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Electromyographic analysis of rotator cuff muscles in patients with rotator cuff tendinopathy: A systematic review

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ABSTRACT

The shoulder is inherently an unstable joint which heavily relies on the neuromuscular activation of the rotator cuff (RC) complex for stability during movement. Currently, there is no consensus regarding how the activity of RC muscles is affected among individuals with a RC tendinopathy (RCTe). This study reviewed the evidence of studies comparing the electromyographic (EMG) activity of any RC muscle of shoulders with a symptomatic RCTe to asymptomatic shoulders. Eight databases were searched. Data from 343 participants (201 symptomatic and 209 asymptomatic shoulders) were analyzed from 10 out of 402 included studies. Strong evidence for the infraspinatus and supraspinatus during isometric contractions and limited evidence for the supraspinatus and infraspinatus during isokinetic contractions suggest that the muscular activity is not altered among individuals with a RCTe during these types of contraction. Very limited evidence indicates reduced muscle activity for the infraspinatus and subscapularis in the presence of a RCTe during isotonic contractions, and no alterations for the supraspinatus or teres minor were identified. Lastly, conflicting to moderate evidence suggests alterations in RC muscle activity during unrestrained movements and swimming. These findings indicate that EMG deficits associated with a RCTe can best be appreciated during unrestrained movements.

1. Introduction

Shoulder disorders are very common (point prevalence ranging from seven to 66.7%) (Luime et al., 2004) and are associated with substantial functional limitations that tend to increase with age. Rotator cuff tendinopathy (RCTe) is the most common source of shoulder pain (Alqunaee et al., 2012) and represents an estimated 66 to 85% of all shoulder cases (Tekavec et al., 2012). RCTe is an umbrella term, which encompasses several diagnoses related to various tendon signs and symptoms (e.g. tendinosis/ tendinitis, supraspinatus tendinopathy / tendinosis / tendinitis, subacromial impingement, subacromial bursitis) (Hanratty et al., 2012; Desmeules et al., 2015), combining pain and impaired function (Factor and Dale, 2014).

While there is no consensus regarding etiological mechanisms (de Witte et al., 2011; Lopes et al., 2015), several factors have been suggested to explain the persistence of symptoms and functional limitations in individuals with an RCTe. Among these factors, a lack of coordination (Wadsworth and Bullock-Saxton, 1997; Hess et al., 2005; Clisby et al., 2008) and neuromuscular balance (Bertoft, 1999; de Witte et al., 2011) between the RC muscles, which includes the supraspinatus (SS), infraspinatus (IS), subscapularis (SB), and teres minor (TM), has been identified. Proper RC musculature activation is crucial for shoulder stability control, as it increases glenohumeral joint stiffness, thereby maintaining a stabilizing congruency between the humeral head and the glenoid fossa. In addition, RC muscles are activated together with other scapulothoracic and scapulohumeral muscles to properly align the humeral head with respect to the glenoid fossa, thereby preventing the impingement of the subacromial structures during arm elevation that would otherwise result from superior migration of the humeral head (Sharkey and Marder, 1995).

Changes in muscle activation patterns of the RC muscles could explain, in part, the dynamic narrowing of the subacromial space and the alterations in upper limb kinematics that have been observed in individuals with RCTe during arm elevation (Ludewig and Cook, 2000; Roy et al., 2008; Savoie et al., 2015). In fact, the neuromuscular deficits of RC muscles have been targeted by

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several investigations evaluating the effects of rehabilitation intervention for RCTe (Brox et al., 1997; Muth et al., 2012; Røe et al., 2000; Savoie et al., 2015; Tate et al., 2010). Examination of RC muscular activity is, therefore, essential for a thorough evaluation of shoulder neuromuscular control. A recent systematic review on EMG activity of the shoulder complex (Chester et al., 2010) concluded that individuals with an RCTe may present with altered EMG activity; however, this review was inconclusive due to inconsistencies during data retrieval, and inclusion of studies only evaluating scapulothoracic and middle deltoid muscles (evidence related to the EMG activity of RC muscles was not included). To our knowledge, there are currently no published systematic reviews compiling evidence of RC muscles activity in patients with an RCTe. Thus, the aim of this study was to review systematically the evidence concerning the EMG activity of RC muscles in individuals with RCTe. Presentation of this systematic review follows the recommendations outlined by PRISMA.

2. Methods

2.1. Identification and selection of studies

Bibliographical searches were performed in eight databases (Medline/PubMed, Science Direct, Scopus, EMBASE, ISI Web of Science, PSYCInfo, CINAHL and Scielo) from their inception to August 2016 addressing three concepts (outcomes, patients/symptoms, and anatomical site/muscles) with the following search strategy: (EMG OR electromyograph* OR "musc* activity") AND (tendinopathy* OR impingement OR "subacromial pain") AND (infraspinatus OR supraspinatus OR "teres minor" OR subscapularis OR "rotator cuff muscles"). This strategy was adapted for each database using the appropriate truncation and medical subject heading (MeSH) (see Appendix A for an example of a search strategy). Reference lists of the retrieved studies were also searched to identify additional relevant publications. Published studies written in English, Spanish, French or Portuguese were included. After removal of duplicates, two reviewers (FCLO, JSR) independently screened the study titles and abstracts using a blinded standardized protocol. The selection criteria for the full-text review were: (a) reporting on the EMG activity of any RC muscles, (b) including individuals with RCTe, and (c) comparing impaired shoulder to unimpaired (painful to pain-free shoulders in the same individuals or individuals with a painful shoulder to asymptomatic individuals). Thereafter, the same two reviewers scrutinized the full-text of all potentially eligible studies, independently, to decide on their inclusion. Disagreements concerning study eligibility were resolved by consensus. If no consensus was reached, a third reviewer made the final decision (LJB).

2.2. Assessment of characteristics of studies

2.2.1. Qualitative analysis (critical appraisal)

The *Standard Quality Assessment Criteria for Evaluating Primary Research Papers* (QualSyst), a quality appraisal tool developed by Kmet et al. (2004) was used. It evaluates methodological quality and risk of bias of quantitative and qualitative studies. Items 5, 6 and 7 (random allocation and blinding) were excluded to tailor the QualSyst to the studies included (Table 1).

Two raters (FCLO, ALA) independently evaluated each article using the QualSyst checklist. After each independent evaluation, the pair of raters met to discuss each article. Each specific domain was openly discussed to reach a consensus. A pre-consensus inter-rater agreement was calculated for the final scores with an intraclass correlation coefficient (ICC). As summary scores were not yet associated with different qualitative categories, the following index was used: "high quality" (HQ) representing scores greater than 80.0%, "good quality" (GQ) for scores between 70% and 80.0%, "moderate quality" (MQ) for scores between 50.0% and 69.9%, and "low quality" (LQ) for scores less than 50.0%.

2.2.2. EMG scale of assessment

A critical appraisal scale for reporting EMG was developed for this study (Appendix B). This scale is based on the *Unit, Terms, and Standard for Reporting EMG Research*, reported by the Ad Hoc Committee of the International Society of Electrophysiological Kinesiology to guide the reporting of EMG research. The scale is composed of 13 items, evaluating the reporting of electrodes type and position, raw signal processing (amplification, filtering,

Table 1

Assessment of methodological quality (critical appraisal) after a consensus between the researchers.

	Item number and corresponding score														Points	FS_{qual} score
	1	2	3	4	5[a]	6[a]	7[a]	8	9	10	11	12	13	14		
Bandholm et al. (2006)	Y	Y	Y	P	n/a	n/a	n/a	Y	P	Y	Y	P	Y	Y	19	0.86
Clisby et al. (2008)	Y	P	Y	Y	n/a	n/a	n/a	Y	P	Y	Y	P	Y	Y	19	0.86
Lopes et al. (2015)	Y	Y	Y	Y	n/a	n/a	n/a	Y	Y	Y	Y	Y	Y	Y	22	1.00
Michaud et al. (1987)	Y	Y	Y	P	n/a	n/a	n/a	P	P	Y	P	P	P	P	15	0.68
Myers et al. (2009)	Y	Y	Y	Y	n/a	n/a	n/a	Y	Y	Y	Y	P	Y	Y	21	0.95
Pink et al. (1993a)	Y	P	P	Y	n/a	n/a	n/a	P	Y	P	P	P	Y	Y	16	0.73
Reddy et al. (2000)	Y	P	P	P	n/a	n/a	n/a	Y	P	P	N	P	P	P	12	0.55
Roy et al. (2008)	Y	P	Y	Y	n/a	n/a	n/a	Y	Y	Y	Y	Y	P	Y	20	0.91
Ruwe et al. (1994)	Y	Y	P	P	n/a	n/a	n/a	Y	P	P	P	P	P	P	14	0.64
Skolimowski et al. (2009)	Y	P	Y	Y	n/a	n/a	n/a	Y	Y	Y	Y	N	N	P	16	0.73

Studies presented in alphabetic order. Y: yes (2 points); P: partial (1 point); N: no (0 points); n/a: not applicable.

