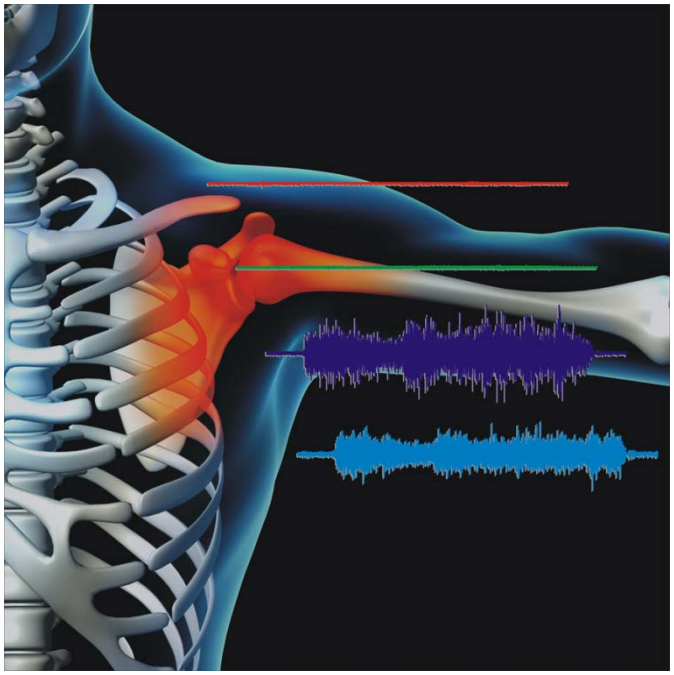
Ph.D. Thesis

Neuromuscular function in patients with Subacromial Impingement Syndrome and clinical assessment of scapular kinematics



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Odense 2013

Title page illustration:

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Preface

This thesis was accomplished at the Department of Sports Science and Clinical Biomechanics, with enrolment at the Faculty of Health Sciences, University of Southern Denmark, Odense. Supervision was provided by Professor Karen Søgaard, PhD, as the main supervisor and Associate Professor Birgit Juul-Kristensen, PhD, as co-supervisor, both from the Department of Sports Science and Clinical Biomechanics at the, University of Southern Denmark.

All experiments were performed in the Department. The studies presented in this thesis were approved by the Committee for Biomedical Research Ethics for the Region of Southern Denmark, Denmark (Project ID S-20090090) and conformed to the Declaration of Helsinki 2008.

I am grateful to the National Research Fund for Health and Disease and the Research Fund for the Region of Southern Denmark, the Arthritis Research Association, as well as the Danish Physiotherapy Research Foundation for financially supporting this PhD project.

List of papers

This thesis is based on the following three papers which will be referred to by their roman numerals in the text:

I. Larsen CM, Søgaard K, Chreiteh SS, Holtermann A, Juul-Kristensen B. Neuromuscular control of scapula muscles during a voluntary task in subjects with Subacromial Impingement Syndrome. A case-control study.
(Published in Journal of Electromyography & Kinesiology, vol. 23:5, 2013)

II. Larsen CM, Juul-Kristensen B, Olsen HB, Holtermann A, Søgaard K. Selective activation of intra-muscular compartments within the trapezius muscle in subjects with Subacromial Impingement Syndrome. A case-control study.
(Accepted for publication, Journal of Electromyography & Kinesiology)

III. Larsen CM, Juul-Kristensen B, Lund H, Søgaard K. Measurement properties of existing clinical assessment methods of scapular positioning and function. A systematic review
(Conditionally accepted and in -revision, Physiotherapy Theory and Practice)

Abbreviations

BMI	Body Mass Index
CI	Confidence Interval
CINAHL	Cumulative Index to Nursing and Allied Health Literature
COSMIN	COnsensus based Standards for the selection of health Measurement INstruments
HR-PRO	Health Related-Patient Reported Outcome
ICC	Intraclass Correlation Coefficient
MVE	Maximal Voluntary EMG
MVIC	Maximal Voluntary Isometric Contraction
LT	Lower Trapezius
LWT	Lower part of Trapezius
PICOS	Participants, Interventions, Comparisons, Outcomes, Study design
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RMS	Root Mean Square
SD	Standard Deviation
SEM	Standard Error of Measurement (Paper III)
SEM	Standard Error of Mean (Papers I, II)
SIS	Subacromial Impingement Syndrome
SA	Serratus anterior
sEMG	Surface Electromyography
UT	Upper trapezius
VAS	Visual Analogue Scale
2D	Two-dimensional
3D	Three-dimensional

Thesis at a glance

Paper/design/ material	Hypotheses/research question	Aim	Methods	Conclusion
I Case-control study 16 patients (SIS) 15 controls (No-SIS	The SIS group compared to the No-SIS group would have a higher muscle activity in the upper part of the trapezius compared to the lower part and SA, as well as higher ratios of activation and delayed timing of the onset of activity in the lower trapezius and SA.	To investigate whether the activity of the trapezius and serratus muscles is different during a voluntary arm movement task in a general population with SIS compared to a matched population without SIS.	Surface EMG Voluntary movement task (shoulder elevation)	Between-group differences in neuromuscular activity of Trapezius and SA was not confirmed. The tendency for a higher relative muscle activity in SIS could be due to a pain-related increase in co-activation or a decrease in maximal activation.
II Case-control study 15 patients (SIS) 15 controls (No-SIS	The SIS group compared to the No-SIS group would have a poorer ability to selectively activate the lower compartments of the trapezius both with and without EMG biofeedback.	To investigate whether patients with SIS were able to selectively activate the neuromuscular compartments within the trapezius muscle to the same extent as healthy controls (No-SIS) in sessions with and without EMG biofeedback, respectively.	Surface EMG Selective activation/ biofeedback	Without biofeedback, No-SIS had superior scapular muscle control. However, when provided with visual EMG feedback the SIS group performed equally as well as the No-SIS group. This indicated that individuals with SIS may benefit from biofeedback training to gain control of the neuromuscular function of the scapular muscle.
III Systematic literature review 46 articles comprising 55 assessment methods	Which clinical scapular assessment methods are available for evaluating scapular positioning and function in shoulder patients and what is the methodological quality of the clinimetric properties being examined?	To compile a schematic overview of all clinical scapular assessment methods available for clinical practice, and to critically appraise the methodological quality and relevant clinimetric results of the involved studies for each measurement property of these assessments, in order to recommend assessment methods for clinical use.	Database search Schematic overview COSMIN checklist	This review revealed a substantially larger number of clinical assessment methods for scapular position and function than previously reported. The methodological quality of the included measurement properties in the reliability and validity domains was in general 'fair' to 'poor'. None were examined for all three domains: reliability, validity and responsiveness and only a few clinical assessment methods have sufficient clinimetric properties and can therefore be recommended for clinical use.

SIS = Subacromial Impingement Syndrome, EMG = Electromyography, COSMIN = COnsensus-based Standards for the selection of health Measurement Instruments

Introduction

Subacromial Impingement Syndrome

Disorders of the musculoskeletal system are a considerable problem in western society (Paoli and Merllié 2001;Punnett and Wegman 2004). They not only contribute significantly to health care costs for the society, but they result in a reduced quality of life for the individual due to pain and functional impairment. Shoulder pain is responsible for approximately 16 percent of all musculoskeletal complaints, and shoulder impingement comprising both shoulder pain and disability is one of the most common shoulder disorders registered in primary care (House and Mooradian 2010;Ostor et al., 2005). Normally two types of impingement are described:, internal and external. Internal impingement comprises encroachment of the rotator cuff tendons between the humeral head and the glenoid rim. External or Subacromial Impingement Syndrome (SIS) is characterised by pain and shoulder dysfunction mainly with respect to forward flexion, abduction and external rotation of the shoulder. This may be due to compression and/or inflammation of subacromial structures, such as rotator cuff muscle tendons and the subacromial bursa underneath the antero-inferior aspect of the acromion and coraco-acromial ligament (Fu et al., 1991;Neer 1972), potentially caused by an inappropriate scapulo-humeral movement (Belling Sorensen and Jorgensen 2000;Page 2011). The mechanical encroachment of the soft tissue in the subacromial space takes place in the mid-range of motion, often causing a 'painful arc' during active shoulder abduction (Michener et al., 2009).

The prevalence of SIS has been found to be especially high in overhead sports, as well as in overhead work with consequent high demands for dynamic shoulder stability (Belling Sorensen and Jorgensen 2000;Cools et al., 2003;van Rijn et al., 2010).

Historic information and physical examination of patients with shoulder impingement has traditionally been a cornerstone of the diagnostic process, however, ultrasonography, magnetic resonance imaging (MRI), magnetic resonance arthrography (MRA) and arthroscopy are also used for diagnostic purposes (Ottenheijm et al., 2011;Smith et al., 2012). Generally, there is a lack of consensus regarding diagnostic criteria and the classification of shoulder disorders. A recent review and meta-analysis of clinical examination tests of the shoulder concluded that there are very few tests that appear to be discriminatory regarding diagnosis and, therefore, useful in the clinic (Hegedus 2012). Previously, shoulder impingement was described as a specific pathology or diagnosis, but today shoulder impingement is considered to be a cluster of symptoms, rather than a single pathology (Kibler et al., 2013). Therefore, a group of tests may be suggested as a diagnostic tool and this is, in fact, supported by the results in previous reviews (Hegedus 2012;Michener et al., 2009). A clinical reasoning algorithm based on a standardised sequence of clinical tests has recently been developed as a screening tool for the early detection of underlying causes of impingement syndrome, including SIS, based on various impingement related symptoms found in/reported by overhead athletes. For the classification of SIS, a battery of four commonly accepted shoulder tests has been widely used: Jobe's Test, Neer's Test, Hawkins' Test and the Apprehension Test) (Cools et al., 2008a). In a recent study, we tested this algorithm for inter-examiner reproducibility of the four selected tests and the criteria for classifying SIS based on the algorithm,

as well as the mutual dependency of the individual tests. Within the study population of overhead athletes, there was an almost perfect inter-examiner reliability of these tests and criteria for SIS, with each of the selected tests (Jobe's, Neer's, Hawkins' and Apprehension Tests) presenting high levels of agreement and reliability (Vind et al., 2011).

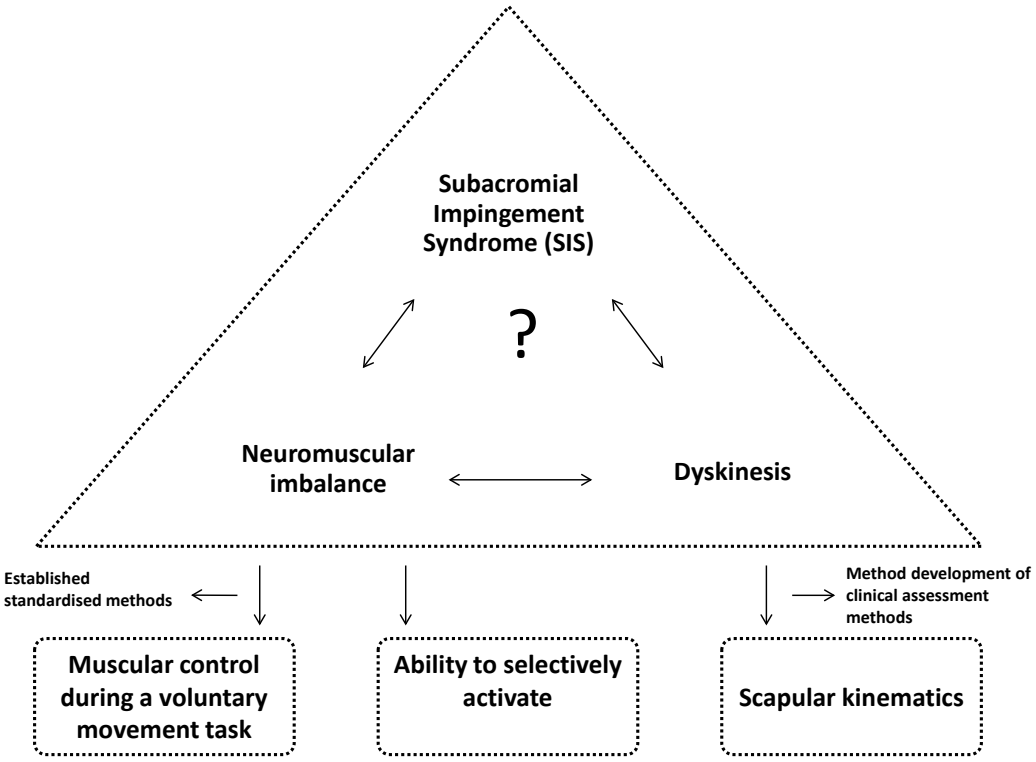

Figure 1. Conceptual framework representing a formative model of the relationships between the focal points included in this thesis (displayed within the triangle). The boxes below reflect the main focus of the three included papers.

Patho-mechanisms of Subacromial Impingement Syndrome

Figure 1 presents a possible conceptual framework for the inter-relationship between SIS and its underlying pathology. The triangular model (Figure 1) contains the multiple mechanisms described in the literature by which SIS may occur (Ludewig and Braman 2011;Michener et al., 2003).

In the gleno-humeral joint, the ball of the humerus fits onto the glenoid 'cavity' of the scapula. It is classified as a ball-and-socket joint, and due to its large range of motion the shoulder complex relies on muscles to provide dynamic stability to obtain sufficient flexibility and strength.

Functional or structural conditions may be some of the causes of subacromial impingement. A deficit in motor control or strength (functional condition) leading to low activity or force contribution in any of the agonistic muscles must be compensated for by increased activity of the synergistic muscles or muscle subparts. This may lead to overload and eventually to impaired function of the compensating muscles. The changed share of the muscle loading can be seen as a muscular imbalance that can lead to changes in arthro-kinematics and

movement impairments involved in impingement and may ultimately result in structural damage (Page 2011). In addition, anatomic abnormalities of the humerus and/or acromion (structural condition) have been implicated in impingement (Zuckerman et al., 1992).

Besides the requirement of the scapula to move in a coordinated manner with the moving humeral head, 1) it must move laterally and medially along the thoracic wall to allow the upper extremity to be placed in different positions, 2) it must rotate upwards as the arm is raised so that the rotator cuff and humeral head can pass beneath the acromion structures, 3) it provides a base for muscle attachment of the scapular stabilisers, and lack of stabilisation can cause abnormal motion of the humeral head relative to the glenoid fossa, and 4) it acts as a link in the kinetic chain and is an essential component for the proximal-to-distal transfer of velocity, energy and forces to the upper extremity (Kibler 1998). During shoulder elevation, asymptomatic subjects normally rotate the scapula upwardly, externally and with posterior tilt. In patients with shoulder impingement, a decreased upward rotation and a reduced posterior tilt of the scapula have been demonstrated. These deviations in scapular motion may be particularly problematic since they potentially bring the greater tuberosity into closer contact with the coraco-acromial arc, with a risk of impinging the underlying structures (Struyf et al., 2011a).

Neuromuscular imbalances

Alteration in neuromuscular activity is an aspect of the neuromuscular scapular function which is thought to be related to SIS, and represents the vertex on the left side of the triangle´s base (Figure 1). During scapular rotation the serratus anterior (SA) works closely in 'force couples' with the upper (UT), middle (MT) and lower parts (LT) of the trapezius (Inman et al., 1944;Kibler and McMullen 2003). Such close coupling of SA and LT muscles may reduce the UT loading, thereby providing a balanced control of scapular orientation and rotation (Inman et al., 1944). The neuromuscular control and coordination of the scapular muscles is considered a main factor for scapular kinematics (Michener et al., 2005) and various parameters have previously been used to describe an impaired scapular neuromuscular activity. Some authors reported a high mean activity in the UT (Chester et al., 2010;Cools et al., 2004;Cools et al., 2007a;Lin et al., 2006;Ludewig and Cook 2000) and a low mean activity in SA in subjects with SIS as compared with subjects without SIS during arm motions in low and high loading conditions (Ellenbecker and Cools 2010;Lin et al., 2006;Ludewig and Cook 2000). Further, a higher ratio of relative activation of the UT and LT (Cools et al., 2007a), and a delay in timing of the onset of shoulder muscle activation during standardised tasks is reported for the MT, and the LT muscle in SIS subjects compared with healthy controls (Cools et al., 2003;Moraes et al., 2008;Wadsworth and Bullock-Saxton 1997). Moreover, longer latencies of muscle activation in the affected shoulder compared with the non-affected shoulder were found for all three parts of the trapezius and SA muscles (Moraes et al., 2008).

The neuromuscular imbalance has mostly been reported during restricted movement tasks. These include maximum isokinetic strength tasks, i.e. concentric protraction/retraction (Cools et al., 2004), isokinetic arm abduction, external rotation (Cools et al., 2007c) and sudden arm perturbation (Cools et al., 2003). Few studies

have included voluntary movements, such as arm elevation (Lin et al., 2006;Moraes et al., 2008) and lifting (Ludewig and Cook 2000), which more closely reflect activities of daily living. Moreover, the included study populations have often been young male overhead athletes (Cools et al., 2003;Cools et al., 2004;Cools et al., 2007a) or middle-aged overhead workers (Ludewig and Cook 2000). Studies have shown SIS to also be provoked by work-related risk factors other than overhead activities, e.g. highly repetitive work and forceful exertion in work, awkward postures, and high psychosocial job demands (Frost and Andersen 1999;van Rijn et al., 2010). However, imbalance of scapular muscle activation has not been studied in a more general SIS population during a voluntary movement task.

Therefore the first part of this thesis was a comparison of the neuromuscular control between SIS cases and controls, and this particular topic is addressed in Paper I.

