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DEPARTMENT OF PHYSIOTHERAPY

An Evidence-based Assessment Model for the Comprehensive Assessment of the Scapulohumeral Complex

Thesis submitted to the Faculty of Health Sciences,

University of the Witwatersrand, Johannesburg, South Africa, in fulfilment of the requirements for the degree of Doctor of Philosophy

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Declaration

I, Sonia Briel, acknowledge that the work presented in this research manuscript is solely my own, except where indicated in the preface as a proportion of contribution to peer-reviewed publications. Where information has been derived from other sources, I confirm that this has been identified and referenced within the thesis.

This thesis is submitted for the degree of Doctor of Philosophy in Physiotherapy at the University of the Witwatersrand, Johannesburg, South Africa.

This thesis has not been submitted elsewhere for any degree or examination.

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To my GOD and Saviour, Soli Deo Gloria, All Glory be to GOD……

"The important thing is not to stop questioning. Curiosity has its own reason for existing"

Albert Einstein

Summary

A comprehensive assessment of shoulder dysfunction is currently lacking. Current shoulder assessment models often fail to address the complexity of shoulder dysfunction. The scapulohumeral complex is the anatomical complex with the most movement in the human body, however stability is compromised by the lack of inherent bony stability. Many modifiable musculoskeletal factors influence shoulder function/ dysfunction. In this study modifiable musculoskeletal factors and the influence on the shoulder complex were explored and highlighted. Current literature was extensively researched and analysed. The development of an objective assessment model for the scapulohumeral complex was the end goal.

This thesis contains five original papers. The first paper, a global systematic review with meta-analyses, explores and consolidates current knowledge of 71 studies on the worldwide occurrence of modifiable musculoskeletal factors in both an athletic and non-athlete population. This study highlighted the presence of definite modifiable musculoskeletal factors in painful shoulders and identified gaps in present research.

The second paper, an analytical cross-sectional study design, investigated the strength profile of the superior cuff (included the supraspinatus muscle and its tendon) and of the inferior cuff (includes the infraspinatus and teres minor muscles and their tendons) in participants aged between 18 to 75 years of age in both non-painful and painful shoulders. This study was a first of its kind to propose and to explore the force couple ratio between the supraspinatus muscle (SS) and the anterior deltoid muscle (AD) with isometric dynamometry. The force couple ratios were concluded in both the superior force couple SS:AD and in the inferior force couple between the external (ER) and the internal rotators (IR).

The third paper, an analytical cross-sectional study, reported on the flexibility of the periscapular musculature in the age group 18 to 75 years of age in both non-painful and painful shoulders. It was the first study to the authors' knowledge to explore the flexibility of the latissimus dorsi (LD), the pectoralis minor (PMm), subscapularis and the posterior capsule (PC) in terms of range of motion (ROM) in a non-athlete population group. Decreased range of external rotation (ER), internal rotation (IR), flexion, and abduction were linked to painful shoulders.

The fourth study, a nominal group technique, gauged the opinions of practicing physiotherapists (clinicians and academics) on the inclusion of various factors to be considered in an evaluation model for shoulder assessment.

The fifth study, a pilot reliability study, tested the novel assessment model for the shoulder based on the findings of all the previous studies (1,2,3 and 4).

The findings of this thesis identified modifiable musculoskeletal factors that were associated with shoulder dysfunction. An evidence-based scapulohumeral complex assessment model using current research is therefore proposed based on the findings of the current thesis. The guidelines provided with the present thesis can serve as a starting point for more research in the shoulder field.

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List of Abbreviations

AD = anterior deltoid

BMI = body mass index

CRD = centre for reviews and dissemination

d = effect size

DASH = disability of the arm, shoulder and hand

EMG = electromyographic

EBP = evidenced based practice

ER = external rotation

ER0 = external rotation in neutral

ER45 = external rotation at 45°

ERG = external range of motion gain

ERABD/ER = external rotation in abduction at external rotation

ERF = external rotation in flexion

ER0 = external rotation in neutral

ER90 = external rotation in 90 degrees

GIRD = glenohumeral internal rotation deficit

HHD = handheld dynamometer

ICC = intraclass Correlation Coefficient

IR = internal rotation

IR0 = internal rotation in neutral

IR45 = internal rotation at 45 degrees

IRABD/ER = internal rotation abduction in external rotation

IR F = internal rotation during flexion

JBI = Johanna Briggs Institute

L = left

LD = latissimus dorsi

MOOSE = Meta-analysis of observational studies in epidemiology

NGT = nominal group technique

OR = odds ratio

P = painful, NP = non-painful,

PMm = pectoralis minor

RCRSP = rotator-cuff related shoulder pain

PC = posterior capsule

PCSL = posterior capsule side-lying

PRISMA = Preferred reporting items for systematic reviews

R= right

RR = risk ratio

ROM = range of motion

TROM = toral range of motion

SD = standard deviation

SE = standard measurement of error

SHB = short head of the biceps

SR = systematic review

SMD = standard mean deviation

SPADI = shoulder pain and disability index

SR = systematic review

SS = supraspinatus

SWiM = synthesis without meta-analysis

VAS = verbal analogue pain scale

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Glossary of terms

Modifiable musculoskeletal factors:

Pectoralis minor, latissimus dorsi muscle, shorth head of biceps and posterior capsule indices, strength of the rotator cuff (supraspinatus, infraspinatus, teres minor, and subscapularis) and of anterior deltoid.

Scapulohumeral complex: Rotator cuff musculature, scapular stabilisers, glenohumeral range of motion scapular and thoracic range of motion.

Force couple ratio: strength ratio between two muscles/ muscle groups.

Conference presentations emanating from the work presented in this thesis

A poster presentation at the South African Society of Physiotherapy in September 2022; Stellenbosch Cape Town South Africa. Titled: Modifiable musculoskeletal factors and their association with shoulder function in adults: A systematic review and meta-analyses of etiology and risk protocol.

Chapter 1 Introduction

1.1 Background

Shoulder pain is ranked as the third highest of all reported musculoskeletal conditions (Urwin et al. 1998; Lucas et al. 2022) with point prevalence of 26% and lifetime occurrence of 67% (Luime et al. 2004). In the systematic review of Lucas et al. (2022) the occurrence of shoulder pain in different communities ranged from 0.67% to 55.2%. In the study of Monrad et al. (2018) the male to female ratio was found to be 51:49. However, in a later study women were determined to be affected more than men and estimates of shoulder pain was determined to be higher in higher income countries (Lucas et al. 2022).

Globally the working age is increasing with people working until a higher age and having longer careers (Monrad et al. 2018; Lynch et al. 2022; Djade et al. 2019). Higher prevalence of shoulder pain has been reported in rural areas compared to urban areas in their study (Monrad et al. 2017). Furthermore, increased incidences of shoulder pain have been reported in the more physical demanding occupations than in office-based occupations (Leclerc et al. 2016). The authors Leclerc et al. (2016) found increased shoulder pain episodes to increase linearly with increased working years in physically demanding occupations, e.g. manual labour (Leclerc et al. 2016). Work related factors resulting in an increased incidence of shoulder pain have been linked to working in a horizontal position or above shoulder height, with repetitive arm movements and handling of heavy weights (Miranda et al. 2008; Shanahan, 2016; Smith, 2001). The burden of shoulder related conditions on society is increasing, with both negative economical and psychological impacts on the life of the patient (Virta et al. 2012; D'Almeida et al. 2008; Ostör et al. 2005; Cho et al. 2013).

Shoulder pain episodes in the athletic populations and especially in the overhead athlete is also well known (Byram, et al. 2010; Keller et al. 2018; Hill et al. 2015; Dutton et al. 2019; Olivier et al. 2020) Shoulder pain leads to loss of play, loss of income and often premature termination of the athlete's career (Jacobs et al. 2022; Olivier et al. 2020; Pritchard et al. 2025).

A reason for the high burden of shoulder dysfunction, might be attributed to the scapulohumeral complex which comprises of the most mobile joint of the human body; but stability is compromised by the inherent lack of bony stability (Warner et al. 1998; Kelkar et al. 2001). Stability, both static and dynamic and control of the scapulohumeral complex is executed mainly by muscular forces (Goetti et al., 2020; Lugo et al. 2008). A good functional shoulder is needed for the execution of everyday activities, for recreation and sporting activities, for work related activities and for professional sporting activities in both underhand and overhead activities (Cools et al. 2016; Forthomme et al. 2018; Kolber et al. 2017; Nordqvist et al. 2021).

The early diagnosis and rehabilitation of the shoulder regardless of profession or sport is hence imperative. The benefit of physiotherapy on improved function and pain relief and quicker return to work or sport has been established (Garcia et al. 2024). Standard orthopaedic shoulder tests are mainly used in practice for the diagnoses of shoulder pain (Baigent, et al. 2023 Cadogan et al. 2011). However, major controversies exist in current literature on the validity and efficacy of these tests (Baigent et al. 2023; Bron et al. 2011; Cools et al. 2017; Hughes et al. 2008; Schellingerhout et al. 2008; Roldán-Ruiz et al. 2025). The anatomical validity and the reproduced symptoms have been questioned increasingly during the past couple of years (Hughes et al. 2008; Schellingerhout et al. 2008; Baigent et al. 2023). The call for a different approach with easily reproducible tests or a cluster of tests has been made by numerous authors (Baigent et al. 2023; Dutton et al. 2019; Roldán-Ruiz et al. 2025; Schellingerhout et al. 2008). Many modifiable musculoskeletal factors have been identified to be associated with shoulder dysfunction/ pain and should be investigated in the context of an improved assessment model (Bäcker et al. 2018; Rosa et al. 2021; Kwan et al. 2021; Kim and Jeong. 2024). The knowledge gap in current shoulder research on the effective assessment of the scapulohumeral complex is clearly evident. Shoulder pain is multifactorial in origin and potentially difficult to assess (Monrad et al. 2018; Baigent et al. 2023). Lack of clear assessment findings impedes not only the assessment but also the rehabilitation process (Baigent et al. 2023; Roldán-Ruiz et al. 2025).

1.2 Problem statement

Physical assessment of shoulder dysfunction by physiotherapists involves interpretation and analysis of multiple assessment findings, to manage a patient effectively. Using currently standardised orthopaedic shoulder tests might therefore not be ideal, as these tests have been found to lack diagnostic accuracy (Hughes et al., 2008; Lasbleiz et al., 2014; Baigent et al. 2023). The importance of the biomechanical functioning of all the rotator cuff muscles (supraspinatus, infraspinatus, teres minor and subscapularis) has been highlighted in literature (Goetti et al., 2020; Lugo et al. 2008).

Key soft tissue structures that have been highlighted in section 1.1, to increase the occurrence of shoulder dysfunction, should be identified and incorporated from first contact with the patient into the rehabilitation programme as applicable. The evaluation of only certain isolated factors, normally through standardised orthopaedic shoulder tests, might therefore not be sufficient to identify important contributing factors to shoulder pain, regardless of the clinical diagnosis.

1.3 Research aims

The aim was to develop a comprehensive and evidence-based shoulder assessment model.

1.3.1 Objectives of the research

The research objectives are listed below, structured according to the applicable chapters and studies.

Chapter 4 Research objective (Study one): systematic review.

The objective of this systematic review of etiology was to determine the association between biomechanical and arthrokinematical factors, and shoulder dysfunction. Based on the findings of this study, biomechanical and arthrokinematical factors were included in the comprehensive assessment model for the scapulohumeral complex.

Chapter 5 and 6 Research objectives (Study two and three): physical testing

The objective was to determine the following in individuals with pain free and in individuals with painful shoulders:

The force value of the rotator cuff (supraspinatus, subscapularis, infraspinatus and teres minor) and of the anterior deltoid.

The superior cuff ‘s force couple ratio between the supraspinatus and the anterior deltoid.

The inferior rotator cuff ’s force ratio between the external and the internal rotators.

The length of subscapularis, pectoralis minor, Latissimus dorsi and the posterior capsule.

To compare the above results within participants with pain free shoulders and within participants with painful shoulders.

Chapter 7 Research objective (Study four): assessment model development

The objective was to develop a comprehensive and evidence-based assessment model for the scapulohumeral complex assessment through group participation. The key findings as concluded in study one and two were discussed. Objectives were to determine:

- The inclusion/exclusion of key findings of the present study, in the proposed shoulder assessment model.
- An evidence based objective and comprehensive shoulder evaluation model applicable to clinical practice for the shoulder joint.

Chapter 8 Research objective (Study five): reliability study

The objective was to assess the test-retest, inter and intra-reliability of the developed comprehensive assessment model for the scapulohumeral complex.

1.4 Significance of the study

An assessment model for the scapulohumeral complex, using measurable evidence-based outcomes was established based on current and new evidence from the current study. Values for the ratios of the external versus internal rotator cuff muscles in all ranges of motion in shoulders with/without pathology were determined to underpin certain aspects of the assessment model. It is important for clinicians and researchers to establish reliable and accurate tests and tools that can be applied to clinical practice. In theory, restoration of all the modifiable musculoskeletal factors leading to shoulder dysfunction may lead to normalising of the arthrokinematics of the scapulohumeral complex and pain free movement. However, determining cause and effect, of modifiable musculoskeletal factors is not the aim, but only the association and relationship thereof, in pain free and painful shoulders.

