<tr>
<td>2 Standing Feet positioned shoulder width and legs straight</td>
<td>Trunk supported and feet positioned on the ground</td>
<td></td>
</tr>
<tr>
<td>3 Static bipedal squat Feet placed shoulder width with both knees positioned at a 90° angle above the feet</td>
<td>Feet positioned shoulder width and legs straight</td>
<td></td>
</tr>
<tr>
<td>4 Static lunge Contralateral leg in front with the knee in a 90° angle. Distance between both feet individually determined by taking the distance between the ASIS and the medial malleolus of the dominant side.</td>
<td>Feet placed shoulder width with both knees positioned at a 90° angle above the feet</td>
<td></td>
</tr>
<tr>
<td>5 Static unipedal squat Contralateral knee placed above the foot in a 45° angle</td>
<td>Contralateral leg in front with the knee in a 90° angle. Distance between both feet individually determined by taking the distance between the ASIS and the medial malleolus of the dominant side.</td>
<td></td>
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<tr>
<td>6 Dynamic bipedal squat Starting position as static version. Concentric phase of arm movement during concentric squat.</td>
<td>Starting position as static version. Concentric phase of arm movement during concentric squat.</td>
<td></td>
</tr>
<tr>
<td>7 Dynamic lunge Starting position as static version. Concentric phase of arm movement during concentric lunge.</td>
<td>Starting position as static version. Concentric phase of arm movement during concentric lunge.</td>
<td></td>
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<tr>
<td>8 Dynamic unipedal squat Starting position as static version. Concentric phase of arm movement during concentric squat.</td>
<td>Starting position as static version. Concentric phase of arm movement during concentric squat.</td>
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Table 1. The 8 Variations of the High Scapular Retraction Exercise.
Part III  Trapezius muscle activation during scapular retraction exercises in a kinetic chain

<table>
<thead>
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<th>Age</th>
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<th>Female</th>
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<td>60-69kg 70-85kg</td>
<td>50-59</td>
<td>60-69kg 70-85kg</td>
</tr>
<tr>
<td>18-20</td>
<td>7</td>
<td>8 9</td>
<td>5</td>
<td>6 7</td>
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<tr>
<td>21-23</td>
<td>8</td>
<td>9 10</td>
<td>6</td>
<td>7 8</td>
</tr>
<tr>
<td>24-26</td>
<td>9</td>
<td>10 11</td>
<td>7</td>
<td>8 9</td>
</tr>
<tr>
<td>27-30</td>
<td>10</td>
<td>11 12</td>
<td>8</td>
<td>9 10</td>
</tr>
</tbody>
</table>

Table 2. Pulley Resistance (in kg) applied to the subjects (age in years).

Figure 1. High scapular retraction exercise variations (1: sitting; 2: standing; 3: static bipedal squat; 4: static lunge).
Figure 2. High scapular retraction exercise variations (5: static unipedal squat; 6: dynamic bipedal squat; 7: dynamic lunge; 8: dynamic unipedal squat).

All raw EMG signals were analog/digital converted (12-bit resolution) at 1000 Hz and markers were placed at the beginning of each phase. After cardiac artifact reduction, rectification and smoothing (root mean square= 100ms), the EMG activity during 2 s after the markers was calculated for each muscle and each phase. Then, the total muscular activity across the different phases was determined by calculating the mean activity of the second, third and fourth repetition of each exercise. The first and last repetitions were not used for further analysis in order to avoid any distortion due to
habituation and fatigue. All data were analyzed by the Myoresearch 98 Software Program®.

All statistical analyses were performed with the Statistical Package for the Social Sciences, version 16.0 for Windows (SPSS Inc., Chicago, IL). Means and standard deviations were calculated across participants for normalized EMG activity during all exercises. Because a Kolmogorov-Smirnov test showed normal distribution of the data, parametric tests were used for statistical analysis.

ANOVA for repeated measures with the within-subject factors “exercise” (8 levels), “muscle part” (2 levels) and “phase” (3 levels) was used to determine whether there were any differences between exercises in EMG amplitudes for each muscle. A .05 α level was chosen a priori to denote statistical significance for these comparisons. For any significant difference, a Bonferroni post hoc analysis was used to denote significance for follow-up analysis.

**Results**

Means and standard deviations were calculated across subjects for normalized EMG activity of each muscle for all exercises (Table 3). The ANOVA model revealed that sphericity could not be assumed, and a Greenhouse-Geisser correction was used to interpret all results. No three-way interaction was found with p<0.05. Subsequently, two-way interactions including the factor “exercise” were of interest, but none of them showed significant results. So, in none of the exercises the muscle activation was significantly different between phases, and none of the exercises activated a particular muscle part (UT or LT) to a greater extent compared to the other. However, main effects were identified for “exercise” (F=2.60; p=0.037) and “muscle part” (F=25.44; p<0.001).
Pair-wise comparisons were performed with Bonferroni post hoc correction for multiple comparisons with significant differences between (1) muscle parts across exercises and (2) exercises across muscle parts. The mean values for UT and LT amounted to 6.59% and 15.93% of MVIC, respectively. Lower trapezius showed significantly higher muscle activation across exercises compared to UT with a mean difference of 9.34% MVIC (p<0.001). Standing in an unipedal squat position on the contralateral leg resulted in a significantly higher trapezius muscle activation compared to the conventional seated performance of the exercise (mean difference= 3.93% MVIC; p=0.019).

<table>
<thead>
<tr>
<th>Exercise</th>
<th>UT</th>
<th></th>
<th>LT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Sitting</td>
<td>4.84±0.72</td>
<td>7.32±1.23</td>
<td>5.23±0.85</td>
<td>14.10±2.01</td>
</tr>
<tr>
<td>Standing</td>
<td>5.14±0.65</td>
<td>6.59±0.92</td>
<td>4.24±0.55</td>
<td>18.34±2.96</td>
</tr>
<tr>
<td>SBS</td>
<td>5.61±0.60</td>
<td>7.09±0.89</td>
<td>7.33±1.02</td>
<td>20.76±4.51</td>
</tr>
<tr>
<td>SL</td>
<td>5.82±0.93</td>
<td>7.62±1.21</td>
<td>4.83±0.67</td>
<td>18.54±2.31</td>
</tr>
<tr>
<td>SUS</td>
<td>6.63±0.89</td>
<td>8.45±1.23</td>
<td>6.13±0.84</td>
<td>21.89±4.23</td>
</tr>
<tr>
<td>DBS</td>
<td>7.00±0.99</td>
<td>7.24±1.19</td>
<td>8.41±1.13</td>
<td>19.50±4.00</td>
</tr>
<tr>
<td>DL</td>
<td>6.27±0.86</td>
<td>7.98±1.01</td>
<td>5.78±0.71</td>
<td>16.04±1.87</td>
</tr>
<tr>
<td>DUS</td>
<td>7.17±1.04</td>
<td>8.68±1.42</td>
<td>6.79±0.89</td>
<td>17.50±2.69</td>
</tr>
</tbody>
</table>

**Table 3.** Means and standard deviations for normalized EMG activity of UT and LT for each phase of all exercise. Values expressed as mean percentage of maximum voluntary isometric contraction ±standard deviation (UT= upper trapezius, LT= lower trapezius; 1= concentric phase, 2= isometric phase, 3= eccentric phase of each exercise; SBS= static bipedal squat, SL= static lunge, SUS= static unipedal squat, DBS= dynamic bipedal squat, DL= dynamic lunge, DUS= dynamic unipedal squat)
Part III  Trapezius muscle activation during scapular retraction exercises in a kinetic chain

Discussion

Particular retraction exercise variations might have an influence on the recruitment patterns of specific shoulder muscles. However, the conventional focus on individual joint training has resulted in a limited knowledge of scapular muscle recruitment during exercises that activate the entire kinetic chain system. Therefore, we investigated UT and LT muscle activation during eight kinetic chain variations of a high scapular retraction exercise which is thought to be relevant in the rehabilitation of scapular dyskinesis and related impingement symptoms. The main findings of this study were that all exercises recruit LT over UT muscle activation and that a contralateral single squat position stimulates higher trapezius muscle activation levels.

With respect to the first finding, the results support the notion that all exercises might be effective in treating scapular neuromuscular dysfunctions in athletes struggling with a decreased control of LT in combination with excessive UT activation. Several researchers have tried to select exercises with high LT muscle activation, some of which studied scapular retraction or rowing exercises in non-lying positions starting from different arm positions. In general, LT activity has been found to be relatively low at angles less than 90° of scapular abduction and flexion, with exponential increases from 90° to 180°. More particularly, Bressel et al. showed the LT to be most active during the performance of a scapular retraction movement at 130° of shoulder elevation in a seated position. Andersen et al. found the LT to be predominantly activated over the UT during a one-arm row exercise performed in a bend position resulting in an unknown amount of arm elevation. Additionally, a recent paper of Wattanaprakornkul et al. has shown similar results during a row exercise performed in sitting on a gym equipment with constant resistance. However, the amount of forward flexion during their exercises was probably too low to result in statistically different activation levels.
between both muscle parts. Similarly, McCabe et al. could not find differences between UT and LT while people performed a scapular retraction exercise at an 80° degree forward flexion angle.\textsuperscript{19} In our study, the pulley apparatus was set at head level depending on the participant’s posture, resulting in a forward flexion position of more than 90° in each subject. Probably, this could clarify why, in our study, the LT was recruited over the UT during all exercises.\textsuperscript{20}

Mean UT and LT muscle activations were below 20% MVIC in our study. According to McCan et al., our values should be considered minimal, as moderate activation levels require 21-50% MVIC and marked activation levels >50% MVIC.\textsuperscript{21} Some other studies found higher values. In an EMG analysis for resistance-tubing exercises for throwers, Myers et al. found moderate activation (defined as >20% of MVIC) during unilateral high retraction exercises performed in a standing position with mean LT values of 51.2% MVIC.\textsuperscript{6} McCabe et al. found marked activity in both the LT (51±29% MVIC) and UT (50±36% MVIC) during a scapular retraction exercise.\textsuperscript{19} Similarly to our results, Hintermeister et al. found average amplitudes of 9.2% and 7% MVIC in the trapezius muscle during a seated rowing exercise depending on the applied load. Rather low values for UT and LT (between 4.99% and 18.73% MVIC) were also found by Cools et al. (2007) in some of the phases during a high rowing exercise. Although they could not select high rowing as an optimal exercise for rehabilitation of scapular muscle balance based on low UT/LT ratio data, these values suggest the exercises to be useful in retraining neuromuscular control rather than strength training of the trapezius muscle.\textsuperscript{22} However, it should be noted that comparing the results of different studies has limited value, since differences in specific exercise prescriptions, load determination and normalization techniques vary between studies.
Recent guidelines have strongly promoted the use of kinetic chain exercises throughout the rehabilitation program rather than starting with exercises that isolate the shoulder and then gradually incorporate the rest of the body.\textsuperscript{23} With respect to our second finding, namely that an unipedal squat position on the contralateral leg increases trapezius muscle activation, the results are in line with previous evidence of kinetic chain influences on shoulder muscle activation during medical exercise training. Maenhout et al. found an 8.82\% MVIC increase of LT activation influenced by contralateral lower extremity position during a knee push up plus exercise.\textsuperscript{12} They recorded minimal changes in the activation levels caused by proximal kinetic chain influences, which might be relevant, since the scapulothoracic joint almost solely depends upon muscle activity for its functional stability.\textsuperscript{24} In our study, a small difference of 3.93\% was found. Up till now, no research has established a cut off for EMG activity (\%EMG) to be considered clinically important when comparing multiple exercises. Although a 10\% difference in muscle activation might be needed in terms of muscle strengthening purposes, no such a value is available in the literature with regard to neuromuscular training.\textsuperscript{25} In addition, there is still an ongoing debate on how to define clinical relevance in relation to statistical data.\textsuperscript{26} Therefore, the clinical benefit of the unipedal squat exercise remains unknown until comparative effectiveness studies are presented in the literature. Interestingly, none of the upright exercises resulted in an increased UT muscle activation without altering the LT muscle when comparing the data with those of the seated exercise. This justifies all exercise variations to be useful in the transition from easy to more challenging types of rehabilitation. Moreover, the use of kinetic chain scapular retraction exercises may also be suited for other training purposes than influencing specific shoulder muscle activation since they promote the integration of the scapular retraction movement to the hip. These motions tend to be
coupled in the cocking phase of throwing, which indicates the relevance of adding lower extremity movements to the scapular retraction exercise.\textsuperscript{27}

Myofascial structures connecting the shoulder, trunk and lower extremity have been identified and might serve as a potential underlying mechanism to explain proximal kinetic chain influences on scapular muscle recruitment.\textsuperscript{12, 28} However, as specific physiological evidence for its effectiveness has not yet been described, other possible underlying explanations should not be ruled out when interpreting our results. For example, the maintenance of a static unipedal squat position throughout the different phases of the exercise could also explain the difference found between both exercises since this might have resulted in minimal changes in joint position, length-tension relationships, movement of skin over the muscles and consequently in acquisition of EMG activity signals from different motor units.\textsuperscript{29} Additionally, it should be taken into account minimal spinal rotations could have occurred in some subjects, resulting in slightly higher trapezius activation levels during the unipedal squat exercise. Although not monitored by three-dimensional analysis, this was minimized by constantly instructing the participants to keep neutral spinal alignment.

Some limitations considering this study need to be addressed. First, the use of surface EMG during dynamic contractions has been a topic of discussion in the literature regarding skin displacement, movement artifacts, influences of contraction type on the EMG signal and normalization methods.\textsuperscript{30, 31} Second, we did not capture the activation of other muscles, such as the middle trapezius, rhomboid major and serratus anterior, which limits the interpretation in terms of force-couple and co-contraction behavior.
Third, the use of young healthy overhead athletes limits the generalization of the results to older people and patients with impingement symptoms.

The results of our study also provide a basis for future research. First, the additional use of three-dimensional analysis would give information on the relationship between joint kinematics and neuromuscular parameters. The influence of proximal posture and stability on upper extremity muscle recruitment could also be a topic of interest. Second, synergistic activation of shoulder, trunk and lower extremity muscles could be investigated during various exercises by using the coactivation method. Third, short- and long-term effects, including various relative loads and the use of instruction, demonstration and extrinsic feedback could be performed in both healthy athletes and patients with secondary impingement.