Biofeedback as muscular stimulator

Measurement and evaluation of scapular neuromuscular activity can be performed in several ways. An imbalance in the muscle compartments of the trapezius in subjects with impingement could also arise from a reduced ability to selectively activate the lower parts of the trapezius, which act as a main stabiliser of the scapula. This aspect of reduced ability to selectively activate muscle compartments is the second part of this thesis, illustrated in the middle of the base of the triangle (Figure 1). A central element in rehabilitation of patients with SIS is to maintain or restore normal activation of the intra-muscular parts of the trapezius muscle (Cools et al., 2008b;Ellenbecker and Cools 2010;Holmgren et al., 2012). Motor control of the trapezius muscle refers to the timing and control of the different intramuscular subdivisions of the muscle which can be independently controlled. In this aspect, it remains unclear if SIS patients lack efficient motor control strategies for the trapezius muscle. A promising and recommended approach for (re)learning functional motor control in rehabilitation settings is electromyographical (EMG) biofeedback (Basmajian 1981). In EMG biofeedback training, electronic equipment is used to instantaneously reveal certain physiological events. Subjects can be taught to control these otherwise involuntary events by manipulating the displayed signals (Basmajian 1981). This technique is believed to allow subjects to learn how to control the activities of muscles, including their roles as stabilisers/force couples during movements (Basmajian 1981;Holtermann et al., 2010). Previously, EMG biofeedback with visual guidance was shown to be effective in selective activation of intra-muscular compartments within the trapezius muscle of healthy subjects (Holtermann et al., 2009). Specifically, all subjects were able to selectively activate intra-muscular compartments of the trapezius muscle (e.g. the lower), while voluntarily deactivating other intra-muscular compartments (e.g. the upper) after approximately one hour with EMG biofeedback guidance (Holtermann et al., 2009). The application of EMG biofeedback in clinical settings may thus be a promising approach for training and restoring scapular muscle balance in patients with neck and shoulder disorders (Vollenbroek-Hutten et al., 2005;Weon et al., 2011). Since an imbalance in these muscle compartments of the trapezius in SIS could be due to a reduced ability to selectively activate the muscle, it is valuable to know whether patients with shoulder disorders have a poorer ability than healthy subjects to selectively activate these intra-muscular compartments and if they can

benefit from biofeedback. Therefore neuromuscular control of the trapezius muscle was investigated to determine the ability to selectively activate subdivisions of the muscle in patients with SIS compared with healthy controls. This topic is covered in Paper II.

Scapular dyskinesis

The complex relationship between dyskinesis, muscular imbalance and SIS is illustrated in the right corner of the triangle´s base in Figure 1. In addition to evidence of altered motor control, the presence of a changed scapular kinematics among SIS patients as theoretically assumed, should be investigated. Further, is it possible at this stage to detect a potential neuromuscular imbalance displayed as altered kinematics with clinically reliable and valid measures of both the static and dynamic scapular function? Clinically, muscle imbalance of the scapular stabilising muscles is usually characterised as scapular dyskinesis. The word ´dyskinesis` is composed of, *'dys'* (alteration of) *'kinēsis´* (movement). It is the general term reflecting the loss of normal control of scapular motion during coupled scapula-humeral and scapula-thoracic movements (Comerford and Mottram 2001;Kibler and McMullen 2003;Mottram 1997). Scapular dyskinesis is often qualitatively described as winging or pseudo-winging. As early as in 1723, Winslow reported the first case of scapular winging, and later in 1837, Velpeu described scapular winging from SA dysfunction as a condition developed due to a long thoracic nerve palsy (Simovitch et al., 2006). The descriptions that follow clearly show that the scapular position/function has been an object of particular attention for centuries.
An alternative term that is often used interchangeably 'dyskinesia'. However, dyskinesia is applied to abnormally active (voluntary) movements mediated by neurologically controlled factors such as tardive dyskinesia. Since there are many other factors that can cause the altered position and motion, the more inclusive term dyskinesis is preferred in the current thesis. Dyskinesis by itself is not an injury or a musculoskeletal diagnosis. Scientifically, multiple causative factors exist for scapular dykinesis e.g. bony (e.g. fractures) and joint-related factors (e.g. glenohumeral joint internal derangement), as well as neurological factors (e.g. Long Thoracic Nerve Palsy). More common causative mechanisms of scapular dyskinesis seem to involve the soft tissue, such as alterations in the scapular stabilising muscles (Kibler et al., 2012). Furthermore, the scapular dyskinesis concept is regularly integrated into the rehabilitation process, despite an apparent lack of specificity regarding the nature of the pathology (Bak 2010;Baskurt et al., 2011;De Mey et al., 2012;Kibler et al., 2001;Ludewig and Braman 2011). Clinical evaluation of scapular dyskinesis constitutes a challenge due to the three-dimensional (3D) movements of the scapula and the inaccessibility due to a superficial layer of soft tissue on top of the scapula, complicating direct measurements of its bony positioning. Numerous assessment methods have been developed to assess the degree of scapular dyskinesis objectively: visual evaluation and quantitative measurements of static and dynamic scapular positioning in relation to the trunk by 3D electromagnetic devices (Ludewig et al., 2002;Ludewig and Cook 2000;Morais and Pascoal 2013;Shaheen et al., 2013), as well as two-dimensional (2D) , more clinically applicable methods (Johnson et al., 2001;Juul-Kristensen et al., 2011;Tate et al., 2009). However, clinimetric outcome measures of the clinical scapular assessment methods differ and some are even lacking (Struyf et al., 2012). Reliability is a necessary

condition for a measurement to be considered valid or responsive to change, and it is essential to determine whether a measurement is valid (truly represents what is being measured), and if it can detect clinically important changes before and following rehabilitation interventions (responsiveness) (da Costa et al., 2010;Mokkink et al., 2010c). Furthermore, to be of value, clinical tests must have acceptable diagnostic accuracy since the findings of clinical tests and measurements are used by clinicians to inform the clinical reasoning process (Lewis and Valentine 2007). Since advanced equipment (i.e. with a capacity for 3D motion analysis) is rarely available in the clinic, the clinician needs applicable assessment tools to classify scapular dyskinesis. The increasing focus on evidence-based rehabilitation of shoulder pain patients also requires proper clinical tests that can detect and examine changes after a treatment approach (De Mey et al., 2012;Ellenbecker and Cools 2010;Struyf et al., 2013).

Narrative and anecdotal reviews have previously been conducted within this area offering clinician and therapist recommendations for some reliable and valid clinical assessments of both static and dynamic scapular positioning in patients with shoulder disorders (Kibler et al., 2012;Kibler and Sciascia 2010;Nijs et al., 2007;Uhl et al., 2009). However, these reviews have not included a systematic literature search or a methodological quality appraisal of the involved studies. Only one very recent, systematic review exists on diagnostic accuracy of selected scapular physical examination tests, concluding that none of the tests was found to be useful in differentially diagnosing pathologies of the shoulder (Wright et al., 2012). The relationship between dyskinesis and shoulder symptoms is unclear. Scapular dyskinesis may directly cause, contribute to, or be the result of, shoulder symptoms, but it may also exist in asymptomatic shoulders. Therefore, the goal of a proper scapular assessment is to be able to identify altered scapular position/motion (dyskinesis), determine a relationship between dyskinesis and symptoms, as well as identify the underlying causative factors for the positioning or movement dysfunction (Kibler et al., 2013). An apparent diversity in the results of clinical scapular assessment methods argues for the research to summarise the evidence on the methodological quality of these studies, and on the basis of the evaluated measurement properties, discuss which assessment methods, if any, seem most appropriate to use in daily clinical practice. Therefore, the first approach was to systematically scrutinise the literature of what was already known and critically appraise the methodological quality of the involved studies. This topic is covered in the last paper, Paper III, of this thesis.

Aims of the thesis

Overall aims

The overall aims of this thesis were to examine potential impairments in neuromuscular function using EMG in patients with Subacromial Impingement Syndrome (SIS) and to evaluate the clinical assessment methods for scapular kinematic abnormalities (scapular dyskinesis).

Specific aims

1. To investigate whether the activity of the trapezius and serratus muscles is different during a voluntary arm movement task in a general population with SIS compared to a matched population without SIS (Paper I).

    a. Hypothesis: The SIS group compared to the No-SIS group would have a higher muscle activity in the upper part of the trapezius compared to the lower part and SA, as well as higher ratios of activation and delayed timing of the onset of activity in the lower trapezius and SA.

2. To investigate whether patients with SIS were able to selectively activate the neuromuscular compartments within the trapezius muscle to the same extent as healthy controls (No-SIS) in sessions with and without surface EMG biofeedback, respectively (Paper II).

    a. Hypothesis: The SIS group compared to the No-SIS group would have a poorer ability to selectively activate the lower compartments of the trapezius both with and without EMG biofeedback.

3. To compile a schematic overview of published clinical scapular assessment methods available for clinical practice (Paper III), and

4. To critically appraise the methodological quality of the involved studies on the measurement property of these assessments in order to identify the best assessment method (Paper III).

    a. Research question: Which clinical scapular assessment methods are available for evaluating scapular positioning and function in shoulder patients and what is the methodological quality of the clinimetric properties being examined?

Methods

Papers I, II

Participants

The study design was a case-control study using a convenience sample of patients and controls, group-matched on age and gender, recruited from physiotherapy clinics and from among acquaintances. For the SIS group, the inclusion criteria were at least 30 days with pain/discomfort in the shoulder/neck region within the last year (Juul-Kristensen et al., 2006), but no more than three regions of pain/discomfort in order to exclude generalized musculoskeletal diseases. In relation to the clinical diagnosis of SIS we included an algorithm for clinical reasoning that is widely used by clinicians. To qualify a SIS case, two or more positive impingement tests based on the Jobe, Neer, Hawkins and Apprehension Tests were required (Cools et al., 2008a). As described in the introduction of this thesis, we assessed the reliability of this clinical algorithm in a previous study and found high levels of agreement and reliability (Vind et al., 2011). For the healthy control group (No-SIS), the inclusion criteria were less than 8 days with pain/discomfort in the shoulder/neck region during the last year, as well as no more than three regions of pain/discomfort elsewhere (Juul-Kristensen et al., 2006), and no positive impingement tests. Males and females in the age of 20-65 years were included in both groups. Overall exclusion criteria were: history of severe shoulder-neck pathology/trauma, orthopaedic surgery, documented life-threatening diseases, cardiovascular diseases, rheumatoid arthritis, generalised pain, adverse psycho-social conditions or pregnancy, and positive clinical tests for cervical radiculopathy (i.e. Spurling A Test, Neck Distraction Test, Involved Cervical Rotation Test (less than 60°) (Wainner et al., 2003). The inclusion and exclusion criteria were identified via a questionnaire and detailed interview, validated in previous studies (Andersen et al., 2008;Sandsjo et al., 2006;Sjogaard et al., 2010), as well as a clinical examination of the upper limb and neck. A detailed overview of the recruitment flow is shown in Figure 2.

Table 1. Baseline characteristics of study participants included in Papers I & II

Population	Paper	N (no.)	SEX (Females, Males)	Age (years)	BMI (kg/m^2)	VAS (1-100) (Pre-test)	VAS diff. (Pre-Post test)
SIS patients	I	16	8 F 8 M	41 ± 14	25 ± 3	24.3 ± 22	7.8 ± 15
Controls	I	15	8 F 7 M	39 ± 12	24 ± 2	1.8 ± 3	4.6 ± 10
SIS patients	II	15	8 F 7 M	40 ± 13	26 ± 3	26 ± 3	8 ± 15
Controls	II	15	8 F 7 M	39 ± 12	24 ± 2	1.8 ± 3	4.6 ± 10

BMI = body mass index (body weight/height^2); VAS = Visual Analogue Scale, pain reported before test; VAS diff = Difference in VAS score reported before/after test.

A total of 69 subjects volunteered to participate. However, six subjects were excluded during a preliminary telephone interview because of severe disease or trauma. In total, 63 fulfilled the inclusion criteria, 59 accepted the invitation to participate in a screening procedure, and of these, 22 subjects were excluded due to the above exclusion criteria, inadequate data collected (n=3), or drop out due to personal circumstances (n=3).

Subjects who, based on the screening procedure, qualified as either a SIS case or a healthy control (No-SIS) (n=31) were invited to participate in the study, comprising 16 subjects with SIS (8 women and 8 men) and 15 No-SIS (8 women and 7 men). In Paper II, one additional subject was excluded due to inadequate EMG biofeedback data collection. Demographic details of subjects included in Papers I and II are shown in Table 1.

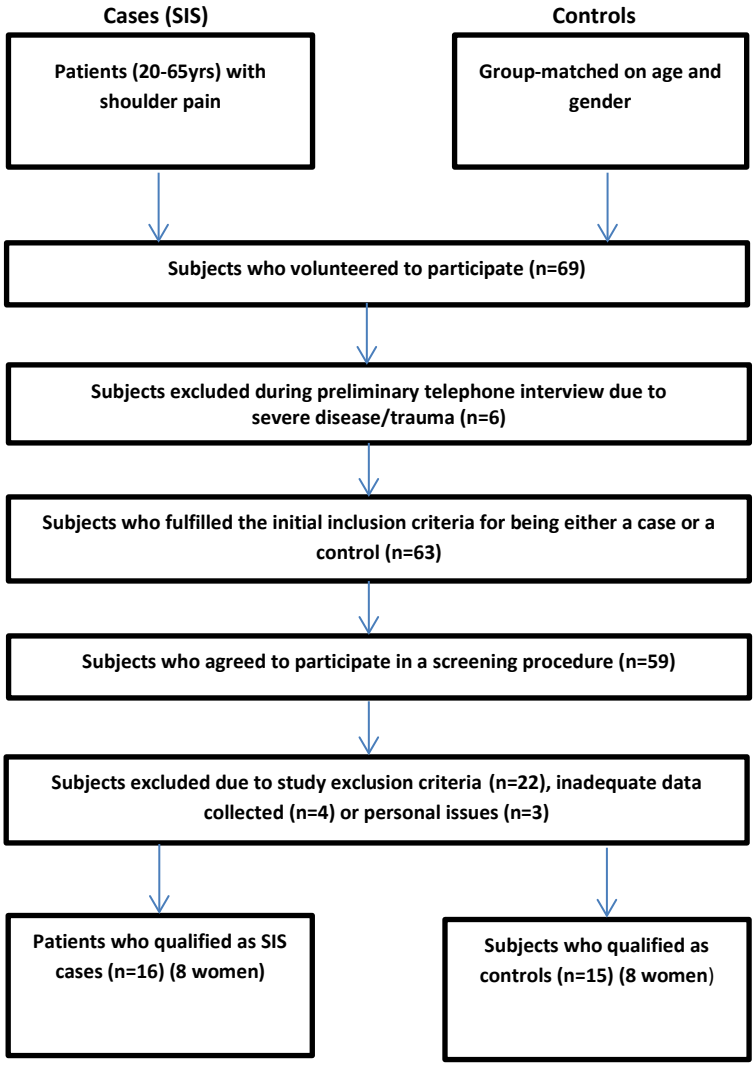

Figure 2. Flow-chart of the project recruitment process of Subacromial Impingement Syndrome patients and controls.

Subjects' physical activity level and occupational background were reported at the clinical examination. By answering 'yes' to participation in sporting activities, the level of physical activity was reported, ranging from no strenuous exercise to very strenuous exercise. Additionally, information on the type of sporting activities, the number of hours a week and the overall level (regular, competition, elite) of participation were also provided. Regarding occupational background, subjects reported the type of work, the number of hours a week engaged in work, and if the work was physically homogeneous, e.g. mostly sitting.

All subjects were informed about the purpose and content of the project and gave informed written consent to participate. The study conformed to the Declaration of Helsinki 2008 (Vollmann and Winau 1996) and was

approved by the Committee for Biomedical Research Ethics for the Region of Southern Denmark, Denmark (Project ID S-20090090).

Electromyography measurements

For an overview of outcomes in Papers I and II, see Table 2.

Instrumentation

Bipolar circular surface electromyographical (EMG) electrodes (10 mm diam, Ambu R Blue Sensor M, Olstykke, Denmark) were placed at the anatomical subdivisions: UT, MT, and LT of the dominant/involved trapezius and SA muscles during prone lying. For Paper II, EMG recordings were obtained from four anatomical subdivisions of the trapezius muscle (i.e., clavicular, descending, transverse and ascending dominant/involved trapezius muscle). A normal standardised procedure for electrode positions was used (Holtermann et al., 2009;Holtermann et al., 2010). All electrodes were placed in line with the muscle fiber directions with an inter electrode distance of 2 cm (Hermens et al., 2000), with reference electrodes at the acromion and the C7 vertebra.

Pain intensity was evaluated on a 10 cm Visual Analogue Scale (VAS) (Wewers and Lowe 1990) before and after the tests. Surface EMG was recorded from the trapezius and SA of the involved arm in SIS subjects, (dominant arm of the No-SIS subjects). For normalisation of the EMG signals to Maximal Voluntary Electrical activity (MVE), all subjects initially performed maximal voluntary isometric contractions (MVIC) for each of the parts of the trapezius and SA muscles. The resting signal level of surface EMG data was collected for 30 s in the resting prone lying position. All maximal contractions of the trapezius and SA were performed bilaterally with bilateral resistance, provided proximal to the elbow joints in an externally rotated shoulder position. Three attempts of 5 s duration were performed with verbally encouragement, with 1 minute´s rest in between. For the clavicular and descending MVE, the subject performed isometric arm elevation in a standing position with both arms elevated to 90 degrees in the scapular plane. For the transverse and ascending MVE, the subject performed arm abduction in the prone lying position, with both arms horizontally abducted to 90 and 180 degrees in the scapular plane, while for the SA MVE, the subject performed isometric arm protraction during supine lying with the arms elevated to 90 degrees, with bilateral resistance (Cools et al., 2007b;Ekstrom et al., 2005;Holtermann et al., 2009). The peak root mean square (RMS) value recorded during MVE was used for EMG normalisation (% MVE). EMG signals were amplified (gain 400) and analogue band pass filtered with a second order Butterworth filter with cut-off frequencies at 10-400 Hz and they were then sampled at 1000 Hz (16 bit CED 1401, Spike2 software, Cambridge Electronic Devices, UK).