A significant contribution to the assessment of the scapulohumeral complex specific to the physiotherapy profession was established with the current study. Based on the findings of the present study, modifiable musculoskeletal factors contributing to the biomechanical and arthrokinematical stability of the scapulohumeral complex were included in the assessment model for the scapulohumeral complex.

1.5 Outline of the Thesis

The different sections of the thesis are presented next in an outline of what is covered in each chapter.

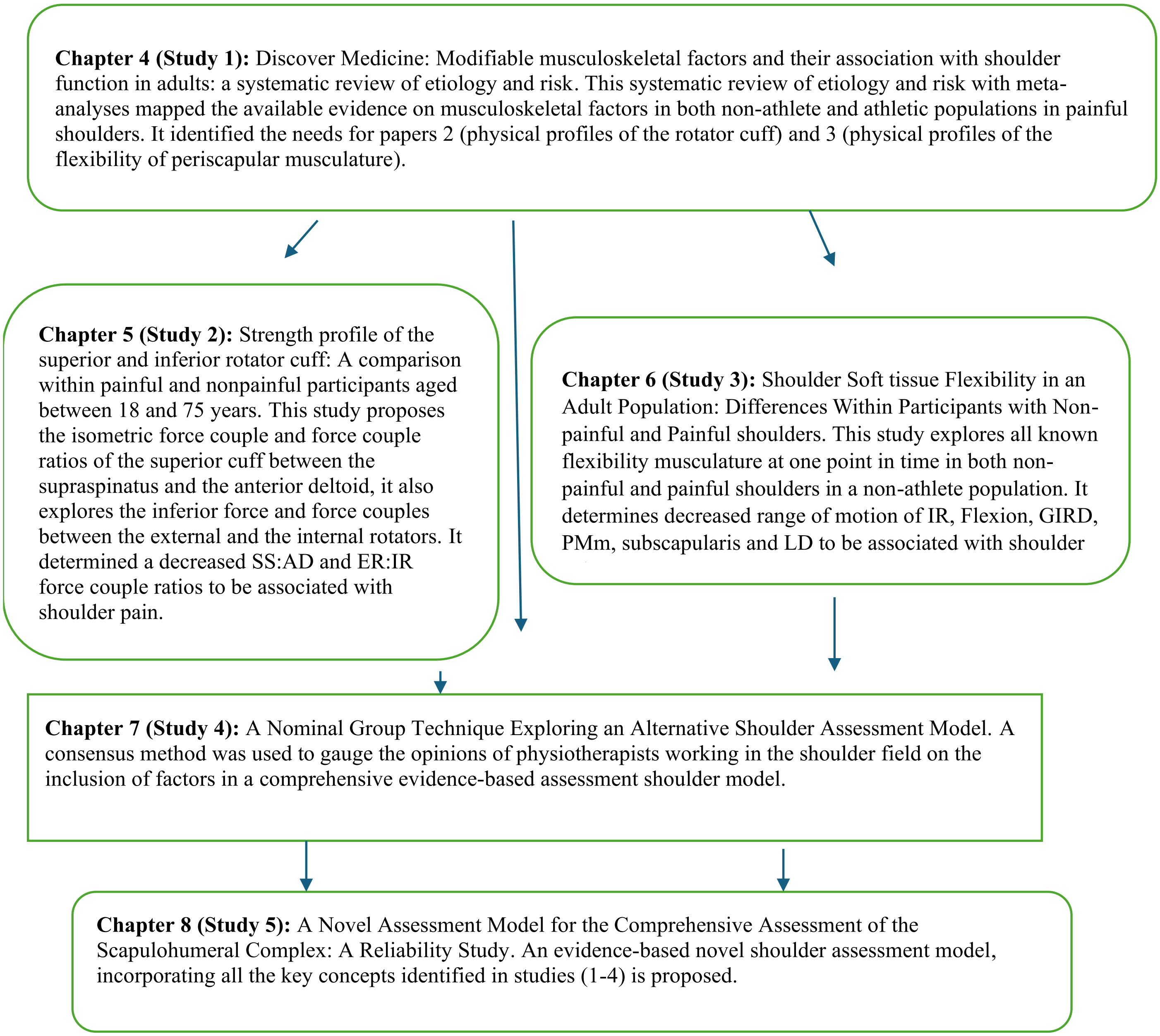

Figure 1: Outline of the thesis.

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Chapter 2 Literature review

This chapter explores the current literature of the scapulohumeral complex is explored in terms of: static stabilisers (the articular surfaces of the glenohumeral joint, the ligamentous structures of the glenohumeral joint); the dynamic stabilisers (the rotator cuff, the scapular stabilisers force), and the force couple ratios.

2.1 Prevalence of shoulder dysfunction

The incidence of shoulder pain has been rated as the third highest of all reported musculoskeletal conditions after back pain and knee pain (Urwin, 1998). A significant increase in the reported incidence of shoulder pain has been noted in the years between 1996 to 2013 (Monrad et al. 2018). The rapid increase in shoulder related pain was re-iterated in a more recent study of Monrad et al. (2018). Even though the incidence of shoulder pain is high, uncertainty still exists on the cause, diagnosing and treatment of reported shoulder symptoms (Shanahan, 2011, Cools et 2017; Sundhedsstyrelsen, 2011).

Although studies on the prevalence of shoulder pain are dearth, a number of studies have investigated the prevalence of shoulder pain in different professional groups. A South African study conducted among dentists during a twelve-month period determined the prevalence of shoulder pain to be as high as 72.4%. Mean age of dentists was 36.5 years and both females (n=116) males (n=222) were included in the study. The average years of practicing ranged from <9 years to >40 years (Botha et al. 2014). Prolonged static posture has been linked with the prevalence of shoulder pain in their study. In a global systematic review of teachers in various disciplines ranging from; pre-primary, primary, secondary, special education, and music teachers, the prevalence of shoulder pain ranged from 15% and 83.1%, varying among countries. The highest prevalence of shoulder pain was determined in South Africa at 83.1% followed by China at 73.4% of reported shoulder pain episodes. Associated risk factors were determined to be increasing age, female gender, previous injury, psychosocial factors, length of employment and increased time spent writing on the blackboard. Females were concluded to be at a 1.40 increased relative risk ratio to develop shoulder pain (Nyawose & Naidoo, 2019).

Shoulder prevalence studies have also been conducted in the general population. Pribicevic (2012) in his narrative review of shoulder epidemiology concluded the prevalence of shoulder pain to be as follows in the respective countries; Norway 20.2%, UK 20%, Holland 15.1%, Finland 17%, Sweden 19%, and Europe 19%. A strong relationship was determined between increased age (45-65 years) and shoulder pain prevalence. Females were affected more than men. The prevalence of shoulder pain was associated with increased physical load and vibration experienced when working with machines in manual workers, poor postural load, increased duration of computer and mouse use in the office setting, psychosocial factors such as high mental demands, poor job satisfaction and poor social support (Pribicevic, 2012).

A few studies were conducted on pain prevalence in athletes. Lepera (2010) concluded the prevalence of shoulder pain among professional wheelchair basketball athletes in Gauteng, South Africa, to be as high as 72.4%. Associated factors were increased time and years of the wheelchair basketball players spent in the wheelchair. In a study conducted of master swimmers in South Africa conducted over a three-year period, pain prevalence was determined to be 62.4%. Another study conducted on high school water polo players from Kwa Zulu Natal, South Africa, concluded the prevalence of shoulder pain to be 51.04% (Ellapen et al. 2013). Risk factors associated with it were rapid rotational movements, overtraining, collision impact and struck with the ball. It was found that the prevalence of shoulder pain in professional wheelchair basketball athletes in Gauteng was 72.4% (Lepera, 2010). In a study of shoulder pain prevalence among master high school swimmers in South Africa, the pain prevalence was 62.4% (Kruger et al. 2012).

It has been found that musculoskeletal shoulder pain persists in 50% of patients, from the first reported episode (Kuijpers, 2004; Rangen, 2015). The other concern is that the impact of shoulder pain is far reaching, affecting activities of daily living including, work, social and sporting activities, also often impacting the psychological wellbeing of patients (Billberg et al. 2014; Ostör et al. 2005; Judge et al. 2014). A high socioeconomical burden, as high as 80%, is placed on society, as concluded in a Swedish study (Virta, 2012).

2.2 Concepts related to static stability

2.2.1 Articular surfaces of the glenohumeral joint

The glenohumeral joint is a di-arthrodial ball and socket joint. The glenohumeral joint is incongruent with the humeral head, which is slightly smaller, approximately 3mm (Soslowsky et al. 1992). This anatomical fact contributes to the large range of motion of the glenohumeral joint (Veeger and Helm, 2007). With compression of the humeral head into the glenoid cavity, due to compliant subchondral endplates, the joint surfaces become more congruent (Frich et al. 1997).

The end result of shear force, compression force and humeral head translation cause concavity compression to occur (Veeger and Helm, 2007). The intra-articular synovial fluid lubrication helps decrease friction in the glenohumeral joint (Veeger and Helm, 2007). One of the stabilising mechanisms of the glenohumeral joint, has been attributed to the negative intra articular pressure in the non-pathological glenohumeral joint, to which the labrum contributes (Fick 1911; Gibb et al. 1991; Veeger and Helm, 2007). The role of the glenohumeral labrum is not well understood however, in general it is thought to play a role in joint lubrication (Veeger and Helm, 2007).

2.2.2 Ligamentous structures of the glenohumeral joint

The glenohumeral joint comprises of the coracohumeral and the superior glenohumeral ligaments, which acts as inferior stabilisers of the abducted shoulder (Burkart and Debski 2002) (Figure 1). They also limit external rotation (Helmig et al. 1993). Antero-superior stability and external rotation from 0° to 90°of abduction is thought to be mainly provided by the middle glenohumeral ligament (Burkart and Debski, 2002). The stabilising function of the glenohumeral ligaments are mainly at play at end of range motion when they are fully stretched (Malicky et al. 2002). Therefore, the contribution to joint stability in midrange is minimal.

Joint stability in midrange is mainly through the active co-contraction of the rotator cuff muscles (Veeger and Helm, 2007). The anteroinferior stability is brough about by the inferior glenohumeral ligament complex (Veeger and Helm, 2007). The strong coracoclavicular ligament forms the link between the clavicle and the scapula and allows for 20° of acromioclavicular scapular-clavicular motion (Harris et al. 2000; Koh et al. 2005).

2.3 Concepts related to dynamic stability

2.3.1 Rotator cuff functioning and current assessment methods

The earlier alteration of any movement pattern contributing to biomechanical dysfunction of the shoulder, is identified the sooner the shoulder symptoms can be corrected (Hess, 2000). Standardised orthopaedic shoulder tests are mainly used in clinical practice for the diagnosis of shoulder conditions. A wide array of shoulder tests is used in practice; however, different views are expressed in current literature on the use of standardised orthopaedic shoulder tests used in clinical practice. In their systematic review, Hughes et al. (2008), investigated the diagnostic accuracy of the Hawkins-Kennedy, Infraspinatus, Napoleon, Lift-off, Belly Press or Drop Arm and Empty Can test. Their overall conclusion was that these tests were inaccurate in diagnosing subacromial impingement syndrome (SIS) and they did not recommend these tests for clinical use. Their main reason cited against the use thereof, was that the anatomical validity of these tests was poorly related to pathology.

Many structures in the shoulder could potentially be the cause of symptoms elicited by these tests (Hughes et al. 2008). Lasbleiz et al. (2014) also investigated the diagnostic accuracy of the Jobe's and Full Can test for diagnosing supraspinatus tears, the Resisted Lateral Rotation test for diagnosing infraspinatus tears, the Lift-off test for diagnosing subscapularis tears and the Yergason test for tendinopathy of the long head of biceps. The authors however, also concluded that no relevant clinical test exists for the diagnosis of tendinopathy of the supraspinatus, infraspinatus or subscapularis tendons (Lasbleiz et al. 2014).

The controversy of existing standardised orthopaedic tests was reiterated again recently by Baigent et al. (2023). It is therefore clear that the debate continues on which tests should be used to conclusively diagnose rotator cuff pathology in clinical practice. Many modifiable musculoskeletal factors can contribute to shoulder dysfunction which complicates the assessment.

Supraspinatus A-

anterior and posterior part

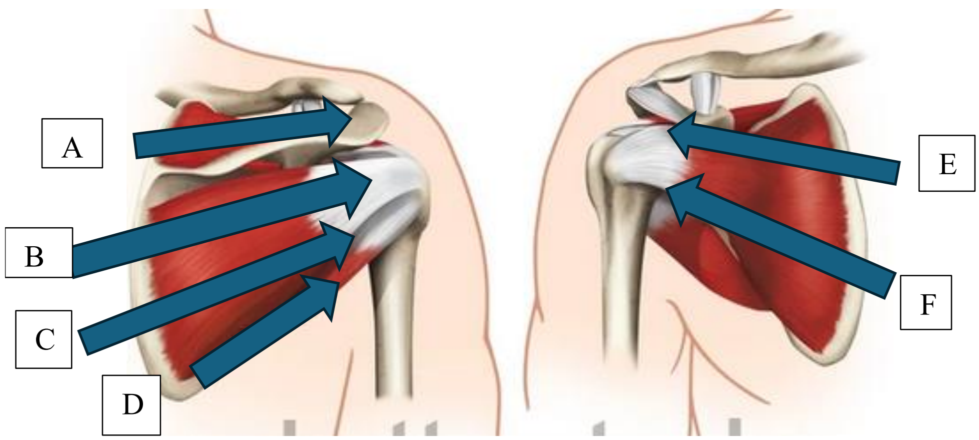
Infraspinatus- transverse fibers B

Infraspinatus- oblique fibers C

Teres minor D

Subscapularis- upper fibers E

Subscapularis- lower fibers F



Supraspinatus A, Infraspinatus- transverse fibers B, Infraspinatus- oblique fibers C, Teres minor D, Subscapularis- upper fibers E, Subscapularis- lower fibers F.