Points mean the sum of scores for each item. Score are the points divided by the maximum possible score (22).

FS_{qual} was calculated dividing the total sum (TS) of rates by the maximum possible score (PS).

TS = "*number of yes*" × 2 points + "*number of partial*".

PS = (22) – "*number of not applicable*" * 2.

(1) Question/objective sufficiently described? (2) Study design evident and appropriate? (3) Method of subject/comparison group selection or source of information/input variables described and appropriate? (4) Subject (and comparison group, if applicable) characteristics sufficiently described? (5) If interventional and random allocation was possible, was it described? (6) If interventional and blinding of investigators was possible, was it reported? (7) If interventional and blinding of subjects was possible, was it reported? (8) Outcome and (if applicable) exposure measure(s) well defined and robust to measurement/misclassification bias? Means of assessment reported? (9) Sample size appropriate? (10) Analytic methods described/justified and appropriate? (11) Some estimate of variance is reported for the main results? (12) Controlled for confounding? (13) Results reported in sufficient detail? (14) Conclusions supported by the results?

Kmet LM, Lee RC, Cook LS. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Alberta Heritage Foundation for Medical Research; 2004.

[a] Items removed to make the QualSyst tailored for this research.

sampling, normalization), and crosstalk. Again, two raters (FCLO, JSR) independently evaluated each article with the EMG scale, followed by a meeting where a consensus was reached (Table 2). A pre-consensus inter-rater agreement was also calculated for the final scores with reported ICC values.

2.2.3. Data extraction

A first reader extracted the data (FCLO). A second reader (JSR) then corroborated or completed the extraction if data was found to be missing. A third reader (LB) with an expertise in EMG analysis verified all extracted EMG parameters. Data were extracted for participants' characteristics, task/intervention, EMG technique, EMG variables, muscles evaluated, detection and processing of EMG data, and normalization.

EMG activity was the main outcome of this systematic review. It included any variable examined during EMG analysis (e.g. muscle activation profile, coactivation ratio, as well as maximal and submaximal amplitudes). Parameters extracted included types of electrodes and their position, sampling rate, amplification, gain, A/D conversion and processing, high and low-pass cut-off frequencies, filter type, noise processing, signal rectification, and EMG processing.

2.2.4. Data analysis

Studies included in this review could not be pooled into a meta-analysis due to differences in the type of EMG analyses performed in each study. Therefore, a qualitative review of the evidence was conducted.

Following the qualitative review, the body of evidence and the strength of our recommendations were established after considering four domains (number of studies/participants [imprecision], methodological quality [risk of bias], methodological and outcomes similarities [indirectness], and direction of results [inconsistency]). Thereafter, the level of evidence was classified as strong, moderate, conflicting, limited, and very limited (van Tulder et al., 2003; Barton et al., 2013).

> *Strong evidence:* multiple HQ studies with consistent results, regardless of methodological heterogeneity.
> *Moderate evidence:* multiple studies, including at least one HQ study; or multiples MQ or GQ studies; or multiple LQ studies, homogeneous methodologies; always providing consistent results.
> *Conflicting evidence:* multiple studies regardless of the methodological quality, with inconsistent results.
> *Limited evidence:* multiple studies, with heterogeneous methodologies and/or inconsistent results; or single GQ study or higher.
> *Very limited evidence:* results from single LQ or MQ study.

3. Results

Four hundred and two articles were retrieved. After removal of duplicates, title/abstract screening, and full-text analysis, 10 articles met the inclusion criteria (Fig. 1). Summaries of the included studies are available in Table 3.

3.1. Characteristics of the studies

Outcomes measures addressed in the evaluated studies included muscle activation (Michaud et al., 1987; Pink et al., 1993a; Ruwe et al., 1994; Reddy et al., 2000; Bandholm et al., 2006; Roy et al., 2008; Skolimowski et al., 2009; Lopes et al., 2015), coactivation ratios (Myers et al., 2009), and muscle contribution (Clisby et al., 2008) (Table 4).

Table 2
Scores of EMG scale of assessment after a consensus between the researchers.

	Types of electrodes	Electrodes technical information	Amplification procedure	Amplification reports	Band pass filters and filter types	Frequency range (ISEK standards)	Wave rectification	EMG processing	Nyquist theorem	A/D Board information	Preliminary training (MVC)	Details of contraction analysis	EMG crosstalk	Total (0 to 26)	Final Score
Bandholm et al. (2006)	Y	Y	P	Y	N	Y	N	Y	Y	N	Y	P	P	17	0.65
Clisby et al. (2008)	Y	Y	P	P	P	P	N	Y	P	P	Y	Y	P	17	0.65
Lopes et al. (2015)	Y	P	P	Y	P	P	Y	N	Y	N	Y	Y	N	16	0.62
Michaud et al. (1987)	Y	Y	P	N	P	P	P	Y	Y	N	Y	Y	P	17	0.65
Myers et al. (2009)	Y	Y	Y	Y	Y	P	N	Y	Y	N	Y	Y	N	19	0.73
Pink et al. (1993a)	P	N	N	N	N	N	N	P	N	N	N	Y	N	4	0.15
Reddy et al. (2000)	Y	P	N	P	P	P	N	P	Y	P	P	P	P	13	0.50
Roy et al. (2008)	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	Y	Y	Y	25	0.96
Ruwe et al. (1994)	Y	Y	N	P	P	N	N	Y	Y	P	Y	P	P	15	0.58
Skolimowski et al. (2009)	Y	P	N	N	P	N	N	P	N	N	N	N	N	5	0.19

Studies presented in alphabetic order. Y: yes (2 points); P: partial (1 point); N: no (0 points); n/a: not applicable.
Points mean the sum of scores for each item. Score are the points divided by the maximum possible score (26).
FS_{EMG} was calculated dividing the total sum (TS) of rates by the maximum possible score (PS).
TS = "*number of yes*" × 2 points + "*number of partial*".
PS = (26) − "*number of not applicable*" * 2.