Table 2. Overview of outcomes in Papers I, II, III

Outcomes	Paper I	Paper II	Paper III
Surface electromyography recordings (EMG)			
Magnitude of activation (%MVE)	x		
Ratio of activation (%MVE)	x		
Onset difference between muscles (sec)	x		
Selective activation, "active" (i.e.>12%MVE) and "rest" (i.e<1.5%MVE) of muscle compartments		x	
Selective activation (%), ratio (i.e.≥95%) between muscle compartments		x	
Systematic literature search			
Number of clinical assessment methods			x
Clinimetric outcome measures (e.g. reliability, validity, diagnostic accuracy)			x
Quality assessment (COSMIN)			
Domains (e.g. reliability, validity) and measurement properties assessed (e.g. construct validity/criterion validity)			x
COSMIN score (4-point rating scale, i.e., 'poor', 'fair', 'good', or 'excellent')			x

Experimental procedure and data reduction

In Paper I, the movement task was a shoulder elevation task performed under three conditions: 1) no external load, 2) holding a 1 kg load, and 3) holding a 3 kg load (Figure 2). The order of load conditions was not randomised. Arm movements were performed bilaterally with extended elbows in the scapular plane, from 0 degrees to maximum arm elevation (up), followed by lowering (down) to 0 degrees (Ludewig and Cook 2000). The movements were guided with a metronome, to ensure a similar speed in each task, and the subject was verbally guided. Each trial consisted of 2 s elevation (concentric) and 2 s lowering (eccentric), followed by 4 s pause, with five repetitions per block (loading) condition (Figure 3). There was a 1 min pause between each loading condition. The EMG amplitude was calculated by RMS with a moving window (1 s duration and moving in 100 ms steps) during the maximal EMG recording. Due to activity coherence (pre-analysis) the % MVE of the middle and lower part of the trapezius were pooled in the analysis (called LWT). The onset of muscle activity was defined by visual inspection of the EMG signal (Hodges and Bui 1996). The time periods for the painful arc, between 60° – 120° part of the 180° swing during concentric and eccentric muscle work (Michener et al., 2009) were 0.7s long, starting 0.7 s after the visually determined onset and from the most elevated point of motion, respectively:

$$\textit{Time period starts at:} \qquad t(60°) = \left(\frac{60°}{180°}\right) + 2\,\text{sec} \Rightarrow t(60°) = 0.667\ sec$$

$$\textit{Time period stops at:} \qquad t(120°) = \left(\frac{120°}{180°}\right) + 2\,\text{sec} \Rightarrow t(120°) = 1.334\ sec$$

The peak RMS value recorded during MVE was used for EMG normalisation (%MVE). Moreover, the analysis of %MVE was based on the mean of trials 2, 3 and 4 under the conditions of no-load, 1kg, and 3kg.

Normalised muscle activity level (%MVE) of all muscles and activation ratios between UT, LWT and SA were calculated for the periods of painful arc.

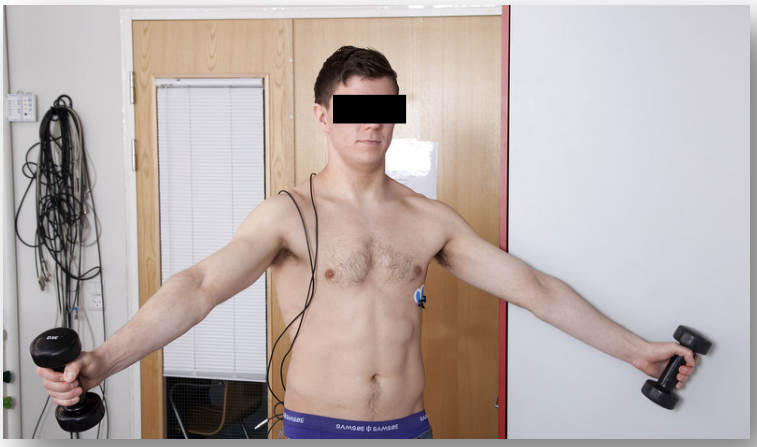

Figure 3. Voluntary movement task (No-load. 1 kg, 3 kg).

Onset difference was given as the time delay between e.g. UT and LT, where a negative value represents initial activity in UT before LT activity, whereas a positive value represents the initial activity in LT (Figure 4).

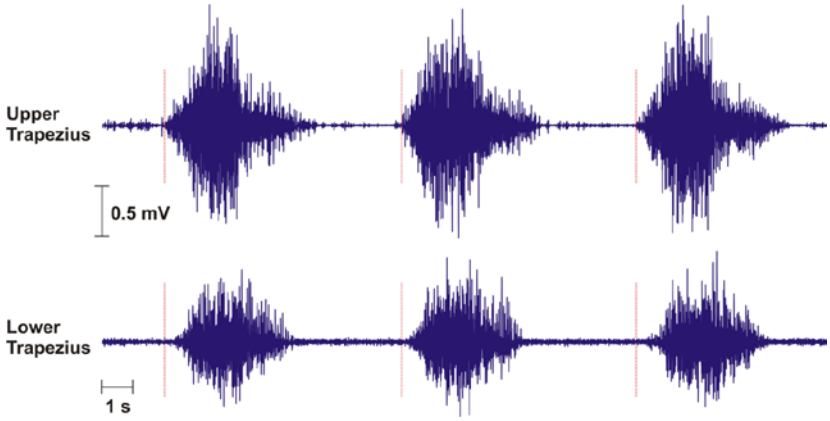

Figure 4. Raw electromyograms from UT and LT, illustrating that onset difference was given as the time delay between the two compartments.

In Paper II, including a biofeedback session, the subjects lay prone on a bench with appropriate head support and arms alongside the body and were told not to move their arms, shoulders and head. The subjects received on-line biofeedback of muscle activity from each anatomical compartment, visualised by horisontally displayed EMG signals on a monitor (Figure 5). The subjects were allowed about 10 minutes to familiarise themselves with the biofeedback information during the trapezius activity. We conducted a slightly modified version of a protocol used by Holtermann 2009 which had six selective activation tasks of the anatomical compartments, where each one lasted 3 minutes including visual biofeedback (Holtermann et al., 2009). Each task was introduced and explained with standardised verbal cues and a light touch on the skin by the experimenter.

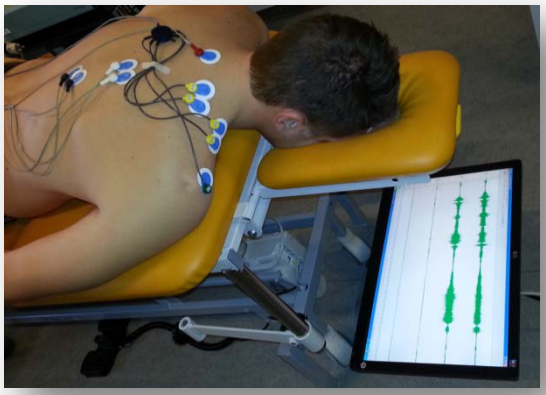

Figure 5. Picture of experimental setup and electrode placement at clavicular, descending, transverse and ascending compartments of the trapezius muscle. Reference electrodes (REF) was placed at the acromion and C7.

Subsequent to the session with biofeedback, the screen was turned off and the subject was given three attempts of 30 s each to perform the selective activation in the absence of EMG biofeedback. During the course of the experiment, the lead experimenter was blinded to the subjects' status (SIS, No-SIS). The EMG amplitude was calculated by RMS with a moving window (1 s duration and moving in 100 ms steps) throughout the entire EMG recording. The lowest RMS value (average of 2 s duration) during the 30 s of the instructed rest period was subtracted from the entire EMG recording. The ability to selectively activate was evaluated based on two definitions: first, isolated activity in the respective muscle compartment above 12% MVE with activities in the remaining compartments below 1.5% MVE; and second, during the attempt to selectively activate, the activation ratio was calculated as the activity of the respective muscle compartments (two upper or two lower) relative to the total activation in all muscle compartments in one second time bins. In detail, for both the two upper and two lower compartments normalised EMG RMS amplitudes, the measurements from the two compartments were computed as a percentage of the summation of the total normalised EMG RMS amplitude. For each task, the largest one s value was taken as the peak value. Selective activation was obtained when the peak value was equal to, or exceeded, 95 % of the summed activation (definition 2). The second definition allowed some activity in the non-selected muscle parts by focusing on the relative activation, while the first definition emphasised the depression of activity to resting level in the non-selected muscle parts.

Statistics

Sample size calculation

In Paper, I the sample size calculation was based on previous results (Ludewig and Cook 2000), showing a standard deviation of 40% in MVE and a 20% difference in MVE between the two groups with a sample size of 26 in each group. In this present study, a 30% difference was required as a clinically meaningful difference. Based on these data, a power calculation of 80% and an alpha level of 0.05 revealed a minimal sample size of

14 subjects to be sufficient in each group. However, we included a minimum of 15 subjects to be able to account for missing data. In Paper II, a sample size calculation was not conducted a priori due to a lack of comparable data. According to the knowledge that informed this thesis, no data exist regarding a minimum clinically relevant size of a difference in selective activation. Also, we could not find any existing studies on the ability and variation of selective activation among shoulder patients. Therefore, it was not possible to conduct a proper power analysis. However, the size of this exploratory study was estimated partly on the basis of studies in the literature that showed clinically relevant differences in physiological variables in shoulder patients and partly on the experience of our research group with selective activation among healthy subjects (Holtermann et al., 2009;Holtermann et al., 2010).

Basic statistics

The independent t-Test and Fisher's Exact Test (1-sided) were used to compare subject characteristics between cases (SIS) and controls (No-SIS) (Papers I, II).

Paper II: For each group, successful selective activation from both definitions 1 and 2 were summed and a Fisher's Exact Test (1-sided) was applied to test between-group differences. Furthermore, means and standard error of the means were calculated for activation ratios of both lower and upper compartments, and since data were normally distributed, the independent *t*-Test and paired *t*-Test were used to test between- and within-group differences, respectively.

Multivariate statistics

Paper I: For each of the three muscles: SA, UT and LWT, the dependent variables were relative muscle activity of the muscle parts, activation ratios between the muscles and onset differences within all muscles. A linear mixed model was used to evaluate group differences for each dependent variable with 'subject' as the random effect and adjusted for 'group' (SIS/No-SIS), gender (M/F), load (no-load, 1 kg, 3 kg), age and body mass index (BMI). The interaction effect between group and load was also included in the model. The residuals of the linear mixed models were checked for normal distribution. If data did not follow the Gaussian distribution, they were log-transformed or ranked before analysis, but in the figures and tables, they are still presented as non–log-transformed means or medians. To specify potential significant main effects Bonferroni post hoc tests were subsequently performed. A Spearman's Rank Order correlation analysis was performed (rs) to assess the relationship between the pre-test VAS score and relative and ratio muscle activity in SA, UT and LWT for all loading conditions. Furthermore, a correlation was run to determine the interrelatedness between muscles.

All statistical analyses were performed with the Statistical Package for Social Sciences (PASW), version 18.0.0 (released July 30, 2009) and a pre-specified level of significance was considered to be $p<0.05$.

Paper III

For an overview of outcomes in Paper III, see Table 2.

Design and selection criteria

In Paper III, a systematic review was conducted and reported according to the protocol outlined by PRISMA (Moher et al., 2009) using a research question framed by the PICOS methodology - **P**articipants (shoulder pain/healthy), **I**nterventions (clinical scapular assessment methods used to evaluate scapular position and/or function), **C**omparisons (e.g. control group), **O**utcomes (e.g. reliability) and **S**tudy design (e.g. reliability study). Selection criteria and methods of analysis were specified in advance and documented in an unpublished protocol. The overall method used in this review can be divided into four steps: 1) Compile an exhaustive list of scapular assessment methods on the basis of an initial search (Search 1); 2) Additionally search for studies including clinimetric outcome measures of the identified assessment methods (Search 2); 3) Critically appraise the methodological quality of the identified measurement properties in each study; and 4) Identify the assessment methods with acceptable results in the domains of validity and reliability as well as responsiveness, from studies which best meet the standards for acceptable methodological quality. Furthermore, the review sought to recommend clinical scapular assessment methods on the basis of acceptable results in the domains of validity and reliability as a minimum.

With no restrictions on the date of publication, the included articles had to meet the following criteria in Search 1:

-be originally published in peer-reviewed journals involving human participants with a minimum age of 18 years.

-include a clinical assessment method aimed at evaluating scapular position and function (both observational and quantitative measurements).

-be reported in English.

Studies were excluded if they contained:

-3D analysis as the primary clinical assessment and not as a reference assessment.

-only information that had previously been published and was already included in this review.

-only abstracts or theses.

On the basis of Search 1, Search 2 was initiated and the articles were included if they:

- explicitly outlined a purpose for evaluating clinimetric properties of a scapular assessment in order to be included in a critical appraisal of the methodological quality of the selected studies.

-included at least one of the clinimetric properties of reliability and validity.

To avoid confusion in relation to the terminology of clinimetric properties, this paper relates to the COSMIN terminology defined as follows:

***Reliability**: Measurement error*: expressed by the standard error of measurement (SEM), the smallest detectable change (SDC), or limits of agreement (LOA) and minimal important change (MIC) and *Reliabiliy;* the proportion of the total variance in the assessment, which is due to 'true' differences between subjects. This aspect is reflected in the intraclass correlation coefficient (ICC) or Cohen's Kappa (Mokkink et al., 2010c;Schellingerhout et al., 2011).

***Validity**: Criterion validity:* the extent to which scores from an assessment method are an adequate reflection of a 'gold standard'. If both the gold standard and the assessment method (index test) under study have a dichotomous outcome, the criterion validity of the assessment method, also referred to as the diagnostic accuracy, is expressed by sensitivity and specificity. Depending on the various levels of measurement for the gold standard and the index test, different statistical parameters can be calculated, which include: sensitivity/specificity pairs, likelihood ratios, diagnostic odds ratios, receiver operating characteristic curves (ROCs), ICCs and Bland and Altman plots (Bossuyt et al., 2011;Griner et al., 1981;Habbema et al., 2008).

Construct validity: the degree to which the scores/measurements of a clinical assessment are consistent with the hypotheses. Construct validity can be evaluated on the relationship with scores of other instruments, or on differences between groups/subjects who are known to have the condition and those who do not (discriminative ability). Correlation coefficients are most often calculated (Mokkink et al., 2010b;Mokkink et al., 2010c;Portney and Watkins 1993).

***Responsiveness**:* the ability of an assessment to detect change over time in the construct to be measured. Responsiveness is an aspect of validity. Approaches are (i) correlation between change scores of two measures which should be in accordance with predefined hypotheses, and (ii) calculation of area under the receiver operating characteristic curve (AUC) (Mokkink et al., 2010c;Schellingerhout et al., 2011).

Studies were excluded if they only reported information that had previously been published in another paper that was already included in this review.

Search strategy and data Sources

A search strategy was developed and used for a comprehensive computer-assisted literature search in four databases (Medline, CINAHL, SPORTDiscus and EMBASE) from inception to June 2011. Reference lists in articles and methodology literature were also screened for publications. In order to make sure no relevant articles would be left out, the literature search was divided into two phases (Searches 1 and 2) (Figure 6). The decision on relevant studies was made based on titles and abstracts by two of the researchers. For studies that appeared to meet or potentially meet the inclusion criteria, based on the title and/or abstract, the full paper was obtained for detailed assessment. The references contained in retrieved articles were also screened for additional relevant studies.

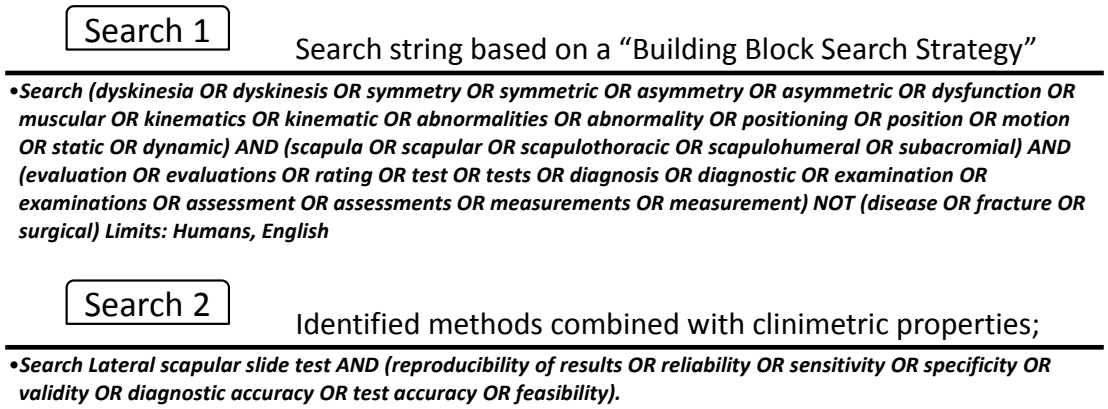

Figure 6. Search strings from Searches 1 and 2.

Two author pairs (CML/BJK and CML/KS) independently assessed the results of the literature search (half the articles for each pair) and agreed upon a final list of assessment methods to be included in the current review. If there were any disagreements, they were discussed and resolved by consensus. If necessary, a third person was consulted (KS or BJK). From Search 1, the compiled list of names was made of all identified clinical assessment methods. In Search 2, each name for the identified methods was used as a term for a further search of the electronic databases combined with clinimetric properties.

A flow chart showing the number of articles remaining at each stage in Search 1 describes the selection process (Figure 7). Search 2 was administred by the first author.

Data extraction and quality assessment

Data extraction regarding study design, characteristics of the study population, clinical assessment, sampling procedure, as well as clinimetric outcome measures were performed by the first author. To assess the methodological quality, the **CO**nsensus-based **S**tandards for the selection of health **M**easurement **IN**struments (COSMIN) checklist were applied (Mokkink et al., 2010a;Terwee et al., 2011). Since the COSMIN checklist primarily was developed to evaluate the methodological quality of studies on measurement properties of health-related patient-reported outcomes (HR-PROs), a modification was necessary. This modification was carried out after personal communication with an experienced user of the checklist, as well as with one of the authors of the checklist (Terwee CB).

The measurement properties to be assessed include the three domains of reliability, validity (diagnostic accuracy incorporated), and responsiveness (Terwee et al., 2011).