Conclusions

In view of the recent tendencies with respect to functional kinetic chain training, we investigated UT and LT muscle activation during a series of eight variations of the high scapular retraction exercise. The results show higher LT compared to UT muscle activation in all exercises. We can conclude that standing in a squat position on the contralateral leg stimulates higher trapezius muscle activation levels compared to a seated performance of the exercise suggesting kinetic chain influences on the shoulder muscle activation level. However, further research is required in order to substantiate the clinical relevance of these findings.
Practical implications

- Scapular retraction exercises seem useful for trapezius neuromuscular coordination training in overhead athletes because of their low upper trapezius muscle activation levels compared to those of the lower trapezius muscle.
- Several kinetic chain variations might be useful because none of them result in excessive upper trapezius activation in healthy athletes.

Acknowledgements

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Part III Trapezius muscle activation during scapular retraction exercises in a kinetic chain

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Part IV The effect of scapular muscle rehabilitation exercises in overhead athletes with mild shoulder impingement symptoms
Study V Scapular muscle rehabilitation exercises in overhead athletes with impingement symptoms: the effect of a 6-week training program on muscle recruitment and functional outcome

Kristof De Mey, PT*; Lieven Danneels, PT, PhD*; Barbara Cagnie, PT, PhD*; Ann M. Cools, PT, PhD*

*Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University Hospital, Ghent, Belgium


Impact factor: 3.792
ABSTRACT

Background: Previous research has identified some specific exercises to correct scapular muscle balance and onset timing in healthy subjects. However, evidence for their effectiveness in overhead athletes with impingement symptoms is lacking until now.

Hypothesis: A 6-week exercise program consisting previously selected exercises is able to improve muscle activation and onset timing during shoulder elevation. This program may also change pain and functionality levels in overhead athletes with mild impingement symptoms.

Study Design: Case series; Level of evidence, 4.

Methods: Forty-seven overhead athletes with mild impingement symptoms (25 men and 22 women) were enrolled in this study. Before and after the 6-week training program, the Shoulder Pain and Disability Index (SPADI) score was individually obtained and maximum voluntary isometric contraction (MVIC) values were determined by surface electromyography. Mean muscle activation levels, muscle ratio data and muscle onset timing were assessed for the upper (UT), middle (MT) and lower (LT) trapezius and serratus anterior (SA) muscle during arm elevation in the scapular plane.

Results: Forty subjects completed the exercise program. The SPADI scores significantly decreased from 29.86±17.03 during initial assessment to 11.7±13.78 during post-measurements (P<.001). The three trapezius muscle parts showed increased MVIC values and decreased activation levels during arm elevation, while this was not the case for the SA muscle. After the training program, UT/SA significantly decreased, while UT/MT and UT/LT did not change (P<.05). No differences in muscle timing between pre- and post-measurements could be identified. Lower trapezius showed significant earlier activation compared to UT (-0.47; P<.001) and MT (-0.49; P<.001).
Serratus anterior showed significant earlier activation compared to UT (-0.74; P<.001), MT (-0.76; P<.001) and LT (F=0.27;P=.046).

**Conclusions:** This is the first longitudinal study to demonstrate that previously selected exercises (1) improve pain and function based on SPADI scores, (2) reduce relative trapezius muscle activation and (3) alter UT/SA ratios. However, they were unable to change the timing of the scapular muscles during arm elevation when compared before and after a 6-week training program in overhead athletes with mild impingement symptoms.

**Clinical relevance:** Although the underlying mechanisms still remain debatable, a 6-week exercise program consisting only four exercises can be clinically effective in athletes with mild impingement symptoms.

**Key Terms:** scapula, impingement, training, electromyography
INTRODUCTION

Shoulder impingement symptoms are very common in athletes participating in sports with overhead arm motions. They are associated with a wide range of underlying mechanisms and injuries such as scapular dyskinesis, posterior shoulder stiffness, rotator cuff tendinopathy, and glenohumeral instability. Although the origin is considered multifactorial, overuse is one of the main causes of symptom development. In most cases, the diagnosis is made after the athlete has stopped training because of aggravating pain levels and functional limitations. Therefore, resistance training exercises over the full range of motion with considerable load are an inappropriate treatment strategy at that moment. However, a significant number of athletes experience pain but have not yet stopped training or contacted the team physician and, as a result, do not experience time loss due to their injury. In these athletes with less severe, mild symptoms, a resistance training program might be useful in order to prevent their complaints from becoming a chronic condition.

Impingement symptoms typically exacerbate when the arm is elevated or when overhead throwing activities are performed. During these movements, scapular dyskinesis is a major contributor of impingement symptom development, as recent literature has indicated. Alterations in the scapular muscle performance have been found in subjects with scapular dyskinesis. Hyperactivity of the upper trapezius (UT) with reduced middle (MT) and lower trapezius (LT) muscle activation in addition to insufficient serratus anterior (SA) muscle function has been related to decreased amounts of scapular upward rotation, external rotation and posterior tilt in patients. Furthermore, some authors have found a delayed onset of scapular muscle activation between patients with and without symptoms. These findings suggest that timing of
muscle activation is another important factor in the relationship between the dynamic muscular actions and the scapular kinematics.

According to recent review articles, exercise training alleviates symptoms in patients with impingement. The current evidence indicates that therapeutic exercise is more effective in reducing pain and improving function than placebo in both short- and long-term follow-up and more effective than no intervention in short-term follow-up. Several studies have examined the muscle activation patterns of various resistance exercises that focus on improving scapular muscle recruitment. In the rehabilitation process of shoulder impingement, exercises focusing on selective activation of weaker muscle parts with minimal activity in the hyperactive ones are an important component. Recently, Cools et al. selected 4 exercises to rehabilitate the scapular muscle balance based on low UT/MT and UT/LT ratios in healthy subjects: (1) side-lying forward flexion, (2) side-lying external rotation, (3) prone horizontal abduction with external rotation and (4) prone extension in neutral position (Figure 1). In a later study, De Mey et al. revealed early MT and LT muscle activation when compared with the UT during side-lying external rotation, prone horizontal abduction with external rotation and prone extension. They speculated that these exercises might alter the timing of the scapular muscles during dynamic activities. However, none of these studies have investigated the potential impact on the pain, function and recruitment pattern of the scapular musculature during arm elevation. In addition, most studies investigated the effect of exercise in relation to other treatment modalities such as manual therapy, corticosteroid injection or radial extracorporeal shockwave, making it impossible to evaluate the beneficial effect of exercise in isolation. Therefore, the aim of this study was to evaluate the effect of the 4 exercises in a clearly defined population of overhead athletes with mild impingement symptoms. It was hypothesized that after a 6-week
exercise program containing these exercises, all subjects would experience pain reduction and improved functionality accompanied by a change in muscle activation levels and onset timing during shoulder elevation. The results of this trial could add evidence to the limited body of knowledge on the effect of physical therapy in patients with shoulder impingement symptoms.

FIGURE 1. Four selected exercises performed daily during 6 weeks. The order was altered each week (Week 1: 1, 2, 3, 4; week 2: 4, 3, 2, 1; week 3: 1, 4, 2, 3; week 4: 4, 1, 3, 2; week 5: 1, 3, 2, 4; week 6: 4, 2, 3, 1).
MATERIALS and METHODS

Subjects

Forty-seven subjects participated in this study (25 men and 22 women), with a mean (SD) age of 24.6 years (7.81), an average weight of 72.55 (11.45) kg and an average height of 178.48 (7.98) cm with a body mass index (BMI) of 22.70 (2.68). They spent a mean of 6 hours a week playing competitive overhead sports, including volleyball (17), tennis (10), canoe polo (2), baseball (2), swimming (11) and badminton (5). The subjects’ mean (SD) sporting experience was 6 (1.5) years. Subjects were recruited over 2 seasons: 2010-2011 and 2011-2012. None of them had stopped training or contacted the team physician for their complaints, so they did not experience any time loss due to their injury. Forty-three subjects were right-handed and 4 were left-handed. In 2 subjects, the nondominant side was affected. All athletes had shoulder impingement symptoms for at least 3 months. Shoulder impingement was diagnosed on the basis of previous research and clinical examination.\(^\text{10, 12}\) The latter consisted of positive Neer, Hawkins, Jobe, apprehension and relocation testing. Subjects were included if they met at least 2 of the following 5 criteria: (1) positive Neer sign: reproduction of pain when the examiner passively flexed the humerus to end range with overpressure; (2) positive Hawkins sign: reproduction of pain when the shoulder was passively placed in 90° of forward flexion and internally rotated to end range; (3) positive Jobe’s sign: reproduction of pain and lack of force production with isometric elevation in the scapular plane in internal rotation; (4) pain with apprehension: reproduction of pain when an anteriorly directed force was applied to the proximal humerus in the position of 90° of abduction and 90° of external rotation; and (5) positive relocation: reduction of pain after a positive apprehension test when a posteriorly directed force was applied to the proximal humerus in the position of 90° of abduction.
and 90° of external rotation. No subjects were included in the study based on the last 2 criteria alone. It was thought that patients with minor instability and secondary impingement would experience pain but no apprehension during these tests. In addition, only subjects presenting with altered scapular resting positions and dyskinesis were included. This was determined on the basis of dynamic clinical examination using a simple yes/no method. A “yes” means the clinician states that an abnormal dyskinesis pattern is observed. Uhl et al. demonstrated this method has a sensitivity and positive predictive value of 76% and 74% respectively when compared with the results of a 3-dimensional analysis. Subjects were excluded if they had a dislocation, had undergone shoulder surgery, or exhibited symptoms related to the cervical spine. They were not retained for this study either if they were currently taking nonsteroidal anti-inflammatory medications, received a steroid injection in the past 12 months, did not reach full range of motion during shoulder elevation (end range pain was allowed), or were already enrolled in a physical therapy program. The study was approved by the Ethical Committee of the Ghent University Hospital and all subjects gave their written consent to participate.

Exercise program

The subjects were tested before and after a 6-week daily home exercise program consisting of the exercises presented in Table 1. Recent literature has demonstrated that home exercises may be as effective as supervised exercises. In our study, a 6-week training period was used because the most significant improvement was expected in this time period. In addition, it was assumed a daily home exercise program consisting of only 4 exercises should not be performed over a longer period because of
motivational issues. According to a recent review article, 6 weeks of training is in line with the current recommendations for exercise training studies.\textsuperscript{37} Before starting with the program, the athletes were thoroughly instructed in the 4 exercises by a physical therapist, and illustrations with specific exercise instructions were provided, as well as a compliance log. All subjects performed the exercises with the affected side on a daily basis. Three sets of 10 repetitions for each exercise were prescribed, with a 1-minute rest between sets. Initial exercise weights were determined based on gender and body weight but were further individualized by 10 repetition maximum (RM) testing.\textsuperscript{11} Pain up to a visual analog scale (VAS) pain level of 5 was allowed during 10RM testing, although only in the case that the pain subsided immediately after the exercise was completed. Sporting activities were allowed during the whole training program, but no additional upper limb strength training was permitted. In order to monitor progress, ensure correct movement pattern, and control load progression, the subjects were either seen in the clinic or followed up by telephone by the physical therapist at 2 and 4 weeks of training. Progression of exercises was decided on the basis of the same criteria as were used during initial instructions. Subjects experiencing higher pain levels (above 5 on a VAS scale) could reduce their weight accordingly. To minimize repetitive overload, the order of the exercises was altered each week. Such type of planned variation is generally recommended by the American College of Sports Medicine to ensure efficient gains in response to strength training.\textsuperscript{1}
Part IV  The effect of scapular muscle rehabilitation exercises in overhead athletes with mild shoulder impingement symptoms

Exercise Description

**Prone extension**  The subject is prone with the shoulders resting in 90° forward flexion. From this position the subject performs bilateral extension to neutral position with the shoulder in neutral rotation. The subject is in side lying position, with the shoulder in neutral.

**Forward flexion in side lying**  The subject performs 90° unilateral forward flexion in a sagittal plane.

**External rotation in side lying**  The subject is side lying with the shoulder in neutral position and the elbow flexed 90°. From this position the subject performs 90° external rotation of the shoulder with a towel between the elbow and trunk to avoid compensatory movements.

**Prone horizontal abduction with external rotation**  The subject is prone with the shoulders resting in 90° forward flexion. From this position the subject performs bilateral horizontal external rotation abduction to horizontal position, with an additional external rotation of the shoulder at the end of the movement.

TABLE 1. The four previously selected exercises used in the 6-week exercise program.

Testing procedure

Pre- and post-testing was performed in the same setting, with the same standardized examination protocol, assessment methods and testing equipment. Initial data collection occurred on the day the exercises were provided. First, the Shoulder Pain and Disability...
Index (SPADI) score was individually obtained by the same researcher. The SPADI is a valid and reliable self-administered questionnaire, is quick to complete, and does not change significantly in stable subjects.\textsuperscript{45, 49} Higher scores indicate a greater level of pain and disability (0-100). The SPADI has shown to be valid and very responsive in assessing shoulder pain and function, and it is therefore highly recommended for use in patients with impingement.\textsuperscript{7} Second, in line with previous studies, bipolar surface electrodes (Blue Sensor; Medicotest, Ølstykke, Denmark) were placed with a 2 cm inter-electrode distance over the UT, MT, LT and SA of the subject’s dominant shoulder.\textsuperscript{11} If necessary, the skin was shaved and further preparation was performed with alcohol to reduce skin impedance (typically $\leq 10$ kOhm). A reference electrode was placed at the ipsilateral clavicle. To ensure consistency with electrode placement, all electrodes were placed by 1 researcher. The electrodes were then connected to a 16-channel Noraxon Myosystem 2000 electromyographic receiver (Noraxon USA, Inc., Scottsdale, Arizona). The researcher confirmed that the electrodes were correctly placed by inspecting the electromyography (EMG) signals on a computer screen during specific muscle testing. The sampling rate was 1000Hz. All raw myoelectric signals were preamplified (overall gain=1000, common rate rejection ratio 115 dB, Signal to Noise Ratio $<1\mu$V root mean square [RMS] baseline noise). Subsequently, the researcher verified the quality of the EMG signal for each muscle by having the subject perform maximal voluntary isometric contractions (MVIC) in manual muscle test positions specific to each muscle of interest (Table 2).\textsuperscript{33, 52} Subjects performed three 5-second MVICs against manual resistance from the researcher. A 5-second pause occurred between muscle activations, and a metronome was used to control the duration of muscle activities. With the objective to minimize the influence of pain on the MVIC, subjects reporting pain during testing were excluded. After rectification, electrocardiogram (ECG) reduction and smoothing, the
peak average EMG value over a window of 2 seconds was calculated for each trial. Further calculations were performed with the mean of the repeated trials as a normalization value (100%).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Electrode placement</th>
<th>MVIC testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT</td>
<td>Midway between the spinous process of the seventh cervical vertebra and the posterior tip of the acromion process along the line of the trapezius</td>
<td>Resistance applied to abduction of the arm from a seated position</td>
</tr>
<tr>
<td>MT</td>
<td>Midway on a line between the root of the spine of the scapula and the third thoracic spinous process</td>
<td>Resistance applied to horizontal abduction in external glenohumeral rotation in a prone position</td>
</tr>
<tr>
<td>LT</td>
<td>Obliquely upward and laterally along a line between the intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process</td>
<td>In a prone position, with the arm placed diagonally overhead in line with the lower fibers of the trapezius, resistance applied against further elevation</td>
</tr>
<tr>
<td>SA</td>
<td>Parallel to the muscle fibers, below the axilla, anterior to the latissimus dorsi and posterior to the pectoralis major</td>
<td>Resisting humeral elevation at an angle of 135° of forward flexion</td>
</tr>
<tr>
<td>PD</td>
<td>In the middle of the muscle belly on the midline between the deltoid tuberositas and the posterior part of the acromion</td>
<td>None</td>
</tr>
</tbody>
</table>

**TABLE 2.** Electrode Placement and MVIC testing for normalization of EMG: MVIC, Maximum Voluntary Isometric Contraction; EMG, electromyography; UT, upper trapezius; MT, middle trapezius; LT, lower trapezius; SA, serratus anterior; PD, posterior deltoid.