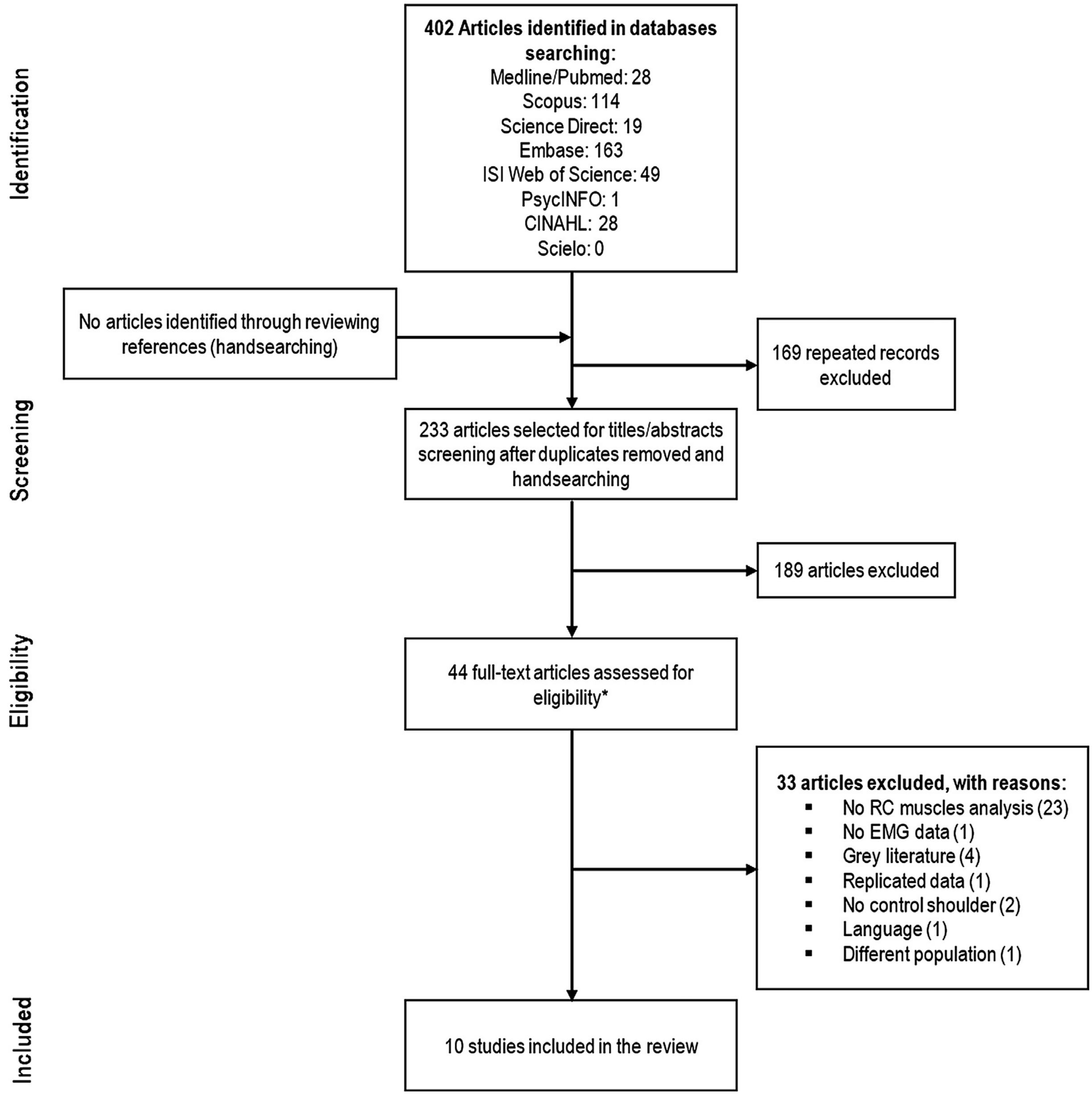

Fig. 1. Flowchart describing the article selection process.

The infraspinatus (IS) was the most investigated RC muscle as 9/10 studies investigated its activity. Supraspinatus (SS) was examined by seven studies, subscapularis (SB) by four, and teres minor (TM) by three (Table 5).

A single study used isokinetic (Bandholm et al., 2006) and isotonic contractions (Reddy et al., 2000), whereas four studies used isometric contractions to examine muscle activity (Michaud et al., 1987; Bandholm et al., 2006; Clisby et al., 2008; Skolimowski et al., 2009). Other six studies used unrestrained dynamic movements (Pink et al., 1993a; Ruwe et al., 1994; Roy et al., 2008; Myers et al., 2009; Skolimowski et al., 2009; Lopes et al., 2015), including two that examined aquatic sports movements (Pink et al., 1993a; Ruwe et al., 1994). EMG activity was collected using surface electrodes in seven studies, intramuscular fine wire in two, and Basmajian-needle technique in four. In total, 343 participants were investigated (196 with RCTe [unilateral or bilateral shoulder pain] and 205 with healthy shoulders), resulting in 201 symptomatic and 205 asymptomatic shoulders. Sample sizes of the included studies ranged from nine to 58 participants.

3.1.1. Diagnostic criteria and labeling

Clinical diagnostic tests (Hawkins-Kennedy, Neer, Jobe/Empty Can, arc of movement, isometric contractions) were performed in nine out of 10 included studies to determine the diagnosis of an RCTe. Three studies (Michaud et al., 1987; Clisby et al., 2008; Reddy et al., 2000) also used diagnostic imaging (radiography, arthrography, and arthroscopy). The labeling of an RCTe was mostly homogenous across included studies as seven labeled them as subacromial or shoulder impingement, two simply as impingement (Pink et al., 1993a; Ruwe et al., 1994), and one as supraspinatus tendinitis (Michaud et al., 1987). Details on the diagnostic criteria and labeling are listed in Table 5.

3.1.2. Methodological quality

QualSyst scale (Table 1): Scores ranged from 12/22 (54.5%) to 22/22 (100.0%), with a mean score of 79.1 ± 14.7%. Five studies had methodological procedures classified as “high quality”, two as “good”, and three as “moderate”.

Table 3
Evidence table of included studies.

Authors	Sample	Objectives/purposes	Diagnostic criteria and labeling	Task/ Intervention	EMG technique	EMG variables	Muscles evaluated†	Available information on detection and processing of EMG data	Normalisation	Results (EMG analysis)	Score QualSyst (classification)	Score EMG assessment (classification)
Bandholm et al. (2006)	Experimental: n = 9 (gender not informed) Age: 28.2 ± 5.3 yrs (21–38) Control: n = 9 (gender not informed) Age: 27.7 ± 4.2 yrs (22–37)	To examine the effects of SIS on shoulder sensory motor control, expressed as submaximal shoulder ABD force steadiness and related muscle activity, and maximal shoulder muscle strength	Clinical evaluation: Painful arc of movement; Hawkins-Kennedy test. Labeling: Subacromial Impingement Syndrome (SIS).	Isometric contractions in 45° and 90° of shoulder ABD. Concentric contractions in 40–55° and 95–110° of shoulder ABD. Eccentric contraction in 110–95° and 55–40° of shoulder ABD.	Surface EMG; Intramuscular EMG.	Force steadiness in 20%, 27.5% and 35% of the maximum shoulder abductor torque.	Supraspinatus, Infraspinatus, Anterior Deltoid, Middle Deltoid, Upper Trapezius, Lower Trapezius, Serratus Anterior, Latissimus Dorsi.	Sampling rate: 1000 Hz Amplification: custom-built differential amplifier. HP filter: 10 Hz LP filter: 1000 Hz Noise processing: CMRR > 100 dB EMG processing: RMS 1-s window (10, no overlapping, 100-ms intervals).	MVC at 45° of isometric ABDs, ADDs, internal and external rotations of the upper arm. MVC at 90° of isometric ABD of the upper arm.	Muscle activity was unaffected by the SIS† Isometric contractions: No differences in any muscle activity. Concentric contractions: No differences in any RC muscles activity. Eccentric contractions: No differences in any muscle activity.	86% (high)	65% (moderate)
Clisby et al. (2008)	Experimental: n = 14 (5 men, 9 women) Age: 51.07 ± 11.06 yrs Control: n = 18 (6 men, 12 women) Age: 42.17 ± 7.64 yrs	To evaluate the conditions of resisted isometric ER that optimized the contribution of the IS and the load of ER at which ADD was most effective at reducing the DE contribution, in the symptomatic shoulders of patients with SAI. To compare the IS and PD muscle activation between symptomatic and asymptomatic shoulders.	Clinical evaluation: Painful arc of movement; Hawkins-Kennedy test; 90° Scaption isometric resistance; Anterior and lateral pain on the shoulder. Imaging diagnostic: Radiography. Labeling: Subacromial Impingement (SAI).	Isometric external rotation; ADD + Isometric external rotation.	Surface EMG	Muscle contribution at 10%, 40%, and 70% of MVC of isometric ER, with and without shoulder ADD.	Infraspinatus, Posterior Deltoid, Middle Deltoid, Pectoralis Major.	Gain: 1000× A/D processing: storage in a computer. HP filter: 20 Hz LP filter: 500 Hz EMG processing: RMS 32 Hz	The average RMS over the middle 5 s for each muscle at 10%, 40% and 70% MVIC.	Symptomatic × asymptomatic shoulders The activation patterns in the SAI sample were similar to those found in the asymptomatic shoulders† SAI: 8.239 ± 4.500 kg Asymptomatic: 9.856 ± 3.621 kg). IS: More active at 40% MVIC in ER and ER + ADD. ADD did not change the infraspinatus contribution. No differences in the relative contributions at any load of ER with or without ADD for SAI and asymptomatic groups).	86% (high)	65% (moderate)
Lopes et al. (2015)	Experimental: n = 19 (12 men, 7 women) Age: 40.2 ± 13.8 yrs Control: n = 19 (11 men, 8 women) Age: 46.4 ± 10.9 yrs	To characterize scapular kinematics and shoulder muscle activity in patients with SIS, with and without visually identified scapular DYSK.	Clinical evaluation: Painful arc of movement; Hawkins-Kennedy test; Jobe test. Labeling: Subacromial Impingement Syndrome (SAIS).	Ascending and descending shoulder flexion.	Surface EMG	Muscle activity during ascending and descending phases of weighted shoulder flexion in subjects with SIS (DYSK) and NODYSK.	Infraspinatus, Upper Trapezius, Lower Trapezius, Serratus Anterior.	Sampling rate: 960 Hz Gain: 10.000× A/D processing: storage in a computer. HP filter: 20 Hz LP filter: 400 Hz Filter type: Notch filter (59–61 Hz) Noise processing: CMRR > 92 dB at 60 Hz Rectification: Full wave	For normalization, surface EMG data were collected during 2 trials while participants performed a reference contraction against resistance for 5 s at the midpoint of the testing motion at 90° of flexion in the sagittal plane.	Symptomatic × asymptomatic group No significant differences between groups (DYSK and NODISK) for IS. DYSK (Ascending): 30–60°: 10.7 ± 2.3% 60–90°: 12.8 ± 2.9% 90–120°: 16.3 ± 2.7% DYSK (Descending): 30–60°: 7.5 ± 1.5% 60–90°: 6.0 ± 1.2% 90–120°: 7.2 ± 1.7% NODYSK (Ascending): 30–60°: 15.8 ± 2.3% 60–90°: 10.8 ± 2.9% 90–120°: 18.7 ± 2.7% NODYSK (Descending): 30–60°: 8.4 ± 1.5% 60–90°: 4.5 ± 1.2% 90–120°: 13.1 ± 1.7%	100% (high)	62% (moderate)