Figure 1: Illustrative compressive forces of the superior and inferior rotator cuff of the rotator cuff musculature.

Underlying the controversy of the inconclusive nature of the standardised shoulder tests may be the fact that stability of the round shaped humeral head in the relatively shallow glenoid fossa depend mainly on the static and dynamic stabilisers (Farrar et al. 2013; Inman et al. 1944). The rotator cuffs' (supraspinatus, infraspinatus, teres minor and subscapularis) compressive force aids in the centralisation of the humeral head on the glenoid surface and therefore counterbalances the upwardly directed force of the deltoid (De Luca and Forrest 1973; Farrar et al. 2013) (Figure 1). Mid-range stability of the glenohumeral joint is largely due to simultaneous activation of all the rotator cuff muscles (Veeger and Helm, 2007). Contraction of the rotator cuff muscles direct the joint reaction forces (JRF) into the glenoid and aids the stability of the glenohumeral joint (Veeger and Helm, 2007).

Electromyography (EMG) analysis confirmed the earlier finding by De Luca and Forrest (1973) that the balanced co-activation of the rotator cuff muscles and the deltoid force couple, is essential for preventing impingement of the rotator cuff tendons under the subacromial arch (Meyers et al. 2005). Historically, Inman et al. (1944) proposed the concept of the force coupling of the deltoid and the rotator cuff during elevation of the glenohumeral joint. Later research echoed this finding, in that a finely balanced act is needed between the inwardly, downwardly and combined forces of the rotator cuff, to oppose the upward directed force of the deltoid muscle, to ensure optimal stability of the glenohumeral joint (Bassett et al. 1990; Payne et al. 1997).

Supraspinatus is the first to be activated over and above the other musculature of the rotator cuff during flexion and abduction (Howell et al. 1986) (Figure 1). Stability of the humeral head into the glenoid cavity is enhanced by the compressive force of the supraspinatus (Inman et al. 1944). The EMG study of Abboud and Soslowsky (2002) determined contractions of both the subscapularis and the infraspinatus to be present in the abduction plane from 60° to 150°. Infraspinatus consists of a smaller transverse and a main oblique part (Mochizuki et al. 2009; Kato et al. 2012).

Recent research has identified that the transverse part of the infraspinatus attached to the anterior most area of the greater tuberositas, close to the attachment of the supraspinatus muscle (Mochizuki et al. ,2009; Kato et al. 2012). Due to this attachment infraspinatus also aids abduction of the glenohumeral joint (Mochizuki et al. 2009; Kato et al. 2012). In an EMG study of Hughes et al. (2014), the oblique part of the infraspinatus was determined to be active during external rotation in neutral, flexion and abduction, but increased activity was noted during resisted external rotation in neutral and flexion (Hughes et al. 2014) (Figure 1). The transverse fibres demonstrated the most EMG activity in shoulder flexion and external rotation (Hughes et al. 2014) (Figure 1). It can hence clearly be seen that the different fibre orientation, oblique and transverse, of infraspinatus act slightly different and this must be considered in the rehabilitation process. Functions of the subscapularis muscle were concluded to be both a humeral head depressor and stabiliser as well as an internal rotator of the humeral head (Reinold et al. 2009; Kelley et al. 2013) (Figure 1).

Injury or weakness of the rotator cuff can lead to disruption of the force coupling action of the rotator cuff. Decentering of the humeral head in the glenoid cavity may subsequently be a result of the altered muscle force coupling (Hess, 2000; Matsen, 1990). Decreased activation of the force coupling of both supraspinatus-infraspinatus and subscapularis-infraspinatus and increased middle deltoid activation from (0° - 30°) were concluded in the EMG study of Meyers et al. (2009). Their EMG study was conducted in participants presenting with impingement syndromes (Meyers et al. 2009). In support of the previous findings Millet et al. (2006) proposed that if the compressive force of supraspinatus is lost, the upward directed force from deltoid will contribute to the development of impingement syndrome. The results from the above-mentioned study echoed the earlier findings of Labriola, (2004), that the end result of decreased proprioception of the infraspinatus, either through weakness or injured tissues, will add to the destabilising of the humeral head on the glenoid cavity.

Several researchers have investigated the ratio percentages of the rotator cuff, specifically the external versus the internal isotonic strength balance in certain positions of athletes taking part in overhead sport (McDonough et al. 2014, Maestroni et al. 2020; Marcondes et al. 2013). Wilk et al. (1993), testing isotonic contractions of the internal versus the external rotators in baseball player’s shoulders, found an increase in the internal to external strength ratio percentages. However, an increased incidence of shoulder pathology has been reported in baseball players (Burkhardt et al. 2003). This raised the question as to whether the increase in internal to external ratio percentages might not perhaps be linked to a predisposition to injury in baseball players, rather than to the norm in non-painful shoulders. Several authors have determined that a decreased ER:IR ratio was associated with shoulder pain (McDonough et al. 2014, Maestroni et al. 2020; Marcondes et al. 2013). The critical value of external: internal strength ratio, which can predispose athletes to injury has been identified as a 1:1 ratio of IR:ER (Murphy et al. 2020). Murphy et al. (2020) determined that with every 0.1 ratio increase the risk for development of shoulder pain increased by 79%. It can therefore be inferred that an increased IR:ER ratio may predispose individuals to shoulder pain, regardless of occupation. The end result of altered rotator force vector balance can be instrumental in causing structural damage of the humeral head and the glenoid articular joint surfaces (Page, 2011).

The scapulohumeral complex consists of three synovial joints namely the sternoclavicular, the acromioclavicular and the glenohumeral joints; and one physiological joint namely, the scapulothoracic joint (Warner et al. 1998; Kelkar et al. 2001). The orientation and position of the rotator cuff musculature enhances not only dynamic but also static stability of the glenohumeral joint (Lugo et al. 2008). Even though individually the rotator cuff musculature displays independent actions, acting simultaneously they contribute towards joint stability throughout range (Warner et al. 1998; Kelkar et al. 2001; Halder et al. 2000; Abboud and Soslowsky, 2002).

2.3.2 Flexibility of periscapular musculature

In addition, specific other biomechanical factors (the posterior capsule, pectoralis minor, latissimus dorsi, short head of biceps and subscapularis muscle shortening), have been independently identified by various researchers to be contributing factors to developing shoulder dysfunction (Burkhardt et al. 2003; Thomas et al. 2011; Borstad, 2008) (Figure 4). The link between decreased internal rotation and anterior migration of the humeral head have been connected with hypertrophy and shortening of the posterior capsule (Burkhardt et al. 2003; Gerber et al. 2003; Thomas et al. 2011; Tyler et al. 2000).

Contributing factors to developing limited glenohumeral joint internal rotation (GIRD) have been identified as posterior capsule tightness and stiffness of the posterior muscle tendon unit (Van Der Hoeven and Kibler, 2006). Inherently lacking bony support, the glenohumeral and scapulothoracic joints are mainly controlled by muscular forces (Bagg and Forrest, 1988; Kibler et al. 2013). Scapula dyskinesis in the presence of a shortened pectoralis minor muscle have been found by numerous authors (Borstad, 2008; Borstad and Ludewig, 2005; Ludewig and Cook, 2000).

Shortening of the short head of biceps brachii due to the anatomical attachment to the anterior tip of the coracoid process, may theoretically be a contributing factor to scapular dyskinesis (Moore et al. 2011). In competitive swimmers presenting with increased episodes of pain, the presence of both a shortened latissimus dorsi and a pectoralis minor were determined (Tate et al. 2012).

2.3.3 Scapular kinematics and scapular stabilisers

The scapula lacks bony stability and both the static and dynamic stability are largely dependent on symmetry of the scapular stabilisers (Du et al. 2020; Kibler and Sciascia 2010; Kibler et al. 2013; Michener et al. 2016; Sahrmann 2001). The scapular stabilisers acts in force couples to control movement of the scapula (Cools et al. 2004; Inman et al. 1944; Ludewig and Reynolds 2009; Vanderstukken et al. 2020; Briel et al., 2022) (Figure 2).

An important function of the balanced scapular stabilisers is to best position the glenoid for articulation with the humeral head, to improve upper limb mobility (Mottram 1997). Dynamic stability and mobility are provided by the combined synchronous action of all the parts of the trapezius muscle (upper, middle, lower) and all the parts of the serratus anterior muscle (Kibler 1998; Michener et al. 2016, Briel, 2022).

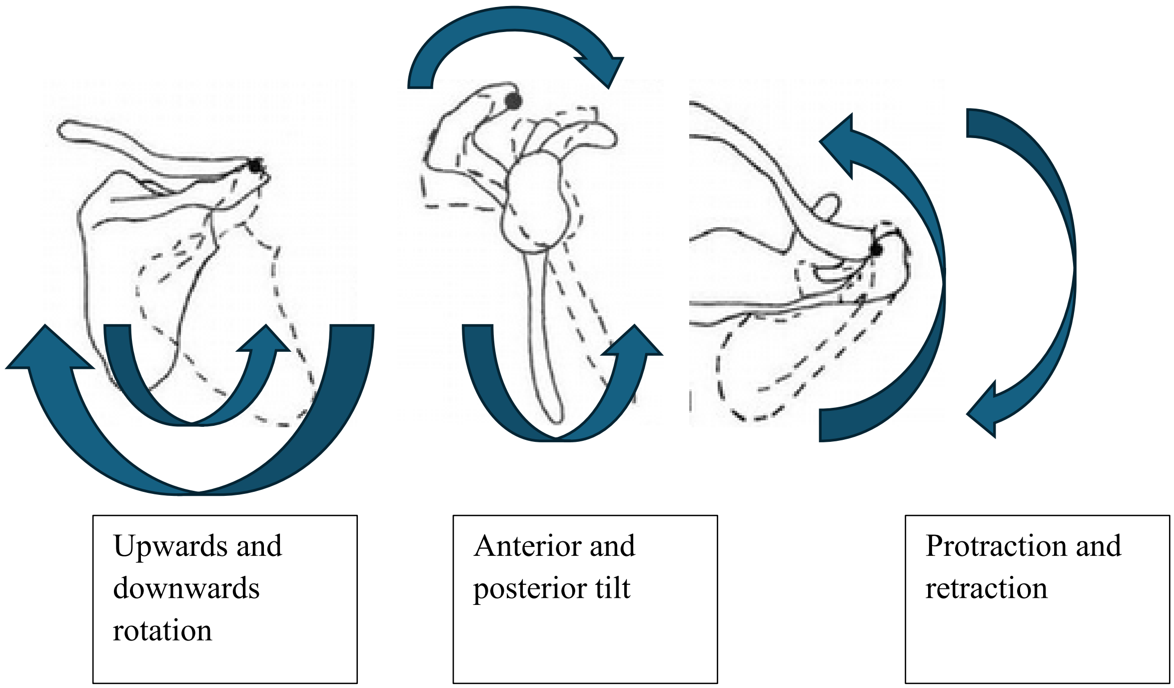


Figure 2. Scapular kinematics.

Both lower fibres of trapezius and lower fibres of serratus anterior contribute to sagittal flexion but serratus anterior lower fibres are more active in frontal abduction (Bagg and Forrest 1986; Briel, 2022) (Figure 3). Weakness of both the lower trapezius and lower fibres of serratus anterior have been established in painful shoulders (Phadke et al. 2009; Castelein et al. 2016; Kibler et al. 2013). Decreased upward rotation of the scapula has been determined in the presence of weakness of the serratus anterior lower fibres and the lower trapezius (Yeşilyaprak et al. 2016; Navarro-Ledesma et al. 2019; Burkhart et al. 2001) (Figure 2). Theoretically, it can therefore be surmised that disruption of the force and force couple ratio as determined in the study by Briel et al. 2022, may contribute to decreased upward rotation of the scapula and contribute to impingement of the subacromial glenohumeral joint.