After MVIC testing, subjects were allowed to rest for 5 minutes. Then, they each performed bilateral arm elevation in the scapular plane (30° anterior to the coronal plane) during three phases (concentric, isometric and eccentric) that each lasted 3 seconds (Figure 2). This was practiced until reliable reproduction of the movement was
achieved at the required velocity. Subjects completed 5 trials of this movement, with 3 seconds rest between each trial. Isometric readings were taken at maximal elevation. With the EMG registration, simultaneous video recordings were made and a metronome was used to control the duration of phases (Sony Handycam, DCR-HC 37; Sony USA, New York, New York). To ensure minimal basic resting level on the EMG recording, arm elevation was performed without any resistance.

**FIGURE 2.** Performing elevation of the arm in the scapular plane.
Data analysis

All EMG signals were processed by means of the 98 Myoresearch software program (Noraxon, Scottsdale, Arizona). The raw EMG signals were analog-digital converted (12-bit resolution) at 1000 Hz. After rectification, cardiac artifact reduction and smoothing, both the average EMG activation of the different muscle parts and the timing of the scapular muscle activation were determined. Mean muscle activation was then normalized according to the MVIC method. This was done by calculating the mean activity of the second, third and fourth repetition of each trial. The first and last repetitions were not used for further analysis to avoid the influence of habituation and fatigue. Muscle ratios UT/MT, UT/LT and UT/SA were also calculated. In order to determine muscle onset timing, only the concentric phase was used for further analysis. As the time of muscle activity initiation, we used the point at which the activity levels in the muscles reached 2 standard deviations above the resting activity with a minimum of 50ms. Muscle onset times were then analyzed relative to the onset time of the posterior deltoid. Each muscular event as determined by the onset algorithm was visually inspected by a researcher to ensure muscular onset validity.

Statistical analysis

The sample size for this study was based on a minimal relevant difference of 10% in EMG findings and an expected 14-point reduction of the SPADI score to be significant at the 5% level resulting in a statistical power of 80%. Based on the results of other studies, the assumed standard deviation was set to 10% in EMG measurements and 20 points of the SPADI score. A 15% drop-out rate was expected. With the objective to study the influence of re-amplifying surface electrodes on the normalized EMG values, the MVIC’s were determined in a separate group of 25 healthy subjects. Surface
electrodes were reamplified after 1 week without intervention, and the between-session reliability was calculated.

All statistical analyses were performed with the Statistical Package for the Social Sciences, version 18.0 for Windows (SPSS Inc, Chicago, Illinois). Means and standard deviations were calculated across subjects for the results of the normalized EMG activity and the timing of each muscle. Muscle ratio data (UT/MT, UT/LT and UT/SA) and SPADI scores were also calculated.

Because a Kolmogorov-Smirnov test showed normal distribution of the data with P < .05, parametric tests were used for statistical analysis. Subsequently, paired t tests were performed to detect differences in the SPADI scores between pre- and posttesting. Statistical significance was accepted at an α level of .05. Analysis of variance (ANOVA) for repeated measures with the within-subject factors “time” (2 levels = pre- and posttesting), “muscle” (4 levels = 4 muscles) and “phase” (3 levels = concentric, isometric and eccentric) was used to determine whether there were any differences between pre- and posttesting for the normalized EMG activity for each muscle during each phase of arm elevation. The same was done for the UT/MT, UT/LT and UT/SA ratios. Because differences in timing between muscle parts at the beginning of arm movement were also of interest, an ANOVA for repeated measures was used with within-subject factors “time” (2 levels = pre- and posttesting) and “muscle” (4 levels = 4 muscles). A α level of .05 was chosen a priori to denote statistical significance for these comparisons. For any significant difference, a Bonferroni post hoc test to denote significance was used for follow-up analysis.
RESULTS

Forty subjects completed the exercise program (Figure 3). Seven subjects dropped out of the study, four because of private reasons and three because of aggravating pain levels. From the 40 subjects who completed the exercise program, 12 were followed up by telephone only. These subjects were contacted more frequently, focusing on guidance to facilitate appropriate performance of the exercises. Completed daily exercise logs were returned in 68% of the subjects. The SPADI scores significantly decreased from 29.86 ± 17.03 during initial assessment to 11.7 ± 13.78 during postmeasurements (P < .001). Seven players achieved a SPADI score of zero during postmeasurement. The paired tests revealed that the 3 trapezius muscle parts exhibited increased MVIC values when compared before and after the exercise program (Table 3). Considering the normalized EMG activities, the ANOVA model revealed a 3-way interaction (F = 2.74, P = .43) with post hoc tests showing decreased activation levels in the trapezius muscle during arm elevation, while this was not the case for the SA (P < .05) (Table 4). The UT was the only muscle showing decreased activation levels during each phase of the movement. For the scapular muscle ratios, no 3-way interaction was found (F = 1.22; P = .307). However, a 2-way interaction time x ratio could be demonstrated (F = 6.33; P = .005), with post-hoc tests revealing that, without differences between phases, UT/SA significantly decreased after the training program, whereas UT/MT and UT/LT did not change (P<.05) (Table 5). Considering muscle timing, no significant 2-way interaction was found (F = 0.44; P = .69). However, a significant main effect for “muscle” was presented (F = 30.38; P < .001), indicating the timing of muscle activation differed between muscle parts, but not between pre- and postmeasurements. Consequently, the lower trapezius showed significant earlier activation compared with the UT (-0.47; P < .001) and MT (-0.49; P < .001), whereas SA
showed significant earlier activation compared to UT (-0.74; P < .001), MT (-0.76; P < .001) and LT (F = 0.27; P = .046) when combining the results of the pre- and postmeasurements (Figure 4).

FIGURE 3. Flow diagram of the study
## TABLE 3.
Mean Electromyographic Activity during Maximum Voluntary Isometric Contraction Measurements before and after the 6-week Exercise Program. Mean is expressed in millivolt; SD, standard deviation; CI, confidence interval; UT, upper trapezius; MT, middle trapezius; LT, lower trapezius; SA, serratus anterior.

<table>
<thead>
<tr>
<th></th>
<th>Mean pre (SD)</th>
<th>Mean post (SD)</th>
<th>Mean difference (95% CI)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT</td>
<td>512.64 (±400.02)</td>
<td>741.22 (±440.63)</td>
<td>-228.58 (-374.21 to -82.95)</td>
<td>.003</td>
</tr>
<tr>
<td>MT</td>
<td>427.77 (±273.23)</td>
<td>542.11 (±356.97)</td>
<td>-114.34 (-213.95 to -14.72)</td>
<td>.026</td>
</tr>
<tr>
<td>LT</td>
<td>482.58 (±308.12)</td>
<td>639.59 (±351.76)</td>
<td>-157.01 (-257.77 to -56.26)</td>
<td>.003</td>
</tr>
<tr>
<td>SA</td>
<td>496.03 (±357.65)</td>
<td>547.74 (±430.89)</td>
<td>-51.71 (-148.38 to 44.95)</td>
<td>.285</td>
</tr>
</tbody>
</table>
### TABLE 4. Mean Normalized Electromyographic Activity<sup>a</sup> During Each Phase of Scapular Plane Elevation before and after the 6-week Exercise Program. Mean is expressed as a percentage of maximum voluntary isometric contraction; SD, standard deviation; MD, Mean Difference; CI, Confidence Interval; UT, upper trapezius; MT, middle trapezius; LT, lower trapezius; SA, serratus anterior; *, statistical significance accepted at the <.05 level.

<table>
<thead>
<tr>
<th></th>
<th>Concentric</th>
<th>Isometric</th>
<th>Eccentric</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT (pre)</td>
<td>39.27 (±26.44)</td>
<td>44.77 (±34.34)</td>
<td>28.67 (±17.60)</td>
<td>37.57 (±25.05)</td>
</tr>
<tr>
<td>UT (post)</td>
<td>25.37 (±8.34)</td>
<td>27.39 (±12.67)</td>
<td>19.06 (±6.64)</td>
<td>23.94 (±8.09)</td>
</tr>
<tr>
<td>MD</td>
<td>13.90</td>
<td>17.39</td>
<td>9.62</td>
<td>13.64</td>
</tr>
<tr>
<td>(95% CI)</td>
<td>(6.18 to 21.63)</td>
<td>(6.29 to 28.48)</td>
<td>(3.96 to 15.28)</td>
<td>(5.84 to 21.43)</td>
</tr>
<tr>
<td>P value</td>
<td>.012*</td>
<td>.036*</td>
<td>.012*</td>
<td>.001*</td>
</tr>
<tr>
<td>MT (pre)</td>
<td>31.34 (±34.73)</td>
<td>30.98 (±27.34)</td>
<td>19.64 (±17.98)</td>
<td>27.28 (±25.63)</td>
</tr>
<tr>
<td>MT (post)</td>
<td>17.48 (±20.63)</td>
<td>21.49 (±23.93)</td>
<td>12.23 (±9.93)</td>
<td>17.07 (±17.65)</td>
</tr>
<tr>
<td>MD</td>
<td>13.75</td>
<td>9.48</td>
<td>7.41</td>
<td>10.22</td>
</tr>
<tr>
<td>(95% CI)</td>
<td>(1.53 to 25.97)</td>
<td>(-0.61 to 19.57)</td>
<td>(1.74 to 13.08)</td>
<td>(1.23 to 19.20)</td>
</tr>
<tr>
<td>P value</td>
<td>.348</td>
<td>.78</td>
<td>.144</td>
<td>.027*</td>
</tr>
<tr>
<td>LT (pre)</td>
<td>31.34 (±26.15)</td>
<td>53.62 (±50.97)</td>
<td>20.89 (±16.56)</td>
<td>35.28 (±29.49)</td>
</tr>
<tr>
<td>LT (post)</td>
<td>16.49 (±10.51)</td>
<td>30.61 (±20.19)</td>
<td>13.41 (±7.70)</td>
<td>20.17 (±11.46)</td>
</tr>
<tr>
<td>MD</td>
<td>14.85</td>
<td>23.01</td>
<td>7.48</td>
<td>15.11</td>
</tr>
<tr>
<td>(95% CI)</td>
<td>(6.80 to 22.89)</td>
<td>(7.19 to 38.83)</td>
<td>(2.03 to 12.93)</td>
<td>(5.94 to 24.28)</td>
</tr>
<tr>
<td>P value</td>
<td>.012*</td>
<td>.072</td>
<td>.108</td>
<td>.002*</td>
</tr>
<tr>
<td>SA (pre)</td>
<td>32.33 (±16.95)</td>
<td>53.35 (±30.21)</td>
<td>24.60 (±12.66)</td>
<td>36.76 (±16.77)</td>
</tr>
<tr>
<td>SA (post)</td>
<td>32.82 (±21.52)</td>
<td>59.02 (±40.64)</td>
<td>26.68 (±14.69)</td>
<td>39.51 (±24.43)</td>
</tr>
<tr>
<td>MD</td>
<td>-0.49</td>
<td>-5.67</td>
<td>-2.08</td>
<td>-2.75</td>
</tr>
<tr>
<td>(95% CI)</td>
<td>(-6.62 to 5.64)</td>
<td>(-16.69 to 5.35)</td>
<td>(-6.92 to 2.76)</td>
<td>(-8.96 to 3.46)</td>
</tr>
<tr>
<td>P value</td>
<td>.87</td>
<td>.303</td>
<td>.389</td>
<td>.376</td>
</tr>
</tbody>
</table>
### TABLE 5. Scapular Muscle Balance Ratios During Each Phase of Scapular Plane Elevation before and after the 6-week Exercise Program. SD, standard deviation; MD, Mean Difference; CI, Confidence Interval; UT, upper trapezius; MT, middle trapezius; LT, lower trapezius; SA, serratus anterior; *, statistical significance accepted at the <.05 level.
FIGURE 4. Schematic representation (means and standard deviations) of the timing of muscle activation of the upper (UT), middle (MT) and lower (LT) trapezius and serratus anterior (SA) relative to the timing of the posterior deltoid (PD). The vertical 0 line represents activation of the PD. Values lower than 0 reflect muscle activation prior to the PD. Values greater than 0 reflect muscle activation after the PD. Since there were no differences between the pre- and post-measurements, the data were combined showing the LT was activated significantly earlier compared to UT and MT (P<.001). SA showed significant earlier activation compared to UT, MT (P<.001) and LT (P=.046).
DISCUSSION

The current study investigated the effect of a 6-week exercise program consisting of 4 previously selected exercises in a specific group of overhead athletes with mild impingement symptoms. The initial hypotheses could partially be accepted. The main findings were that the exercise program was able to induce changes in the activation level of the scapular muscles with accompanied improvements in pain and function based on SPADI scores but could not alter the timing of muscle activation during arm elevation in the scapular plane.