Michaud et al. (1987)†	Experimental: n = 10 (7 men, 3 women) Age: 28.8 ± 6.8 yrs Control: n = 10 (5 men, 5 women) Age: 29.7 ± 3.8 yrs	To investigate the EMG activity of both the SS and MD muscles in normal subjects and patients suffering from an ST.	Clinical evaluation: No details on tests used. Imaging diagnostic: Arthrogram. Labeling: Supraspinatus tendinitis.	Isometric ABD of the arm.	Bipolar electrodes (Needles). Surface EMG	Muscle activity in submaximal contraction of MVC, during ABD of the arm at 0° and 45°.	Supraspinatus, Middle Deltoid.	HP filter: 16 Hz LP filter: 1600 Hz (surface)/ 3200 Hz (intramuscular wire) EMG processing: Integrals (16 voltage reset integrator).	Z-score (Moritani and deVries, 1978).	SS:† No altered muscle activity between 0° and 45° in both groups (experimental and control). No different muscle activity between ST and healthy subjects, in both angles (0° and 45°).	68% (moderate)	65% (moderate)
Myers et al. (2009)	Experimental: n = 10 (5 men, 5 women) Age: 42.70 ± 10.61 yrs Control: n = 10 (5 men, 5 women) Age: 36.58 ± 7.61 yrs	To measure RC coactivation and MD muscle activation in participants with SIS and to determine if there is an abnormal coactivation in these muscles.	Clinical evaluation: Painful arc of movement; Hawkins-Kennedy test; Neer test; Jobe test. Labeling: Subacromial Impingement.	Humeral elevation and depression (ABD and ADD).	Surface EMG; Intramuscular EMG.	Muscle coactivation	Middle Deltoid, Infraspinatus, Supraspinatus, Subscapularis.	Sampling rate: 1000 Hz Amplification: Single Gain: 500× HP filter: 15 Hz LP filter: 500 Hz Filter type: Butterworth Noise processing: CMRR 130 Db	Maximal elevation torque was used to calculate the load (25%) to be held during subsequent functional elevation tasks.	SIS group; Control group 0–30° (↓ coactivation) SB-IS* (116.73 ± 25.60%; 143.74 ± 20.55%) SS-SB* (107.50 ± 20.99%; 133.28 ± 26.89%) 30–60° (↓ coactivation) SS-IS* (149.09 ± 17.84%; 170.25 ± 18.32%) IS* (92.00 ± 15.09%; 105.36 ± 13.00%) 60–90° No significant differences. 90–120° (↑ coactivation) SB-IS* (191.28 ± 24.78%; 160.85 ± 35.36%) SS-IS* (204.95 ± 35.01%; 169.22 ± 32.52%)	95% (high)	73% (good)
Pink et al. (1993a)	Experimental: n = 14 (9 men, 5 women) Age: 31 yrs (19–48) Control: n = 20 (17 men, 3 women) Age: 39 yrs (20–67) (Pink et al., 1993b)	To compare the muscle firing patterns in competitive swimmers with painful and normal shoulders during the butterfly stroke	Clinical evaluation: Hawkins-Kennedy test; Neer test; Speed test. Labeling: Impingement.	Butterfly swim stroke	Basmajian Needle technique.	Muscle activity	Anterior Deltoid, Middle Deltoid, Posterior Deltoid Serratus Anterior, Upper Trapezius, Rhomboids, Supraspinatus, Infraspinatus, Teres Minor, Subscapularis, Latissimus Dorsi, Pectoralis Major.	Sampling rate: 2500 Hz EMG processing: Integrals 20 ms	Maximal Manual Muscle Test (MMT)	Swimmers painful Shoulders × Swimmers with normal shoulder SS* (25 ± 24% × 52 ± 26%, EPT) (1 ± 1% × 5 ± 3%, MPT) (21 ± 19% × 47 ± 31%, LR) IS*(15 ± 17% × 4 ± 4%, MPT) (67 ± 32% × 35 ± 25%, LPT) (78 ± 35% × 46 ± 24%, LPT) TM*(9–20% × 28–80%, EPT) (6 ± 3% × 14 ± 9%, LR) (4 ± 3% × 14 ± 9%, LR) SB* (42 ± 19% × 21 ± 16%, MPT)	73% (good)	15% (low)
Reddy et al. (2000)	Experimental: n = 15 (12 men, 3 women) Age: 53.5 yrs (40–66) Control: n = 16 (12 men, 4 women) Age: 29 ± 4 yrs (23–36)	To compare data on DE and RC muscle activity during scapular plane ABD (scaption) in subjects with known SIS with data obtained from subjects with normal shoulders.	Clinical evaluation: No details on tests used. Imaging diagnostic: Radiography; Arthroscopy. Labeling: Subacromial Impingement	Isotonic scaption from 30° to 120° of arm elevation with the elbow extended and holding a load of 25% of their NMW.	Basmajian single-needle technique.	Muscle activity	Middle Deltoid, Infraspinatus, Supraspinatus, Subscapularis, Teres Minor.	Sampling rate: 2500 Hz A/D processing: storage in a computer. HP filter: 10 Hz LP filter: 1000 Hz	Within the 5-s maximum MMT for each muscle, the highest half-second interval of integrated EMG signal was selected as 100% effort.	General decreased muscle activity in SIS population. 30–60° MD: 62%; IS: 32%; SB: 18% 60–90° IS: 43% No significant changes in 90–120°. No significant changes for SS and TM.	55% (moderate)	50% (moderate)
Roy et al. (2008)	Experimental: n = 33 (11 men, 22 women) Age: 47.9 ± 8.7 yrs (26–59) Control:	To characterize upper limb motor strategies in individuals with and without shoulder impingement during reaching in natural speed and to evaluate	Clinical evaluation: Painful arc of movement; Hawkins-Kennedy test; Neer test;	Reaching towards two targets (frontal and oblique plane) in two speeds (natural and fast), both	Surface EMG	Reaching speed, upper limb kinematics, and EMG activity.	Upper Trapezius, Middle Trapezius, Lower Trapezius, Serratus anterior, Infraspinatus, Anterior Deltoid,	Sampling rate: 5000 Hz Gain: 4000× A/D processing: storage in computer at 1000 Hz. HP filter: 10 Hz LP filter: 500 Hz	Percentage of reference condition (calculated by maintaining the arm at 90° elevation with a 1 kg load during 5 s).	Patients with SIS × healthy controls IS† No significant differences in the EMG activity in all 3 phases, for both conditions (natural and fast speed) in both planes (frontal and oblique).	91% (high)	96% (high)

(*continued on next page*)

Table 3 (*continued*)