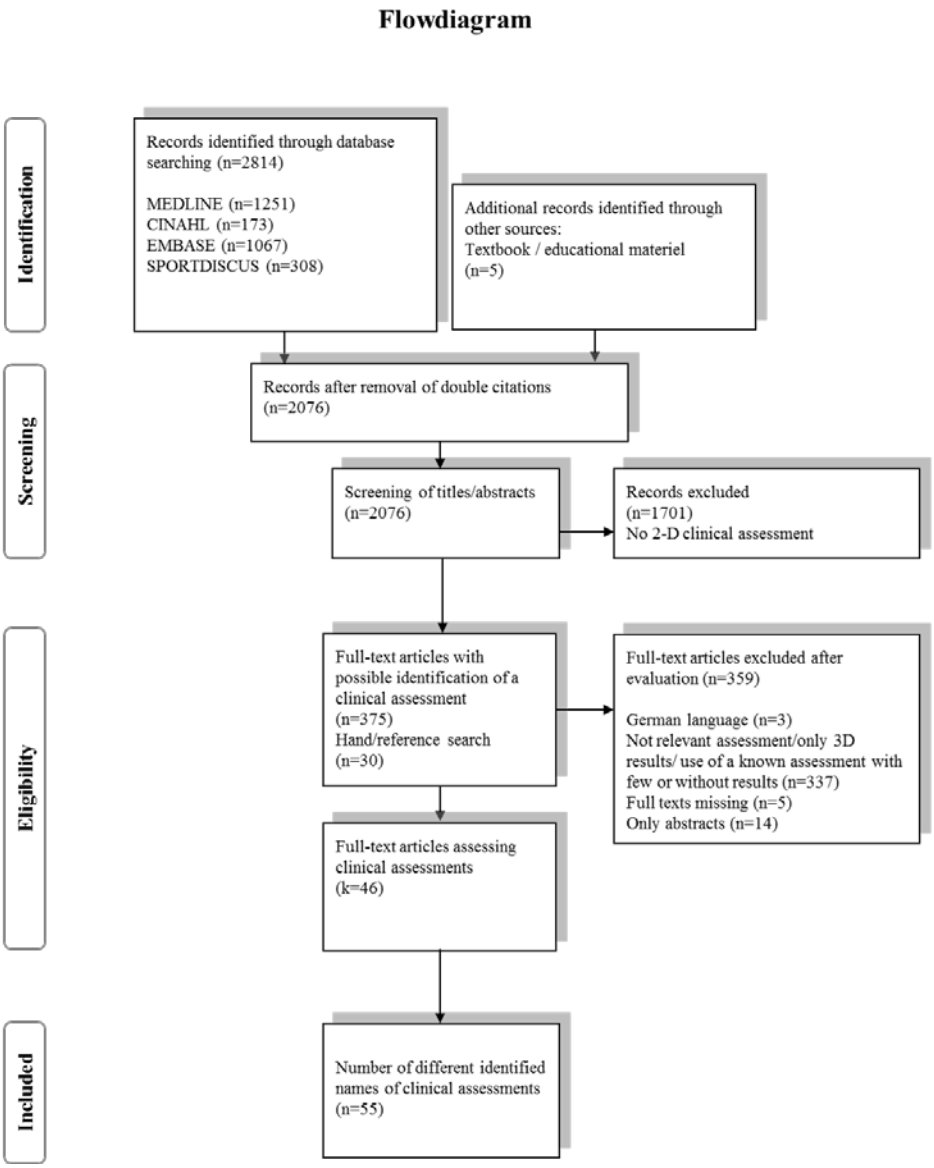

Figure 7. Flow diagram of articles reviewed (k) and inclusion of clinical assessment methods (n).

For Paper III, a modified version of the COSMIN checklist was used consisting of five boxes was included: box A - Reliability (14 items), box C - Measurement error (11 items), box F - Hypotheses testing (10 items), box H - Criterion validity (9 items), box I - Responsiveness (18 items) (Additional information in Paper III) (Mokkink et al., 2010b;Terwee et al., 2011).

The COSMIN checklist has been examined for inter-rater agreement and reliability of each item score of the checklist. Overall, percentage agreement was appropriate (68% was above 80% agreement), and the kappa coefficients for the COSMIN items were low (61% were below 0.40, 6% was above 0.75) due to the need for subjective judgment, and familiarity with different standards, terminology and definitions. The authors subsequently adjusted/improved the instructions for using the COSMIN checklist into the current version, but still recommend training and practice in rating the studies (Mokkink et al., 2010a).

In the COSMIN checklist, a number of items are included in all boxes because they refer to general design issues relevant for the quality assessment of all measurement properties, such as: “Was the percentage of missing items given?”, “Was there a description of how missing items were handled?”, “Was the sample size included in the analysis adequate?” and finally “Were there any important flaws in the design or methods of the study?”.

Items related to adequate sample size specifically refer to HR-PRO-instruments, and attention was paid to the impact of the item ‘small sample size’ (<30) on the final property score, meaning that regardless of the scores of other items, the property would be rated as ‘poor’ if the sample size was small.

The score ‘minor methodological flaws’ and ‘other important methodological flaws’ were given according to predefined criteria (Paper III).

Each item was scored on a 4-point rating scale (i.e., ‘poor’, ‘fair’, ‘good’, or ‘excellent’), in the COSMIN checklist. An overall score for the methodological quality of a study was determined for each measurement property separately, by taking the lowest rating of any of the items in a box. The methodological quality of a study was evaluated for each measurement property. In order to evaluate studies on diagnostic accuracy, the following two items were added in box H (criterion validity), based on a previous checklist assessing diagnostic accuracy studies (30): “Was there an independent handling of the index test/reference test?” and “Was there an appropriate sampling of the target population?” The construction of these two items was carried out according to the COSMIN approach, meaning that the lowest score possible justified an overall ‘poor’ property score. For a precise description of the included measurement properties and associated items, refer to the COSMIN homepage (http://www.cosmin.nl).

The assessment of (methodological) quality of the reliability and validity domains, respectively, was done in author pairs independently (CML and BJK) and (CML and KS). In the case of disagreement between the two reviewers, there was a discussion in order to reach consensus. If necessary, a third reviewer (KS or BJK) was consulted and consensus was established. Table 7 presents the clinimetric results per assessment method on a general level (presented in detail in Paper III). For interpretation and categorisation of results, previously suggested guidelines/cut-off criteria on ICC (Fleiss 1986), Kappa (Landis and Koch 1977) and correlation coefficients (Cohen 1988) were applied.

Analysis and synthesis

All extracted descriptive information, both the general information and the information related to all scored items of the included measurement properties, was synthesised and presented in tables.

Results

Paper I, II

Demographics

In both Papers I and II, the two groups were similar regarding age, sex and BMI. As expected, a significantly higher level of pre-test pain (measured on a VAS) was found for SIS, but there was no significant difference between groups in the change in pain levels from pre- to post-test (Table 1).

The majority of subjects in both groups were to some extent physically active (gymnastics, walking, running, cycling etc.) in their leisure time. Only a few subjects from each group had overhead work as a part of their job or participated in overhead sports on a regular basis. None were elite overhead athletes. The occupational background of the included subjects was rather broad, however, most of them had office work as their primary task.

Neuromuscular activity

Paper I: By and large, no significant differences between groups were found. Results showed no significant interaction effects (group * load) for the mean muscle activity for any of the muscle parts, nor any significant main effect of group (UT (p=0.30), LWT (p=0.11), SA (p=0.10)). However, SIS displayed a non-significantly higher relative level of muscle activity in all muscle parts during all loading conditions. As expected, a significant effect of load was found and post hoc comparison revealed significantly higher relative activity of all muscle parts in all load/no-load conditions in both the SIS and No-SIS groups ($p \leq 0.001$) (Figure 8).

For activation ratios, no differences were demonstrated between the SIS and No-SIS groups. No significant interaction effects were observed when comparing group and loading conditions for any of the muscle pairs. In addition, no significant main effects of group (SIS vs. No-SIS) were found (UT/LWT (p=0.98), UT/SA (p=0.83) and LWT/SA (p=0.80)) (Figure 9). For both groups, the activation ratios of UT/SA and UT/LWT showed a higher relative activation of UT, indicated by a ratio between 1.21-1.54, whereas the LWT/SA ratio ranged from 0.89-1.11, indicating similar relative activation.

No differences were found in muscle activity onset when SIS subjects were compared with No-SIS subjects. The interaction effects (group * load) of onset differences between all muscle pairs were non-significant and similar results were observed for the group main effects for all muscle pairs (UT-LWT (p=0.98), UT-SA (p=0.78) and LWT-SA (p=0.53)). Load had a significant effect on the differences in onset between UT-LWT and UT-SA ($p \leq 0.05$) displayed as delay in activity of LWT and SA, especially in loading conditions. The Bonferroni corrected tests showed a significantly larger difference in onset activity for UT-SA at no-load and 3 kg compared with 1 kg in both the SIS and No-SIS groups. For the onset difference between LWT-SA, similar onset times were demonstrated (Paper I). No significant relationships were observed between VAS pain score and relative muscle activity (r_s=0.046-0.313, p=0.092-0.808), as well as for ratio values (r_s= -0.064-0.124, p=0.514-0.736). Significantly positive relationships were observed for the activity between all

three muscles (r_s=0.385-0.510, p=0.003-0.03), however, the relationship for no-loading conditions were not statistically significant.

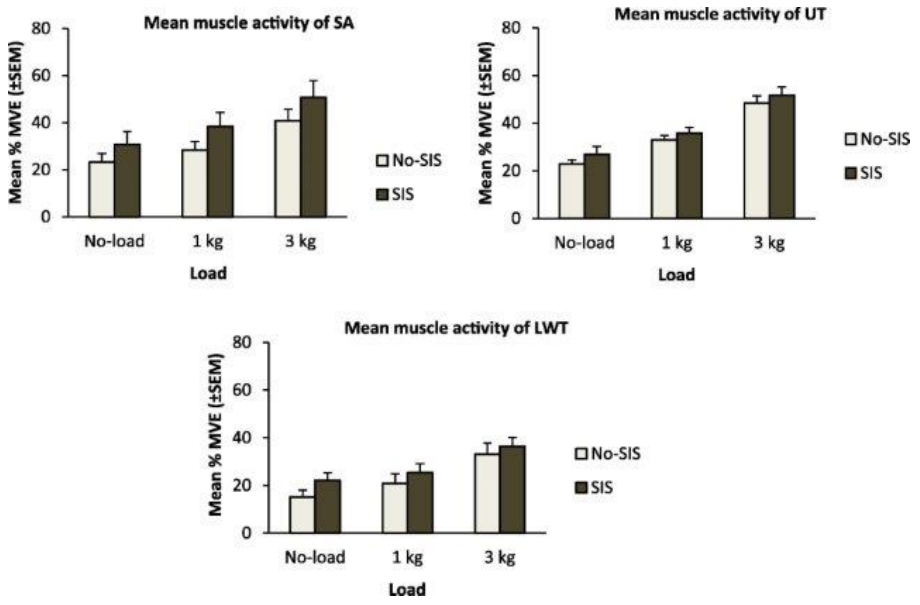

Figure 8. Muscle activity of Serratus Anterior (SA), Upper trapezius (UT) and lower trapezius (LWT) in SIS (n=16) and No-SIS (n=15) groups. Muscle activity is expressed as percentage of maximal voluntary EMG for each muscle. Group data are shown as mean % EMG (SEM) during a voluntary arm movement task with no-load, 1 kg and 3 kg.

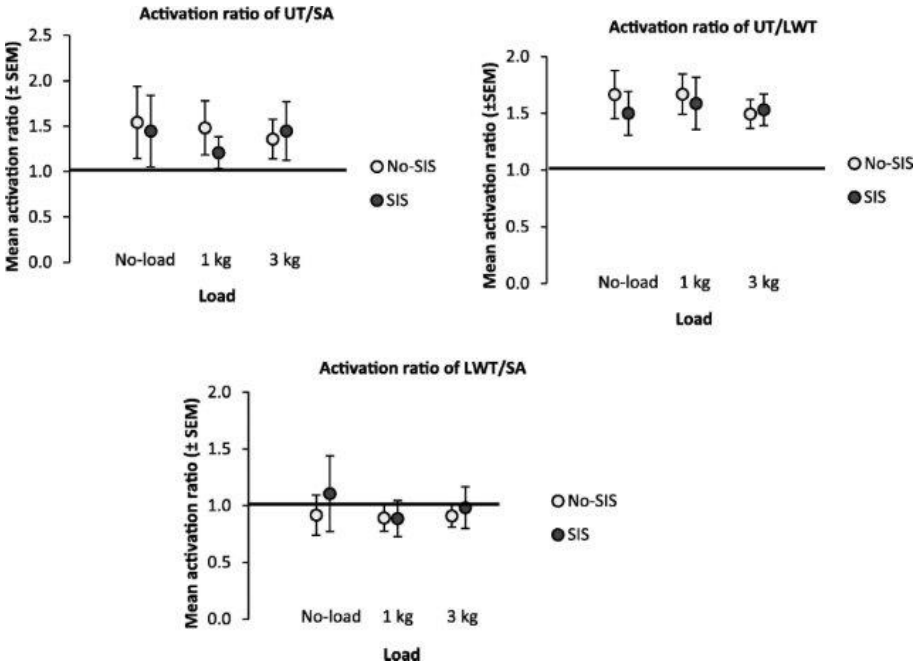

Figure 9. Activation ratio of muscle activity for Serratus Anterior (SA)/Upper trapezius (UT), and UT/lower trapezius (LWT), as well as LWT/SA in SIS (n=16) and No-SIS (n=15) groups. Data are shown as mean % EMG-(SEM) during a voluntary arm movement task with no-load, 1 kg and 3 kg.

Selective activation with EMG biofeedback

Paper II: No differences were found between the groups (SIS vs. No-SIS) during the two tasks involving selective activation (>12% EMGmax) of the lower (transverse and ascending) and upper (clavicular and descending) compartments, respectively, while keeping the remaining muscle compartments at rest (<1.5% EMGmax). Approximately half of all subjects in the SIS (8/15) and No-SIS (8/15) groups (p=1.00) attained selective activation of the lower compartments by voluntary command. Furthermore, one subject from each of the SIS and No-SIS groups succeeded in selectively activating the upper compartments.

Regarding the peak activation ratio, the first column in Table 3 shows that with the use of biofeedback there was no difference between the SIS and No-SIS groups in mean peak activation ratios of lower or upper compartments (p=0.65-0.92) (between-group p-values are not included in Table 3).

Table 3. Selective activation ratios with and without biofeedback (definition 2).
Values are calculated as ratios (lower/upper compartments) for all subjects in each group, SIS (n=15) and No-SIS (n=15). Group data are shown as mean % of total activation (SEM) in a biofeedback-guided session, followed by a session without biofeedback according to definition 2 (activation ratio).

	Activation ratio With Biofeedback Mean (SEM)	Activation ratio Without Biofeedback Mean (SEM)	Between-session difference (p-value)
Selective activation of lower compartments (def.2)			
SIS group	95.6% (1.5)	90.5% (1.6)	(p≤.05)
No-SIS group	96.4% (0.7)	93.4% (1.1)	(p≤.05)
Selective activation of upper compartments (def.2)			
SIS group	85.7% (2.1)	67.5% (3.8)	(p≤.001)
No-SIS group	85.3% (3.3)	70.2% (3.7)	(p≤.001)

In addition, the majority of subjects in both groups (SIS=12/15, No-SIS=10/15) (p=0.34) attained high activation ratios (equal to or higher than 95%) of the lower compartments, as opposed to the upper compartments where only one subject from each group displayed high ratios of activation (p=1.00) (Results not displayed in tables).

Figure 10 illustrates examples of raw and normalised RMS values from the two lower and two upper compartments with biofeedback provided from the upper and the lower compartments of trapezius, respectively.

Selective activation without EMG biofeedback

Paper II: In the absence of EMG biofeedback, significantly fewer subjects in SIS group than in the No-SIS group (0/15 vs. 5/15) were able to fulfill the requirements of selective activation of the lower compartments, according to definition 1 (p=0.02). In contrast, none of the subjects were able to selectively activate the upper compartments without the lower compartments, or a single compartment without the remaining compartments when deprived of EMG biofeedback (Table 4). In relation to definition 2, the second column in table 3 shows no differences between SIS and No-SIS subjects in lower and upper compartments of mean peak activation ratios (p=0.17-0.61). As further shown in Table 3, both the SIS and No-SIS groups displayed a significantly lower activation ratio of the lower and upper compartments without EMG biofeedback compared with EMG biofeedback (p<0.05 vs. p<0.001). However, as displayed in Table 4, significantly fewer SIS than No-SIS

subjects (3/15 vs. 9/15) attained an activation ratio equal to or higher than 95% of the lower compartments (p=0.03), compared to the upper compartments, where none of the SIS or No-SIS subjects reached this activation ratio.

Table 4. Selective activation without biofeedback (definition 1 and 2).
Summation of subjects in SIS (n=15) and No-SIS (n=15) who were able to fulfill the requirements of selective activation in lower and upper compartments in a session without biofeedback from both definition 1 (>12% EMGmax / <1.5% EMGmax) and 2 (activation ratio).