Previous studies on the effect of exercise in the treatment of shoulder impingement show statistically and clinically significant effects on pain reduction and improved function but not on increased range of motion or strength. They also found manual therapy augments the effects of exercise.\textsuperscript{36, 37} However, when comparing the results of our study with those of others, it must be taken into account various studies investigated the effect of different exercises, in a different study population, under different training modalities, and with different outcome measures, making it difficult to interpret the results of our study in relation to previous research on this topic. In addition, some authors did not provide much detail regarding their programs for strengthening, other than reporting that muscles of the rotator cuff and scapula stabilizers were involved.\textsuperscript{37} Most authors used elastic bands and allowed joint movement for isotonic exercise while others relied on static resistance with isometric contraction. Nevertheless, the current study is similar to the one of Merolla et al.\textsuperscript{42} who studied the effect of the 4 selected exercises in a case series of professional volleyball players with scapular dyskinesis. Merolla et al. found increased infraspinatus strength after a 6 month training program. They identified decreased pain scores on a visual analogue scale from $7.2 \pm 1.3$ to $2.4 \pm 1.8$ at 3 months ($P < .01$) and to $2.6 \pm 1.4$ at 6 months. However, the exercises where
combined with SA strengthening and were performed during 6 months, whereas in our study, the athletes performed the 4 selected exercises in isolation during 6 weeks.

The purpose of our study was to evaluate the influence of reeducation of muscle balance and normalization of activation timing by performing only 4 exercises in a specific subgroup of overhead athletes with mild impingement symptoms related to the presence of scapular dyskinesis. The results of the SPADI scores in our study confirm mild symptoms to be present in the selected athletes since the values were lower compared to similar studies in which subjects were included on an intention-to-treat basis. The SPADI values decreased from 29.86 to 11.70 after 6 weeks of training. In the literature, a SPADI score of 8 to 13.2 points is reported as being the minimal clinically important difference. In our study, this was the case in 23 athletes. In seven players, full recovery was attained based on a SPADI score of zero during postmeasurements. The results of this study are very promising, since limiting shoulder symptoms in active overhead athletes suffering from persistent mild symptoms might serve as a secondary injury prevention measure, limiting continued low-grade shoulder pain, fear avoidance and ultimately surgical management requirement.

Concerning the activation levels in the scapular muscles when compared before and after the training program, decreased amounts of trapezius muscle activation, significantly decreased UT/SA, but no changes in the UT/MT and UT/LT ratios were revealed. Consequently, our participants' values were in line with those found in healthy subjects. Roy et al. already demonstrated significantly decreased EMG activity compared to baseline values immediately after and 24 hours after movement training with feedback in patients with shoulder impingement symptoms. However, this is the first study investigating the effect of the 4 previously selected exercises on the muscle recruitment around the scapula during arm elevation. Previous research provides
evidence of reduced activation of the MT, LT and SA in persons with shoulder pain, combined with an increased UT activation, which is often viewed as a compensatory strategy used by people with painful conditions to elevate their arm. In our study, the UT was the only muscle showing decreased activation levels during each phase of arm elevation when compared before and after the training program. Changes in muscle activation levels after training may be caused by neural adaptations associated with short-term exercise training or they may simply be connected with reduced pain levels rather than being a direct result of the training program.\textsuperscript{3,5,17} Andersen et al.\textsuperscript{3} described these phenomena in their “Wheel of Pain Reduction”. They propose that pain reduction is a result of training, as increased strength leads to increased maximal muscle activation with lowered relative exposure during low-force tasks such as arm elevation. Indeed, the MVIC values of the 3 trapezius muscle parts were significantly increased in our study, while those of the SA were not. Therefore, being able to perform arm elevation with lower relative trapezius muscle activation levels might limit the pathogenetic cascade and might lead to limited impingement symptom development in some athletes.\textsuperscript{23} The finding that the UT showed decreased activation levels during each phase of arm movement adds further evidence for this statement, since this is the muscle part which is often overactivated in subjects with impingement. However, no changes in the UT/MT and UT/LT ratios were found despite the exercises were selected on the basis of favorable trapezius muscle ratios. This could possibly be caused by already finding rather low ratio’s during the pre-measurements (1.19 for UT/LT) when compared to those with more severe symptoms as in the study of Smith et al.\textsuperscript{53} (3.15 for UT/LT).

Concerning muscle onset timing, this is the first study examining the effect of a shoulder training program. In general, early activation of muscles might be a means of increasing
muscle stiffness in anticipation of an applied load that would otherwise result in an unwanted change in bony position. The timing of scapular muscle activation has been assessed by several authors, both in healthy and injured overhead athletes. Initially, Wadsworth and Bullock-Saxton\textsuperscript{56} showed muscle latency of middle and lower SA to be bilaterally delayed in subjects with impingement and demonstrated that there was an apparently increased variability associated with muscle latencies in subjects with shoulder pain, as indicated by larger within- and between-subject variance. However, Moraes et al.\textsuperscript{44} did not detect any differences between groups. In addition, the presence of Latent Trigger Points in upward scapular rotators has been found to be of influence.\textsuperscript{40} During functional activities such as arm abduction in the scapular plane, Wadsworth and Bullock-Saxton\textsuperscript{56} stated that an initial activation of the UT is normal and required for optimal scapula contribution to shoulder complex elevation. Furthermore, Kibler et al.\textsuperscript{34} demonstrated that the muscle activation at the shoulder during sport specific movements (eg, serving in tennis) consists of an activation of the UT before the LT in healthy athletes. On the other hand, Wickham et al.\textsuperscript{59} pointed to an early MT activation during elevation. Although onset timing has been found to be changeable due to therapeutic exercise in the knee and trunk, our results did not reveal any alterations in muscle timing when compared before and after the 6-week exercise program.\textsuperscript{13} The statistics only permitted an evaluation of muscle timing when pre- and postmeasurements were combined. Those results reveal the LT was activated significantly earlier compared to UT and MT, while SA showed significantly earlier activation compared to UT, MT and LT. The results are in line with those found by Glousman et al.\textsuperscript{25} in injured athletes. However, in the literature, there is no real consensus regarding a normal versus pathological pattern of muscle activation during arm elevation, mainly because of methodological differences between studies, small
sample size and low power. In addition, none of the existing studies has prospectively investigated the effect of a shoulder exercise program, maybe because the mechanisms for changes in the temporal characteristics of muscle activation are still not definitive. Possibly, timing of muscle activation is the result of a global response, making motor control training more effective than resistance training exercises in altering muscle timing. Therefore, the results of this study are to be seen as a first step in evaluating the efficacy of shoulder exercise therapy with the objective to alter the timing of scapular muscle activation. Future research is necessary before any definitive conclusions on this topic can be made.

The strengths of the present study are the specific subgroup of patients, the specific exercise regime used in isolation, and the good attendance of the participants. In addition, the standardized exercise protocol provides guidance about content, dose and progression, which enables implementation into everyday practice. However, the results should also be interpreted in light of the methodological limitations of this study. First, the issue of comparing electromyographic data across sessions needs critical discussion. In general, normalization to a MVIC is recommended for diminishing the influence of crosstalk. However, investigating normalized EMG data in a longitudinal design is challenging. Since comparing the absolute level of EMG activity between sessions is inappropriate, normalization is required in spite of its assumed lack of precision. Nevertheless, drawing conclusions about the modification of EMG patterns should be done in light of the within-session and between-session variability data for each muscle. Within-session variability was found very low in our study with intraclass correlation coefficient (ICC) values ranging from 0.96 to 0.99 for the MVIC tests. The between-session reliability was also calculated with the objective to study the influence of reamplification of surface electrodes on the MVIC values. Therefore, MVICs were
determined in a separate group of 25 healthy subjects before and after a 1-week period without intervention. The ICC values were found lower (0.65 to 0.89) compared to the within session results, but no statistical differences between both measurements were found, suggesting minimal influence of electrode reamplification (P < 0.05). These results are in line with previous findings of good reproducibility of normalized EMG amplitude reported in the literature. \(^{28}\) Although interpretation of the absolute muscular effort expressed as a percent of MVIC may still be affected by the MVIC testing, we believe the within-subject design of this study provides a solid comparison of the relative difference in muscular effort among the pre- and postmeasurements when interpreted in light of its methodological concerns. Second, using a general yes/no method for inclusion of scapular dyskinesis ensures that no conclusions can be made regarding exercise training effects in a specific case, characterized by a particular type of dyskinesis. This rather “simple” method was used in our study because it has been shown to have a high sensitivity and positive predictive value when compared with the results of a 3-dimensional analysis and because further classification into Kibler’s 4 types of dyskinesis has been found to show low reliability in a recent paper on professional baseball players. \(^{18, 55}\) In addition, Wang and Trudelle-Jackson\(^ {57}\) have shown that there were no significant differences between patients that were issued customized exercises and those that were given standard exercises on measures of pain intensity, functional status, shoulder range of motion and strength, suggesting further individualization in exercise treatment might not to be necessary. Nevertheless, overhead athletes with mild impingement symptoms related to the presence of scapular abnormalities can still be considered a very specific group of subjects. Third, the outcome measures were not obtained by a blinded assessor, which is a limitation in this study, as blinded assessment is important to prevent bias and assure internal validity in
a clinical trial. With the objective to minimize such influences, this was managed by
blinding each investigator to the pretest results.

The findings from this study also provide a basis for further research. First, randomized
controlled trials are necessary to rule out that the natural maturation of the symptoms
may have influenced the results. Little is known about natural recovery in patients with
subacromial impingement. The use of a control group was done in some studies,
demonstrating statistically significant improvement in pain for exercise compared with
controls. The results of the current study, a prospective case series, cannot be
compared with those of a matched control group, which is a methodological limitation
inherent to this type of design. The lack of a control group precludes the study’s ability
to compare the results of the program with any spontaneous improvement that might
occur over a 6-week period. A randomized clinical trial is generally the preferred study
design, but the external validity can be compromised by the ability to recruit a
representative sample. In addition, a recent paper emphasized the influences from this
research method on clinical decision making can still be limited. Second, future
studies could simultaneously investigate the effect on the 3-dimensional movement
pattern of the scapula in combination with the electromyographic analysis or they could
evaluate the effect on additional parameters such as the strength of the scapular
muscles by using hand-held or isokinetic dynamometer testing. Third, it could be of
interest to focus on follow-up studies investigating secondary injury risk and cost-
effectiveness of a home exercise program compared to other treatment modalities.
Further research is also needed to evaluate the efficacy of other physiotherapy
protocols for shoulder impingement symptoms and to assess comprehensive treatment
that is tailored to individual patients, as occurs in clinical practice.
In conclusion, this is the first longitudinal study investigating the effect of 4 previously selected exercises for rehabilitation of scapular muscle performance in overhead athletes with mild impingement symptoms. The results indicate that a 6-week scapular exercise program improves pain and function based on SPADI scores, reduces relative trapezius muscle activation, and alters UT/SA ratios, but does not change the timing of the scapular muscles during arm elevation in the scapular plane. Studies evaluating the efficacy of exercise treatment in overhead athletes who experience pain but were not yet enrolled in a physical therapy program are scarce. The current study evaluating an exercise program based on previously selected exercises adds valuable knowledge for managing patients with mild impingement symptoms. Future research is necessary to confirm or refute our findings.
REFERENCES


Part IV: The effect of scapular muscle rehabilitation exercises


(44) 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. *J Shoulder Elbow Surg* 2008 January;17(1 Suppl):48S-53S.


Part V  General discussion
1. SUMMARY AND CLINICAL IMPLICATIONS OF THE RESULTS

The main purpose of this dissertation is to make a valuable contribution to the field of scapular muscle training in overhead athletes with scapular dyskinesis and related impingement symptoms. In order to give an answer to various research questions related to this topic, we investigated muscle activity and timing during particular shoulder exercises and studied the effectiveness of an exercise program in a case series study. In clinical practice, a multitude of exercises are used to restore shoulder function or to prevent various pathologic conditions such as glenohumeral shoulder impingement.\textsuperscript{30,39,42,123} Scapular muscle training has become an essential part of such progressive training protocols.\textsuperscript{55,75,123} The current dissertation delivers further insight into the scapular muscle activation levels and muscle onset timing patterns during scapular muscle exercises for the overhead athletic population.

Since neuromuscular coordination and strength training exercises, such as the four selected by Cools et al.\textsuperscript{26} are often part of both rehabilitation and injury prevention programs, the first four studies were performed on healthy subjects. Based on EMG findings, the first study made clear that clinicians should focus on conscious scapular orientation during the prone extension and side-lying external rotation exercise. It also appeared that all four exercises remain relevant for trapezius muscle balance rehabilitation purposes when initial conscious scapular orientation is applied. In the third study, the same exercises were investigated on their muscle timing activation patterns, since it is believed that overhead athletes should also work on facilitating correct timing of muscle recruitment.\textsuperscript{31} The prone extension and prone horizontal abduction with external rotation exercise appeared to promote early activation of the stabilizing parts of the trapezius muscle. The clinical relevance of these findings is that these 2 exercises might be useful in the treatment of altered timing activation patterns of the scapular muscles in overhead athletes. If the early activation of the scapular stabilizing muscles could lead to a better stabilization and synchronization of the scapular movements, this could possibly help to provide enough clearance under the acromion, which might increase the capacity of the rotator cuff muscles to stabilize the glenohumeral joint.\textsuperscript{50,62,84}
In our fifth study however, no differences in the timing of scapular muscle activation could be identified between the pre- and post-measurements. The statistics only permitted an evaluation of muscle timing when pre- and post-measurements were combined. Those results revealed that the LT appeared to be active before the UT and MT. SA showed significant earlier activation compared to UT, MT and LT. In contrast, Worsley et al.\textsuperscript{145} could find improvements in muscle onset timing of SA and LT after a motor control retraining exercise program. However, timing of muscle activation in that study was expressed as the arm position where muscle onset during the elevation phase occurred, which was determined using visual interpretation of the EMG signal. In our study, we used the point in time where the muscle showed $>10\%$ activation above baseline value, which limits the ability to compare the results of both studies.