Authors	Sample	Objectives/purposes	Diagnostic criteria and labeling	Task/ Intervention	EMG technique	EMG variables	Muscles evaluated†	Available information on detection and processing of EMG data	Normalisation	Results (EMG analysis)	Score QualSyst (classification)	Score EMG assessment (classification)
	n = 20 (7 men, 13 women) Age: 46.6 ± 9.9 yrs (27–60)	their adaptation to higher speeds of movement.	Jobe test; ER isometric resistance. Labeling: Shoulder Impingement Syndrome.	at 90° of arm elevation.			Middle Deltoid.	Filter type: Butterworth Noise processing: CMRR 93 dB; input impedance 10^9 Ω, gain 23 Wave rectification: Full-wave EMG processing: Smoothing, threshold value > 2 SD beyond baseline for 25 ms.				
Ruwe et al. (1994)	Experimental: n = 14 (9 men, 5 women) Age: 31 yrs (19–48) Control: n = 25 (19 men, 6 women) Age: 39 yrs (20–67)	To describe and compare electrical activity patterns in 12 shoulder muscles during the breaststroke in competitive swimmers with normal and painful shoulders.	Clinical evaluation: Hawkins-Kennedy test; Neer test; Supraspinatus test. Labeling: Impingement.	Breast swim stroke	Basmajian single-needle technique.	Muscle activity	Anterior Deltoid, Middle Deltoid, Posterior Deltoid Serratus Anterior, Upper Trapezius, Rhomboids, Subscapularis, Supraspinatus, Infraspinatus, Teres Minor, Latissimus Dorsi, Pectoralis Major.	Sampling rate: 2500 Hz A/D processing: storage in computer at 2500 Hz HP filter: 100 Hz LP filter: 1000 Hz EMG processing: Computer integration	Peak 1-s of Maximal isometric MMT in water.	Swimmers painful Shoulders × Swimmers with normal shoulder SB* (↑EMG activity for painful) 46 ± 36% × 19 ± 11%, EPT) 47 ± 31% × 22 ± 15%, EPT) 44 ± 18% × 23 ± 12%, MPT) 45 ± 17% × 19 ± 12%, MPT) 49 ± 21% × 13 ± 7%, MPT) 41 ± 22% × 9 ± 8%, TPT) 25 ± 22% × 7 ± 7%, TPT) SS* (↓EMG activity for painful) (15 ± 14% × 35 ± 11%, MR) (17 ± 13% × 39 ± 11%, MR) (14 ± 13% × 38 ± 14%, MR) (15 ± 14% × 41 ± 24%, LR) (16 ± 15% × 39 ± 22%, LR) (17 ± 15% × 34 ± 21%, LR) IS* (↑EMG activity for painful) (28 ± 25% × 9 ± 7%, MR) TM (trend to ↓EMG activity, PT)	64% (moderate)	58% (moderate)
Skolimowski et al. (2009)	Experimental: n = 58 (19 men, 39 women) Age: 56 yrs (24–85) Control: n = 58 (19 men, 39 women) Age: 56 yrs (24–85)	To evaluate the changes of bioelectric activity of the chosen muscles in people with impingement syndrome and the effect they have on the functioning of the shoulder joint.	No details on the methods used to diagnose RCTe. Imaging diagnostic Radiography; Arthroscopy. Labeling: Subacromial Impingement	Maximum isometric contraction (resisted) and unrestrained in the internal and external rotation, ABD, flexion, and extension.	Surface EMG	Bioelectric muscular activity	Deltoid, Supraspinatus, Infraspinatus, Latissimus Dorsi, Pectoralis Major, Biceps Brachii.	Filter type: Butterworth 4th order EMG processing: RMS	No information on normalization.	SIS shoulders × healthy shoulders IS: ER (unrestrained)* 0.038 ± 0.036 mV × 0.130 ± 0.115 mV (↓ EMG activity) ER and IR (isometric) 0.042 ± 0.029 mV × 0.077 ± 0.046 mV SS: ER and IR (unrestrained) 0.028 ± 0.020 mV × 0.017 ± 0.013 mV ER and IR (isometric) 0.030 ± 0.027 mV × 0.018 ± 0.016 mV ABD (unrestrained) 0.099 ± 0.074 mV × 0.092 ± 0.080 mV ABD (isometric) 0.053 ± 0.035 mV × 0.092 ± 0.056 mV	73% (good)	19% (low)

Ω: ohms; HP: high-pass filter; LP: low-pass filter; RC: rotator cuff; ROM: range of motion; ABD: abduction; ER: external rotation; IR: internal rotation; SAI: subacromial impingement; SIS: subacromial impingement syndrome; RT: rotator tendinosis; ST: supraspinatus tendinitis; DYSK: scapular dyskinesis; NODYSK: normal scapular motion; MMT: manual muscle test; NMW: normalized maximum weight; MVC: maximum voluntary contraction; ADD: adduction; ABD: abduction; IS: infraspinatus; SS: Supraspinatus; SB: Subscapularis; TM: Teres minor; DE: Deltoid; LD: Latissimus Dorsi, PM: Pectoralis Major; BB: Biceps Brachii; AD: Anterior Deltoid; MD: Middle Deltoid; PD: Posterior Deltoid; SA: Serratus Anterior; T: Trapezius; UT: Upper Trapezius; MT: Middle Trapezius; LT: Lower Trapezius; RB: Rhomboids; PT: pull-through; EPT: early pull-through; MPT: mid-pull-through; LPT: late pull-through; TPT: terminal pull-through; MT: mid-recovery; LR: late recovery; RCTe: Rotator cuff tendinopathy.

*Indicates significance ($p \leq 0.05$; †Results reported without clear details on values.

Only significant results, reported by each study, are described in Results (EMG analysis) column.

†Only rotator cuff muscles were analyzed in this study.

Table 4
Overview of the level of evidence for the outcomes.

Outcomes analyzed	Participants (studies)	Trials	Methodological quality	Level of evidence	Results
Coactivation ratio	n = 20 (1 study)	Myers et al.	HQ	**Limited** due to imprecision	Muscle coactivation (SB-IS; SS-IS) affected by RCTe
Muscle contribution	n = 32 (1 study)	Clisby et al.	HQ	**Limited** due to imprecision	No differences in the relative contributions
Muscle activation	n = 311 (8 studies)	Bandholm et al.	HQ	**Conflicting** due to indirectness, inconsistency	SS, IS muscle activation unaffected by RCTe
		Skolimovsky et al.	GQ		
		Lopes et al.	HQ		
		Roy et al.	HQ		
		Pink et al.	GQ		Several methodological differences leading to various results (altered and unaltered muscle activation), concerning all RC muscles.
		Reddy et al.	MQ		
		Michaud et al.	MQ		
		Ruwe et al.	MQ		

The bold terms refer to the level of evidence, which did not consider the EMG quality. Imprecision: a single study or data from less than 100 participants. Risk of bias: methodological quality determined by the rating system adopted in this review. Indirectness: methodological heterogeneity between studies. Inconsistency: Results/findings in different directions.

Table 5
Muscle investigated and general findings of the included studies.

	Infraspinatus (IS)	Supraspinatus (SS)	Subscapular (SB)	Teres minor (TM)
Studies				
Bandholm et al. (2006)	x	x		
Clisby et al. (2008)	x			
Lopes et al. (2015)	x			
Michaud et al. (1987)		x		
Myers et al. (2009)	x	x	x	
Pink et al. (1993a)	x	x	x	x
Reddy et al. (2000)	x	x	x	x
Roy et al. (2008)	x			
Ruwe et al. (1994)	x	x	x	x
Skolimowski et al. (2009)	x	x		
Muscle activity altered/affected by RC tendinopathy				
Myers et al. (2009)[a]	x	x	x	
Pink et al. (1993a)	x	x	x	x
Reddy et al. (2000)	x		x	
Ruwe et al. (1994)	x	x	x	x
Skolimowski et al. (2009)	x			
Muscle activity non-altered/affected by RC tendinopathy				
Bandholm et al. (2006)	x	x		
Clisby et al. (2008)	x			
Lopes et al. (2015)	x			
Michaud et al. (1987)		x		
Reddy et al. (2000)		x		x
Roy et al. (2008)	x			
Skolimowski et al. (2009)	x	x		
Increased muscle activity				
Pink et al. (1993a)	x		x	
Ruwe et al. (1994)	x		x	
Myers et al. (2009)[a]	x	x	x	
Reduced muscle activity				
Myers et al. (2009)[a]	x	x	x	
Pink et al. (1993a)		x		x
Reddy et al. (2000)	x		x	
Ruwe et al. (1994)		x		x
Skolimowski et al. (2009)	x			

[a] Measurements of the coactivation of rotator cuff muscles.

EMG Scale (Table 2): Scores ranged from 4/26 (15.4%) to 25/26 (96.2%), with a mean score of 56.8 ± 2.4%. Eight studies failed to provide important information on band pass filter or filter type. Seven studies did not fully respect the ISEK standards concerning frequency range (low and high-frequency cut-off). Most studies (70.0%) did not describe wave rectification, and information on the A/D conversion was absent in six articles. Lastly, four studies did not report the strategies used to determine or avoid EMG cross-talk contamination.

Pre-consensus inter-rater agreement on the total scores was high for both QualSyst (ICC = 0.96 [95% IC: 0.83–0.99]) and EMG (0.99 [95% IC: 0.96–1.00]) scales.

3.2. EMG activity of RC muscles in patients with RCTe

As the 10 included studies used different procedures to evaluate muscle activity with an RCTe, we decided to group them into four functional groups: isometric, isokinetic, isotonic, and unrestrained dynamic movements (including sporting movements).