	Lower Without biofeedback Sum. of subjects	Between-group difference (p-value)	Upper Without biofeedback Sum. of subjects	Between-group difference (p-value)
Selective activation (>12% / <1.5% EMGmax) (def.1)				
SIS group	0/15	(p=0.02)	0/15	(p=1.00)
No-SIS group	5/15		0/15	
Selective activation (activation ratio) (def.2)				
SIS group	3/15	(p=0.03)	0/15	(p=1.00)
No-SIS group	9/15		0/15	

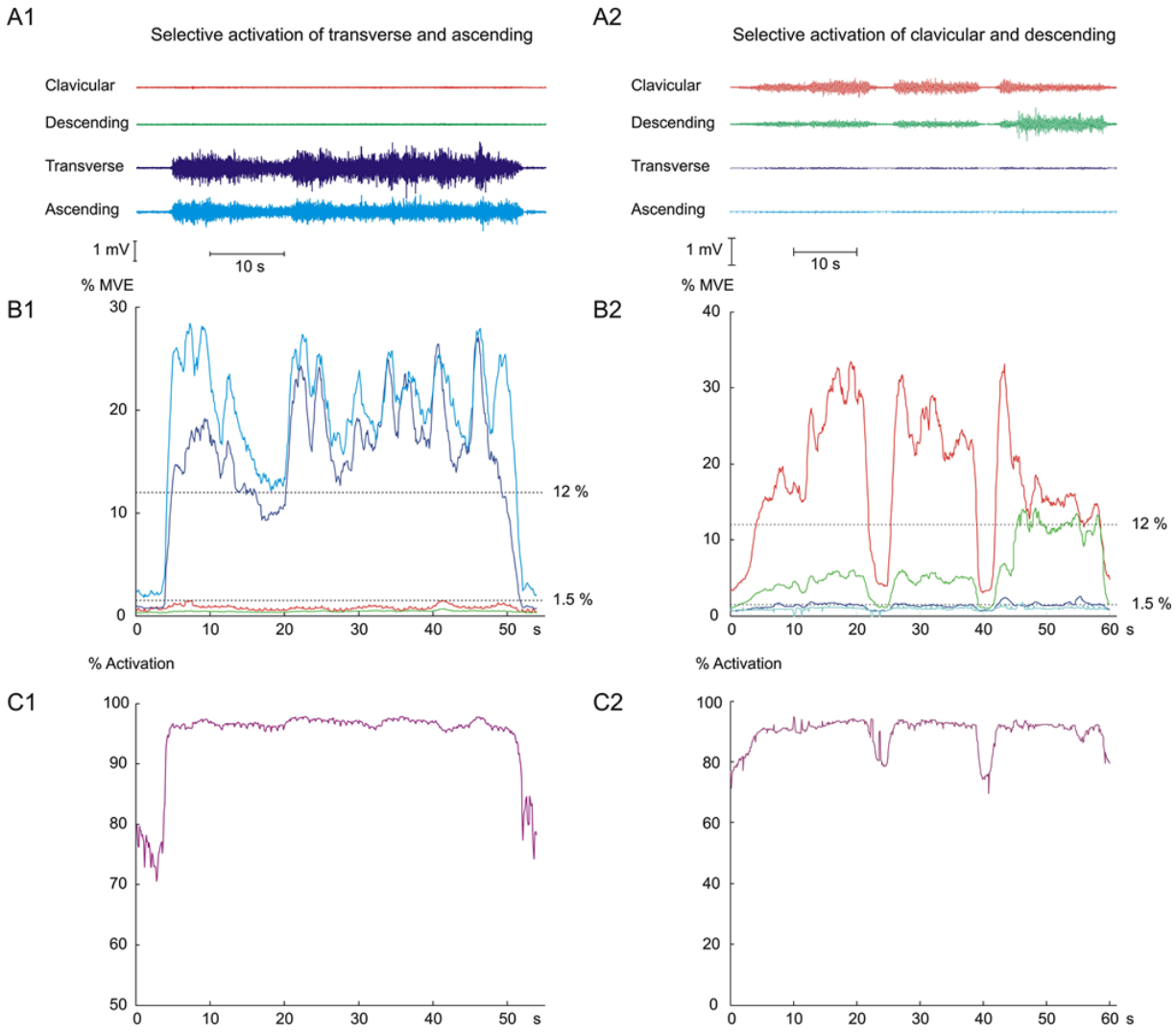

Figure 10. Left and right column show selective activation of the lower (transverse and ascending) and upper (clavicular and descending) compartments, respectively. A: Raw electromyograms from all four compartments, B: Normalised RMS values from all four compartments. The threshold for "active" (i.e.>12%MVE) and "rest" (i.e<1.5%MVE) are indicated by horizontal dotted lines. C: Activation ratio between upper and lower compartments.

Paper III

Literature search and quality assessment

The strategy of Search 1 yielded 2814 records (MEDLINE n=1251, CINAHL n=173, EMBASE n=1067, SPORTDISCUS n=308) (Figure 7). Of these, 738 duplicates were removed, leaving 2076 titles with abstracts for screening. Due to the lack of a clinical assessment method, 1701 records were excluded. After this first step of screening, 405 full-text articles were retrieved where identification of an assessment method might have been possible, and from these, a list of a total of 55 different names for clinical assessment methods was compiled. Table 5 presents a list of all the identified clinical assessment methods in alphabetical order distributed into three groups (n=55): Static positioning assessment (measurement/observation during static positioning) (n=19), Semi-dynamic positioning assessment (static measurement/observation in different joint positions) (n=14), and Dynamic functional assessment (observation during dynamic movement/isometric hold) (n=22) (Figure 11). Despite having different names, several of the assessments methods were more or less similar in method description. The subsequent search on names of clinical assessment methods (Search 2) did not yield any additional assessment methods and provided no further information on clinimetric properties of already identified assessment methods from Search 1. Finally, 46 articles were included in this review and the general characteristics of these studies are presented in Paper III, Appendix 1. Of these, 31 studies, comprising 38 assessment methods, have included the aim of evaluating one or more clinimetric properties of the assessment method, and the following domains/properties were included: Reliability domain - reliability n=27, measurement error n=18; and Validity domain - hypotheses testing n=4, criterion related validity n=12. In 12 studies, both the reliability and validity domains were assessed. The remaining 15 of the 46 studies, comprising 22 assessment methods (five of which were examined in other studies), only included a description of the assessment method and/or presented limited clinimetric outcome measures with no aim to evaluate clinimetric properties of the assessment method. These assessment methods have been left out for further evaluation. None of the included studies aimed at addressing responsiveness validation, and consequently the responsiveness domain could not be assessed. The methodological quality of each measurement property in the separate studies is presented in Table 6 in alphabetical order.

Figure 11: Examples of the three clinical assessment categories.

A: Static positioning assessment (distance from inferior angle to nearest spinous process), **B:** Semidynamic positioning assessment (upward rotation with the use of inclinometers). **C:** Dynamic functional assessment (visual observation of scapular movement).

By COSMIN definition, the methodological quality of the included properties was 'poor' to 'fair'. In a single study, the property concerning validity reached the score of 'good'. The results per assessment group will be presented below (static, semidynamic and dynamic positioning assessment method) for studies with a 'fair' or 'good' property score. The rating results for those lower score studies which would have been rated 'fair' if the sample size had been higher are identified with an asterisk in Table 6.

Static positioning assessment

In this group, 10 of the 12 presented assessment methods are included in seven studies (Gibson et al., 1995;Juul-Kristensen et al., 2011;Lewis and Valentine 2008;Lewis and Valentine 2007;Neiers and Worrell 1993;Peterson et al., 1997;Plafcan et al., 1997) where properties in both the reliability and validity domains were rated as having 'fair' methodological quality (Tables 6 and 7).

Overall, the results of the static scapular positioning assessments demonstrate both acceptable intra- and inter-rater reliability, with ICC ranging from 0.61- 0.99, Kappa 1.00 and ICC 0.91-0.97, respectively (Paper III, Table 7). However, for the 'normalised scapular abduction' assessment (Neiers and Worrell 1993), the reliability of normalised scapular distance could not be established (ICC 0.34) due to high levels of measurement error. Despite the relevance of results on measurement error, two studies comprising four assessment methods did not report such results (Juul-Kristensen et al., 2011;Peterson et al., 1997), however in one study, data were provided to calculate LOA (Juul-Kristensen et al., 2011).

Criterion-related validity was addressed in two assessments (Lewis and Valentine 2007;Peterson et al., 1997) (Paper III, Table 7). The Lewis and Valentine study examined the diagnostic accuracy of the 'Pectoralis minor length test' using an expert physician diagnosis, that included impingement and instability shoulder disorders as a criterion, and reported high sensitivity (100%) but very poor specificity (0%), demonstrating sufficient evidence for ruling in, but not ruling out, shoulder dysfunction (Lewis and Valentine 2008). Peterson et al. addressed the criterion validity between radiographic measurement and measures of scapular resting position and forward shoulder posture as the distance between the cervical spine and the anterior tip of the acromion (Peterson et al., 1997). However, the validity of these methods could not be established due to a questionable 'gold standard' and large intra-subject variability. Although the correlation coefficients ranged from 0.57 to 0.77, the standard errors of the estimates (SEE) were relatively large (1.14-1.41). A single study assessed the discriminative (construct) validity of three methods for alignment, lower horizontal distance and scapular winging during rest, and reported that the trapezius myalgia cases with the largest lower horizontal distance from inferior angle to the spine reported general health to be significantly worse than the controls with the smallest lower horizontal distance (cm) (2.33 vs. 3.00, p=0.003 (Juul-Kristensen et al., 2011)).

Semi-dynamic positioning assessment

Six of nine assessment methods were reported in eight studies (da Costa et al., 2010;Gibson et al., 1995;Johnson et al., 2001;Juul-Kristensen et al., 2011;Koslow et al., 2003;Odom et al., 2001;Shadmehr et al., 2010;Struyf et al., 2009) with all the properties rated as having 'fair' methodological quality (Tables 6 and 7).

The measurement error properties were assessed in all eight studies, but one (Koslow et al., 2003). By and large, the semi-dynamic positioning methods possessed adequate levels of intra-rater reliability with ICC ranging from 0.64 to 0.97. However, more varying and less reliable results were demonstrated for inter-rater reliability, especially in Kibler´s Lateral Scapular Slide Test (LSST) and in modified versions of the initial method description (Gibson et al., 1995;Odom et al., 2001;Shadmehr et al., 2010). For several years, the LSST has been used as a clinical test to evaluate scapular position/movement asymmetry, since it measures the displacement of the inferior angle along the thoracic wall while the arms are abducted to 0º, 45º and 90º. In the current study, it represented the most frequently described assessment method. This assessment method's inter-rater reliability was generally low, depending on a number of factors including the level of humeral elevation, and in some studies it had large SEM values. The calculations of ICC varied from 0.18 to 0.95. Three studies assessed the criterion validity of the LSST and used physician/orthopedic diagnosis/referral as a criterion standard for shoulder dysfunction in a symptomatic versus a non-symptomatic population (Koslow et al., 2003;Odom et al., 2001;Shadmehr et al., 2010) (Paper III, Table 7). Both the Koslow et al. and the Odom et al. studies demonstrated poor diagnostic accuracy, whereas the Shadmehr et al. study found high sensitivity (83-100%), but low specificity (4-26%). Johnson et al. examined the criterion validity for another assessment method of scapular upward rotation and demonstrated 'good' to 'excellent' validity for inclinometry compared with a magnetic tracking device under semi-dynamic and dynamic conditions (Johnson et al., 2001). Semi-dynamic comparisons between both instruments (r=0.74-0.92) showed a better correlation than did static inclinometer measures, compared with magnetic tracking device measurements during dynamic movements (r=0.59-0.73). One study assessed the construct validity of the travelling distance of the inferior angle during flexion in shoulder/neck cases and controls, but the test did not show any discriminative ability in relation to work ability or general health (Juul-Kristensen et al., 2011).

Dynamic functional assessment

In this dynamic assessment group, eight of the 22 assessment methods were included in six studies (Juul-Kristensen et al., 2011;McClure et al., 2009;Rabin et al., 2006;Struyf et al., 2009;Tate et al., 2009;Uhl et al., 2009) where all properties were rated as having 'fair' methodological quality and one study included one domain rated as having 'good' methodological quality (Tate et al., 2009) (Tables 6 and 7).
In all studies where it was relevant, the measurement error property was assessed (Paper III, Table 7).
One of the studies assessed intra-rater reliability of four clinical methods including manual and observational assessment of dynamic scapular movement and found satisfactory reliability (ICC 0.64-0.73, Kappa 0.84-1.00) (Juul-Kristensen et al., 2011). One other study examined the inter-rater reliability of a shoulder symptom alteration test (Modified SAT) and reported a moderate reliability, classifying the method acceptable for clinical use (Rabin et al., 2006). Juul-Kristensen et al. also assessed the discriminative (construct) validity of the included dynamic assessment methods of initial scapular movement and scapular winging with/without weight, but this validity could not be established (Juul-Kristensen et al., 2011).

McClure et al. (McClure et al., 2009), Uhl et al. (Uhl et al., 2009), and Struyf et al. (Struyf et al., 2009) assessed inter-rater reliability for different clinical observational assessment methods and found that reliability was moderate under most of the studied conditions, Kappa ranging from 0.48-0.61, 0.41-0.44 and 0.42-0.78, respectively (Paper III, Table 7). However, the assessment methods were simple and rated as useful for clinical practice. The criterion-related validity property was assessed in two studies comparing the criterion of a three-dimensional with an observational assessment method, the Scapular Dyskinesis Test (SDT) (Tate et al., 2009) and dichotomous (yes/no) classification modified on the basis of an ordinal scale with four classes (0-4), suggested by Kibler (Uhl et al., 2009). The validity of the SDT was demonstrated by significant differences in scapular posterior tilt and upward rotation between those having and not having scapular dyskinesis ($p<.001$). The simple dichotomous classification was formed by defining a 'yes' score as a composite of the three subtypes of dyskinesis. By using this dichotomous classification, sensitivity (76%) and predictive value (74%) were higher compared to using the ordinal scale of four classes by Kibler. Even so, the specificity of the dichotomous classification was only 30%. Tate et al. also assessed discriminative (construct) validity of the SDT method, where the presence of scapular dyskinesis was not related to self-reported shoulder symptoms (Penn Shoulder Scale) (Tate et al., 2009) (Paper III, Table 7).

Table 5. List of identified scapular assessment methods. Studies marked in grey included only descriptions with or without few clinimetric results.

Assessment category	Study
Static positioning assessment (n=19);	
· Alignment	Juul-Kristensen et al. 2011
· Angular/linear measurements	Lewis and Valentine 2008
· Forward shoulder posture (Baylor/double square)	Peterson et al. 1997
· Infera; dropped scapula	Burkhart et al. 2003
· Lower horizontal distance	Juul-Kristensen et al. 2011
· Normal scapular position and depression	Azevedo et al. 2007
· Pectoralis minor muscle length	Borstad 2008
· Pectoralis minor muscle length (indirect measure)	Host 1995
· Pectoralis minor length test	Lewis and Valentine 2007
· Posterior scapular displacement	Plafcan et al. 1997
· Scapula rotation	Greenfield et al. 1995
· Scapular resting position	Host 1995
	Petersen et al. 1997
· Scapula evaluation tool	Macchi et al. 2002
· Scapular winging during rest	Juul-Kristensen et al. 2011
· Scapular lateral displacement (protraction)	Burkhart et al. 2003
· Scapular abduction	Gibson et al. 1995
· Scapular abduction (displacement)	Burkhart et al. 2003
· Normalized scapular abduction	Neiers and Worrell 1993
	DiVeta et al. 1990
· The Lennie test	Sobush et al. 1996
Semi-dynamic positioning assessment (n=14);	
· Acromial distance (modified Host)	Nijs et al. 2005
	Struyf et al. 2009
· Lateral Scapular Slide Test (LSST)	Kibler 1998
	Koslow et al. 2003
	Odom et al. 2001
	Nijs et al. 2005
	Shadmehr et al. 2008
	T´Jonk et al. 1996
	Schwellnus 2003
	Gibson et al. 1995
	Wang 2001
· Modified Lateral Scapular Slide Test (MLSST)	Davies and Dickoff-Hoffman 1993
	Struyf et al. 2009
· Modified Scapular Slide Test (MSST)	Schwellnus 2003
· Superior/Inferior Kibler Lateral Slide (SKLS/IKLS)	McKenna et al. 2004
· Scapular abduction (modified DiVeta)	T´Jonk et al. 1996
· Scapular abduction (different description)	Host 1995
· Scapular upward rotation	Johnson et al. 2001
	Watson et al. 2005
· Scapular and glenohumeral angles	Doody et al. 1970
· Scapular rest position in multiple planes	Plafcan et al. 2000
· Scapular resting position (modified Host)	Nijs et al. 2005
· Scapular protraction and depression	da Costa et al. 2010
· Scapular elevation/depression	Hallaceli 2002
· Travelling distance	Juul-Kristensen et al. 2011
Dynamic functional assessment (n=22);	
· Initial scapular movement	Juul-Kristensen et al. 2011
· Infraspinatus Scapular Retraction Test (ISRT)	Merolla et al. 2010
· Isometric pinch of the scapular	Kibler 1998
· Medial Rotation Test (MRT)	Morrisey et al. 2008
· Modified qualitative clinical evaluation system	Uhl et al. 2009
· Modified Scapular Assistance Test (SAT)	Rabin et al. 2006
· Observational motion analysis	Hickey et al. 2007
· Proprioception\reposition	Juul-Kristensen et al. 2011
· Scapular Assistance Test (SAT)	Kibler 1998
· Scapular Dyskinesis Test (SDT)	McClure et al. 2009
	Tate et al. 2009
· Scapular flip sign	Kelley 2008
· Scapular/glenohumeral rotation	Youdas et al.
· Scapular observation	Struyf et al. 2009
· Scapula reposition test	Tate et al. 2008
· Scapular Retraction Test (SRT)	Kibler 2006
· Scapular stabilizing test	Warner and Navarro 1998
· Scapular winging	Warner and Navarro 1998
· Scapular winging with weight	Juul-Kristensen et al. 2011
· Scapular winging without weight	Juul-Kristensen et al. 2011
· Scaption	Madsen et al. 2011
· Qualitative clinical evaluation system	Kibler 2002
	Uhl et al. 2009
· Wall-push-up	Kibler 1998
	Madsen et al. 2011

Table 6 . Methodological quality of each study per measurement property. Studies with lowest score, could be rated as 'fair' if sample size were higher, are given an asterisk.