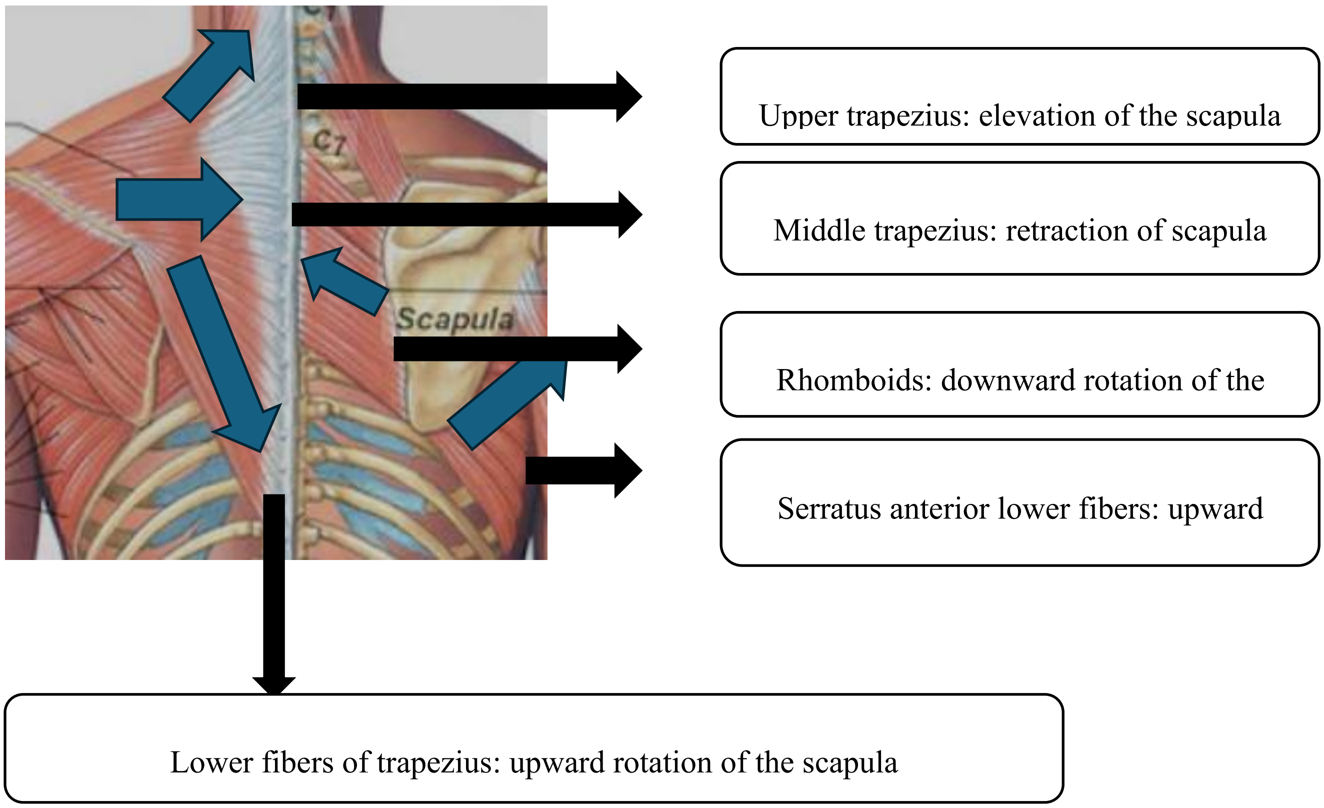


Figure 3: Scapular stabilisers, lines of muscular action.

2.4 Conceptual framework

2.4.1 Muscular force

When considering muscle force, it is important to test a muscle not in isolation, but to consider the agonist and the antagonistic force couple ratio (Magarey and Jones 2003; Kibler 1998b; Kibler and Chandler 1994). The optimal functioning of a particular joint is dependent not only on muscle force but also on the ideal force couple ratio, this is especially true during functional activity of that particular joint (Magarey and Jones 2003 Kibler 1998b; Kibler and Chandler 1994). Labriola et al. (2004) highlighted the importance of understanding muscular forces and their contributions towards joint stability but also joint instability in their study. In the glenohumeral joint which is mainly controlled by the rotator cuff, and the scapulothoracic joint which is mainly stabilised by the scapular stabilisers, the notion of optimal force couple ratios is therefore applicable. Isolated muscle strength testing without considering both the agonistic and antagonistic muscle strength may provide skewed results (Magarey and Jones, 2003).

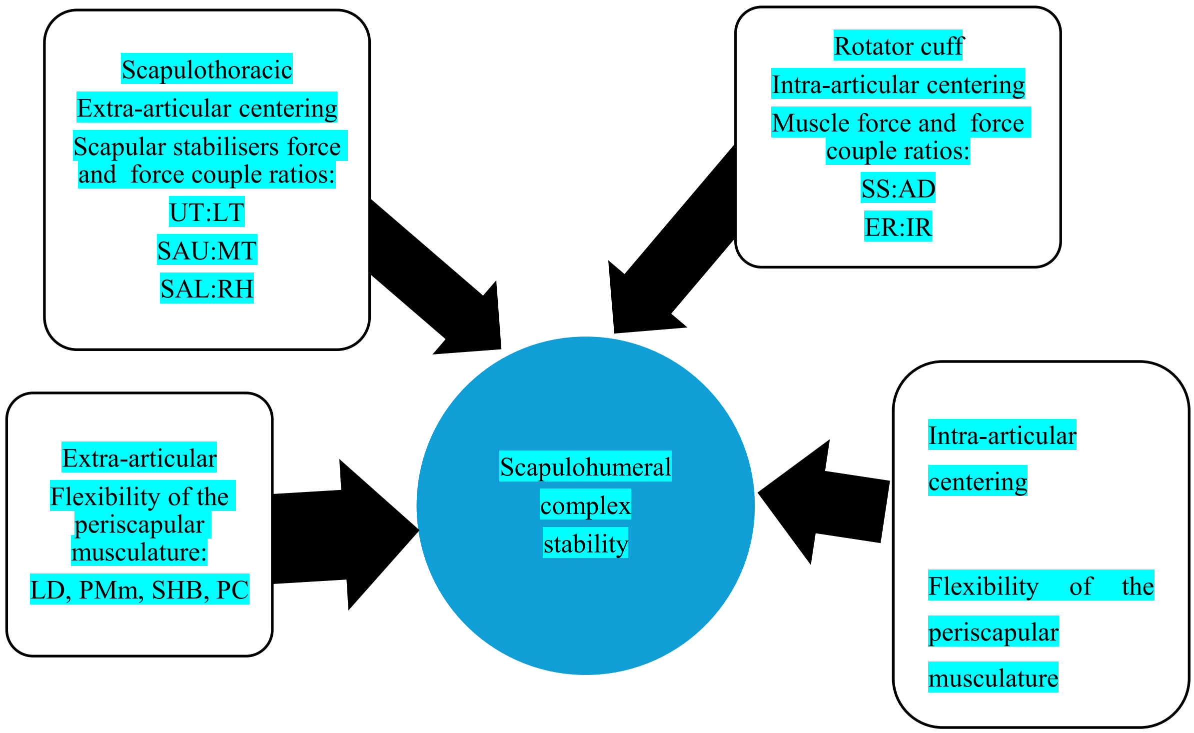


Figure 4: Conceptual framework of scapulohumeral complex stability.

Investigation of these modifiable musculoskeletal factors were incorporated into the current study where the association of modifiable musculoskeletal factors with shoulder dysfunction, in both athletic and non-athlete populations were explored; first through a global systematic review (Chapter 4, Study 1) and secondly with physical testing (Chapter 5, Study 2 and Chapter 6, Study 3). Modifiable musculoskeletal factors included the rotator cuff musculature and the periscapular musculature (Studies 2-3) (Figure 4).

2.5 Conclusion

Cools *et al*., (2016) suggested that the assessment of the glenohumeral joint should include subjective and objective assessments, range of motion (ROM) as well as muscle strength assessments. It is thus deemed important to know the muscle strength values, and more importantly, the optimal external versus internal strength ratios of the rotator cuff muscles. Establishing values in shoulders without and with pathology, can perhaps lead to early identification and correction of biomechanical imbalances.

To quote Sahrman (1988) in her paper "As the expertise of physical therapists grows in this area, they are increasing their ability to identify the key factors that underlie movement and movement dysfunctions that most often are separate from the medical problem that may have initiated movement impairment" (Sahrman 1988:1705). Several authors have identified the need for a cluster of tests to improve the assessment of the scapulohumeral complex (Dutton et al. 2020; Baigent.2023). Therefore, assessment of the scapulohumeral complex (rotator cuff, scapular stabilizers, and all the periscapular soft tissues surrounding the joints), should preferably be done at the same time, to establish baseline data to inform assessment decisions. This could result in an informed protocol development with effective treatment strategies for the scapulohumeral complex.

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Chapter 3 Methodology

3.1 Introduction

In this thesis there are five phases included, with each phase including an original study (Figure 1). This chapter gives an overview of the phases, while the detailed methodology and findings are integrated in the papers presented in Chapters 4-8.

Phase one (Chapter 4, Study 1) was the systematic review with meta-analyses on the global presence of modifiable musculoskeletal factors in both a non-athlete and athletic population. Phase two (Chapter 5, Study 2) was an observational study on the presence of the force couple ratios of the rotator cuff within non-painful and painful shoulders of a non-athlete population. Phase three (Chapter 6, Study 3) consisted of an observational study investigating the flexibility of modifiable musculoskeletal factors in a non-athlete population; while phase four (Chapter 7, Study 4), a nominal group technique, investigated the opinions of physiotherapists practicing in the shoulder field. The last phase, phase five (Chapter 8, Study 5), piloted a reliability study conducted on the findings of the scapulohumeral assessment model.

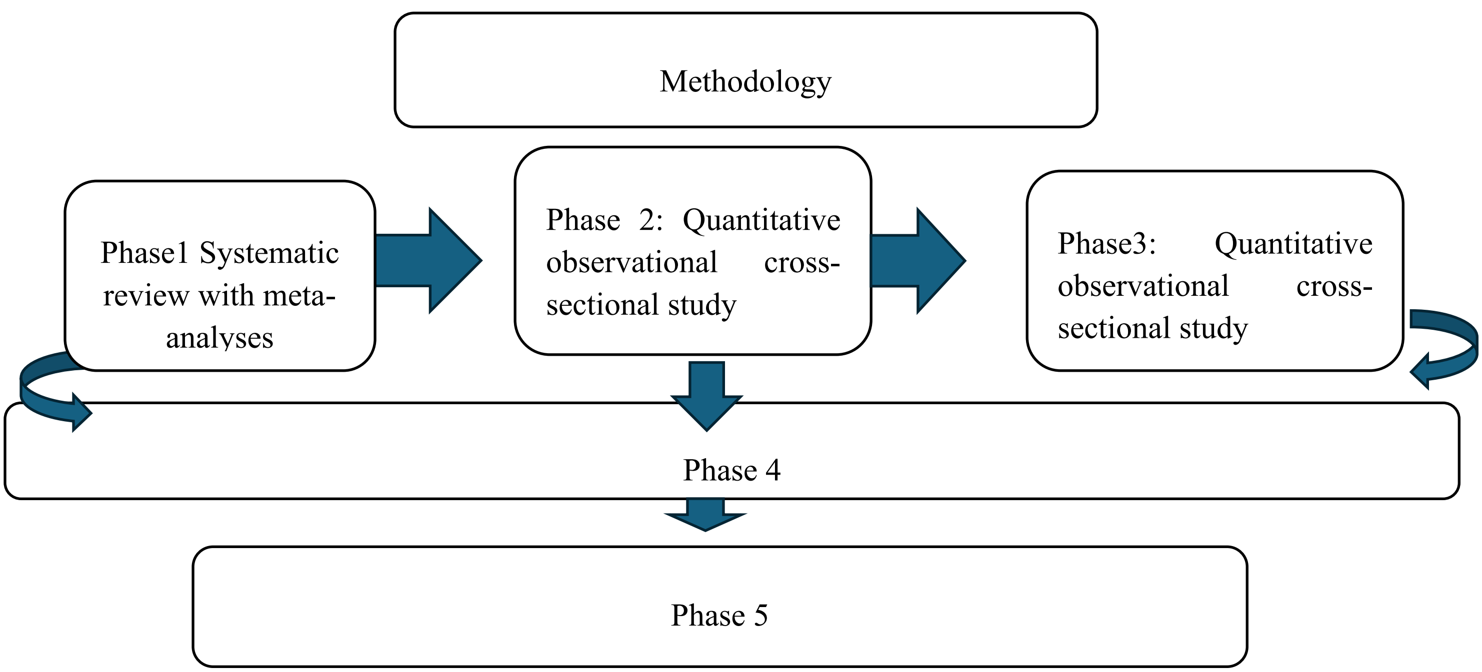

Figure 1: Methodology followed in the thesis.

3.1.1 Phase 1

The objective of study one was to investigate the presence of musculoskeletal factors in painful shoulders in non-athletic and athletic population groups globally (Figure 1). The aim was twofold; 1) to investigate musculoskeletal factors playing a role in painful shoulders and to identify gaps in current literature on the existence of modifiable musculoskeletal factors in painful shoulders; and 2) to determine the risk ratio for developing shoulder dysfunction in the presence of modifiable musculoskeletal factors (Chapter 4, Study 1).

A priori systematic review protocol was developed, and a preliminary investigation was conducted on the presence of modifiable musculoskeletal factors in both an athletic and non-athletic population. Enough data was gathered with the priori systematic review to then conduct a systematic review and meta-analysis on the presence of modifiable musculoskeletal factors (Chapter 4, Study 1). An investigation of all known modifiable musculoskeletal factors associated with shoulder pain in both non-athletic and athletic population groups globally, was conducted as a systematic review of etiology and risk study design. Modifiable musculoskeletal factors identified to be present in both population groups were pooled, where possible, and synthesized results tested with meta-analyses to increase the value/ credibility of the observed individual findings. The systematic review of etiology and risk was essential in providing evidenced-based answers to inform the investigation on modifiable musculoskeletal factors for further exploration in a physical data collection study. The rigour followed in the systematic review which identified research gaps that were explored with the following studies (Studies 2, 3, 4 and 5).

An athletic and non-athlete population group, aged between 18 to 75 years were included in the review (Chapter 4, Study 1). An Etiology and Risk Systematic Review study design was followed, based on The Joanna Briggs Institute guidelines (JBI) and the Preferred Reporting Items for Systematic Reviews (PRISMA) (Moher, et al., 2009) principles. Meta-Analysis of Observational Studies in Epidemiology (MOOSE) (Stroup, *et al*., 2000) checklists were used.