3.2.1. Impact of RCTe on EMG activity during isometric contractions

There is strong evidence for the IS and SS, that their activation is not altered in individuals with RCTe during isometric contractions (Table 6), as four studies (n = 128) that have looked at RC muscle activity during this type of contractions did not observe any significant differences between the symptomatic and asymptomatic shoulder (Michaud et al., 1987; Bandholm et al., 2006; Clisby et al., 2008; Skolimowski et al., 2009). Skolimowski et al. (2009) reported no changes in both IS and SS muscle activity, as recorded by surface EMG, in 58 patients with unilateral RCTe compared to their healthy shoulder during isometric internal rotation, external rotation, and abduction contractions. EMG data were processed through Root Mean-Square (RMS). Michaud et al. (1987) compared the EMG activity of SS muscle during isometric submaximal contraction at 0° and 45° of abduction of 20 patients suffering from RCTe to 20 healthy controls (surface electrodes, Z-score used for normalization, data processed through integrals EMG). Bandholm et al. (2006) also compared individuals with RCTe (n = 9) to healthy controls (n = 9) using surface electrodes during isometric submaximal and maximal voluntary contractions (MVC) at 45° and 90° of abduction (data expressed as relative muscle activity, normalized to MVC, and processed through RMS 1-s window). Both studies found that SS muscle activity was unaffected by RCTe during the isometric abduction contractions. Bandholm et al. (2006) also reported no difference in IS muscle activity. Clisby et al. (2008) further support IS muscle activity to be unaffected by RCTe while comparing isometric contractions during external rotation in 14 symptomatic individuals to 18 healthy controls (surface electrodes, RMS at 32 Hz to process EMG data, MVC as normalization method).

3.2.2. Impact of RCTe on EMG activity during isokinetic contractions

There is limited evidence that SS and IS muscle activity is not altered during isokinetic contractions in individuals with RCTe (Table 6). A single HQ study (Bandholm et al., 2006) found no changes in EMG activity during either eccentric (110–95° and 55–40°) or concentric (40–55° and 95–110°) contractions of shoulder abduction for the SS and IS muscles in individuals with RCTe. The same parameters as described above for isometric contractions were used.

3.2.3. Impact of RCTe on EMG activity during isotonic contractions

Very limited evidence exists that IS and SB muscle activity is reduced in individuals with an RCTe during isotonic contractions, whereas SS and TM muscle activity is not altered (Table 6). A single MQ study used the Basmajian technique to compare muscle activity of all four RC muscles during 30–120° of scaption among individuals with RCTe (n = 15) to healthy controls (n = 16) (data normalized to MVC and processed by IEMG). No significant between-group differences for SS and TM were found. In contrast, a significant decrease in EMG activity in the 30–60° movement range for IS and SB and in the 60–90° range for IS was reported.

Table 6
Overview of the level of evidence for the functional grouping.

Functional group	Participants (studies)	Trials	Methodological quality	Level of evidence	Results
Isokinetic contraction	n = 18 (1 study)	Bandholm et al.	HQ	**Limited** due to imprecision	SS, IS unaffected by RCTe (1)
Isotonic contraction	n = 31 (1 study)	Reddy et al.	MQ	**Very limited** due to imprecision	IS, SB affected by RCTe (1) SS, TM unaffected by RCTe (1)
Isometric contraction	n = 96 (3 studies)	Michaud et al. Bandholm et al. Skolimovsky et al.	MQ HQ HQ	**Strong**	**Consistent findings** SS unaffected by RCTe (3)
	n = 108 (3 studies)	Bandholm et al. Clisby et al. Skolimovsky et al.	HQ HQ GQ	**Strong**	**Consistent findings** IS unaffected by RCTe (3)
Unrestrained movements	n = 222 (5 studies)	Roy et al. Lopes et al. Skolimovsky et al. Pink et al. Ruwe et al.	HQ HQ HQ GQ MQ	**Conflicting** due to inconsistency	IS unaffected by RCTe (2) IS affected by RCTe (3)
	n = 151 (4 studies)	Myers et al. Skolimovsky et al. Pink et al. Ruwe et al.	HQ GQ GQ MQ	**Conflicting** due to inconsistency	SS unaffected by RCTe (1) SS affected by RCTe (3)
	n = 93 (3 studies)	Myers et al. Pink et al. Ruwe et al.	HQ GQ MQ	**Moderate** due to imprecision, indirectness	SB affected by RCTe (3)
	n = 73 (2 studies)	Pink et al. Ruwe et al.	GQ MQ	**Moderate** due to imprecision, indirectness	TM affected by RCTe (2)
Sporting movements	n = 73 (2 studies)	Pink et al. Ruwe et al.	GQ MQ	**Moderate** due to imprecision, indirectness	All RC muscles affected by RCTe (2)

The bold terms refer to the level of evidence, which did not consider the EMG quality. Imprecision: a single study or data from less than 100 participants. Risk of bias: methodological quality determined by the rating system adopted in this review. Indirectness: methodological heterogeneity between studies. Inconsistency: Results/findings in different directions.

3.2.4. Impact of RCTe on EMG activity during unrestrained active and sports movements

The strength of evidence within this functional group is either conflicting or moderate (Table 6). The conflicting evidence is for the impact of an RCTe on SS and IS muscle activity since important between-study differences were observed. Two studies (Roy et al., 2008; Lopes et al., 2015) looked at IS muscle activity during arm movements and found no altered muscle activity in individuals with RCTe. In the study of Lopes et al. (2015), IS activity of 19 patients with RCTe was compared to 19 healthy controls during dynamic elevation of the arm in forward flexion (surface EMG, two reference trials for normalization). Roy et al. (2008), evaluated IS muscle activity in 33 individuals with RCTe and 20 healthy participants, during end-range reaching 90° of elevation (surface EMG, reference conditions used for normalization). By contrast, four studies (Pink et al., 1993a; Ruwe et al., 1994; Myers et al., 2009; Skolimowski et al., 2009) reported altered muscle activity in people with RCTe. Two of them (Myers et al., 2009; Skolimowski et al., 2009) observed decreased muscle activity for IS during shoulder movements, whereas the other two (Pink et al., 1993a; Ruwe et al., 1994) found increased SB and IS muscle activity during swimming. Skolimowski et al. (2009) observed a decreased IS muscle activity during unrestrained internal and external rotations in the involved shoulder (n = 58) compared to their healthy shoulder (surface electrodes, processed by RMS). Myers et al. (2009) reported similar findings when comparing coactivation ratio of RC muscles (surface and intramuscular EMG, maximal elevation torque used for normalization) of 10 individuals with RCTe to 10 healthy controls during unrestrained humeral elevation. They reported that individuals with RCTe exhibited altered muscular coactivation between RC muscles: less subscapularis-infraspinatus and supraspinatus-subscapularis coactivation between 0° and 30°, accompanied by an increase in middle deltoid activation when compared to the healthy group. Furthermore, supraspinatus-infraspinatus coactivation was reduced between 30° and 60°, and accompanied by diminished IS activation, while subscapularis-infraspinatus and supraspinatus-infraspinatus coactivation were higher between 90° and 120°.

Finally, moderate evidence suggests that the muscular activity of all four RC muscles is altered in individuals with RCTe during swimming, based on two studies (Pink et al., 1993a; Ruwe et al., 1994) that have investigated symptomatic swimmers during the butterfly and breast swim strokes (Basmajian technique, MVC used for normalization) (Table 6). Pink et al. (1993a) indicated that all RC muscles had significant alterations in activation patterns, as evaluated during a butterfly stroke, in 14 painful shoulders compared to 20 pain-free shoulders of controlled participants. Using a similar design, Ruwe et al. (1994) also found differences in muscle activity between swimmers with and without shoulder pain during breaststroke. In both studies, SB and IS muscular activity was increased in shoulders with RCTe, whereas SS and TM were decreased.

4. Discussion

The goal of this study was to systematically review the evidence concerning the pattern of EMG activity of RC muscles in individuals with RCTe. Ten studies with a mean methodological score of 80.4% were included. Overall, very limited to strong evidence infers that muscular deficits vary according to the task performed. Undoubtedly, the most interesting findings came from studies showing alterations in muscular activity during unrestrained dynamic movements. Despite not presenting strong evidence, these findings contribute to the understanding of the mechanisms underlying the dynamic narrowing of the subacromial space, during movements, within this population.

RCTe is frequently labeled as impingement syndrome, based on the underlying mechanism, which includes encroachment of soft tissue underneath the coracoacromial arch as the arm is actively elevated. Therefore, deficits related to this injury tend to be more prominent during dynamic activities in elevated arm positions. For example, acromiohumeral distance has been shown to be reduced at 45° and 60° of active shoulder abduction, but not in a neutral position (Savoie et al., 2015). Findings from this systematic review support this reasoning since alterations in muscular activity were mostly observed during movements when the arm was actively elevated. Yet, some between-study differences were found during dynamic movements. This can be explained by the choice of imposed movements, as well as by the parameters used for EMG processing and analysis, including the normalization method, which will be further discussed in the following sections.