Study	Year	Reliability	Measurement error	Construct validity (hypothesis testing)	Criterion validity	Responsiveness
Borstad	2008	…….	…….	…….	POOR*	
da Costa et al.	2009	FAIR	FAIR	…….	…….	
Gibson et al.	1995	FAIR	FAIR	…….	…….	
Hickey et al.	2007	POOR*	NR	POOR*	…….	
Juul-Kristensen et al.	2011	FAIR	FAIR (possible to calculate LOA)	FAIR	…….	
Johnson et al.	2001	FAIR	FAIR	…….	FAIR	
Kibler et al.	2002	POOR	NR	…….	…….	
Koslow et al.	2003	…….	…….	…….	FAIR	
Lewis and Valentine	2007	FAIR	FAIR	…….	FAIR	
Lewis and Valentine	2008	FAIR	FAIR	…….	…….	
Merolla et al.	2010	POOR*	POOR* (possible to calculate LOA)	…….	…….	
McKenna et al.	2004	POOR*	POOR*	…….	…….	
McClure et al.	2009	FAIR	NR	…….	…….	
Madsen et al.	2011	POOR*	NR	…….	…….	
Morrissey et al.	2008	…….	…….	…….	POOR*	
Neiers and Worrel	1993	FAIR	FAIR	…….	…….	
Odom et al.	2001	FAIR	FAIR	…….	FAIR	
Nijs et al.	2005	POOR*	POOR* (possible to calculate LOA)	POOR*	…….	
Plafcan et al.	1997	FAIR	FAIR	…….	…….	
Plafcan et al.	2000	POOR*	POOR*	…….	POOR*	
Peterson et al.	1997	FAIR	NC	…….	FAIR	
Rabin et al.	2006	FAIR	NR	…….	…….	
Schwellnus	2003	POOR*	NC	…….	…….	
Shadmehr et al.	2009	FAIR	FAIR	…….	FAIR	
Sobush et al.	1996	POOR*	POOR*	…….	POOR*	
Struyf F et al.	2009	FAIR	FAIR	…….	…….	
T´Jonk et al.	1996	POOR*	POOR*	…….	…….	
Tate et al.	2009	…….	…….	FAIR	GOOD	
Watson et al.	2005	POOR*	POOR*	…….	…….	
Uhl et al.	2009	FAIR	NR	…….	FAIR	
Youdas	1994	POOR	NC	…….	…….	

ABV. NR: not relevant. NC: not calculated

Discussion

This thesis is based on the results of three studies (Papers I, II and III) investigating potential impairments in neuromuscular function in patients with Subacromial Impingement Syndrome (SIS) and an evaluation of the ability to clinically assess scapular kinematics. The first part of the discussion addresses each aim separately and the results of this thesis will be compared to findings in the literature. The second part describes methodological considerations (strength and weaknesses) for Papers I, II and III.

Summary of results

The main findings of this thesis were: 1) No differences regarding magnitude of muscle activation, ratio of activation or timing of shoulder muscle activation onset between the SIS and No-SIS groups were found in this general population of impingement patients. However, SIS subjects displayed a general, non-significant trend to a higher level of mean muscle activity compared to No-SIS subjects in all muscles (SA, UT, LWT) and during all loading conditions; 2) Without EMG biofeedback, significantly fewer subjects in the SIS group were able to selectively activate and attain activation ratios higher than 95% of the lower compartments. However, when provided with EMG biofeedback there were no significant differences between the SIS and No-SIS groups in their ability to selectively activate the lower or upper compartments of the trapezius. Further, it could be noted that both groups benefitted from the visual biofeedback since both groups showed a significantly higher activation ratio for the lower and upper compartments in the sessions where EMG biofeedback was available; 3) A large number of clinical scapular assessment methods were identified for scapular position and function. The assessment methods ranged from merely static to more dynamic assessment methods, measured both quantitatively and qualitatively. The COSMIN checklist was found to be applicable and methodological quality of the included measurement properties in the reliability and validity domains were in general ‘fair’ to ‘poor’. None were examined for all three domains: reliability, validity and responsiveness. Despite the limitations of the results and methodological shortcomings, visual evaluation systems and scapular upward rotation assessment seem to have an acceptable evidence base to be recommended for clinical use.

Activity of the Trapezius and Serratus muscles during a voluntary arm movement task

Paper I: The previously reported pattern of decreased muscle activity of SA and increased activity of UT in studies of overhead athletes and workers with SIS was not found in our study which included a general population with SIS. Similarly, previous studies have also reported no significant differences in SA activity (de Morais Faria et al., 2008;Finley et al., 2005). However, most of these studies reported a trend towards a decreased SA EMG activity for the patient group (Chester et al., 2010), whereas our results show an increase in muscle activity. The present increased SA-activity could be due to a pain-related increase in co-activation, as opposed to a pain-related decrease in muscle activation. This may be due to differences in methodological procedures or in the performed tasks, such as, concentric/eccentric arm elevation, wheelchair transfer and

isometric abduction with/without hand-held or isokinetic load applied in the different studies. Furthermore, various inclusion criteria for the patient population may play a key role. While the increased UT activity in SIS is in line with previous studies (Cools et al., 2007a;Ludewig and Cook 2000) only one study has reported increased LT activity (Ludewig and Cook 2000). That study also emphasised that mechanisms of shoulder impingement may be dependent upon previous exposure and therefore may differ between SIS groups selected, based on occupational work load such as overhead work or specific sports activities such as swimming or badminton.

The similar activation ratios in SIS versus No-SIS subjects in our study did not support previous findings of a SIS-related unbalanced activation ratio of the scapular muscles. The varying results may be due to different tests (maximal versus sub-maximal tasks), as well as different movement tasks (against resistance/strictly guided versus elevations with/without handheld loads) across studies. Different performance strategies in voluntary movement tasks may result in larger intra- and inter-individual variations. Altered muscle activation therefore, may not be a dominant feature characterising SIS patients.

The onset differences between UT-LWT and UT-SA displayed a minor but non-significant delay in activity of LWT and SA, especially in no-loading conditions. These findings relate to our study hypotheses, but no significant between-group differences were observed. The similar onset times for SIS and No-SIS are in agreement with Moraes et al. (Moraes et al., 2008), but in contrast with other studies (Cools et al., 2003;Wadsworth and Bullock-Saxton 1997). Again, the different testing conditions may be the explanation. In our study the non-significant findings and the variation in estimates of both the activation ratios and the onset differences probably also reflect the range of patients included. However, it should be emphasised that all patients fulfilled the standardised set of tests for SIS commonly used in the clinical examination of shoulder patients.

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

Selective activations of the neuromuscular compartments within the trapezius muscle

Paper II: This study included both patients and healthy controls and can be seen as a continuation of previous studies, which built on the knowledge of the anatomical compartments of the trapezius muscle, indicating that

these compartments can be independently controlled with appropriate biofeedback in a healthy population (Holtermann et al., 2009;Holtermann et al., 2010).

This independent control most likely reflects a selective excitatory input to individual compartments which is in accordance with the diverted innervation of the spinal accessory nerve to the upper and lower parts of the human trapezius muscle (Kierner et al., 2001). Our finding of the selective activation of the lower compartments in a SIS patient group corresponds well with previous results on healthy subjects (Holtermann et al., 2009). In addition, the high proportion of subjects who were able to produce a high activation ratio of the lower compartments with EMG biofeedback further supports these results. In our study, the proportion of subjects fulfilling the requirements of selective activation of the lower or upper compartments was lower than previously reported in healthy subjects, but this might reflect our use of a stricter protocol, as sessions with EMG biofeedback only lasted 3 minutes, compared with 10 minutes in previous studies (Holtermann et al., 2009;Holtermann et al., 2010).

Most interestingly, we did not observe any differences between the SIS and No-SIS groups, in muscle activation with EMG biofeedback, which suggests the SIS group was able to selectively activate the lower compartments to the same extent as the No-SIS group. This may be an important clinical factor since most rehabilitation programs include a focus on increased activation of the lower compartment of the trapezius muscle to restore the muscle imbalance of the scapular stabilisers. However, these programs presuppose that SIS subjects have a clinically meaningful reduction in the activation of this muscle part. The difficulty for both the SIS and No-SIS groups to selectively activate and produce high activation ratios of the lower compartments without EMG biofeedback supports the notion that EMG biofeedback may be a relevant and helpful tool for patients learning activation and control of specific muscles in rehabilitation. More specifically in this setting, it may be feasible to use EMG biofeedback to focus on activation of the lower compartments of the trapezius muscle, in individuals with impingement syndrome if relevant. In line with our study, another recent study concluded that real-time visual feedback facilitates activation of scapular stabilising muscles and improved movement of the scapula during shoulder flexion in subjects with scapular displacement (Weon et al., 2011).

The reduced ability for SIS subjects to fulfill the two defined requirements for selective activation of the lower compartments without EMG biofeedback could relate to the proprioceptive mechanism of the trapezius muscle and scapular-thoracic joint. Previous studies have reported that patients with SIS have impaired kinesthetic (proprioceptive) sense of the affected shoulder, which suggests that they have altered their shoulder's afferent feedback mechanisms or altered central processing of afferent inputs, perhaps related to the chronic shoulder pain (Anderson and Wee 2011;Myers and Lephart 2000). Our findings support the claim that subjects suffering from shoulder pain could have an altered proprioceptive sense by being more dependent on visual afferent inputs to fulfill the same activation tasks than subjects without shoulder pain. These results might further indicate that No-SIS subjects have a superior scapular muscle control compared with SIS subjects.

Schematic overview of all available clinical scapular assessment methods

Paper III: A necessary process was to initially define a clinical scapular assessment. A decision was made that the assessment method should either include a direct assessment of the scapula (measurement/ observation/manual) or an indirect measure of a specific muscle that, based on functional anatomy, could affect scapular kinematics. Clinical assessment methods only measuring isolated force of muscles or assessment methods primarily examining gleno-humeral motions were not considered to be clinically relevant for the purpose of this study, despite previous studies (Kibler et al., 2013;Struyf et al., 2012) describing such tests as being clinically relevant for the scapular function.

The variety of scapular assessment methods found in this review ranged from measurement of scapular positioning at rest, and at different degrees of shoulder elevation, to symptom alteration methods, in addition to observational methods of the scapula at rest and during motion. The substantial number and range of the published assessment methods within each group suggest a current potential lack of consensus regarding appropriate measures. Compared with recent literature/anecdotal reviews (Kibler et al., 2012;Kibler et al., 2013;Struyf et al., 2012), the current review provides an additional number of clinical assessment methods, both with and without clinimetric assessments. However, to the authors' knowledge, this is the first review to systematically appraise all available scapular assessment methods. A careful selection of the terms was necessary in order to obtain the least amount of irrelevant hits, by the current two-step procedure. Additionally, the authors are not aware of any reviews on the shoulder using a similar two-step search strategy. Most reviews of upper extremity function have only included one general overall search strategy (Hegedus 2012;Williams et al., 2010;Wright et al., 2012). Although the different aspects of clinimetric outcome measures mentioned in this review are not directly included in the search terminology of Search 2 due to the careful selection of terms, it seems most unlikely that this comprehensive search would have missed relevant research within this field.

Methodological quality per measurement property and recommendations

Paper III:

Methodological quality, COSMIN

The COSMIN checklist facilitates a separate judgment of the methodological quality of the included studies and to some extent, the results are in line with the methodology of systematic reviews of clinical trials. Although the COSMIN checklist is a relevant standardised tool for design requirements and a preferred statistical method for assessing clinimetric properties of health measurement methods, some of the measurement properties and items are not relevant/applicable for clinical assessment methods. Moreover, adding two items adopted from the QUADAS checklist was necessary in order to evaluate assessment methods for diagnostic accuracy (Whiting et al., 2003). For many items in the checklist, a subjective judgment was performed. For example, in each box, the item 'Were there any important flaws in the design or the

methods of the study?' was included (besides those already covered by the other items). The COSMIN guidelines are not very specific on the definition of methodological flaws and when assessing either patient-reported outcome (PRO) instruments or clinical assessment methods, the judgment criteria will vary. The most frequent reasons for 'minor flaws' in both the reliability and validity domains were: inclusion of only asymptomatic subjects (only reliability domain), having only one trial per measurement session and no information on the inclusion or otherwise of any training phase. The importance of a training phase has previously been recommended (Patijn and Remvig 2007). For the last two flaws, it can either be a lack of reporting or an insufficient design. None of the studies were scored in the item of 'other important flaws'.

Another aspect is the item indexation in sample size. To be given an 'excellent' score, this item would require a sample size of ≥100, which is considered large in the types of studies included in this review, where the sample size ranged between 10 and 142. A requirement of above 30 subjects in order to be rated 'good' (50-99) or 'fair' (30-49) is supported by a standardised protocol for clinical reliability and validity studies, including three phases: (i) a training phase, (ii) an overall agreement phase and (iii) a test phase, requiring about 10, 20, and 40 subjects, respectively (Patijn and Remvig 2007). Studies with a small sample size, very often assessed the shoulders bilaterally, thereby increasing the sample size. However, such within-subject measures are more likely to be dependent and therefore the sample size item was answered on the basis of the number of subjects included.
Despite the large number and range of assessment methods, less than half (45%) of the assessed studies were given a rating of 'poor' in one or more clinimetric properties. Even though the sample size item to some extent was a contributing factor, many studies still had methodological limitations or, at best, inadequate reporting of methods.

Results from the highest ratings of measurement properties and recommendations

Paper III: Only a few of the examined assessment methods demonstrated acceptable reliability and validity results, while also being included in studies rated as having 'fair' or 'good' measurement properties and furthermore did not include more special non-commercial measuring equipment, e.g. hand-made of wooden material. These methods are presented below by assessment group.
In the static assessment group, six assessment methods included in four studies (Gibson et al., 1995;Juul-Kristensen et al., 2011;Lewis and Valentine 2008;Neiers and Worrell 1993) were supposed to reliably measure the static positioning of the scapula. Only one of these assessment methods (horizontal distance of the inferior angle) showed an ability to discriminate between neck-shoulder cases with the highest degree of scapular dyskinesis and reduced work ability and general health (Juul-Kristensen et al., 2011). However, due to an overall lack of validity assessment of these static methods and the fact that the literature showed no consensus on the scapular rest position in asymptomatic subjects and patients (Struyf et al., 2011a), the clinical validity of such tests seems low.

In the semi-dynamic assessment group, three easily applicable methods were examined both for reliability and validity, comprising the Lateral Scapular Slide Test (LSST) (Koslow et al., 2003;Odom et al., 2001;Shadmehr et al., 2010), scapular upward rotation (Johnson et al., 2001) and travelling distance (Juul-Kristensen et al., 2011). However, Koslow et al. did not report an ability of the LSST to provide any additional clinical examination benefit with regard to diagnosing shoulder pain/dysfunction. Similarly, Juul-Kristensen et al. did not report an ability of the travelling distance to discriminate between controls and neck-shoulder cases with the highest degree of scapular dyskinesis and reduced work ability and general health. According to the results on the LSST, it seems doubtful as to whether the criterion of a physician/orthopaedic diagnosis/referral can be considered an adequate 'gold standard'. Only the scapular upward rotation method showed acceptable clinimetric results for reliability and criterion validity with an adequate reference standard.

In the dynamic assessment group, three methods included in two studies were examined for both reliability and validity (Tate et al., 2009;Uhl et al., 2009). The three assessment methods were characterised as visual observation methods, classifying the presence of scapular dyskinesis during shoulder motion. Acceptable reliability and criterion validity measures were found for two of the methods: the modified qualitative evaluation system of abnormal scapular movement (Uhl et al., 2009) and the Scapula Dyskinesis Test (SDT) (Tate et al., 2009). Both methods were evaluated using 3D as a 'gold standard'. Although the simple dichotomous (yes/no) classification adequately identified the subjects who truly have scapular dyskinesis, the low specificity of this method indicated a substantial risk of false-positive findings. The validity of the SDT method was established, since subjects scored as having/not having dyskinesis displayed differences in scapular kinematics. However, the presence of scapular dyskinesis was not related to shoulder symptoms measured by a self-reported questionnaire (Penn Shoulder Score).

Despite the limitations of the clinimetric results and the methodological shortcomings of the studies, both the visual dichotomous evaluation system and the SDT method, as well as the scapular upward rotation assessment seem to have acceptable clinimetric results and property scorings, and thus could be deemed appropriate clinical methods at this stage. However, as this research area is relatively new, several of the remaining assessment methods may have the underlying potential for further clinimetric evaluation and hence may display acceptable clinical utility at some future time point.

Table 7. General categorisation and interpretation of clinimetric results per assessment method. Studies marked in grey were given a 'poor' rating.