3.1.2 Phase 2

Following on the findings from the systematic review (Study 1), Study 2 was a quantitative study following an observational cross-sectional design (Figure 1). Both the painful and non-painful shoulders of participants aged between 18 and 75 years of age, both women and men were tested. This was determined in an adult non-athlete population. (Chapter 5). The muscle force as well as the muscle force couple ratios were determined. The superior force couple ratio between the supraspinatus (SS) and the anterior deltoid (AD) were determined, as well as the inferior force couple ratio between the external rotators (ER) versus the internal rotators (IR) in all ranges. The objective of Study 2 was to provide data on the research gap identified in Study 1; the isometric force couple ratio of the superior cuff between the supraspinatus and the anterior deltoid. This study was the first of its kind to propose the force couple and force couple ratios of the superior cuff, namely the supraspinatus and the anterior deltoid, in both an athletic and non-athletic population.

3.1.3 Phase 3

The flexibility of many modifiable musculoskeletal factors are affected in painful shoulders (Figure 1). Limited information on the correlation of the flexibility of the modifiable musculoskeletal factors, such as the latissimus dorsi (LD), the subscapularis, the short head of biceps (SHB), the PMm muscles, the posterior capsule (PC), and the presence of pain in shoulders are available in a non-athlete population group. This study investigated the flexibility alterations in the LD, the subscapularis, the SHB, the PMm and the PC in a non-athlete population, at one point in time, in terms of range of motion (ROM) in both non-painful and painful shoulders. ER ROM, IR ROM, flexibility of the LD, the subscapularis, the SHB, the PMm length, and the PC were assessed.

In this study (Chapter 6), an observational cross-sectional study, included 85 participants, forty with painful and forty-five with non-painful shoulders in an adult female and male population aged between 18 and 75 years were assessed. Descriptive and inferential statistics were used to analyse the data.

3.1.4 Phase 4

Following the outcomes of Phase 1-3, the opinions of physiotherapists with a special interest in shoulders, were explored using a nominal group technique.

The objective of Study 4 (Chapter 7) was to gauge the opinions of physiotherapists working in the shoulder field of Physiotherapy on what factors should be included in a comprehensive assessment of the scapulohumeral complex. A qualitative consensus, study design using the Nominal Group Technique (NGT) was conducted (Figure 1). One-hundred physiotherapists were recruited via a questionnaire, using Research Electronic Data Capture system (REDCap). Twenty physiotherapists with a special interest in shoulder conditions were invited to participate in a nominal discussion group. Ordering and ranking of presented key findings determined in both the SR (Study 1) and in the physical data collection studies (Study 2 and 3) occurred. Their opinions were sought in what factors should be included in the assessment of the scapulohumeral complex based on the findings of Studies 1-3. The generation of new perspectives on clinical practice in the shoulder field, based on the key findings identified in this study was the main aim. A novel comprehensive assessment model for the scapulohumeral complex, was therefore proposed incorporating the key findings identified with Studies 1, 2, 3 and 4.

3.1.5 Phase 5

This study was a quantitative reliability study (Figure 1, Chapter 1). The objective of Study5 (Chapter 8) was to pilot a novel assessment model for the comprehensive assessment of the scapulohumeral complex, by means of a reliability study. The intra-rater and inter-rater reliability were assessed using the intraclass correlation coefficients (ICC) for all the continuous variables. Statistical significance was set at 95%. This pilot reliability study assessed five healthy participants with non-painful shoulders. Each participant were tested at their right shoulder, where testing was conducted once and repeated seven days later and once by each rater on both days.

3.2 Conclusion

Physiotherapists in their day-to-day practice are used to dealing with many musculoskeletal dysfunctions. Using evidence-based practices are important to better manage with musculoskeletal complaints and to tailor rehabilitation strategies effectively. An objective comprehensive assessment model for the scapulohumeral complex, using evidence-based outcomes from the individual studies, were established based on current and new evidence collected with the present thesis.

Ethical clearance was obtained from the Human Research Ethics Committee (Medical) (M190984) (Appendix K).

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Chapter 4 Modifiable musculoskeletal factors and their association with shoulder function in adults: A systematic review and meta-analyses of etiology and risk (Discover Journal).

The aims and objectives of this chapter are presented in Chapter one, page 21.

This chapter is presented as a published manuscript in Discover Medicine Journal.

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Abstract

Objective

The objective of this systematic review of etiology and risk was to determine the association between modifiable musculoskeletal factors and shoulder dysfunction in an adult population.

Background

There is still a paucity of evidence in the literature on shoulder function and the influence of modifiable musculoskeletal factors on function. The present study aimed to explore current and past research on all reported modifiable musculoskeletal factors to clarify the multifactorial etiology of shoulder dysfunction in an adult population.

Methods

The methodology and meta-analysis process were performed as detailed in the JBI Reviewer's Manual for Etiology and Risk, and the following guidelines were used according to the PRISMA (Preferred Items for Systematic Reviews and Meta-Analysis) statement. When a meta-analysis of the data was not possible, the SWiM (synthesis without meta-analysis) approach was used for the synthesis of pooled modifiable musculoskeletal factors. The outcome measure considered was shoulder dysfunction. The exposure parameters measured were modifiable musculoskeletal factors leading to the development of shoulder dysfunction. Patients aged between 18 and 75 years were included. A total of 7628 studies were identified worldwide through searching 12 databases. The results yielded by 91 studies were included in the systematic review. The risk of bias was low for 88 studies. Both females (2441) and males (3117) were included. The systematic review included cross-sectional and longitudinal studies investigating most sporting subpopulations (swimming, rugby, weightlifting, wheelchair, volleyball and baseball; 1003 participants) and members of the general population (4651). Pooling of the results into five meta-analyses was possible.

Results

The results revealed that affected musculoskeletal factors led to a decrease in the strength of shoulder dysfunction during external rotation, with $I^2=0$ indicating a large positive effect size of 0.59 ($p=0.00$), a decreased external versus internal muscle strength ratio, with $I^2=46$ indicating a large negative effect size of -0.69 ($p=0.002$); decreased flexibility of the posterior capsule, with $I^2=0$ indicating a small negative effect size of -0.0 ($p=0.45$); decreased internal rotation, with a large negative effect size of -1.00 ($p=0$); and a glenohumeral internal rotation deficit. Participants were 1.29 times more likely to develop shoulder dysfunction in the presence of decreased external rotation strength.

Discussion

A comprehensive evaluation of the shoulder joint should include all identified musculoskeletal factors of the present systematic review at one point in time. Modifiable musculoskeletal factors include the strength of the (ERs) and the (IRs); the strength ratio of the (ERs): (IRs); the IR ROM movement; the TROM; GIRD; PMm length; and scapular stabilizer strength and strength ratios.

This protocol has been registered in PROSPERO (CRD 42021261719).

Key Points

Decreased external rotation strength, decreased external versus internal rotation strength ratios, decreased internal rotation and GIRD predispose a shoulder to dysfunction.

All musculoskeletal factors identified with this systematic review should be addressed at one point in time during both the evaluation and rehabilitation process.

1 Introduction

Shoulder pain affects 16% to 21% of the general population [1,2]. In addition to being highly prevalent, shoulder pathology is potentially a debilitating and challenging diagnosis [3]. Various researchers have concluded that the rotator cuff is responsible for shoulder pain among patients [4-6]. In their study of imaging pathology, the rotator cuff was concluded to be the main pain driver in shoulder pain, determined to be as high as 50% on ultrasound imagery and 65% on magnetic resonance arthrogram [6]. The pathogenesis of rotator cuff injuries (RCIs) is multifactorial and controversial, but the shape of the acromion is still thought to be a contributing factor to the development of shoulder pain [7]. The confirmed findings that tears of the supraspinatus muscle are located mainly within the tendon or on the articular side of the joint contradict the acromial impingement syndrome model [8-10].

The force coupling mechanism of rotator cuffs can be disrupted by weakening or injury to the rotator cuff muscles [11,12]. This destabilization of the humeral head on the glenoid cavity occurs when the muscle length and force are abnormal therefore, arthrokinematics are disrupted [11,12]. Abboud and Soslowsky [13] concluded that altered force couple vectors of the rotator cuff can lead to instability and thus destabilization of the humeral head on the glenoid cavity. An imbalance in this muscular system might be conducive to the development of structural damage in the glenohumeral joint [14].

The supraspinatus is the first muscle to activate during elevation [15]. The compressive force provided by the supraspinatus contributes to the stability of the humeral head in the glenoid cavity [16]. In their electromyography (EMG) study, Abboud and Soslowsky [13] reported that from 60° to 150° in the abduction plane of movement, contractions of both the subscapularis and the infraspinatus occurred. The subscapularis muscle not only functions as a humeral head depressor but also stabilizes the humeral head and functions as an internal rotator of the humeral head [17,18].

Additionally, other specific musculoskeletal factors (shortening and tightness of the posterior capsule, pectoralis minor, latissimus dorsi, short head of the biceps and subscapularis) have been independently identified by various researchers as contributing factors to the development of shoulder pain [19-21]. The anatomical attachment of the short head of the biceps brachii to the anterior tip of the coracoid process can contribute to scapular dyskinesis [22].

Posterior capsule tightness and a decreased range of motion, specifically the internal range of motion, have been associated with an increased incidence of shoulder pain [23]. Shortening and hypertrophy of the posterior capsule have been associated with decreased internal rotation and resultant anterior migration of the humeral head [24-26]. Factors contributing to the development of glenohumeral joint internal rotation deficit include posterior capsule tightness and stiffness of the posterior muscle tendon unit [27].

The combined actions of the force couples of all the parts of trapezius (upper, middle and lower) and the serratus anterior provides active stability to the scapula [28,16,29,30]. Bdaiwi [30] observed an increased acromiohumeral distance with simultaneous stimulation of the lower trapezius and lower fibres of serratus anterior. Upward rotation of the scapula is executed predominantly by the lower trapezius and the lower fibres of serratus anterior [31,32]. Imbalances of the EMG ratios of middle trapezius and serratus anterior were concluded in an injured population groups [33,34].

A preliminary search of the JBI Evidence Synthesis, Cochrane Database of Systematic Reviews, MEDLINE (PubMed), and PROSPERO databases was conducted using the following search terms: rotator cuff, shoulder, scapulothoracic joint, musculoskeletal, GIRD, scapular dyskinesis and subacromial impingement syndrome (SIS). To the best of our knowledge, only two systematic reviews were conducted that identified potential risk factors predictive of shoulder pain Hill [35] conducted one and the other was by Keller [36]. In their systematic review, Hill [35] explored risk factors such as GIRD, internal and external rotation strength of the rotator cuff and clinical instability leading to shoulder pain in a subpopulation of swimmers. In their systematic review with meta-analysis, the authors investigated only GIRD and increased external rotational gain as risk factors favouring injuries in a subpopulation of overhead athletes [36]. In their study on volleyball players, Reeser [37] stated that an understanding of modifiable risk factors is essential for preventing shoulder pain and providing optimal care for players presenting with shoulder pain.

Lewis [38] concluded that considerable deficits still exist in our current understanding of rotator cuff-related shoulder pain (RCRSP). These include (1) the exact origin of symptoms, (2) the determination of more accurate diagnostic labels, (3) better epidemiological studies of symptomatic shoulder pain patients, (4) more accurate establishment of symptomatic tissues to target treatment, and (5) determination of the best treatment modalities for symptomatic shoulder pain patients [38]. His main conclusion was that there is a need for ongoing research to seek a better understanding of the underlying etiology, better assessment models and the development of better management protocols [38]. There is a need for clarification and a better understanding of the influence of musculoskeletal factors and their association with shoulder function. The current models used in the diagnosis of shoulder dysfunction might thus be outdated and not appropriate or applicable in clinical practice.

The overall aim of this systematic review was to determine modifiable musculoskeletal factors and their associations with shoulder function in adults aged between 18 and 75 years. The purpose of this review was ultimately to identify a cluster of musculoskeletal tests to determine the risk factors associated with shoulder dysfunction.

2 Methodology

This systematic review was conducted in accordance with the JBI methodology for Systematic Reviews of Etiology and Risk [39].

2.1 Inclusion criteria

2.1.1 Participants

Studies including females and males globally with and without shoulder dysfunction aged between 18 and 75 years were covered in this review. Studies on participants from both the general population and the athletic population were included (athletic subgroups could be classified as any sporting fraternity, e.g., overhead sport, tennis, cricket or underhand such as rugby). Studies involving participants with postoperative shoulder dysfunction were not included.

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2.1.2 Exposure of interest

Studies that investigated modifiable musculoskeletal factors impacting the biomechanical and arthrokinematical functioning of the shoulder joint, as independent variables, were explored and included in the study. Only modifiable musculoskeletal factors were included, which were defined as the musculoskeletal and capsular factors listed below; therefore, factors such as bony factors were excluded. The following modifiable musculoskeletal factors were included:

- Pectoralis minor and latissimus dorsi muscle indices; muscle shortening; muscle lengthening in different testing positions were measured with a caliper, goniometer or tape measure and muscle activity/ rest were investigated.