Overhead athletes suffering from mild symptoms, who not yet stopped training or contacted the team physician, might benefit from the exercises selected by Cools et al.\textsuperscript{8,26} Indeed, the results of our fifth study suggest that the athletes might limit their continued low-grade shoulder pain and functional limitations by performing a 6-week home exercise program only consisting the four exercises, but the underlying mechanisms were not exactly clear. Based on a case series study design, the results indicated that a 6-week exercise program is able to change pain and improve function at a statistically and clinically important level. In a recent case series of 16 athletes by Worsley et al.\textsuperscript{145}, the authors found similar results as in our study after a 10-week motor control intervention for shoulder impingement. In a randomized controlled study, Holmgren et al.\textsuperscript{55} and Struyf et al.\textsuperscript{120} also showed that strengthening the scapular stabilizers is effective in reducing pain and improving shoulder function in patients with subacromial impingement syndrome. However, no EMG measurements were taken in those investigations, despite the excellent quality of the papers. In our study, increased MVIC values were found in the 3 trapezius muscle parts after the training program in which the four scapular exercises were performed every day for 6 weeks. Trapezius muscle activation during arm elevation decreased, while this was not the case for the SA muscle. The UT/SA ratio significantly decreased, while UT/MT and UT/LT did not change. The question remains if the alterations in muscle recruitment can be attributed to the clinical improvements which were found.\textsuperscript{74,105} Generally, reducing UT activation is often a challenge to the clinician. The results of our study revealed that the UT showed decreased activation levels during each phase of arm elevation when
compared before and after the training program. This reduced UT activation probably limits the excessive scapular elevation which is often seen in patients. However, our results also indicated that, although the training program consisted of exercises with low UT/MT and UT/LT muscle ratios, the program was not able to change these ratios. Instead of altering the UT/MT and UT/LT ratio, the UT/SA ratio decreased in our patients. So, the principle of training specificity was not approved in our study. Possibly, patients didn’t improve because of alterations in scapular muscle recruitment, but because of other factors such as changes in glenohumeral muscle function, exposure reduction or a healing response in the rotator cuff tendons.

Only in the first study, conscious scapular orientation was studied. Generally, its relevance is based on the assumption that there is a setting phase at the beginning of a shoulder movement task, during which the scapula should maintain properly stabilized. However, the question remains whether conscious correction of the scapula prior to movement has an influence on the scapular kinematics during all exercises studied in this dissertation, the more since no three-dimensional movement analyses were performed. The same is true for the influence of early onset of scapular muscle activation, examined in the third study, on the 3-dimensional kinematics of the scapula. Investigations showing early activation in the scapular stabilizers accompanied by increased upward rotation, posterior tilt and external rotation of the scapula in patients have not yet been conducted. In addition, there is no real consensus on either the presence or duration of a setting phase. As already stated by Kibler et al., correction of altered scapular resting positions and impaired overhead movement patterns are two separate entities. Compared to postural scapular correction at the beginning of an exercise, it might be a better approach to focus on proper movement strategies, also taking the subject’s cognitive status and attention into account. In a study by Weon et al., real-time visual feedback was used as an effective method to activate the scapular upward rotator force couple in people with scapular winging during a shoulder flexion task. The authors instructed their participants to protract and elevate the scapula while lifting the arm and found increased muscle activation in the UT and SA as the shoulder flexion angle increased under the visual-feedback condition, but no change in LT muscle activation was noted. Whereas in our approach, based on the work by Mottram et al., we aimed to correct the scapular position before starting the glenohumeral motion in the first study, Weon et al. tried to immediately correct the
movement pattern of the scapula by asking the subjects to protract and elevate the scapula when depression, tilting or winging were observed during real-time visual feedback. An argument for the relevance of this approach would be that neuromuscular activation has its origin in the intention of the movement or task that is performed to attain a particular target. Changes in muscle activation are also seen as an indirect result of the altered motor control strategies which were learned. In addition, this view to the problem is used as an argument to suggest that task-specific training is the preferred method to enhance the outcome of musculoskeletal conditions. Such approach may better induce alterations in muscle timing and activation levels due to training. However, systematic evaluation proving the benefit of movement training (goal oriented) as compared to analytical exercise training methods (muscle oriented) has not yet been performed.

In some cases, training on unstable surfaces during closed kinetic chain exercises is considered relevant for stimulating shoulder muscle activation. Using the Redcord device as an unstable surface has some practical advantages compared to other exercise material such as a gym equipment. It is portable and time efficient, which eliminates the time factor that is a barrier for many people trying to perform their prescribed exercises. However, when using Redcord slings (RS) during four closed kinetic chain exercises, our results showed that not all muscles increased their activation levels. In addition, it was noted that the large glenohumeral muscles were highly activated when using RS, especially the pectoralis major (PM) during the push-up and knee prone bridging exercise and the posterior deltoid (PD) and latissimus dorsi (LD) during the pull-up exercise. Five exercises could be selected on the basis of a low UT/SA ratio: half push-up without and with RS, knee push-up without and with RS and knee prone bridging plus without RS. There was not a single exercise that could be selected based on a low UT/MT and UT/LT ratio. Therefore, we concluded that RS are only preferred over a stable surface when the goal is to increase the activation in the prime mover muscles of the shoulder. The clinical relevance of these findings is that clinicians should be aware that using RS does not necessarily imply that higher activation will be obtained in the muscles responsible for scapular stabilization. Therefore, RS should, in our opinion, not be used in early phases of scapular rehabilitation. However, in later stages of rehabilitation or in a general strengthening
program, RS may be of additional value, since they highly activate the large prime mover muscles around the glenohumeral joint.\textsuperscript{39}

The need for further individualization is reflected by the high standard deviation values in this study. Lehman\textsuperscript{72} already pointed to the inconsistent responses across participants during certain exercises and amongst specific muscles with the addition of unstable surfaces. This suggests that other factors than the equipment which is used, such as the participant’s characteristics, may influence muscle recruitment to a greater extent than surface instability. Indeed, large variability in the inter-individual responses are generally found in papers supporting the use of surface instability as a training tool.\textsuperscript{72} The results of our investigation largely confirm these findings. In addition, variability was also found high in the first and third study. Thus, clinicians should be aware that individual factors may play a large role in how muscle activation levels are recruited during a certain exercise. Individuals can present with markedly varied responses different from the mean, when performing a certain exercise, especially when an unstable surface is used. An argument can even be made that in some cases, the muscle activation is decreased, so also decreasing the stress on the muscle.\textsuperscript{72} The same applies to the onset of muscle timing. This is relevant to the rehabilitation professional when designing exercise programs that attempt to create a training effect over time.

Recent guidelines also point to the relevance of integrating kinetic chain exercises into training programs for overhead athletes.\textsuperscript{90,110,113,126} One argument to promote the use of these exercises, is that they possibly increase the activation in particular shoulder muscles relevant in the treatment and prevention of scapular dyskinesis and related impingement.\textsuperscript{81} However, when looking at the results of the fourth study from this thesis in combination with the findings by Maenhout et al.\textsuperscript{81}, it has to be concluded that the differences between conditions appear rather low. The underlying mechanisms for such changes also remain unclear.\textsuperscript{81} In our study, the main findings were that all scapular retraction exercise variations resulted in higher LT compared to UT muscle activation and that a contralateral single squat position stimulated higher trapezius muscle activation levels when compared to a conventional seated performance of the exercise. Indeed, exercises with high LT activation while minimizing the activation in the UT are often preferred in the treatment of athletes with a decreased control of the LT accompanied by an excessive UT activation.\textsuperscript{26,106} However, no conscious correction of
scapular orientation was asked to the subjects, and muscle onset timing was not analyzed in this study. Nevertheless, the clinical relevance of these findings is that all exercise variations may be useful in the early phases of scapular rehabilitation training. Since none of the upright exercises showed significantly increased UT activation compared to the seated performance, the various kinetic chain exercises may be used in the transition from easy to more challenging types of rehabilitation. But on the other hand, the benefit of performing certain kinetic chain exercises to increase the scapular muscle activation level is debatable. An overview of the conclusions, limitations and implications of the different studies in the dissertation can be found in TABLE 3.
<table>
<thead>
<tr>
<th>Study</th>
<th>Conclusions</th>
<th>Limitations</th>
<th>Implications</th>
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| 1     | • Conscious correction of scapular orientation increases the activation level in the UT, MT and LT during the prone extension and sidelying external rotation exercises in overhead athletes with scapular dyskinesis.  
• It does not alter the favorable UT/MT and UT/LT ratios that have been previously reported. | • Only healthy subjects included.  
• No 3-dimensional movement analysis performed.  
• No consensus on the presence or duration of a setting phase exists.  
• High standard deviation values found, reflecting the need for further individualization. | • Conscious correction of scapular orientation prior to movement may be a useful component of scapular muscle rehabilitation exercises in overhead athletes with scapular dyskinesia, especially in the prone extension and sidelying external rotation exercises. |
| 2     | • Large glenohumeral muscles are highly activated with the use of Redcord slings (RS).  
• Five exercises with low UT/SA ratios could be selected: half push-up without and with RS, knee push-up without and with RS and knee prone bridging plus without RS.  
• No exercises with low UT/MT and UT/LT ratios could be identified. | • Only healthy subjects included.  
• No 3-dimensional movement analysis performed.  
• Scapular dyskinesia was not an inclusion criterion.  
• High standard deviation values found, reflecting the need for further individualization. | • RS should only be used over a stable surface when the goal is to increase the activation levels in the prime movers.  
• RS should only be used in later stages of rehabilitation or within a general strengthening program. |
| 3     | • The prone extension and prone horizontal abduction with external rotation exercise promote early activation of the stabilizing parts of the trapezius. | • Only healthy subjects included.  
• No 3-dimensional movement analysis performed.  
• Scapular dyskinesia was not an inclusion criterion.  
• High standard deviation values found, reflecting the need for further individualization. | • The prone extension and prone horizontal abduction with external rotation exercise might be useful in the treatment of altered timing activation patterns. |
### Table 3: Conclusions, implications and limitations of the different studies in the dissertation.

| 4 | The eight scapular retraction exercise variations may be useful in the early phases of scapular rehabilitation training because of their favorable trapezius muscle balance activation.  
Standing in a squat position on the contralateral leg results in a slight increase in trapezius muscle activation. | Only healthy subjects included  
No 3-dimensional movement analysis performed  
Scapular dyskinesis was not an inclusion criterium  
Only small difference found | Various scapular retraction exercise variations seem useful for trapezius neuromuscular coordination training in overhead athletes because of their low upper trapezius muscle activation levels compared to those of the lower trapezius muscle. |
| 5 | A 6-week exercise program consisting the four selected exercises improves pain and function based on SPADI scores, reduces relative trapezius muscle activation and decreases the UT/SA ratio during arm elevation.  
The program does not change the timing of the scapular muscles in overhead athletes with mild impingement symptoms. | No control group included  
No 3-dimensional movement analysis performed  
Results only applicable to those with general signs of impingement  
No conscious scapular orientation performed  
Different method used for timing calculation as in third study  
No follow up performed | Overhead athletes with mild impingement symptoms might limit their continued low-grade shoulder pain and functional limitations by performing a 6-week home exercise program consisting the four exercises.  
It is unclear whether changes in muscle activation are responsible for the clinical improvements. |
| Taken together | Because of their favorable trapezius and SA muscle activation patterns, particular shoulder exercises seem useful in the treatment and prevention of shoulder impingement related to the presence of scapular dyskinesis, especially for those with mild symptoms.  
Kinetic chain variations have limited influence on the scapular muscle activation levels.  
Sling exercises should only be used in the end phase of rehabilitation or within a general strengthening program. | No consensus exists on normal and abnormal scapular muscle activation patterns  
Four studies performed on healthy patients and only one on patients  
No 3-dimensional movement analysis performed  
Large variability found in the results, limiting the generalizability  
Limited level of evidence inherent to a case series study design  
Reductionistic approach to the problem applied | Individualization is required when prescribing scapular muscle exercises for overhead athletes with scapular dyskinesis and related impingement symptoms.  
Movement training might be more appropriate compared to muscle training when the goal is to improve scapular muscle recruitment.  
Transferring the results from our studies to the field should be done with caution and within a broad clinical perspective. |
While discussing the results of the different studies in this dissertation, one should keep three issues in mind, from which two are related to the use of EMG. First, it should be noted that our studies only provide evidence for the general population of overhead athletes. The clinical relevance of the results to particular subgroups of athletes remains unknown. In our second, third and fourth study, subjects were included regardless of the presence or absence of scapular dyskinesis. Probably, the presence of scapular dyskinesis may have an impact on the results of those studies. Consequently, the influence of RS on the shoulder muscle recruitment, the scapular muscle timing during the four selected exercises and the kinetic chain influences during various retraction exercises could alter in case subjects present with signs of scapular dyskinesis. In addition, it is not yet fully clear if people with scapular dyskinesis activate their shoulder muscles in a different way compared to those without dyskinesis while performing particular exercises. As a result, the need for conscious correction of scapular orientation prior to movement can be questioned. Moreover, different subjects may have different types of scapular dyskinesis, as described by Kibler et al. In the first and fifth study, the subjects had to present with scapular dyskinesis for participation, which was diagnosed by visual inspection, showing high sensitivity and positive predictive value when compared with the results of a 3-dimensional analysis. However, we did not distinguish between subjects presenting with different types of dyskinesis. The reason why we did not do this was because further classification into Kibler’s four types of dyskinesis has been found to show low reliability in a publication on professional baseball players. In the effectiveness study on patients, in the fifth study, one could argue that providing more detailed exercises, dependent on the type of scapular dyskinesis which was present in each participant, were necessary, since no correction of scapular orientation was asked, as was done in the first study. However, Wang and Trudelle-Jackson have shown that there were no significant differences between patients that were issued customized exercises and those that were given standard exercises on measures of pain intensity, functional status, shoulder ROM and strength, suggesting further individualization in exercise treatment might not be necessary. Nevertheless, further research in this area may result in improved guidelines for effective scapular rehabilitation strategies in overhead athletes with an increased risk for developing shoulder impingement symptoms.
The second issue, which is related to the use of EMG, concerns the amplitude level at which the different muscles are activated, and the second concerns the signal processing technique used for scapular muscle timing determination. The amplitude level during a particular exercise is of interest when trying to make clear which exercises are appropriate for neuromuscular training and strength gain purposes.\(^1\) According to McCann et al.\(^87\), “minimal” activation is defined as levels $<20\%$ MVIC, as “moderate” activation levels require 21 to 50\% MVIC and “marked” activation levels $>50\%$ MVIC, whereas Digiovine et al.\(^37\) defined four categories: “low” ($<20\%$ MVIC), “moderate” (20–40\% MVIC), “high” (41–60\% MVIC), and “very high” ($>60\%$ MVIC). Generally, “moderate” to “marked” activation levels are necessary for strength training adaptations, with threshold values of 50-60\% MVIC\(^3,7\), so meaning the activation level should be “high” to “very high” according to Digiovine et al.\(^37\). Consequently, lower values are considered appropriate for neuromuscular training purposes while higher values are relevant for strength training purposes. Although these categories can be used to interpret the results of our studies in terms of possible training benefits over time, it must be noted that several other factors should also be taken into account when comparing the results between various investigations.\(^36\) For example, changing the weight used by a subject will automatically result in altered muscle activation levels, since higher weights require higher levels of muscle activation and vice versa.\(^42\)

Generally, comparing the results across studies is difficult, since some authors employed dynamic exercises\(^26,137,138,144\) and others isometric exercises\(^4,67\). Loads applied during exercises also varied between studies. Some used no weight\(^49,67,69,98\), some used manual resistance by the trainer\(^4\) or used tailored weights to suit each individual\(^18,26,53,57,137,138\), while others used more generalized exercise weights\(^93,141\), having an influence on the activation levels reported in each paper. The relevance of finding differences in muscle activation between pre-and post-training results can also be discussed. In order to have a better insight into the relationship between statistically significant and clinically relevant findings, Seitz and Uhl\(^114\) found that the intra-session minimal detectable change in the trapezius and SA is less than 3\%, while changes exceeding 11.7\% MVIC between sessions are necessary to be true changes that exceed measurement error. Clinically, a 10\% difference in muscle activation might be needed in terms of muscle strengthening purposes.\(^2\) However, no such a value is available in the literature with regard to neuromuscular training. So, one could question how the small changes in muscle activation which were found in our investigations
could be clinically relevant. The scapula dominantly relies on the muscle activation for its functional stability, supporting the notion that even small differences could be of influence. However, further research in this area is necessary before making definitive conclusions on this topic.