Assessment category	Study	Reliability	Measurement error (level)	Construct validity	Criterion validity	Feasibility
Static positioning assessment (n=19);						
· Alignment	Juul-Kristensen et al. 2011	ICC; Good/excellent	NC*	*t*-test, groups/PRO; *no* discrim. ability	---	EA
· Angular/linear measurements	Lewis and Valentine 2008	ICC; Fair/good, Good/excellent	SEM; Low/moderate	---	---	EA
· Forward shoulder posture (Baylor/double square)	Peterson et al. 1997	ICC; Good /excellent	NC	---	---	NCA
· Lower horisontal distance	Juul-Kristensen et al. 2011	ICC; Good/excellent	NC*	*t*-test, groups/PRO; discrim. ability	---	EA
· Pectoralis minor muscle length	Borstad 2008	---	---	---	ICC 3D; Good/excellent	EA
· Pectoralis minor length test	Lewis and Valentine 2007	ICC; Good/excellent	SEM; Low	---	Sens./spec. (+add.); Lacks diagnostic value	EA
· Posterior scapular displacement	Plafcan et al. 1997	ICC; Good/excellent	SEM; Low	---	---	NCA
· Scapular resting position	Petersen et al. 1997	ICC; Good /excellent	NC		(*r*) X-ray; Large/strong	NCA
· Scapular winging during rest	Juul-Kristensen et al. 2011	Kappa; Almost perfect	NR	---	---	EA
· Scapular abduction	Gibson et al. 1995	ICC; Good/excellent	SEM; Low	---	---	EA
· Normalized scapular abduction	Neiers and Worrell 1993	ICC; Poor to excellent	SEM; Moderate/high	---	---	EA
· The Lennie test	Sobush et al. 1996	ICC; Fair/good, Good/excellent	NC	---	(*r*) X-ray; Medium/modest, Large/strong	EA
Semi-dynamic positioning assessment (n=14);						
· Acromial distance (modified Host)	Nijs et al. 2005	ICC; Good/excellent	NC*	(*r*); very small/small	---	EA
	Struyf et al. 2009	ICC; Fair/good	SEM/MDC95% moderate	---	---	
· Lateral Scapular Slide Test (LSST)	Koslow et al. 2003	---	---	---	Spec.; Lacks diagnostic value	EA
	Odom et al. 2001	ICC; Fair/good, Good/excellent	SEM; moderate	---	Sens./spec. Lacks diagnostic value	
	Nijs et al. 2005	ICC; Fair/good, Good/excellent	NC*	(*r*); very small/small	---	
	Shadmehr et al. 2008	ICC; Fair/good, Good/excellent	SEM; Low/moderate	---	Sens./spec. (+add.); Lacks diagnostic value	
	T´Jonk et al. 1996	ICC; Poor to Good/excellent	SEM; Low/moderate	---	---	
	Schwellnus 2003	ICC; Good/excellent	NC	---	---	
	Gibson et al. 1995	ICC; Poor to Good/excellent	SEM; Low to high	---	---	
· Modified Lateral Scapular Slide Test (MLSST)	Struyf et al. 2009	ICC; Fair/good	SEM/MDC95% moderate/high	---	---	EA
· Modified Scapular Slide Test (MSST)	Schwellnus 2003	ICC; Fair/good	NC	---	---	EA
· Superior/Inferior Kibler Lateral Slide (SKLS/IKLS)	McKenna et al. 2004	ICC; Poor to Good/excellent	SEM; Moderate	---	---	EA
· Scapular abduction (modified DiVeta)	T´Jonk et al. 1996	ICC; Poor to Good/excellent	SEM: Low/moderate	---	---	EA
· Scapular upward rotation	Johnson et al. 2001	ICC; Good/excellent	SEM; Low	---	(*r*) 3D; Large/strong	EA
	Watson et al. 2005	ICC; Good/excellent	SEM; low/moderate	---	---	EA
· Scapular rest position in multiple planes	Plafcan et al. 2000	ICC; Poor to excellent	SEM; Low/moderate	---	(*r*) X-ray; Small to Large/strong	NCA
· Scapular resting position (modified Host)	Nijs et al. 2005	ICC; Fair/good	NC*	(*r*); very small/small	---	EA
· Scapular protraction and depression	da Costa et al. 2010	ICC; Fair/good, Good to excellent	SEM/LOA; low	---	---	NCA
· Travelling distance	Juul-Kristensen et al. 2011	ICC; Fair/good	NC*	*t*-test, groups/PRO; *no* discrim. ability	---	EA
Dynamic functional assessment (n=22);						
· Initial scapular movement	Juul-Kristensen et al. 2011	ICC; Fair/good	NC*	---	---	EA
· Infraspinatus Scapular Retraction Test (ISRT)	Merolla et al. 2010	ICC; Good/excellent	SE; Low	---	---	EA
· Medial Rotation Test (MRT)	Morrisey et al. 2008	---	---	---		EA
· Modified qualitative clinical evaluation system	Uhl et al. 2009	Kappa; Moderate	NR	---	Sens./spec. (+add.); screening tool, lacks diagnostic value	EA
· Modified Scapular Assistance Test (SAT)	Rabin et al. 2006		NR	---	---	EA
· Observational motion analysis	Hickey et al. 2007	Kappa; Slight fair/fair	NR	%Agree./ptt.status *no* discrim. ability	---	EA
· Proprioception\reposition	Juul-Kristensen et al. 2011	ICC; Fair/good	NC*	---	---	EA
· Scapular Dyskinesis Test (SDT)	McClure et al. 2009	Kappa; Moderate/ substantial	NR	---	---	EA
	Tate et al. 2009	---	---	Odds ratio; SDT /PRO; *no* discrim. ability	Mixed model; dys.score/sign. alterations in 3D scap. motion	
· Scapular/glenohumeral rotation	Youdas et al.	Mean abs.diff.; Poor	NR	---	---	NCA
· Scapular observation	Struyf et al. 2009	Kappa; Fair/moderate	NR	---	---	EA
· Scapular winging with weight	Juul-Kristensen et al. 2011	Kappa; Almost perfect	NR	---	---	EA
· Scapular winging without weight	Juul-Kristensen et al. 2011	Kappa; Almost perfect	NR	---	---	EA
· Scaption	Madsen et al. 2011	Kappa; Substantial	NR	---	---	EA
· Qualitative clinical evaluation system	Kibler 2002	Kappa; Fair/moderate	NR	---	---	EA
	Uhl et al. 2009	Kappa; Moderate	NR	---	Sens./spec. (pre+pre-/acc.); lacks diagnostic value	
· Wall-push-up	Madsen et al. 2011	Kappa; Substantial	NR	---	---	EA

ABV. Sens.: sensitivity. Spec.: specificity. +Add.: additional measures. Acc: accuracy. Agree: agreement. Dys.: dyskinesis. Sign.: significant. NC: not calculated. NC*: not calculated, but possible to calculate limits of agreement (LOA). NR: not relevant. NCA: not clinically available. EA: easily applicable. Pre: predictive. PRO: patient reported outcome measure. Discrim.: discriminative. Ptt.: patient. SEM: standard error of measurement. ICC: intra class correlation. SE: standard error. 3D: Three-dimensional motion analysis. MDC95%: minimal detectable change with 95% confidence interval. Abs.diff.: absolute difference. *(r)*: correlation coefficient. Scap.: scapular

Considerations on muscle activity in relation to scapular kinematics (outline)

In this thesis, shoulder muscle activity and clinical tests for shoulder kinematics in cases and controls have been studied. This naturally led to the next question on how scapular muscle activity has an influence on scapular kinematics or vice versa and whether group differences in these parameters are present in cases and controls, and this aspect will be discussed in the following section.

Concurrent measurements of muscle activity and scapular kinematics have rarely been conducted, and the kinematics has primarily been studied by 3D motion tracking analyses, and not by clinical tests (De Baets et al., 2013;Ludewig and Cook 2000;Lukasiewicz et al., 1999;Worsley et al., 2013). Ludewig and Cook found some muscular differences in SIS versus No-SIS subjects, displayed as increased activity in upper and lower trapezius and a decreased SA muscle activity. The changed activation was reflected in kinematics as decreased upward rotation, and posterior tilt as well as increased medial rotation of the scapula. However, these finding were only apparent in some positions during humeral elevation and were dependent on the addition of an external handheld load.

In a similar sample of SIS patients, scapular muscle activity and 3D scapular kinematics were investigated in a non-randomised intervention study (Worsley et al., 2013), where healthy subjects provided reference data. More specifically, the extent to which 10 weeks of motor control exercises of the scapular muscles would retrain muscle recruitment patterns and improve scapular kinematics, with the aim of reducing SIS pain, was studied. The study showed that in a small cohort of young shoulder impingement patients, these motor control-based exercises changed scapular kinematics during different arm movements to 90º elevation. The statistical difference of the changes in kinematics between pre- and post-intervention were limited, with the only statistically significant changes seen in scapular upward rotation during sagittal plane arm elevation and scapular posterior tilt during frontal plane arm elevation. Simultaneously, muscle activity was changed significantly post-intervention, due to improved conditions for delayed onset and early termination of SA and LT muscle activity compared with pre-intervention. In a recent case-control study (Huang et al. 2013) the purpose was to investigate the immediate effects of exercises with on-line EMG biofeedback on scapular muscle balance ratios and 3D scapular kinematics during arm elevation. In this sample consisting of 13 SIS subjects and 12 healthy controls, EMG biofeedback improved the scapular muscle balance ratios during training in both groups with no between-group or between-session (with/without biofeedback) differences in scapular kinematics. However, a small sample size, lack of long- and short-term effect of EMG biofeedback and short training time may have been limiting factors.

When searching for studies comprising both muscle activity and scapular kinematics measures for comparison of cases and controls, clinically relevant studies were found to be scarce. However, clinical assessments of scapular kinematics alone have been investigated in a few cross-sectional studies of populations with shoulder/neck disorders and overhead athletes with and without shoulder pathology (Juul-Kristensen et al., 2011;Struyf et al., 2011b;Su et al., 2004;Thomas et al., 2009) (Table 8). Thomas and colleagues (Thomas et al., 2009) found that gleno-humeral internal rotation decreased in asymptomatic female high school overhead

athletes after competing in a 12-week season of swimming, volleyball, or tennis. The study also assessed gleno-humeral external rotation and scapular upward rotation, but the changes found in these parameters were dependent on the degree of shoulder positioning and the type of sport. Another study applied a protocol of various static and dynamic scapular positioning and functional assessments to evaluate the presence of scapular dyskinesis in trapezius myalgia cases compared with controls. The study reported significant differences in measurements of the static scapular positioning and gleno-humeral internal rotation (Juul-Kristensen et al., 2011).

Another recent study evaluated scapular positioning and scapular motor control, however, no statistically significant differences in scapular kinematics between athletes with and without shoulder pain were found (Struyf et al., 2011a). These results of no between-group differences are in line with findings by Su et al. (Su et al., 2004) who measured scapular upward rotation before a swim practice. Although, after a swimming session the impingement group demonstrated reduced upward rotation in three different degrees of humeral elevation. As emphasised in Paper III, a limited number of clinical scapular assessment methods have been examined for the various aspects of validity. Despite variations in the reported findings, the clinical importance of the included assessment methods can be questioned, and it still remains an open question, whether scapular dyskinesis, currently can be clinically measured with adequate validity. Also it is still a question as to whether/or how alterations in scapular kinematics are related to scapular muscle function, shoulder pathology and symptoms.

Table 8. Overview of studies including clinical scapular assessment methods for evaluating scapular kinematics in subjects with or without shoulder and/or neck symptoms.

Study/design	Population	Clinical scapular assessment method	Device	Conclusion
Juul-Kristensen et al. 2011 *Case-central*	Workers with/without neck/shoulder pain	Static and dynamic scapular positioning and function assessments (n=10).	Observation, ruler, laser-pointer, plurimeter	Cases showed significantly larger; 1) medial border misalignment, 2) lower horizontal distance of the inferior scapular angle and 3) passive shoulder internal rotation.
Struyf et al. 2011 *Case-control*	Overhead athletes with/without shoulder pain	Visual observation Acromial distance Scapular upward rotation Scapular motor control (KMRT)	Inclinometer	Athletes with shoulder pain show lack of scapular motor control on their painful side in contrast to their pain-free side. No scapular positioning or motor control differences between athletes with or without shoulder pain.
Su et al. 2004 *Case-control/ pre-post test*	Swimmers with/without shoulder pain	Scapular upward rotation	Inclinometer	Abnormal scapular kinematics in swimmers with impingement syndrome may only be observed after an intense swim practice.
Thomas et al. 2009 *Pre-post test*	Overhead athletes without shoulder pain	Scapular upward rotation Gleno-humeral internal/external rotation	Inclinometer	Female overhead athletes demonstrated decreased internal rotation after only one competitive season.

Findings of cross-sectional studies do not allow a cause-effect analysis. With this in mind, two randomised clinical trials examining the effects of a scapular-focused program and a general shoulder rehabilitation program in patients with shoulder impingement, found that scapular focused/stabilisation exercises resulted in improved self-reported outcome measures and pain scores (Baskurt et al., 2011;Struyf et al., 2013). Interestingly, neither of the treatment protocols was able to change the clinical scapular positioning

parameters. However, one study did report within-group differences in the group receiving the scapular-focused intervention (Baskurt et al., 2011). In all these studies self-reported pain reduction and function improvement is apparent but without measurable differences in scapular function. The question then remains whether there is a clinical difference in certain subgroups, and whether such clinical assessment methods are able to capture scapular kinematic changes, since none of them have been examined for their ability to detect clinically important changes over time (responsiveness) and furthermore, most of the included assessment methods lack sufficient validity assessments.

Methodological considerations

Papers I, II

Subjects

We used strict inclusion criteria in accordance with a clinical decision algorithm intended to obtain the highest clinical between-group contrast between SIS and No-SIS. However, even with the current criteria for defining SIS, pain on the testing day was relatively low for SIS subjects, decreasing between-group contrasts with respect to pain. Regarding workplace exposure, the combined SIS and No-SIS samples were a mixed population since the SIS group was recruited from among those seeking treatment for SIS in physiotherapy clinics, and the healthy No-SIS group was a sample recruited from among university staff. This may have decreased between-group contrasts on muscle imbalance uniformity, compared with previous studies with more homogeneous exposures, e.g. overhead work or sports. If so, exposure probably should also be considered in clinical decision algorithms. Negative results deserve consideration of the size of a clinically relevant difference, and whether the study has the power to detect such a difference. An aspect to consider is the small sample sizes that may increase the possibility of a type II error. In Paper II, a sample size calculation was not conducted a priori due to lack of comparable data. To the authors' knowledge, very few studies have examined selective recruitment of the scapular-thoracic muscles. We therefore estimated the current sample size based on previous laboratory experiments which included a healthy population (Holtermann et al., 2009;Holtermann et al., 2010).

Outcomes

Clinimetric properties of the EMG procedures were not tested in this thesis, but the method used has been standardized to the most possible extend by following the SENIAM (Surface EMG for a Non-Invasive Assessment of Muscles) recommendations (skin preparation, sensors, sensor placement, signal processing/modeling) and by replicating the same method as previously used (Hermens et al., 2000;Holtermann et al., 2009;Holtermann et al., 2010).

In this aspect, however, a recent study reported a fair to very good intra- and inter-session reliability (ICC=0.36-0.99) of absolute mean scapular muscle surface EMG activity during two MVIC trials. Additionally, the results showed good to very good intra- and inter-session reliability of both absolute and normalised mean scapular muscle surface EMG activity during an active lifting task (concentric/eccentric) (ICC=0.66-0.99) (Seitz and Uhl 2012). Although our EMG biofeedback procedure in Paper II is not directly comparable with an active lifting task, electrode placement and MVIC trials are similar in both Papers I and II. In this thesis, EMG was normalised to maximal EMG amplitude during an MVIC. It has been suggested that normalisation to maximal EMG amplitude is not an appropriate procedure in patients since maximal effort may not be reached in the trials used for normalisation due to pain. We did not include muscle strength testing in our experimental procedure, although a previous study including a similar population did not find any reduction in maximal shoulder muscle strength and maximal muscle activity (Bandholm et al., 2006).

However, we did register pain on a 100 mm VAS scale before and after the experimental procedure and no differences were found between groups, indicating that pain was not a limiting factor for maximal effort.

The use of a motion capture system or inclinometric measures in Paper I for a more precise capture of shoulder kinematics during the voluntary movement task could have reduced any variation in shoulder range estimation. Combining measurements of shoulder/scapula movements with surface EMG seems to be the optimal solution for estimation of scapular muscle activity in relation to shoulder movement, but this was not possible in this thesis due to methodological constraints. However, we initially did combine the use of video in some of the subjects which actually gave us a fair estimate of the relationship between EMG and the movement of the arm, whereas it revealed nothing about the scapular movement. In a recent study, we included both the voluntary movement task, measuring muscular activity from the scapular muscles and the elevation angle using a wireless inclinometer from Noraxon (Noraxon, USA). In this experiment, it was difficult to establish a smooth movement curve reflecting concentric and eccentric movement as the freely moving arms encouraged a ballistic movement pattern. However, based on the evaluation of inclinometer data from a sample of 34 subjects, it was shown that the concentric phase is, in general better defined from the scheduled timing compared with the eccentric phase. This could relate to the fact that during the eccentric movement, part of the energy used is provided by the elastic components, not captured by EMG. Therefore, data from the concentric part of the functional task are presented here, although data from the eccentric part as mentioned in the paper showed the same pattern.

Moreover, in Paper I we used visual inspection to identify the onset of muscle activity. Hodges and Bui have emphasised the importance of carefully choosing an appropriate analysis technique, depending on the collected data and the procedure used (Hodges and Bui 1996). The rate of increase in EMG amplitude (e.g. slow movements like the voluntary movement task) especially, could easily result in a delay in onset identification if this is determined by an algorithm. In order to find the most appropriate method, we have included both computer- and visual-based onset identification. In line with Hodges and Bui, we concluded the visual procedure was the most accurate.

In Paper II, the cross-sectional study design does not include baseline reference testing. Therefore, we cannot conclude if a lower ability to selectively activate is due to a difference in learning ability in the biofeedback session. Furthermore, results were not adjusted for potential confounders with respect to sex, age, BMI and pain. However, according to descriptive statistics, the subjects (SIS and No-SIS) who were able to achieve selective activation of the lower part of trapezius without biofeedback (both definitions 1 and 2) approximated the group distributions on sex and other variables, despite being slightly younger.

The experimental setup in Paper II involved the subject in a lying position, in an attempt to eliminate the influence of gravity. This also placed the subjects in a resting position with no need for activity in other muscles to optimize the focus on activating the requested muscle compartments. Furthermore, the method used in this paper was, as previously stated, to be seen as a continuation of previous studies. However, it

would be highly relevant to repeat the biofeedback method in e.g. a sitting position, perhaps reflecting a more functional position.

Paper III

Literature search and the use of COSMIN

Although every effort was made to find all published studies on clinimetric properties of clinical scapular assessment methods, selection bias may have occurred because we included only English-language articles. Publication bias may have resulted in exclusion of relevant clinical methods, but it could also have resulted in an overestimation of clinimetric outcomes, because studies with positive conclusions are more likely to be published (Chan et al., 2004). Validity aspects of assessment methods can also be found in the case-control design, by relating differences in findings between cases and controls by the underlying diagnostic criteria. In the current review, such results were not included if the study did not aim at examining the validity aspect of the assessment methods. This decision might have excluded relevant information.

Furthermore, reviewer bias is also a possible limitation of the current review, since the reviewers were not blinded to the study results during the methodological ratings.