- The strength of the rotator cuff (supraspinatus, infraspinatus, teres minor, and subscapularis) muscles was measured with a dynamometer, and the results included derived measurements such as balance/imbalance of strength ratios of the rotator cuff, e.g., expressed as ratios of internal/external versus external/internal rotators.
- Glenohumeral flexibility, such as anterior and posterior capsule length measured using a goniometer or inclinometer or expressed through range of motion (ROM) measurements. The shoulder range of movement was measured using a goniometer or inclinometer.

2.1.3 Outcome

The outcome of interest was shoulder dysfunction. Shoulder dysfunction, the dependent variable, included any one or a combination of the following: the presence of discomfort, measured with subjective patient self-reports; pain, measured and reported on the visual analogue scale (VAS) or on the numeric pain rating scale (NPRS); or dyskinesis, measured through kinematic analysis. Shoulder dysfunction was also reported with outcome measurement questionnaires such as but not limited to the Shoulder Pain and Disability Index (SPADI).

2.1.4 Type of study

Both observational (cross-sectional, case–control, prospective and retrospective and longitudinal cohort studies; case series and case reports), analytical and descriptive studies were included in this review. Experimental and randomized control trials were excluded from the study because only the association of dysfunction of the shoulder joint with modifiable musculoskeletal factors was established**.**

2.1.5 Search strategy

The methodology and meta-analysis process, as detailed in the JBI Reviewer's Manual for Etiology and Risk [39], were followed, and the guidelines proposed by the PRISMA (Preferred

Items for Systematic Reviews and Meta-Analysis) statement [40] were followed. The Population, Problem, Intervention, Comparison or Control, and Outcome (PICO) methodology [41] was adapted to fit the study design of our systematic review to Population, Etiology, and Outcome (PEO) [42]. The research question and, subsequently, search terms were developed around the PEO concept. The search strategy included both published and unpublished studies. A three-step approach was followed. First, an initial limited search of PubMed Central and CINAHL (EBSCOhost) was undertaken to identify articles on the topic. The text words used were from the titles and abstracts of relevant articles, and the index terms used to describe the articles were used to develop a full search strategy for PubMed Central (Appendix I). Second, for the main review, all identified keywords were explored using both MeSH and text words and were appropriately adapted for each database. Third, all the reference lists of all the studies selected for critical appraisal (backward citation tracking) were screened for additional studies. Forward citation tracking using Google Scholar and Academia.edu was then performed for the identified studies. No restriction was placed on language, but the age was limited to adults aged eighteen years and older**.** Studies published in all languages were included. An in-depth search across twelve databases was conducted from inception to the end of March 2023, and the relevant articles were included. An updated search was conducted from the beginning of April 2023 to the 6th of March 2024, and the applicable articles were imported. The databases searched included PubMed (Advanced), MEDLINE, MEDLINE COMPLETE, Masterfile, and SPORTDiscus via EBSCOhost; the Cumulative Index to Nursing and Allied Health Literature (CINAHL); the Physiotherapy Evidence Database (PEDro); and the Web of Science and Scopus (Elsevier). The information sources of unpublished and grey literature included Open Gray, Gray Matter, and MasterFile Premier (EBSCO) (Appendix I). All the included and excluded studies are depicted by means of the PRISMA flowchart (Figure I) [41].

2.1.6 Study selection

Following the search, all identified citations were collated and uploaded into EndNote X9.3.3 (Clarivate Analytics, PA, USA) (2021), after which duplicates were removed. Potentially relevant studies were retrieved in full, and their citation details were imported into the JBI System for the

Unified Management, Assessment, and Review of Information (JBI SUMARI) [40]. Titles and abstracts of the uploaded articles were subsequently reviewed by two independent reviewers for assessment against the inclusion criteria of the review.

2.1.7 Data extraction

All studies, regardless of the results of their methodological quality, underwent data extraction, and some were synthesized into meta-analyses. Data were extracted from the studies included in the review by two independent reviewers using standardized JBI SUMARI data extraction tools [40]. The extracted data included specific details about the population (participant characteristics, age, sport discipline or sedentary), study methods, aim, context, exposure of interest, study setting and location (country), and outcomes of significance to the review question (Table of Characteristics-Online Resource 2 and Figures 2, 3). No disagreements arose that required the intervention of the third reviewer.

3 Assessment of Methodological Quality

Eligible studies were critically appraised by two independent reviewers (SB and FM-O) at the study level for methodological quality in the review using standardized critical appraisal instruments from the JBI [40]. The numerical scores for the analytical cross-sectional studies were scores out of eight and those for the eligible cohort studies out of eleven (Online resource 3). Methodological quality was deemed high overall for the included studies included in the meta-analyses and for both the eligible analytical cross-sectional and the eligible cohort studies. Two studies, Skazalski [43] and Peckitt [44], were of lower methodological quality because they did not state how confounding factors were dealt with (3).

Methodological quality was documented throughout the appraisal process. All studies, regardless of their methodological quality, underwent data extraction, and some studies were synthesized and combined into meta-analyses (Figures 4, 5, 8, 9, 11). All the data used for generating the meta-analyses were taken from both the eligible analytical cross-sectional and eligible cohort studies.

The data were subjected to double entry by two reviewers (SB and FM-O). The results of the critical appraisal were reported in tabular format with accompanying narratives highlighting the main findings of individual studies (Online Resource 1) and in the Table of Characteristics (Online Resource 2).

3.1 Data synthesis

Clinical, methodological, and statistical heterogeneity was determined [45]. Risk ratio (RR) and odds ratio (OR) data were extracted from the primary longitudinal studies included (Table I), answering the proposed study questions concerning the risk of shoulder dysfunction in the present systematic review. When the RR was unavailable, it was calculated using the SPSS Statistics 28.01.1.1 (15) IBM Corp., Armonk, NY, USA) package, and the results obtained were imported into JBI SUMARI for the generation of a meta-analysis (Figure 2). Studies that reported the mean and standard deviation of the identified primary studies reporting on the cases and on the controls were included in the proposed meta-analysis (Figures 4, 5, 8, 9, 11). The effect size was calculated to measure the strength of association between the groups of the identified studies and was expressed as the standardized mean difference (SMD) for continuous data for all groups. The 95% confidence intervals were calculated for the analysis. Study data were pooled in statistical meta-analyses using the JBI SUMARI to increase the accuracy of the derived overall effect size [40]. Cohen's d method was employed to estimate the pooled SMD and weight using an inverse variance method [46]. Due to the inherent suspected heterogeneity across studies, a random effects model (using the DerSimonian and Laird method) was used to estimate the RR and the SMD.

Five comparative meta-analyses were composed using the JBI SUMARI [40]. The effect sizes (RR) and (OR) were extracted to determine the association between shoulder dysfunction and modifiable musculoskeletal factors (Figure 4). Meta-analysis (1): The risk ratio between musculoskeletal modifiable risk factors and internal rotation (IR) ROM and the development of shoulder dysfunction.

The effect size expressed as SMD was used in the etiology meta-analyses (Meta-analysis 2-5).

Meta-analysis (2): Studies that reported on the external rotation (ERs) strength of the cases and the controls measured using either a handheld dynamometer with isometric testing or isokinetic dynamometry with isokinetic testing were selected.

Meta-analysis (3): Studies reporting on the strength ratio of the (ERs): internal rotators (IRs) of the cases and the controls were included.

Meta-analysis (4): Studies reporting on the internal range of movement) measured using an inclinometer in degrees of the cases and the controls were included in the analysis.

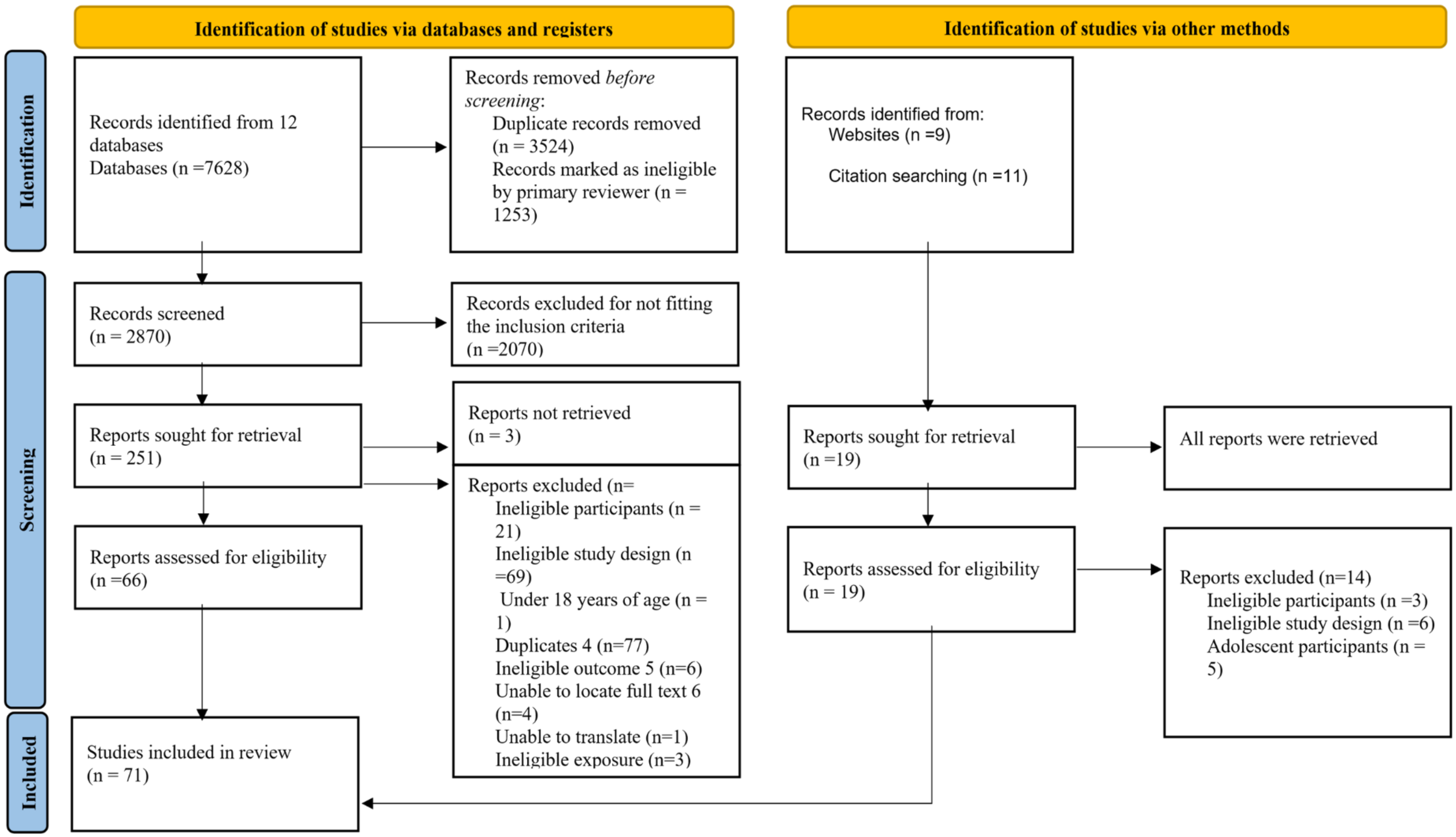
Meta-analysis (5): Studies reporting on the GIRD of the cases and the controls were included in the analysis.

Heterogeneity within the meta-analysis of the results was statistically tested using the I^2 test. Sensitivity analysis was also conducted to explore the impact of the included and excluded studies on the heterogeneity of the meta-analyses. The pooled results of the meta-analyses are graphically presented with forest plots (Figures 4, 5, 8, 9, 11). For funnel plot generation, two variables are needed: the standard error and the effect size. The standard error was calculated in SPSS using the available sample sizes of the different studies and the effect sizes derived from the forest plot data constructed in JBI SUMARI [40]. A funnel plot assessing publication bias was generated in SPSS. Statistical analysis using Egger's test was also performed [47]. When a meta-analysis of the data was not possible, the SWiM (synthesis without meta-analysis) approach was used for the synthesis of pooled modifiable musculoskeletal factors [48].

4 Study characteristics

A total of 7628 studies were identified through searching 12 databases (Figure 1). An additional eight records were identified through alternative sources (grey literature, thesis and reference lists of articles sourced) and added to the potentially applicable studies. Of these, 3524 duplicates were removed, while another 1253 records were removed for not fulfilling the inclusion criteria. The remainder of the 2870 records were screened by the primary reviewer. A total of 2070 records were excluded because they were not deemed applicable to the review question.

Two hundred and fifty-one studies were identified and found to be suitable for meeting the inclusion criteria, and the detailed results were imported into the JBI SUMARI [40]. The updated search, conducted from beginning of April 2023 through the 6th of March 2024, yielded one suitable article that met the inclusion criteria of the present systematic review and was incorporated into the present study. The studies were critically screened in a two-step process within the JBI SUMARI [40]. First, two independent reviewers (SB and FM-O) screened all the studies at the abstract and title levels, and if deemed appropriate for the review question, the full texts were critically screened.