A third issue that should be considered, which is also related to the use of EMG, is the signal processing technique which was used to determine the scapular muscle timing. The methodology which was used differed between the third and last study. In the third study, threshold for muscle onset was determined as a 10% increase in muscle activation above baseline value, while manually calculating the moment in time where this threshold was achieved. In contrast, in the last study, we used the Noraxon software to calculate muscle timing as the point in time at which the activity levels reached two standard deviations above the resting activity, with a minimum of 50ms. Possibly, this is another factor which could explain why no differences in muscle timing were found in the pre-post study design in the fifth study. Although the first method was in line with the study of Cools et al. and the second with the guidelines provided by Hodges and Bui, the onset times were analyzed relative to that of the posterior deltoid in both studies, so maximally stimulating consistency between both studies. Nevertheless, muscle timing calculation may be influenced by the way the PD is activated during the four exercises, since its role as a glenohumeral rotator is still under debate. In general, studying scapular muscle timing and relating these findings to clinical practice remains challenging. Seitz and Uh1 found that reliability of scapular muscle onset times relative to the prime mover (deltoid muscle) is very good within session (ICC = 0.88-0.97) but poor to moderate between sessions (ICC = 0.43-0.73). These findings reinforce the value of studies in which scapular muscle timing is compared between muscle parts during particular exercises, as in our third study, but it also suggests that investigating muscle timing in a pre-post study design, as in our fifth study, has some inherent methodological concerns.
2. STRENGTHS AND LIMITATIONS OF THE THESIS

Thoughtful interpretation of the results presented in this dissertation should be done by including both the strengths and limitations of the different studies which were performed. One of the main strengths is the clinical rationale which was used to design the protocol of each study. Especially, the specific subgroup of overhead athletes and patients with mild impingement symptoms make each study relevant in the field of shoulder rehabilitation and injury prevention for the overhead athletic population. In most studies in this area of research, subjects have been included on the basis of their intention-to-treat, so after they have stopped training and contacted a team physician. In our fifth study however, we focused on the group of athletes experiencing pain, but still active in practice and games. This group is clearly presented in a paper by Bahr (FIGURE 6).8

![FIGURE 6: Hypothetical overview of the onset of tissue injury and pain in a typical overuse injury. (Adapted from Bahr.8)](image-url)
We showed that, when these athletes are provided a simple exercise program, they can limit their low-grade shoulder pain. Consequently, limiting shoulder symptoms in active overhead athletes suffering from persistent symptoms might serve as a secondary injury prevention method, limiting the chance to develop fear avoidance and surgical management requirement. Another strength of this dissertation is the consistency in the methodology which was used, despite the way muscle timing was calculated differed between our third and fifth study. In each investigation, surface EMG was used with the same type of electrodes and normalization techniques. When possible, similar exercise weights were also used across studies. In addition, the fifth study clearly described the type of exercise, and the intensity, frequency and duration used during the exercise protocol, which are precisely those factors which were missed in previous research on this topic. In many studies, the effect of exercise training has been investigated in more severe patients or as part of a post-operative treatment protocol. Although these studies deliver interesting information for effective treatment strategies for patients with severe symptoms, no studies yet investigated a specific exercise program for the rehabilitation of the overhead athlete with mild symptoms, still active in his/her sport. The fifth study is the first to cover this gap in the literature.

Some limitations should also be discussed in detail, both from a clinical as from a scientific point of view. Intuitively, clinicians are often looking for the perfect exercise when working with an athlete. Exercise selection is mostly based on the main goal which is derived from the clinical examination process, often focusing on proper tissue healing of the rotator cuff tendons. Besides those basic conditions, 3 other parameters are considered crucial in selecting the most appropriate exercises for scapular muscle rehabilitation. First, high levels of scapular stabilizer muscle activation and early onset timing are believed to be relevant for scapular muscle rehabilitation, as is outlined in this dissertation. Second, sufficient scapular upward rotation, posterior tilt and external rotation is often preferred when selecting exercises, so taking the 3-dimentional kinematics of the scapula into account. Third, integration of shoulder movements into a kinetic chain pattern is believed to be another important component in scapular rehabilitation training programs. On the basis of these 3 parameters, we present a “scapular exercise model” as a basis for scapular exercise categorization (FIGURE 7).
The first and main limitation of this dissertation can be derived from this model. Only the first of 3 factors has been examined, with the first study supposing that the scapular orientation was improved by performing the “conscious correction of scapular orientation” activity and the fourth study taking kinetic chain influences into account. In addition, a rather reductionistic approach was applied throughout this dissertation, meaning that the underlying philosophy was that fixing the parts may result in better functioning of the whole.\textsuperscript{104} More particularly, exercises with high activation in the stabilizing muscle parts (MT, LT and SA) were suggested to restore the muscle balance which was found to be deviated in previous studies on patients.\textsuperscript{22,78,101} Similarly, exercises with early activation of scapular stabilizing muscle parts were suggested to change the delayed muscles activation which was found in previous investigations.\textsuperscript{28,135} However, recent insights into the neuromuscular function of the body agree that
muscles work in synergistic pairs, meaning that muscles do not function in isolation.\textsuperscript{43,84} This implies that focusing on particular muscle parts may not be the preferred method when the objective is to change the alterations in muscle activation which were previously found. Moreover, there is discussion in the literature on the role of the UT as an upward rotator.\textsuperscript{78,79} Its primary role rather appears to be in generating retraction of the clavicle at the sternoclavicular joint, preventing excessive scapular internal rotation. Therefore, it remains to be determined to which extent scapular exercises targeting the MT, LT and SA muscles while minimizing the activation in the UT can change the muscle recruitment during functional overhead athletic activities such as throwing, hitting or swimming.

Second, one should be critical with regard to the timing studies in the third and last study of the dissertation. In general, there is no real consensus about a normal or abnormal muscle timing pattern during arm movements, mainly because only a limited amount of studies have been conducted in this area of research.\textsuperscript{22,101} Previous studies on this topic showed delayed SA and LT activation during voluntary arm elevation, or as a response to free falling of the arm.\textsuperscript{28,135,145} However, the results of the fifth study suggest that it remains to be determined how voluntary shoulder movement training can be an appropriate method to improve alterations in muscle timing, especially when found as a reflexive response to sudden perturbations.\textsuperscript{28} From a methodological point of view, it should be stated that it is possible that no significant differences in muscle timing between pre- and post-measurements were found because the athletes did not present with altered muscle timing when entering the study. Although this should be considered as a limitation, it was inherent to the design of this investigation.

Third, the case series design in our fifth study only provides limited evidence for the effect of a scapular exercise program. Although case series are within-subject studies, baseline values are needed because no control group is included making clear how e.g. pain fluctuates over time without intervention. Randomized controlled trials could deliver more profound information because they have the ability to rule out that the natural maturation of the symptoms may have influenced the results. The use of a control group was done in some studies, demonstrating statistically significant improvement in pain for exercise compared with controls.\textsuperscript{55,71} However, the results of the fifth study, a prospective case series, cannot be compared with those of a matched control group,
which is a methodological limitation inherent to this type of design. Another point of discussion could be that we did not make clear if the athletes were suffering from primary or secondary, subacromial or internal impingement. Patients with different types of impingement may have different scapular kinematic alterations, accompanied by different muscle recruitment patterns as compared to those with subacromial impingement.\textsuperscript{78,79} Subsequently, when interpreting the results of this study, one should be aware that the subjects were included in our study on the basis of a clinical assessment of impingement signs, which provides an indication of impingement, but does not clarify the mechanism of the underlying pathology. Therefore, conclusions regarding subgroup deviations could not be derived from our results. They only reflect averages from a group of athletes with general signs of impingement.
3. DIRECTIONS FOR FUTURE RESEARCH

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

First, the question remains whether a normal and abnormal muscle timing during various arm movements exists, and if it does, how this should be defined. So, investigating this topic in both healthy subjects and athletes suffering from various pathologic conditions could be of interest. Providing a consensus in how muscle timing should best be calculated from the raw EMG signal would also be relevant, since this could increase the ability to compare the results of different studies from different research groups.

Second, it should be investigated whether or not alterations in scapular muscle performance are associated with improvements in the 3-dimensional kinematics of the scapula. Consequently, further insight may be gained through investigations linking muscle function and kinematic alterations to reductions in the subacromial space, or proximity of structures such as the glenoid and cuff undersurface in patients with impingement.

Third, concerning the influence of an unstable surface on the shoulder muscle recruitment during CKC training, it could be of interest to examine the effect of its role with an individual progression in degree of difficulty. As a consequence, individual proximal weak links may be controlled more precisely and the effect of such training programs may be compared to more traditional ways of training on unstable surfaces.

Fourth, synergistic activation of shoulder, trunk and lower extremity muscles could be investigated during various kinetic chain exercises. The influence of proximal weak links (e.g. lumbopelvic and hip instability) on the upper extremity muscle recruitment during exercises performed in a more sport-specific position could also be a topic of interest. Clinicians often assume that these factors have an influence on the function of the entire kinetic chain system, suggesting that from a clinical standpoint, this would be an
interesting study to perform. Subsequently, it would be relevant to investigate whether correction of the non-optimal proximal stability has an influence on the muscle recruitment of the more distal segments in the body. In addition, the use of instruction, demonstration and extrinsic feedback during functional rehabilitation exercises, typically focusing on whole body movement patterns with sufficient functional stability in each segment, could also be evaluated.

Finally, randomized controlled trials are needed including a group without treatment, to gain more insight into the natural recovery of the athlete’s symptoms. This would increase the level of evidence for the effect of scapular muscle training in patients. In our study, we investigated the effect of a rather simple exercise program consisting of only four exercises, but further research could focus on different batteries of interventions to evaluate which are most effective at reducing scapular muscle impairments, as is often applied in clinical practice. In addition, it could be relevant to study if there is need for a particular dosage response to reduce the scapular dyskinesis which has been found during the clinical examination process. Evaluating the effect on additional parameters such as the strength of the scapular muscles by using hand-held or isokinetic dynamometer testing could also be done. Adequate follow-up should be performed in those studies to evaluate long term benefits of therapeutic exercise in this population. Some studies investigating secondary injury risk and cost-effectiveness of a home exercise program compared to other treatment modalities would also be of interest. More basic science research could then focus on the underlying neurophysiological adaptations necessary for inducing alterations in scapular muscle timing and amplitude levels, especially while measuring muscle function during the sport-specific movements. Lastly, further investigations may be needed in patients with more severe symptoms as compared to the athletes participating in our study, who only suffered from limited pain levels and functional limitations.
4. SCAPULAR MUSCLE TRAINING IN A BROADER CLINICAL PERSPECTIVE

The purpose of this dissertation was to focus on individual scapular muscle recruitment during specific scapular exercise training in overhead athletes. However, the bigger entity of treatment and prevention of overhead athletes with scapular dyskinesis and related impingement symptoms may not be forgotten. Therefore, the purpose of this part of the thesis is to place the current knowledge into a broader clinical perspective. In particular, the place of scapular exercise training in the total treatment program for overhead athletes with shoulder impingement will be described in more detail, with a specific focus on functional rehabilitation. In addition, the current knowledge will be put into the general frame of injury rehabilitation and prevention guidelines for overhead sports. As a consequence, the different studies in this dissertation can better be interpreted in view of the possible implications to the field.