No established or validated criteria or checklist for assessing the quality of reliability and validity studies of clinical or performance-based assessment methods are currently available. Previous systematic reviews on the cervical spine and upper extremity joints have developed their own checklists by adapting previous tools from related areas, such as existing checklists intended for diagnostic accuracy studies and randomised controlled trials (Stochkendahl et al., 2006;Williams et al., 2010).

Therefore, assessing reliability, validity, as well as diagnostic accuracy in the same review would require the use of more than one checklist with the risk of presenting incoherent results. Therefore, the COSMIN approach was adopted for assessing the methodological quality of these methods. The COSMIN checklist has been developed recently and is based on consensus between experts in the field of health status questionnaires (Mokkink et al., 2010b;Mokkink et al., 2010c).

Although the COSMIN panel has set high standards, with the risk of downgrading the methodological quality, we believe that this general overview of the methodological standard will improve future studies on measurement properties, and will demand/challenge readers to be critical when interpreting results.

In future research, we recommend that a specific checklist for evaluating clinical assessment methods be developed according to the suggestions presented in this review.

Conclusions

The main conclusions of this thesis are:

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

2) With EMG-based visual biofeedback, there were no significant differences between the SIS and No-SIS groups in the ability to selectively activate the lower or upper compartments of the trapezius, based on the predefined criteria for successful selective activation. Without biofeedback, however, the No-SIS group has superior scapular muscle control. Whether EMG biofeedback training can help patients with SIS to improve neuromuscular function of the scapula and reduce pain needs to be confirmed in a future intervention study.

3) The systematic review revealed a substantially larger number of clinical assessment methods for measurement and evaluation of scapular position and function than previously reported. The assessment methods ranged from merely static to more dynamic assessment methods, measured either quantitatively or qualitatively.

4) Generally, the methodological quality of the included measurement properties in the domains of reliability and validity were ‘fair’ (55%) to ‘poor’ (45%). None of the included clinical assessment methods were examined for all three domains of reliability, validity (diagnostic accuracy), as well as responsiveness, evaluated by the COSMIN checklist. None of the included studies performed a responsiveness validation. Few of the examined assessment methods used in studies with ‘fair’ or ‘good’ measurement property ratings demonstrated acceptable results for both reliability and validity. Despite the limitations of the results and methodological shortcomings, visual evaluation systems and scapular upward rotation assessment seem to have an acceptable evidence base to be recommended for clinical use. For future research, we recommend a modified version of the COSMIN checklist for evaluating clinical assessment methods. Furthermore, there is a need for high quality studies that specifically investigate the validity, diagnostic accuracy, and, in particular the responsiveness of scapular assessment methods.

Clinical and research implications

This thesis demonstrates that patients with SIS, experiencing frequent shoulder pain, do not display alterations in neuromuscular activity of trapezius and SA compared with healthy controls. However, it is an open question as to whether a uniform neuromuscular activity pattern exists across different SIS populations and testing procedures. According to Hodges and Bui (Hodges 2011) musculoskeletal pain conditions may not induce only one stereotypical change in muscles similar for all conditions. Based on this concept, pain may influence the distribution of activity across regions within or between muscles in an individual- and task-specific manner, with a common goal to protect the painful part from further pain or injury.

The results of this thesis challenge the general clinical opinion that exercises decreasing activity in the upper part of the trapezius and increasing the activity of the SA and the LT should be preferred in rehabilitation as a general treatment concept for the SIS patient group. If an imbalance in activation is not a consistent finding in a SIS population defined by the strict algorithms for clinical testing of SIS, it may not be relevant to apply a change in activation as a general treatment paradigm. Rather, subgroups that may benefit may be formed on the basis of earlier exposure to overhead work and sport.

Accordingly, a more exposure-specific and individual approach may be considered. This is in agreement with Ludewig and Cook (Ludewig and Cook 2000) who state, that “different impingement sites may relate to unique kinematic abnormalities, making it more difficult to ascertain overall group differences between subjects with and without shoulder impingement”. Nevertheless, signs indicating an impaired kinesthetic (proprioceptive) sense of the affected shoulder were observed in SIS patients. This was possibly due to altered afferent feedback mechanisms or altered central processing of afferent inputs, which potentially could be the cause or consequence of shoulder pain and decreased shoulder function, including scapular-thoracic kinematics.

Finally, this thesis proposes the clinically applicable assessment methods of visual observation and inclinometer measurement of scapular rotation for evaluation of scapular kinematics, as a clinical alternative to more advanced equipment as, e.g. 3D motion analysis. A knowledge gap exists in the relationship between muscular activity and the clinical measurement methods. To fill this gap, future research should combine the clinical and advanced methods and the knowledge gained from both measurement methods. This would benefit the treatment and improve the understanding of the patho-mechanisms in scapular kinematics in SIS patients.

Perspectives

In a clinical framework, this thesis has included standardised laboratory methods and a systematic accumulation of the evidence on the clinical assessment methods for evaluating scapular kinematics in patients with shoulder disorders. In contrast to the standardised methods, this last part also addresses aspects of method development.

Additional research perspectives of the topic covered in the thesis is a recommendation for longitudinal studies in order to examine whether muscle activity patterns and scapular kinematics are influenced by the development of SIS and/or the reduction of symptoms or vice versa. This is an important aspect for guiding more specific treatment strategies in the rehabilitation of SIS patients. Furthermore, it is recommended that EMG biofeedback training be examined to determine if it can improve neuromuscular and, potentially, proprioceptive, function of the scapula and thereby reduce pain in patients with SIS. To further increase the scientific foundation in this field and to enhance the clinical possibilities and usefulness of assessing scapular positioning and functioning in shoulder patients, there is a need for high quality studies that investigate the validity, diagnostic accuracy, and the responsiveness of scapular assessment methods.

Acknowledgements

I would like to express my deepest gratitude to all the people who made it possible for me to accomplish this thesis:

- All *subjects* volunteering for the laboratory studies. Without their dedication, it would not have been possible to perform all the experiments.
- *Karen Søgaard*, my main supervisor and Birgit Juul-Kristensen my co-supervisor for their never-ending support, constructive criticism and mentorship. Moreover, I am truly grateful for their ability to provide a smile during all the steps of this thesis, for having confidence in me and introducing me to the field of clinical science, in particular laboratory work including methods like EMG, clinical assessment methods for the upper extremities and 3D motion analysis.
- *Hans Lund*, for his inspiration, inputs and numerous discussions on research methodology.
- *Andreas Holtermann*, for his valuable inputs in manuscript revision.
- *Eleanor Boyle*, for her kindness, statistical and linguistic skills.
- *Henrik B. Olsen and Shadi C. Shamir* for their engineering support, and especially their pedagogical abilities and patience when discussing mechanical methodological issues.
- *Janet Taylor*, for her assistance in structuring a manuscript and giving comments on the English language.
- *Suzanne Capell*, for her editing of my written English and willingness to help.
- My dear office mate and friend *Lotte Nygaard*, for many great hours and good family and scientific discussions as well as scientific collaborations. Also a very special thanks to my additional office mates during the 3-year period for creating a humorous and inspiring working environment.
- *Peter B. Jensen, Katrine T. Pedersen, Nis L. Jensen*, for their dedicated and thorough help with data collection. A special thanks to Katrine for her practical assistance as a student worker.
- *The members of The Research Unit for Physical Activity and Health in Work life* and *The Research Unit for Musculoskeletal Function and Physiotherapy*, for fruitful discussions about research and fabulous social activities.
- All *staff* and *colleagues* at the Department of Sports Science and Clinical Biomechanics for contributing to a great work environment.
- My *family*, my *parents* and *parents-in-law* for their invaluable love and support, especially given the current circumstances, with three lovely young children, one of whom needs special caring.
- And in particular, my dearest husband *Anders*, for his encouragement, discussions on research and loving support throughout this work. Furthermore, our three children, *Sofia, Olivia* and *Sebastian* for their indispensable motivation.

Summary

Subacromial Impingement Syndrome (SIS) comprising both shoulder pain and disability is one of the most common shoulder disorders registered in primary care. Imbalance in neuromuscular activity between the scapular stabilisers is an aspect of the neuromuscular scapular function thought to relate to SIS, although mostly described in restricted tasks and specific populations. A muscular imbalance between the scapular stabilisers may also be due to a reduced ability to selectively activate specific muscle subdivisions, i.e. within the trapezius muscle, and thus influence motor control.

The neuromuscular control and coordination of the muscles stabilising and moving the scapula are considered main factors for scapular kinematics. Thus, based on this theory, an appropriate first step is to search for evidence of muscular imbalance and decreased motor control, which could cause a clinically identifiable change in scapular kinematics among SIS patients compared with controls. The literature on scapula kinematics and SIS patients reveals diversity in the use of clinical methods assessing scapular position and function, as well as in studies on the relationship between muscular imbalance and shoulder pain. This could be due to a lack of knowledge of the clinimetric properties of these clinical methods, and also a lack of standardised criteria for clinically assessing dysfunction in scapular kinematics. This calls for a scientific overview of all available clinical methods that have been applied and a thorough quality assessment of the studies applying these methods and examining the clinimetric properties of the clinical scapular assessment methods. In summary, the aims of this thesis were to understand potential mechanisms for impairment in the neuromuscular function of the scapular stabilisers in a general patient sample with SIS, to survey these methods scientifically and assess the clinimetric properties of clinical assessment methods of scapular kinematics as important aspects for optimising treatment and improving the clinical guidelines in this area.

In the first study, scapular muscle activity was examined during a voluntary arm movement task in a general population consisting of 16 SIS patients and 15 controls (No-SIS). In spite of a general tendency for higher scapular muscle activity among SIS patients, between-group differences were not significant either in activity level, ratio of activation between muscles or in the time of activity onset of the muscles.

The second study examined the ability of 15 SIS patients to selectively activate individual scapular muscle compartments during sessions with and without on-line biofeedback in comparison to 15 No-SIS subjects. Using the defined criteria of: (i) a selective activation above 12% of maximum activation during which other muscle parts were activated below 1.5% or (ii) an activation ratio at or above 95% of the total available activation, significantly fewer SIS subjects than No-SIS subjects achieved selective activation of individual scapular muscle compartments without on-line biofeedback of muscle activity from each muscle compartment of the trapezius muscle.

In the third study, a systematic review was conducted of all available clinical scapular assessment methods and associated clinimetric results, and the **CO**nsensus-based **S**tandards for the selection of health **M**easurement **IN**struments (COSMIN) checklist was used to critically assess the quality of the involved studies for each measurement property. On the basis of 46 included articles, a total of 55 names of clinical assessment methods were identified. Thirty-one of the studies included in the quality assessment of the reliability and validity domains were classified as 'fair' (55%) to 'poor' (45%), with only one study being rated as 'good'. Few of the assessment methods in the included studies with 'fair' or 'good' measurement property ratings demonstrated acceptable results for both reliability and validity. Responsiveness was not investigated.

In this thesis, the hypothesised between-group differences of SIS and No-SIS subjects in neuromuscular activity of scapular stabilising muscles were not confirmed. However, when assessing the neuromuscular function with and without the use of biofeedback, the findings show that without biofeedback, the No-SIS group had superior scapular muscle control. In contrast, when provided with visual EMG feedback, the SIS group performed equally as well as the No-SIS group. When addressing the possibility for measuring scapular kinematics clinically, the findings show a substantially larger number of clinical assessment methods for scapular position and function than previously reported. None of the included clinical assessment methods had been examined for all three domains: reliability, validity (diagnostic accuracy), as well as responsiveness. Based on these results, the current findings question the generalisability of current rehabilitation guidelines to the general population with SIS, they recognise that SIS patients may benefit from biofeedback training. Lastly, these results indicate that few clinical assessment methods have sufficient clinimetric properties to recommend them for clinical use.

Dansk resumé

Subacromial Impingement Syndrom (SIS), som er karakteriseret ved både skuldersmerte og funktionsnedsættelse, er en af de hyppigst rapporterede skulderlidelser i primærsektoren. SIS relateres ofte til en ubalance mellem de skapula-stabiliserende muskler. Indenfor udvalgte specielle populationer med SIS har man under standardiserede bevægelsestests fundet en uhensigtsmæssig neuromuskulær aktivering, der giver en ubalance i aktiviteten mellem de skapula-stabiliserende muskler.
En sådan ubalance i aktiveringen af de stabiliserende muskler omkring skapula kan også skyldes en nedsat evne til selektivt at kunne aktivere indenfor specifikke dele af musklerne, f.eks. i trapezius musklen, og dette vil påvirke den motoriske kontrol.
Neuromuskulær kontrol og koordination af musklerne omkring skapula anses derfor for at være primære faktorer for skapulas kinematik, når skulderleddet belastes ved armbevægelser. Med udgangspunkt i denne teoretiske ramme, vil det være relevant at undersøge evidensen for muskulær ubalance og reduceret motorisk kontrol hos SIS patienter sammenlignet med kontroller. Begge faktorer kan være medvirkende faktorer til klinisk identificerbare ændringer i skapulas kinematik hos f.eks. SIS patienter.
Litteraturen omhandlende skapulas kinematik og SIS patienter afslører, at der anvendes mange forskellige kliniske målemetoder til vurdering af skapulas position og bevægelse, og der er ikke enighed om relationen mellem muskulær ubalance, skapulas position og bevægelse og skulder smerte. Dette kan skyldes manglende viden om og utilstrækkelige klinimetriske egenskaber ved målemetoderne samt manglende standardiserede kriterier til klinisk at vurdere dysfunktion af skapulas kinematik for disse målemetoder. Der har imidlertid manglet et overblik, dels over alle de forskellige kliniske målemetoder, der er tilgængelige for at evaluere skapulas position og bevægelse, dels at vurdere de klinimetriske egenskaber af metoderne og kvaliteten af de studier, der har undersøgt de klinimetriske egenskaber for sådanne målemetoder.
Denne afhandlings overordnede formål er derfor at opnå viden om den neuromuskulære funktion i de skapula stabiliserende muskler hos en general population af patienter med SIS med henblik på at forstå potentielle mekanismer bag en dysfunktion. Endvidere at vurdere mulighederne for en klinisk evaluering af skapulas kinematik ved systematisk at kortlægge mulige metoder og metodernes klinimetriske egenskaber. Disse aspekter anses for at være vigtige i forhold til optimering af behandling og forbedring af de kliniske retningslinjer indenfor skulderområdet.

I det første studie blev den skapulære muskelaktivitet målt under en voluntær armbevægelsestest i en generel population bestående af 16 patienter med SIS og 15 raske kontrolpersoner. Der var en generel tendens til højere muskelaktivitet hos SIS patienterne, men der blev ikke fundet signifikante forskelle mellem de to grupper, hverken for aktiverings niveau, aktiverings ratio eller det relative aktiveringstidspunkt for de forskellige muskler og muskeldele.

I det andet studie blev evnen til selektiv aktivering af de individuelle skapulære muskeldele undersøgt hos 15 patienter med SIS under en session med og uden visuel biofeedback, sammenlignet med denne evne hos 15 raske kontroller. Med udgangspunkt i præ-definerede kriterier for selektiv aktivering, hvor en given muskel aktivering skulle være over 12% af den maksimale aktivering, og i øvrige muskeldele under 1.5%, eller at muskelaktiviteten for de enkelte muskeldele udgjorde 95% eller derover af den totale muskelaktivering, viste resultaterne at signifikant færre patienter med SIS i forhold til kontrolpersonerne opnåede selektiv aktivering af individuelle skapulære muskeldele, når de ikke modtog visuel biofeedback af muskelaktiviteten af de enkelte muskeldele.

I det tredje studie blev der udarbejdet et systematisk review af alle tilgængelige kliniske målemetoder til vurdering af skapulas position og bevægelse samt tilhørende klinimetriske resultater. Den standardiserde "**CO**nsensus-based **S**tandards for the selection of health **M**easurement **In**struments" (COSMIN) tjekliste, blev anvendt til kritisk at vurdere kvaliteten af de inkluderende studiers klinimetriske domæner. På baggrund af 46 inkluderede artikler blev der i alt identificeret navne på 55 kliniske målemetoder. Af disse blev 31 studier inkluderet i kvalitetsvurderingsprocessen og den metodiske kvalitet i domænerne reliabilitet og validitet blev scoret til at være 'rimelig' (55%) og 'dårlig'(45%), og kun et enkelt studie opnåede scoren 'god'. Ganske få af de målemetoder som var inkluderet i studier med en 'rimelig' eller 'god' score, demonstrerede acceptable resultater, både for reliabilitet og validitet. Ingen af metoderne var undersøgt for evne til at respondere på ændringer af skapulas kinematik.

I denne ph.d. afhandling blev de forventede forskelle i den neuromuskulære aktivitet blandt SIS patienter og raske kontrolpersoner ikke fundet. Derimod viste undersøgelsen af den neuromuskulære funktion med og uden brug af visuel biofeedback, at uden brug af biofeedback havde kontrolgruppen en bedre kontrol af de skapulære muskler. Dog præsterede SIS-gruppen og kontrolgruppen ens, når de modtog visuel EMG biofeedback. Ved systematisk at evaluere muligheden for at kunne måle skapulas kinematik ud fra kliniske målemetoder, fandtes der i nærværende afhandling et betydeligt større antal kliniske målemetoder af skapulas postion og bevægelse end tidligere rapporteret. Ingen af de inkluderede kliniske målemetoder havde været undersøgt i alle 3 domæner, herunder reliabilitet, validitet (diagnostisk nøjagtighed) og responsivitet. Baseret på afhandlingens resultater, stilles der spørgsmålstegn ved, om nuværende kliniske guidelines for rehabilitering af denne patientgruppe kan generaliseres til en mere general gruppe af SIS patienter. Dog antyder resultaterne, at SIS patienter kan profitere af biofeedback træning. Endelig, viser litteratur oversigten, at trods et stort antal kliniske målemetoder til vurdering af skapulas position og bevægelse har kun få tilstrækkeligt gode klinimetriske egenskaber til at man kan anbefale dem i klinisk praksis.

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