4.1. EMG activity of RC muscles in patients with RCTe

4.1.1. Normalization of EMG values in symptomatic patients

Lack of between-studies consistency may be explained by differing methodologies, outcomes measures, data acquisition techniques, and raw EMG data processing. Normalization methods, however, may hold the most important impact on the results. MVC is often used to normalize EMG data, although it can be problematic in symptomatic participants since pain may compromise the achievement of true maximal values, leading to an overestimation of relative EMG activity used during movement, and increased data variability. An alternative method to normalize EMG values in symptomatic population uses a reference condition, as described in Roy et al. (2008). In their study, data were normalized by mean EMG activity collected while participants actively held their arm at 90° of elevation against a 1 kg load. This normalization approach also has some limitations, however. Indeed, as the muscular activity is impaired in this population and variable across participants, normalizing using this method may also lead to increased data variability. The lack of a standardized EMG normalization method, therefore, obscures comparison of muscle activation amplitude across studies.

It is important to point out that included studies are relatively dated since 50% of them were published more than 10 years ago (Bandholm et al., 2006; Michaud et al., 1987; Pink et al., 1993a; Reddy et al., 2000; Ruwe et al., 1994). In fact, only one study has been published within the last five years (Lopes et al., 2015). Therefore, it may have influenced the EMG parameters and processing used, especially, normalization and filtering for which guidelines have only been suggested in recent years.

4.1.2. Impact of RCTe on EMG activity during isometric contractions

The four included studies that explored EMG activity during isometric contractions show strong evidence for SS and IS, that the muscle activity of these two muscles is not altered during this type of contraction (Table 6), even in elevated arm positions. Shoulder control required during isometric contractions may not be demanding enough to expose sensorimotor deficits. However, it must be noted that during isometric contraction at 45° of abduction, deltoid EMG activity has been shown to be decreased within this population (Michaud et al., 1987). As the deltoid is one of the primary agonists during shoulder abduction, its inhibition could be a strategy to avoid pain by preventing the superior translation of the humeral head during such contractions (Bertoft, 1999). Details on this perspective should be further investigated.

4.1.3. Impact of RCTe on EMG activity during isokinetic contractions

As only a single HQ study (Bandholm et al., 2006) has examined the RC muscle activity during isokinetic contractions in individuals with an RCTe, the evidence showing no alteration in the SS and IS muscle activity is limited. During isokinetic movements, no alterations in the muscular length-tension relationship are observed. Given that, the absence of significant alterations in muscle activity during an isokinetic movement is not surprising. Further investigations are needed to provide definite conclusions during isokinetic contractions.

4.1.4. Impact of RCTe on EMG activity during isotonic contractions

During isotonic contractions, muscle tension remains constant, however the muscle length changes (Bigliani and Levine, 1997), providing variation in the production of muscle force to overcome the resistance throughout the motion. Here again, a single MQ study (Reddy et al., 2000) investigated RC muscle activity using this type of contractions and provided very limited evidence of a decrease EMG activity for IS and SB. In our point of view, the reduction in EMG activity of IS and SB during scaption, reported by Reddy et al. (2000), likely occurred due to an inhibition mechanism as a result of shoulder control disturbances generated by mechanical alterations. Possible physiological characteristics observed during isotonic contractions are also present during dynamic movements, especially in eccentric contractions. These common elements may contribute to understanding the changes in the RC muscle activity observed in unrestrained dynamic movements.

4.1.5. Impact of RCTe on EMG activity during unrestrained active movements

Due to a small number of participants, methodological heterogeneity, and the inconsistencies of the reported results, conflicting evidence was observed regarding the SS and IS muscle activity when unrestrained movements were used to evaluate the RC muscle activity. Indeed, alterations in RC muscle activity are not unanimous, as two studies did not report any change (Roy et al., 2008; Lopes et al., 2015). Between these two studies, we highlight that Roy et al. (2008) used a reference condition as a normalization method. This could have increased data variability and limited the capacity to identify between-group differences.

Among the four studies (Pink et al., 1993a; Ruwe et al., 1994; Myers et al., 2009; Skolimowski et al., 2009) that found altered RC muscle activity during dynamic movement, two reported increased IS muscle activity, and the other two reported reduced activities. A possible explanation for these diverging results is that different shoulder movements were used, as the level of muscular activation differs when acting as a prime mover or not. In this case, studies reporting increased activity of IS muscle examined the muscle response during arm elevation (IS is not the prime mover), whereas reduced activity was found during unrestrained humeral external rotation (IS is the prime mover). The choice of different control subjects may also contribute to the divergences between these studies. Indeed, in one study reporting IS activity reduction (Skolimowski et al., 2009), the comparison was made between the symptomatic and the asymptomatic shoulders of individuals with a diagnosed RCTe, while the other studies compared the same shoulder in individuals with and without RCTe.

Findings from Myers et al. (2009) highlight the importance of coactivation among RC muscles. Synchronous control between IS and SB is required to maintain shoulder joint stability in the transverse plane; therefore, altered activation of one of these muscles requires an activation from its antagonist in the same direction. Results from Myers et al. (2009) revealed that between 0° and 30°, coactivation between IS-SB and SB-SS were reduced. Interestingly, after 90° of abduction, coactivation between IS-SB and SS-IS increased above normal. This increase was likely a response mechanism triggered to counteract the superior migration of the humeral head, creating a force coupling to stabilize the humeral head in the glenoid fossa. These findings highlight that properly timed activity between RC muscles plays an important role in avoiding impingement. Despite the relevant findings, the evidence on alteration of SB and TM muscle is considered moderate due to the small sample size and heterogeneous methodologies.

4.1.6. Impact of RCTe on EMG activity in sports movements

The literature showed that swimmers with RCTe had a significant increase in IS and SB muscle activity, whereas SS and TM were decreased (Pink et al., 1993a; Ruwe et al., 1994). The level of evidence of these findings, however, was considered moderate due to the small sample size and methodological heterogeneity, as differing swimming strokes were used for two of the included studies. As several types of swimming strokes require repetitive medial rotation of the arm, SB activity is likely increased during the initial phase of a movement aiming to improve swimming performance. In contrast, to prevent forward humeral head translation during swim-strokes, IS muscle activity could also be increased during the recovery phase. Therefore, these studies propose that increased IS activity could be a response to decreased range of motion (ROM) in lateral rotation, resulting from a failure of the humeral greater tuberosity to pass under the acromion during arm elevation, or increased medial rotation. This requires attention when considering that SB assists the latissimus dorsi in rotating the humerus medially (Pink et al., 1993a), whereas IS counteracts the effects of these muscles by rotating the humerus laterally. Because characteristics of athletes do not necessarily correspond to the profile of the general population, these findings should be analyzed with caution.

4.2. Strengths and limitations of the study

The strengths of this review include the use of a validated tool for the critical appraisal (QualSyst), the determination of the quality of evidence, a rigorous literature search in eight recognized databases and four different languages, as well as the development of a scale for the appraisal of reported EMG activity.

We are aware of some limitations of this review. First, non-scientific journals, unpublished, and gray literature were not included in data search. Thus, it is possible that relevant studies may have been missed due to these criteria. Next, despite analyzing the normalization procedures adopted in each study, this review was not able to identify a standardized manner to normalize EMG data of symptomatic patients with RCTe. Finally, three studies that have looked at IS EMG activity during unrestrained active movements (Lopes et al., 2015; Roy et al., 2008; Skolimowski et al., 2009) have used surface EMG. This may not be appropriate for IS recordings. As surface electrodes are attached to the skin and it is likely that it does not follow the IS muscle during scapular movements leading to the recording of other neighboring muscles (Wickham et al., 2010; Johnson et al., 2011; Waite et al., 2010).

4.3. Future research directions

Future studies addressing EMG activity of RC muscles should follow the ISEK standards to ensure higher quality recordings and reports. Based on some possible points of improvements identified among the included studies, the following recommendations are advised:

(1) Band-pass filter and filter type should be clearly reported, facilitating protocol reproduction.

(2) Procedures for the identification and reduction of crosstalk contamination should be clearly described to increase the confidence of the readers.
(3) Normalization methods not minimized by pain or other symptoms of RCTe should be developed.

Further studies are required to highlight the differences in EMG activity between patients with RCTe and healthy individuals, during dynamic contractions. Finally, most studies focused on the SS and IS; therefore, SB and TM muscle activity should be further investigated.

5. Conclusions

According to the body of evidence summarized, there is strong evidence that individuals suffering from an RCTe have no alteration in the muscle activity of IS and SS muscles during isometric contractions.

The level of evidence regarding the impact of an RCTe on EMG activity of RC muscles varied largely (from conflicting to moderate evidence) during unrestrained dynamic movements. There is moderate evidence to suggest that the SB and TM muscle activity is reduced, while there is conflicting evidence regarding a reduced muscle activity of the IS and SS muscles, during unrestrained movements among individuals with a RCTe. Notwithstanding, moderate evidence indicates that patients affected by RCTe may have the RC muscle activity altered during swimming strokes.