In designing rehabilitation programs for those with shoulder pain, Kibler et al.\textsuperscript{64} proposes to follow a functional progression, starting with proximal segment control, continuing with scapular rehabilitation, and ending with glenohumeral rehabilitation and plyometrics. Compared to the scapular rehabilitation algorithm by Ellenbecker and Cools\textsuperscript{39}, this model points to the relevance of integrating the kinetic chain early in the rehabilitation process. Proximal segment control may include various corrective exercises such as lunges and squats or may be trained more specifically by performing specific exercises for lumbopelvic motor control and lower extremity stabilization, as proper proximal stability is seen as a fundamental principle of shoulder rehabilitation.\textsuperscript{110}
TABLE 4: Rehabilitation flow sheet according to Kibler et al.\textsuperscript{64}

Within both treatment protocols, it is considered beneficial to initially work on proximal mobility and control by using appropriate manual therapy and stretching techniques before starting with exercise training.\textsuperscript{39,123} Common sites of restrictions which should be addressed are the posterior rotator cuff and glenohumeral capsule, levator scapulae, UT and the cervical and thoracic spine.\textsuperscript{12,88} Treating the myofascial trigger points in the hypertensive muscles around the shoulder might also help prior to the beginning a scapular exercise training program.\textsuperscript{51,52,97} However, a clinical assessment of the total body, including the trunk and lower extremity, may provide the most comprehensive information as a basis for selecting the most favorable exercises in a given case.\textsuperscript{117} In particular subgroups of patients with more complex pathologies, the biomedical approach to the problem, as it is outlined in this dissertation, might be too restricted to solve the problem. Instead, the clinician may use the planetary model described by Danneels et al.\textsuperscript{33}, including both the model provided by the International Classification...
of Functioning, Disability and Health (ICF) and the recent insights into the pain mechanisms and psychosocial factors as a basis for clinical decision making. For efficient treatment of those individuals, a multimodal approach can be the appropriate direction via which the shoulder problem can be successfully managed in collaboration with the orthopaedic surgeon.\textsuperscript{102,103,123} In patients, exercises should always be chosen with respect to the tissue’s healing process. Therefore, a progression from low to high demand should be made, especially in patients with severe symptoms or in cases needing post-operative rehabilitation.\textsuperscript{110,142} In addition, proper spinal postural correction might be relevant while performing scapular orientation exercises, especially in those subjects who present with forward head posture and increased thoracic kyphosis.\textsuperscript{60,76,80,124} The use of tape might be helpful in this stage, since Lewis et al.\textsuperscript{76} showed that scapular taping may improve trunk posture and shoulder ROM. There is also evidence to suggest that taping is able to reduce pain levels in patients with impingement symptoms, probably by reducing the UT while stimulating the LT muscle activation.\textsuperscript{56,92,115,118}

After corrected neuromuscular control in the proximal segments and the scapulothoracic joint is achieved, glenohumeral exercises may be prescribed.\textsuperscript{30,77} Appropriate exercise intensity should be applied, so limiting the amount of compensational movements made by the patient to perform a certain exercise. Relevant exercises can be selected on the basis of their increasing activation levels in the scapular and glenohumeral musculature. Interestingly, Schachter et al.\textsuperscript{112} found that the scapular stabilizers function at a similar or even higher intensity than the glenohumeral rotators during internal or external rotation exercises. This highlights the relevance of integrating “glenohumeral exercises” into scapular oriented shoulder training programs. However, the clinician should be aware that performing exercises with high activation levels in the scapular stabilizing muscle parts do not always place the glenohumeral joint in a position of decreased subacromial space, which can create a higher risk for impingement during a particular exercise.\textsuperscript{49} In this way, one cannot expect the rehabilitation exercise to be effective. Therefore, in order to diminish the chance for rotator cuff impingement to occur, one can start with exercises over a limited ROM. Side-lying external rotation and prone extension to 90° with proper scapular control may be utilized first, with progression to the forward flexion in side-lying and prone horizontal abduction with external rotation exercise. Our results suggest the prone extension and prone horizontal abduction with
external rotation exercise to promote early activation of the scapular stabilizers. Conscious correction of scapular orientation may increase pre-activation during the prone extension and side-lying external rotation exercise. However, a variety of exercises can be used for both neuromuscular and strength training purposes, as long as scapular exercises remain implemented in the training program. Our results showed the four selected exercises might be useful in the treatment of overhead athletes with mild symptoms, but further research is necessary to clarify the relevance of these exercises within a comprehensive training program.

Recent research showed good clinical results from exercise programs for patients with glenohumeral impingement on functional outcome, strength and patient satisfaction, especially when scapular exercises were an integral part of the treatment protocol. Exercise training devices providing an unstable surface (such as Redcord) may be of additional value in later stages of rehabilitation or in particular subgroups of patients with signs of glenohumeral instability. However, the current literature indicates that its use does not necessarily lead to increased muscle activation levels in the stabilizing muscle parts around the shoulder and therefore, it should be applied with constant feedback from the therapist to avoid unwanted substitution patterns by the patient. Another way to train the shoulder in these subjects is to apply principles of reactive neuromuscular training, so focusing on the dynamic stability of the shoulder. In addition, when training the glenohumeral musculature, rotator cuff exercises and heavy load eccentric training may be of interest, especially in the subgroup of patients suffering from rotator cuff tendinopathy. Finally, the focus in the exercise program can be on training in diagonal patterns with increasing resistance. Plyometric exercises to strengthen the rotator cuff and enhance the throwing accuracy and velocity of the athlete can be progressively applied. Some authors found these exercises of particular interest for overhead athletes, for example in baseball players.

In the end stage of rehabilitation, the transition from the clinic to the field may not be ignored. Wilk et al. described this as phase 4 of their nonoperative rehabilitation protocol, after sufficient treatment in phase 1 (acute phase), 2 (intermediate phase) and 3 (advanced strengthening phase) is provided. To define when a player is ready to return to sport, general guidelines have already been described. However, specific guidelines for overhead athletes with impingement symptoms are currently lacking.
addition, there is a discussion in the literature on who should take the responsibility to decide when it is safe to resume sport participation.\textsuperscript{86} Nevertheless, it is clear that traditional rehabilitation exercises cannot reproduce the speed or the joint forces generated during movements such as throwing. With this in mind, the concept of “functional training” has received a considerable amount of attention.\textsuperscript{59,125} Functional training has been defined as “training the respective muscle groups and involved areas to work in the same manner as they are used in activity”.\textsuperscript{111} Advocates of functional training point to the concept of “training specificity” to support their training philosophy. Most authors point to the value of integrating functional exercises as early as possible in the rehabilitation process.\textsuperscript{90,126} Various functional kinetic chain exercises can be integrated into the athlete’s conditioning program. Clinicians often start with exercises integrating the trunk and lower extremity, partly because it is suggested that this will increase the activation in particular shoulder muscles. However, only limited influences have been found in the current available studies, as it is also described in our fourth study on the differences between 8 variations of a scapular retraction exercise. In general, it is suggested that exercises trying to integrate the shoulder with the core and lower extremity, without actually performing the sport-specific movement, may have little value in correcting the biomechanics needed during practice and games.\textsuperscript{126} The current literature points out that neuromuscular plasticity is task-specific, and that motor programs developed by practicing only part of a movement may not carryover to the whole task.\textsuperscript{126} The exercises studied in our investigation promote the integration of the scapular retraction movement in conjunction with hip extension, coupled motions in the cocking phase of throwing. However, they cannot be considered as real sport-specific exercises. The exercises may rather be useful in the transition from traditional (muscle oriented) to more functional (movement oriented) types of rehabilitation.\textsuperscript{16} Subsequently, exercises and functional progressions should be chosen with increased awareness of the individual personal context. Employing creativity to progressively vary functional kinetic chain exercises may then lead to the neuromuscular adaptations which are responsible for improvements of the sport-specific biomechanics.\textsuperscript{113,126}

Training programs focusing on the throwing velocity have been found to have promising results for e.g. pitchers and position players in baseball.\textsuperscript{40,41} However, true sport-specific rehabilitation guidelines for overhead athletes might be preferable, for example as “interval sport programs” (ISP).\textsuperscript{5,6} ISP’s are designed to gradually return upper extremity
function after injury by slowly progressing through graduated sport-specific activities. Another goal is to minimize the chance of re-injury by performing adequate warm-ups and proper total body biomechanics during sports. Such programs have already been developed for baseball, softball, tennis and golf and may be individualized based on the playing position and the characteristics of the subject to meet the specific needs of each individual athlete.\textsuperscript{107} The subject can begin an ISP following a satisfactory clinical examination demonstrating full ROM, minimal pain or tenderness, adequate dynamic stabilization and sufficient muscle endurance and strength. By using an ISP in conjunction with a structured rehabilitation program, the athlete should be able to return to full competition status. However, one should keep in mind that performing sport-specific movements may not be the best option in every case, since repetitively performing the same movements is labeled as the cause and not as the solution for the maladaptations which are often present.\textsuperscript{91} So instead of rehabilitating the athlete with sport-specific exercises, specific retraining exercises should sometimes be preferred to limit chronic overuse, whether or not in combination with other measures such as exposure reduction.\textsuperscript{96,122,145} When an athlete still presents muscle dysfunction and signs of scapular dyskinesis, these issues should be addressed first, before progression is made to full body overhead sport movements. The latter may then be trained by focusing on sufficient levels of endurance to avoid functional fatigue which could become the origin of pain and functional limitations.\textsuperscript{127,128}

In addition to advanced insights into the rehabilitation of overhead athletes with impingement, injury prevention research has generally received greater attention.\textsuperscript{70} Recommendations for shoulder injury prevention in the overhead athlete have been developed, for example by limiting the amount of pitches thrown by young baseball players.\textsuperscript{146} To prevent overuse at the start of the season to result in an onslaught of injuries, ISP´s are also an excellent strategy for those uninjured athletes who are preparing themselves for the new season, especially when proper supervision is provided. However, the most common injury prevention method is to perform corrective exercises which make the body more tolerated to repetitive loading. The same principles as for patients apply to those training for injury prevention purposes. A comprehensive pre-participation screening can be used to define the sites for retraining in a specific case.\textsuperscript{23,24} When an injury prevention program should be integrated in the athlete’s daily routine, one could better be aware that the current insights into the
psychology of goal orientation and behavior change are applied to enhance the athlete’s motivation and adherence to the program, especially in youth sports. Some research has specifically focused on the implementation of such injury prevention strategies, which is often challenging for the therapist. Finch points to the fact that real-world implementation of sports injury intervention needs to take into account the broad ecological context in which they are introduced. Whereas the current literature focuses on intrapersonal factors, many other factors combine to influence an individual’s protective or risk-reduction behavior, such as interpersonal, organizational, community and societal levels of influence. If clinicians neglect these items, there is little chance that the current insights into specific exercise programs for overhead athletes with a high risk for shoulder impingement will prove their worth. In addition, such integral view on sport injury prevention in overhead athletes may be of tremendous importance, the more since preventing injuries and staying healthy is an issue for everybody across the lifetime. With this being stated, physical therapists and future researchers in the field of scapular exercise training may find much joy in their work when interpreting the results of their studies into this broader clinical perspective.
5. FINAL CONCLUSIONS

Overhead athletes frequently suffer from impingement symptoms, especially in the presence of scapular dyskinesis. In the treatment of these individuals, exercise training is an important component in each stage of rehabilitation. The current dissertation delivers further insight into the amplitude level and timing sequences of the scapular musculature during specific exercises.

Based on the results of the first study, it could be suggested that conscious correction of scapular orientation is an important intervention during the prone extension and side-lying external rotation exercise. The results of the second study showed that using RS does not necessarily imply that higher activation will be obtained in the muscles responsible for scapular stabilization. Since its use results in high activation in the large prime mover muscles, it is suggested that RS should only be used in later stages of rehabilitation, or as part of a general strengthening program. The third study revealed that the prone extension and prone horizontal abduction with external rotation exercise promote early activation of the stabilizing parts of the trapezius muscle. Consequently, it could be suggested that these 2 exercises might be useful in the treatment of altered timing activation patterns of the scapular muscles. In the fourth study, kinetic chain influences on the UT and LT muscle activation were studied during 8 variations of a scapular retraction exercise. Since in none of the upright exercises, significantly increased UT activation was noted compared to the seated performance, the 8 kinetic chain exercises which were studies, may be used in the transition from easy to more challenging types of rehabilitation. Standing in a squat position on the contralateral leg increased trapezius muscle activation. However, only small differences were found, suggesting minimal influence of the kinetic chain on the shoulder muscle activation. Finally, the results of the fifth study showed that athletes suffering from mild impingement symptoms can limit their continued low-grade shoulder pain and functional limitations by performing a 6-week home exercise program consisting of four exercises. However, the underlying mechanisms for these improvements are debatable, since the exercises selected on the basis of low UT/MT and UT/LT ratios altered the UT/SA ratio (and not the UT/MT and UT/LT ratio), neither the exercises were able to change the timing of muscle activation after 6 weeks of training.
The results of this dissertation add evidence to the aspect of appropriate muscle recruitment during scapular muscle training. However, there are still many issues requiring further research in this area of physical therapy, which may counter the limitations of the studies presented in this thesis. In the meanwhile, the results can be interpreted as part of a broad clinical perspective, including the existing knowledge on effective shoulder impingement rehabilitation and prevention strategies for overhead athletes.
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Part VI Nederlandstalige samenvatting
Impingementklachten ter hoogte van het glenohumeraal gewricht zijn een frequente oorzaak van schouderpijn bij bovenhandse sporters. Ze worden geassocieerd met een aantal onderliggende mechanismen en pathologieën zoals tendinopathie van de rotator cuff, glenohumerale instabiliteit, scapulaire dyskinesie en posterieure schouderstijfheid. Ondanks de etiologie multifactorieel van oorzaak is, blijft overbelasting één van de voornaamste redenen voor het ontstaan van de symptomen. De voorbije decennia is door middel van een groot aantal wetenschappelijke publicaties vrij veel inzicht ontstaan in de relatie tussen de glenohumerale en scapulothoracale gewrichten. Daaruit bleek dat de scapula een cruciale rol speelt in het veilig en efficiënt gebruik van de schouder. Heel wat studies hebben aangetoond dat disfuncties in de scapulaire spieren een belangrijke factor kunnen zijn in het ontstaan van het impingement dat zo vaak voorkomt bij diverse bovenhandse sporten zoals tennis, volleybal en baseball. Meer bepaald heeft men vastgesteld dat de stabiliserende spieren van het schouderblad (de middenste en onderste bundel van de trapezius en de serratus anterior) een tekort aan activatie vertonen. Eveneens zijn er aanwijzingen om te stellen dat deze spieren ook te laat activeren. Deze verstoorde spieractivatiepatronen worden dan ook gezien als een belangrijke oorzaak voor de veranderde bewegingspatronen van de scapula, welke kunnen bijdragen aan het ontstaan van de inklemmingsklachten van de rotatorcuffpezen onder het acromion, aangeduid als “scapulaire dyskinesieën”.