Identification of studies via databases and registers
Identification of studies via other methods
Identification
Screening
Included
Records identified from 12 databases
Databases (n =7628)
Records removed before screening:
Duplicate records removed (n = 3524)
Records marked as ineligible by primary reviewer (n = 1253)
Records identified from:
Websites (n =9)
Citation searching (n =11)
Records screened (n = 2870)
Records excluded for not fitting the inclusion criteria (n =2070)
Reports sought for retrieval (n = 251)
Reports not retrieved (n = 3)
Reports sought for retrieval (n =19)
All reports were retrieved
Reports excluded (n=
Ineligible participants (n = 21)
Ineligible study design (n =69)
Under 18 years of age (n = 1)
Duplicates 4 (n=77)
Ineligible outcome 5 (n=6)
Unable to locate full text 6 (n=4)
Unable to translate (n=1)
Ineligible exposure (n=3)
Reports assessed for eligibility (n =66)
Reports assessed for eligibility (n = 19)
Reports excluded (n=14)
Ineligible participants (n =3)
Ineligible study design (n =6)
Adolescent participants (n = 5)
Studies included in review (n = 71)

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi:

10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Figure 1: PRISMA flowchart of the included studies.

Sixty studies were excluded when scrutinized during the abstract and title screening because they were deemed not applicable to the inclusion criteria for the current systematic review (Figure I). The reasons for the exclusion of both title and abstract and for full-text studies that did not meet the inclusion criteria were recorded and are reported in a table of excluded studies (Appendix 2). No disagreements arose between the reviewers at any stage of the study selection process, and there was no need for intervention by the third reviewer. The results yielded 71 studies that were included in the systematic review. The characteristics of the included studies are described in the Table of Characteristics (Online Resource 2).

The study designs included were as follows: quasi-experimental=2; case control=2; diagnostic test accuracy=3; cohort=14; case series=2; case report=1; prevalence=1; text and opinion=5; and analytical cross-sectional=41. Sixteen studies provided sufficient data to be pooled into meta-analyses. Age ranged from eighteen years to seventy-five years. A visual depiction of the countries where the studies were conducted can be found in Figure 2.

Figure 2: Global representation of the geographical location of the primary studies included in the current systematic review.

Assessing confidence in the findings:

To assess the association between shoulder dysfunction and the presence of modifiable musculoskeletal factors, the following studies were included in the current systematic review [43-44,49-68]. Several screening instruments, such as the visual analogue scale (VAS) [65,69], overuse injury questionnaire [43], Nordic [70] and Penn Shoulder score [71], were used for reporting the incidence of shoulder pain in the identified primary studies. Due to the heterogeneity of the different pain and dysfunction scales used for reporting pain, the data could not be pooled into a meta-analysis. The incidence of shoulder pain ranged from 27.2% [43] to 55% [70] in the presence of identified modifiable musculoskeletal factors.

The clinical symptoms and discipline (sport, e.g., tennis; sedentary, e.g., no sport) studied and identified are summarized in the Table of Characteristics (Online Resources 2) and in Figure 3. The etiology of the modifiable musculoskeletal factors causative of shoulder dysfunction was explored with SMD. The Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) [72] approach for assessing confidence in the quality of evidence was used, and a summary of findings (SoF) (Online Resource I) was created. The outcomes reported were SMD (95% CI) and the level of evidence (LOE) determined by the Oxford grading system.

Studies were identified across different subpopulations, ranging from overhead sporting activities to activities of daily living (Figure 3). Data from the primary studies were collected across various sporting fraternities, such as tennis [60], baseball [73], volleyball [43], handball [67], gymnastics [61], weight training [62], rugby [65], wheelchair users [74-75] and a sample of members of the public [55] (Figure 3).

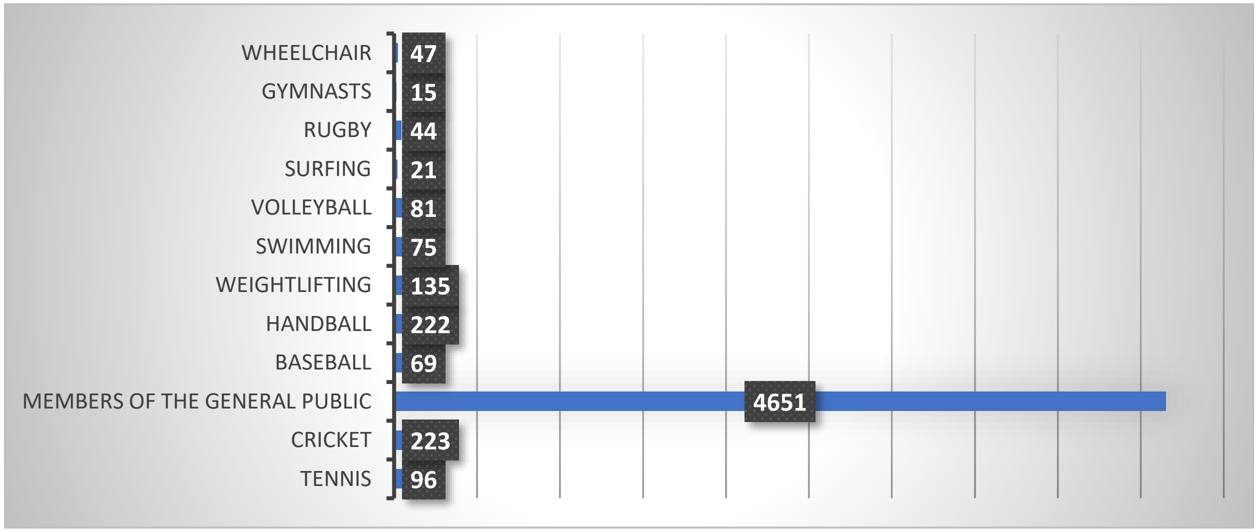


Figure 3: Populations and participants of the included studies in the present systematic review.

Participants who were tested via physical testing (n=5558), both female and male participants (F=2441) and (M= 3117) were included [43-44,49-68].

One study consisted of only a questionnaire (n=5250) completed by both female and male participants [70].

5 Risk analysis

The strength of the association between the development of shoulder dysfunction and the presence of modifiable musculoskeletal factors was explored using the RR and OR (Table I and Figure 4).

6 Etiological analyses

The SMD was used for the reported effect size of the identified modifiable musculoskeletal factors between the cases and the controls (SoF) (Online Resource I). For data collection from the primary studies used for the SMD calculations, measurements were extracted and documented in the following way: strength testing was conducted with either isometric dynamometry or using handheld dynamometers and reported in kilograms (kg) or Newtons (N) (SoF) (Online Resource 1). The results of the tests conducted with an isokinetic dynamometer (Cybex) were reported in Newtons/Kilograms (Nm/kg), and with manual muscle testing techniques, the Oxford grading scale was used.

The ROM was measured using either a digital or plastic handheld or bubble inclinometer and was documented in degrees. In one study, digital photography was used for measurements of degrees. Kinematic analysis was performed, and the results were documented using inertia motion sensors. For muscle length measurements, callipers, a rigid plastic square, a carpenter square, or a flexible tape measure were used, and the results are reported in centimetres (cm).

The etiology of the development of shoulder dysfunction was based on the following modifiable musculoskeletal factors: the rotator cuff musculature, the strength ratio of the inferior cuff (external versus internal strength), the supraspinatus muscle, differences in the length of the pectoralis minor muscle, the latissimus dorsi muscle length and posterior capsule flexibility. Specifically, the ROM, IR, GIRD, total range of motion (TROM), external rotation gain (ERG), external rotation deficit (ERD) of the glenohumeral joint, pectoralis minor muscle changes and scapular dyskinesis were reported. The previously mentioned exposure variables have been highlighted in this review in the findings and discussion sections (Online Resource I) [37,43-44,48-69,71,73,75,77-89].

The modifiable musculoskeletal factor variables were compared between the cases and controls among both females and males in the included primary studies. The outcome variables, namely, shoulder dysfunction, where causation was determined, were labelled case (dysfunctional shoulders) and control (non-dysfunctional shoulders).

7 Results

The Summary of Findings (SoF) Table I and (SoF) (Online Resource I) reflect the results of the included primary studies for the meta-analyses performed.

To determine the associations between the exposure variables, namely, the modifiable musculoskeletal risk factors ROM, ER and IR and muscle strength (ER and IR), and the outcome variable (shoulder dysfunction), the risk ratio (RR) and odds ratio (OR) were used.

7.1 Shoulder dysfunction:

7.2 Risk analysis results

The extracted results provided by five studies [43,63,65,77,78] revealed an association between the development of shoulder dysfunction and the incidence of modifiable musculoskeletal factors (Table I).

The results are expressed from the primary studies pooled into the RR meta-analysis (Figure 4). concluded that participants were at a 1.21-fold increased risk of developing shoulder pain in the presence of decreased IR ROM [65,77] and that participants were at a 1.08-fold increased risk of developing shoulder pain in the presence of increased ER ROM (Table I).

Determining the association between strength and shoulder dysfunction, the OR calculation revealed an increased incidence of 1.29-fold increased risk for patients to present with a supraspinatus tear in the presence of decreased (ERs) strength (Table I) and a 1.18-fold increased risk for presenting with a supraspinatus tear in the presence of decreased abduction strength (Table I). The risk of developing shoulder dysfunction was 1.026 times greater in participants presenting with GIRD [78] (Table I).

A positive association was detected between IR ROM differences [77, 65] and an increased incidence of pain in the shoulders of participants, according to the risk ratio calculated in meta-analysis (1) (Table I). A positive association was determined between decreased ER and abduction strength and a supraspinatus tear [63] (Table I). A positive correlation was determined between the development of shoulder dysfunction and GIRD [78] (Table I). Only the ROM primary risk association studies could be pooled into a meta-analysis.

Table 1: Risk analysis (RR) and (OR) reported for the risk variables of the included primary longitudinal studies.

Author	Association measurements (RR/OR) 95% CI	Risk factors and incidence of shoulder dysfunction
Olivier et al., 2020 **Longitudinal cohort**	RR 1.99 (1.40. 2.59)	Decreased ROM (IR). Shoulder dysfunction=28%
McDonough et al., 2014 **Longitudinal cohort**	RR 0.42 (-0.21. 1.04)	Decreased ROM (IR). Shoulder dysfunction= 36%
Skazalski et al., 2020 **Longitudinal cohort**	OR 1.08 (0.99. 1.17)	Increased ROM (ER). Shoulder dysfunction= 27.1%

Miller et al., 2016 Longitudinal cohort	OR 1.18 (1.06. 1.32)	Decreased ABD strength and supraspinatus tear. Shoulder dysfunction= 39%
Miller et al., 2016 Longitudinal cohort	OR 1.29 (1.14. 1.48)	Decreased ER strength and supraspinatus tear. Shoulder dysfunction= 39%
Olivier et al., 2018 Longitudinal cohort	OR 1.001 (1.026. 1.052)	GIRD and shoulder pain. Shoulder dysfunction= 39.2%

RR= risk ratio; OR= odds ratio; ROM=range of motion; IR= internal rotation; ER= external rotation; ABD= abduction; GIRD= glenohumeral internal rotation deficit.

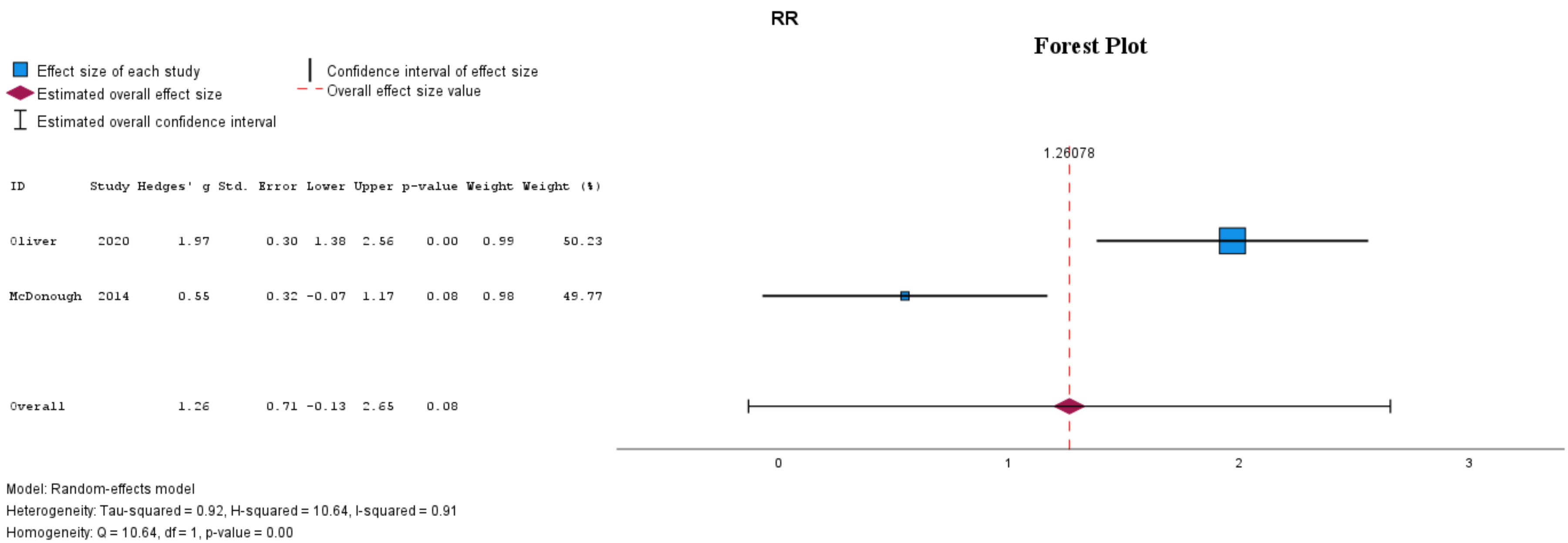


Figure 4: Meta-analysis (1): The risk ratios for the associations with IR ROM were calculated for the included primary studies.