Altered RC muscles activity may compromise joint stability, resulting in increased shoulder dysfunction. Therefore, our results show the importance of evaluating muscle performance and shoulder motor control in individuals suffering from RCTe during dynamic tasks. Further investigations are required to define RC muscle activity of this population during dynamic movements.

Competing interests

Fábio Oliveira, Dr. Laurent Bouyer, Amanda Ager, and Dr. Jean-Sébastien Roy declare that they do not have a conflict of interests to declare.

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Appendix A. Terminology employed for the search strategy

Concept 1:	Concept 2:	Concept 3:
Outcomes	Patients/Symptoms	Muscles
Electromyography [MeSH]	*Rotator cuff injuries* [MeSH]	*Rotator cuff muscles* [Mesh]
electromyograph*	tendinopath*	infraspinatus
EMG	impingement	supraspinatus
musc* activity	subacromial pain	teres minor
		subscapularis
		rotator cuff muscles

Terms used in the search strategy in the Pubmed database using a combination of keywords, as follows: ‘OR’ within each concepts, and ‘AND’ between the concepts.

Appendix B. Checklist for assessing the EMG reports in studies

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
Electrodes					
1	Types of electrodes clearly described?				▨
2	General technical information on electrodes				▨
Amplification					
3	Description of the amplification procedure				▨
4	Relevant information on the amplification procedure adequately reported?				▨
Filtering					
5	Band pass filters and filter types clearly described and well applied?				▨
6	Frequency range according to the ISEK standards?				▨
Rectification					
7	Wave rectification well described?				▨
8	Method of EMG processing adequately reported?				▨
Sampling into the computer					
9	Nyquist theorem well applied?				▨
10	Information on A/D Board available?				▨
Normalization					
11	Preliminary subjects training to obtain the MVC?				
12	Muscle contraction analysed in sufficient details?				▨
EMG Crosstalk					
13	Information on EMG crosstalk				

SUMMARY SCORE (SS)

Total Sum (TS): *(number of "YES" $*$ 2) + (number of "PARTIAL")*
Possible Sum (PS): *26 – (number of "N/A" $*$ 2)*
Summary Score (SS): TS/PS

Definitions and Instructions for Assessment Scoring of EMG reports in randomized controlled studies

1. Types of electrodes clearly described?

(If the type of electrodes used to acquire the EMG data is described: *surface EMG, intramuscular wire, needle electrodes,* including basic characteristics of it as *material, geometry, size, single- or multi-strand, insulation material and etc.*)

Yes: The type of electrodes used in the data acquisition is easily identified in the section material and methods/methodology.

Partial: The type of electrodes is vaguely or incompletely reported or it is reported in other section.

No: The type of electrodes is not reported.

N/A: Should not be checked in this question.

2. General technical information on electrodes?

(If the study reports some of the most relevant technical information on the electrodes used, according to the type of EMG measurement.)

For Surface EMG: interelectrode distance, placement, orientation and cleansing the skin (skin preparation).

For Intramuscular wire: length of exposed tip, method of insertion, depth of insertion, single or bipolar wire, location of insertion in the muscle, interelectrode distance, type and location of the ground.

For Needle electrodes: material, size of conductive contact points at the tip, depth of insertion and accurate location in the muscle.

Yes: Most relevant technical information of the electrodes is reported (taking into consideration the EMG type chosen).

Partial: The information/characteristics of the electrodes used are identified but most relevant technical information of the electrodes is missing.

No: Most relevant technical information of the electrodes is not reported.

N/A: Should not be checked in this question.

3. Description of the amplification procedure (gain range, single, differential, double differential, etc.).

Yes: The amplification procedure is clearly identified in the section material and methods/methodology.

Partial: The amplification procedure is vaguely or incompletely reported or they are reported in other section.

No: The amplification procedure is not described.

N/A: Should not be checked in this question.

4. Relevant information on noise processing.

(If the study reports the most relevant information on noise processing: *input impedance, Common Mode Rejection Ratio (CMRR) and signal-to-noise ratio.*)

Yes: Most of the relevant information on noise processing is approached in the section material and methods/methodology.

Partial: Most relevant information on noise processing is not clear, incomplete or, when reported, it is reported in other section.

No: There is no information on the noise processing available in the manuscript.

N/A: Should not be checked in this question.

5. Band pass filters and filter types clearly described and well applied?

Yes: The filtering of raw EMG data is adequately described, permitting the reader to relate the band pass filters (low or high pass filters) and the filter type (ex., Butterworth, Chebyshev, etc.) applied.

Partial: The filtering process is partially or incompletely described or the band pass filter or filter type is not clearly reported.

No: The band pass filters and filter type are not described.

N/A: Should not be checked in this question.

6. Frequency range according to the ISEK standards?

(If the frequency range is appropriately described and according to the ISEK recommendations.)

For Surface EMG: low cut-off equal/below 10 Hz; high cut-off equal/above 350 Hz).

For Intramuscular EMG: band pass filter of 10–450 Hz).

For Needle recording: bandwidth of 10–1500 Hz.

Yes: The frequency range followed the ISEK recommendations, taking into consideration the EMG measurement chosen.

Partial: The parameters of the filter are not fully in line with the ISEK standards (one of the cut-offs is not in line with ISEK recommendations).

No: The frequency range did not follow the ISEK standards for reporting EMG data.

N/A: Should not be checked in this question.

7. Wave rectification well described?

Yes: The wave rectification carried out is adequate and it is well described in the section material and methods/methodology.

Partial: The wave rectification was carried out but the type (full or half wave) is not identified or it is not adequate.

No: The wave rectification is not described.

N/A: Should not be checked in this question.

8. Method of EMG processing adequately reported?

(If the study reports the processing EMG methods applied: smoothing, root mean square, integrals, power density spectra.)

Yes: The method of EMG processing is clearly and adequately described.

Smoothing: band pass filter reported in ms; linear envelope; mean absolute value.

Root Mean Square (RMS): time window.

Integrated EMG: threshold, time or voltage used to reset the integrator.

Power Density Spectra: time epoch used for calculation segment; algorithm like Fast Fourier Transform (FFT); type of windows prior FFT; number of zero padding applied; equation used to calculate the Median Frequency (MDF), Mean Frequency (MNF) and etc.; muscle length at the time of recording.

Others techniques fully scientifically described.

Partial: The method of EMG processing is mentioned but not adequately specified or described.

No: The method of EMG processing is not described.

N/A: Should not be checked in this question.

9. Nyquist theorem applied?

Yes: Sampling theorem well applied and clearly identified.

Partial: Sampling theorem applied but not mentioned by the authors.

No: The sampling theorem not applied.

N/A: Should not be checked in this question.

10. Information on A/D Board available?

(If the study provides information on A/D converter (number of bits, model, and manufacturer), offline analysis and/or storage in a computer.

Yes: Information on A/D board, offline analysis and/or storage in a computer is available in the manuscript.

Partial: Information on A/D board, offline analysis and/or storage in a computer is incomplete or hardly identified.

No: There is no information about the A/D board, offline analysis and/or storage in a computer.

N/A: Should not be checked in this question.

11. Preliminary subjects training to obtain the MVC?

(If the subjects were trained before to obtain the true maximal voluntary contraction (MVC) in force/torque analysis)

Yes: The authors report the subjects were trained.

Partial: There is some information about subjects training but not enough to replicate.

No: There is no information about subjects training or there is information the subjects were not trained before the MVC data acquisition.

N/A: The study did not analyse force/torque.

12. Muscle contraction analysed in sufficient details?

For isometric contraction: joint angle or muscle length, angles of adjoining joint, rate of rise of force.

For non-isometric contraction: rate of rise of force, range of joints angle/muscle length, changes in the muscle length, velocity of shortening/elongation and load applied.

Yes: Most relevant items are clearly reported in the manuscript.

Partial: Some relevant information is missing.

No: There are no sufficient details related to the type of muscle contraction.

N/A: Should not be checked in this question.

13. Information on EMG crosstalk

(If the manuscript provides information on the EMG crosstalk from others muscles near the muscle of interest did not contaminate the recorded EMG signal.)

Yes: The authors made significant efforts to identify, determine and avoid the contamination by EMG crosstalk.

Partial: The authors identify EMG crosstalk or their efforts to avoid signals contamination, but there is no enough information to reproduce it.

No: Efforts to avoid or determine EMG crosstalk contamination is not reported.

N/A: There is no EMG crosstalk in the data acquisition.

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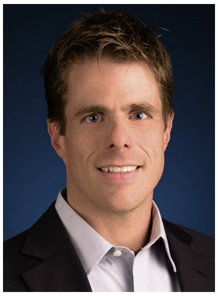

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