Voor de behandeling en preventie van deze disfuncties worden diverse therapeutische technieken toegepast en worden vaak oefenprogramma´s meegegeven. Herstel van scapulaire stabiliteit is daarbij één van de voornaamste doelstellingen. Onderzoekers zijn daarom op zoek gegaan naar de meest geschikte oefeningen die kunnen gebruikt worden binnen de behandeling en preventie van dergelijke klachten en disfuncties. De oefeningen hebben vooral de intentie om de verstoorde spieractivatiepatronen te herstellen. Daarom is men de spieractivatiepatronen tijdens bepaalde weerstandsoefeningen die gericht zijn op het verbeteren van de scapulaire spieractivatie uitvoerig gaan onderzoeken. Vooral oefeningen met een selectieve activatie van zwakkere spieren in combinatie met minimale activatie van hyperactieve spieren worden daarbij als relevant beschouwd. Het is echter nog niet duidelijk welke oefeningen geschikt zijn binnen deze trainingsprogramma´s, en wat het effect is van dergelijke interventies op de pijn, functionele mogelijkheden en spieractivatiepatronen.
Om dit hiat in de literatuur te dichten, werden verschillende studies uitgevoerd die dit hebben geëvalueerd.

In een eerste studie werd de invloed van het bewust corrigeren van de scapulaire oriëntatie, bij aanvang van 4 geselecteerde oefeningen, op de activatiepatronen van de trapezius onderzocht. Het correct oriënteren van het schouderblad wordt namelijk als een basisvoorwaarde gezien voor het correct uitvoeren van deze oefeningen. Daarvoor werden 30 bovenhandse atleten met tekenen van scapulaire dyskinesie geïncludeerd.

De 4 oefeningen werden uitgevoerd zonder en met de bewuste correctie van de scapulaire oriëntatie, en de hoeveelheid spieractiviteit in de 3 bundels van de trapezius werden door middel van oppervlakte electromyografie in beide condities bestudeerd. Ook de scapulaire ratio’s UT/MT en UT/LT werden berekend, omdat het tot nog toe niet duidelijk was of deze zouden worden beïnvloed door deze interventie. De 4 oefeningen waren: extensie in buiklig, exorotatie in zijlig, anteflexie in zijlig en horizontale abductie met exorotatie in buiklig. De resultaten toonden dat de activiteit in de 3 bundels van de trapezius significant waren toegenomen tijdens extensie in buiklig en exorotatie in zijlig, terwijl dit tijdens de andere 2 oefeningen niet het geval was. De ratio’s werden niet beïnvloed door het actief corrigeren van het schouderblad. In het algemeen wordt pre-activatie van stabiliserende spieren als gunstig beschouwd, vooral wanneer ook de activiteit in de bovenste bundel relatief laag wordt gehouden. Er kon dus geconcludeerd worden dat het bewust corrigeren van de scapulaire positie als een klinisch gunstige interventie kan worden beschouwd, vooral wanneer uitgevoerd tijdens de extensie in buiklig en de exorotatie in zijlig oefening. Alle oefeningen vertoonden ook gunstige scapulaire ratio’s, en dit zowel in beide condities. Verder onderzoek zou zich kunnen richten op de relatie tussen de scapulaire kinematica en de spierrecruterings patronen tijdens dergelijke oefeningen, om te zien of de veranderingen in spieractivatie vooral relevant zijn vanuit het standpunt van spierversterkende training en/of vanuit het standpunt van bewegingscorrigerende training.

In een tweede studie werd de invloed van het oefenen met Redcord slings onderzocht. Slings vormen een onstabiel oppervlak waarop gesloten kinetische keten oefeningen kunnen worden uitgevoerd. Dergelijke oefeningen worden vaak geïncludeerd in oefenprogramma’s van bovenhandse sporters omdat ze verondersteld worden de stabiliteit te verbeteren. Nochtans is het nog niet helemaal duidelijk wat de specifieke invloed ervan is op de spierrecruteringspatronen van de scapulaire en glenohumerale
Part VI Nederlandstalige samenvatting

Spieren. Oefeningen waarbij de scapulaire stabilisatoren meer worden aangesproken, terwijl de grotere glenohumerale spieren relatief weinig geactiveerd worden, zouden interessant kunnen zijn bij de groep van sporters met tekenen van scapulaire instabiliteit. Om dit te bestuderen werden 47 gezonde personen getest tijdens het uitvoeren van 4 oefeningen zonder en met de slings: half push-up, knee push-up, knee prone bridging plus en pull-up. De resultaten werden vervolgens geïnterpreteerd aan de hand van voorgaande studies die de waarde van de oefeningen inschatten op basis van hun absoluut (UT, MT, LT en SA) en relatief (UT/MT, UT/LT en UT/SA) spieractivatieniveau. In het algemeen was het zo dat niet elke spier een veranderde spieractivatie vertoonde wanneer dezelfde oefeningen zonder en met de slings met elkaar werden vergeleken. De glenohumerale spieren waren zeer actief wanneer op het instabiel oppervlak werd geoefend. Vooral de pectoralis major tijdens de push-up en de knee prone bridging oefening en de posterieure bundel van de deltoideus en latissimus dorsi tijdens de pull-up oefening. Vijf oefeningen met een lage UT/SA ratio konden worden geselecteerd: half push-up zonder en met slings, knee push-up zonder en met slings en knee prone bridging plus zonder slings. Deze oefeningen zouden van nut kunnen zijn wanneer een tekort aan SA activiteit en een teveel aan UT activiteit aanwezig is. Er kon echter geen enkele oefening worden weerhouden op basis van een lage UT/MT of UT/LT ratio. Daarom wordt geconcludeerd dat slings niet met voorkeur moeten worden gekozen wanneer men de scapulaire stabiliserende spieren wil trainen. Het kan echter wel interessant zijn om slings te gebruiken in de latere fases van de revalidatie omdat dan ook de glenohumerale spieren kunnen worden getraind.

Een derde studie behandelde de timing van de activatie van de trapeziusbundels bestudeerd in relatie tot die van de posterieure bundel van de deltoideus, en ten opzichte van elkaar tijdens dezelfde 4 oefeningen als in de eerste studie. Voorgaand onderzoek kon aantonen dat deze oefeningen de MT en LT in hoge mate activeren, terwijl ze ook de activiteit in de UT laag houden, resulterend in lage UT/MT en UT/SA waarden. In het verleden was nog niet onderzocht of deze oefeningen ook de MT en LT vroeg activeren. Oefeningen met een vroeg activatiepatroon van deze spieren zijn mogelijk relevant in de behandeling van personen die een vertraagde activatie vertonen. Daarom werd bij 30 gezonde proefpersonen de timing van de trapeziusbundels onderzocht. Intermusculaire en intramusculaire verschillen in timing werden teruggevonden. Met uitzondering van de LT ten opzichte van de PD tijdens de
extensie in buiklig, vertoonden de oefeningen extensie in buiklig en horizontale abductie met exorotatie in buiklig een activatie van de MT en LT vóór deze van de UT en PD. Tijdens exorotatie in zijlig waren de MT en LT ook actief vóór UT, terwijl tijdens de anteflexie in zijlig geen verschillen werden teruggevonden.

In een vierde studie werd nagegaan of het uitvoeren van diverse kinetische keten oefeningen een invloed had op de activatiepatronen van de bovenste en onderste bundels van de trapezius. De activiteit in de 2 spierbundels werd geregistreerd bij 30 asymptomatische proefpersonen die 8 variaties van een scapulaire retractieoefeningen uitvoerden, en de resultaten werden vervolgens met elkaar vergeleken. Ondanks lage waarden konden worden teruggevonden, bleek in elke oefening de onderste bundel van de trapezius meer actief te zijn dan de bovenste bundel, wat vaak gewenst is tijdens scapulaire revalidatietraining. De oefening waarbij de proefpersoon in een squat positie op het contralaterale been staat, vertoonde een lichte toename in de activiteit van de trapezius in vergelijking met de klassieke uitvoering in zit, maar geen verschillen tussen de bovenste of onderste bundel konden worden geconstateerd. Op basis van deze bevindingen kan geconcludeerd worden dat elk van de 8 oefeningen zinvol kan zijn in de initiële fasen van de revalidatie en dat het oefenen in een squat positie op het tegenovergestelde been de voorkeur geniet. Verder onderzoek dient na te gaan welke de mogelijke verklaringen zijn voor deze bevindingen alsook of deze oefeningen ook effectief zijn in het herstellen van de musculaire balans bij personen met schouderdisfuncties.

Tenslotte werd in een vijfde studie het effect van een scapulair oefenprogramma onderzocht bij een groep van bovenhandse sporters met impingementklachten die nog steeds actief waren in hun sport. Op basis van onderzoek uitgevoerd op gezonde individuen konden vier oefeningen worden geselecteerd om de scapulaire spierbalans en de timing van de scapulaire spieractivatie te verbeteren. Tot nog toe bestond nog geen evidentie voor de effectiviteit van deze oefeningen bij bovenhandse sporters met impingementklachten. In dit prospectief onderzoek werden 47 bovenhandse atleten met milde impingementklachten geïncludeerd. Door middel van oppervlakte-electromyografie werd de activiteit van de trapezius en SA bestudeerd tijdens het heffen van de arm in het scapulair vlak. Om de pijn en het functionele resultaat te bestuderen werd eveneens de Shoulder Pain and Disability Index (SPADI vragenlijst) van iedereen afgenomen. Veertig atleten beëindigden het programma. De SPADI scores daalden
significant van 29.86±17.03 naar 11.7±13.78 (P<.001). De drie trapeziusbundels vertoonden hogere maximale contractiewaarden en gedaalde activatieniveaus tijdens het heffen van de arm, terwijl dit niet het geval was voor de SA. Na het oefenprogramma was de UT/SA ratio gedaald, terwijl de UT/MT en UT/LT ratio dezelfde bleven (P<.05). De timing van de spieractivatie kon niet gewijzigd worden na 6 weken oefenen. Dit is dan ook de eerste longitudinale studie die aantoont dat een eenvoudig oefenprogramma bestaande uit slechts vier oefeningen (1) de relatieve trapezius activiteit kan verlagen (2) de UT/SA ratio’s veranderen (3) de pijn verminderen en de functionele mogelijkheden kan verbeteren. Deze resultaten zijn hoopgevend omdat deze atleten zo mogelijks voorkomen dat hun vage schouderklachten en functionele beperkingen een chronisch karakter krijgen.

Samenvattend kan men stellen dat de resultaten van deze onderzoeken bijdragen tot de beperkte hoeveelheid kennis die momenteel bestaat omtrent het effect van kinesitherapie bij patiënten met schouderimpingement.
1. SCAPULAR MUSCLE CONTROL EXERCISES

- Conscious scapular orientation
- Low row
- Inferior glide
- Sternal lift
- Scapular retraction step out
- Prone diagonal lifting in neutral
<table>
<thead>
<tr>
<th>Exercise</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prone diagonal lifting in external rotation</td>
<td><img src="image1" alt="Prone diagonal lifting in external rotation" /></td>
</tr>
<tr>
<td>Scapular control</td>
<td><img src="image2" alt="Scapular control" /></td>
</tr>
<tr>
<td>V-W exercise</td>
<td><img src="image3" alt="V-W exercise" /></td>
</tr>
<tr>
<td>Scapular clock exercise</td>
<td><img src="image4" alt="Scapular clock exercise" /></td>
</tr>
<tr>
<td>Wall slide</td>
<td><img src="image5" alt="Wall slide" /></td>
</tr>
</tbody>
</table>
Lawnmower

Retraction with external rotation and trunk extension

Wall washes
2. SCAPULAR MUSCLE STRENGTH EXERCISES

- External rotation in neutral
- External rotation in scapular plane
- External rotation in 90° abduction
- Scaption
- Abduction
Appendix

Prone flexion

Prone extension

Prone horizontal abduction in neutral

Prone horizontal abduction with external rotation at 125°

Prone horizontal abduction with external rotation (1)

Prone horizontal abduction with external rotation (2)

Side-lying external rotation

Side-lying forward flexion
Appendix

Prone extension in 20° abduction with external rotation

Prone external rotation in 90° abduction

Prone rowing

Supine punch

Bend one arm rowing

Reverse fly

High rowing
Press up

D1 flexion

Military press

D2 flexie

D1 extension

D2 extensie
Appendix

Knee push-up

Prone bridging plus

Half push-up

Knee prone bridging plus

Push-up
Pull up

Half push-up in slings

Knee push-up in slings

Knee prone bridging plus in slings

Pull-up in slings
3. ADVANCED EXERCISES

Anteflexion in push-up position

Extension in push-up

External rotation in side bridging

Forward flexion in side bridging

Horizontal abduction with external rotation in push-up

Retraction in push-up

Prone horizontal abduction with external rotation on Swiss ball (T raise)

High rowing in a bipodal squat position (static or dynamic)
High rowing in a lunge position (static or dynamic)

High rowing in an unipodal position (static or dynamic)

External rotation in 90° abduction with squat

Fencing

Diagonal external rotation with squat

Elevation with ipsilateral step up
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Kristof De Mey

March 2013
List of abbreviations
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>CKC</td>
<td>Closed kinetic chain</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>GIRD</td>
<td>Glenohumeral internal rotation deficit</td>
</tr>
<tr>
<td>LD</td>
<td>Latissimus dorsi</td>
</tr>
<tr>
<td>LT</td>
<td>Lower trapezius</td>
</tr>
<tr>
<td>MT</td>
<td>Middle trapezius</td>
</tr>
<tr>
<td>MVIC</td>
<td>Maximum voluntary isometric contraction</td>
</tr>
<tr>
<td>PD</td>
<td>Posterior deltoid</td>
</tr>
<tr>
<td>PM</td>
<td>Pectoralis major</td>
</tr>
<tr>
<td>ROM</td>
<td>Range of motion</td>
</tr>
<tr>
<td>RS</td>
<td>Redcord slings</td>
</tr>
<tr>
<td>SA</td>
<td>Serratus anterior</td>
</tr>
<tr>
<td>SLAP</td>
<td>Superior labrum from anterior to posterior</td>
</tr>
<tr>
<td>SPADI</td>
<td>Shoulder pain and disability index</td>
</tr>
<tr>
<td>UT</td>
<td>Upper trapezius</td>
</tr>
<tr>
<td>UT/LT</td>
<td>Ratio of upper to lower trapezius muscle activity</td>
</tr>
<tr>
<td>UT/MT</td>
<td>Ratio of upper to middle trapezius muscle activity</td>
</tr>
<tr>
<td>UT/SA</td>
<td>Ratio of upper trapezius to serratus anterior muscle activity</td>
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