An increase in the risk of developing shoulder dysfunction of 1.26 times was observed in the presence of decreased IR, as shown in Figure 4.

7.3 Etiology analysis results

7.4 External rotation strength

The second meta-analysis (Figure 5) reported the ER strength of the cases and the controls, and enough homogeneity was present between the studies, using the means and standard deviation (SD) to be pooled into meta-analyses. The participants were measured with isokinetic and isometric dynamometers. The SMD was calculated using the random-effects model for ER strength.

In meta-analysis (2), a high heterogeneity of $I^2 = 74$ and a moderate effect size of 0.54 (95% CI, 0.22-0.85) with a significance of P=0.001 were present, with the results favoring increased ER strength in the controls (Figure 5). Potential sources of heterogeneity could be attributed to age differences between the participants, sex differences and the different testing methods employed. After sensitivity analysis was conducted, the heterogeneity decreased ($I^2 =0$), and a small negative effect size of -0.29 (95% CI, -0.80-0.40) and a nonsignificant difference (p=0.85) were detected (Figure 6). The results still favored stronger (ERs) strength values in favor of the controls.

Publication bias was assessed using a funnel plot (Figure 7), and no publication bias was detected.

Study	Controls Mean	Controls SD	Controls Total	Cases Mean	Cases SD	Cases Total	Weight	Standard Mean Difference IV, Random, 95% CI
McDonough 2014	62.3	19.32	14	56.9	18.39	8	5.87%	0.27 [-0.60, 1.15]
Maestroni 2020	16.4	5.8	67	13	4.5	67	10.62%	0.65 [0.30, 1.00]
Marcondes 2013	19	3.8	22	17.9	2.9	27	8.48%	0.32 [-0.24, 0.89]
Forthomme 2018	0.62	0.1	51	0.63	0.12	57	10.33%	-0.09 [-0.47, 0.29]
McDonough 2014	64.5	25.4	14	54.1	12.28	8	5.82%	0.46 [-0.42, 1.34]
Heck 2021	10.9	3.9	19	10.2	2.9	12	7.03%	0.19 [-0.53, 0.92]
Kolber 2017	0.167	0.044	31	0.132	0.051	24	8.64%	0.73 [0.18, 1.28]
Miller 2016	8.5	1.5	110	5.8	1.9	69	10.65%	1.61 [1.27, 1.96]
Skazalski 2021	0.23	0.03	43	0.21	0.05	38	9.70%	0.49 [0.04, 0.93]
Rosa 2019	102.6	15.3	28	91.7	14.7	25	8.58%	0.71 [0.16, 1.27]
Moreno-Perez 2015	49.3	11.3	28	40.6	11.6	19	8.14%	0.75 [0.15, 1.35]
Laudner 2004	0.17	4.9	11	-0.6	6.16	11	6.13%	0.13 [-0.70, 0.97]
Total (95% CI)			**438**			**365**	100.00%	0.56 [0.27, 0.85]

Heterogeneity: $\tau^2=0.17$, $\chi^2=50.75$, df=11 (P=0) $I^2=72$

Test for overall effect: Z=3.76 (P=0)

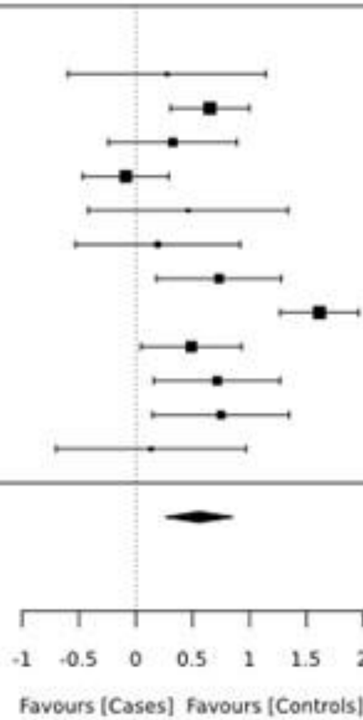


Figure 5: Meta-analysis (3) of isometric and isokinetic strength in the (ERs) between the cases and the controls.

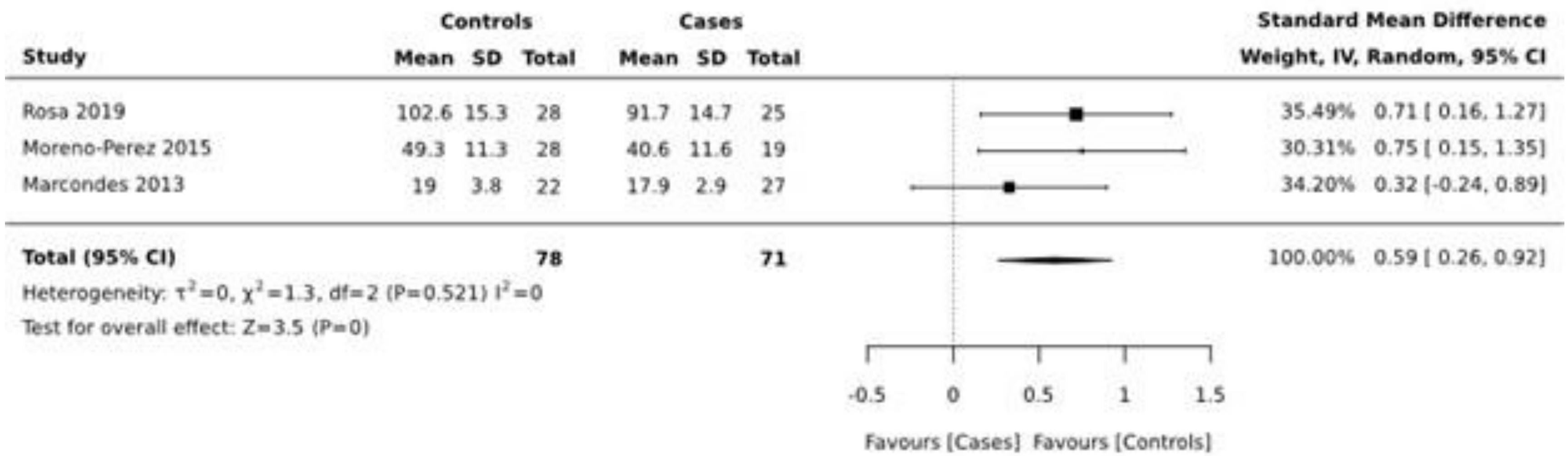


Figure 6: Sensitivity analysis was conducted to reduce heterogeneity.

In an effort to reduce heterogeneity, a study testing isokinetic external rotator cuff strength [67] (SoF) (Online Resource I) was removed from the meta-analysis. To further reduce heterogeneity, a sub analysis of studies with similar sample sizes was performed [55,60,85]. (SoF) (Online Resource I) were constructed. The heterogeneity decreased to I^2 =0%. The overall results still supported the use of stronger (ERs) for the controls, with a large positive effect size of 0.59.

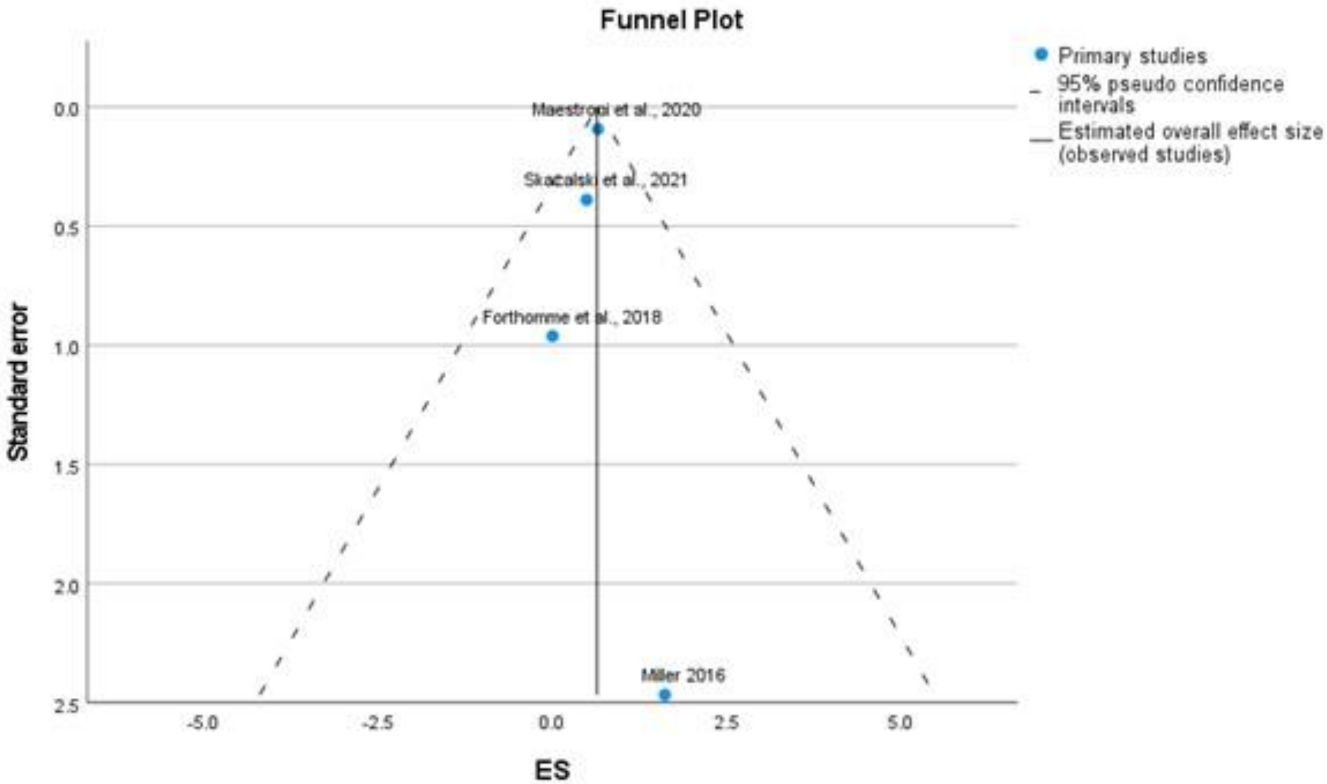


Figure 7: No publication bias was detected in the funnel plot generation from the isometric and isotonic strength values between the cases and the controls.

7.5 External (ER): Internal (IR) strength ratio

The following meta-analysis (3) in Figure 8 presents the ER:IR strength ratio between the cases and the controls of the included pooled studies. Pooling of studies investigating ER:IR strength ratios between the cases and the controls made it possible to employ the means and SDs to estimate the SMD with a random-effects model in a meta-analysis.

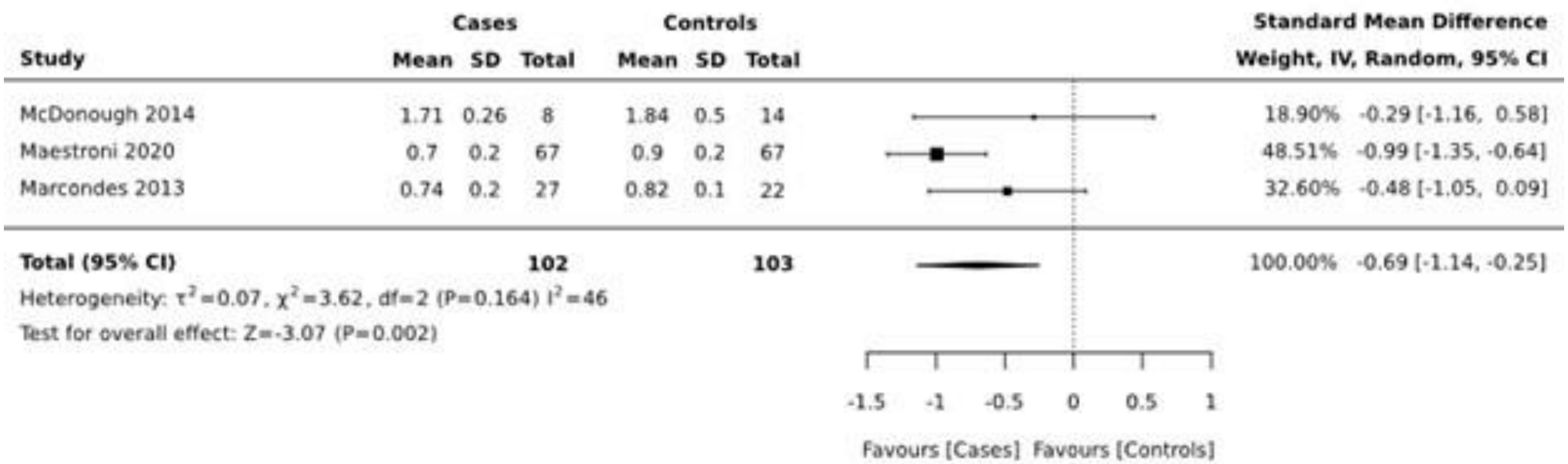


Figure 8: Meta-analysis (3) depicting the ER:IR strength ratios between the cases and the controls.

With a statistically significant presence ($p=0.002$), medium heterogeneity ($I^2 =46$) and a large negative effect size of -0.69, as depicted in Figure 8, overall lower ER:IR strength ratios are shown to favor the cases.

7.6 Internal Rotation ROM

Meta-analysis (4) revealed the difference in the IR ROM between the cases and the controls (Figure 9). Pooling of studies investigating internal rotation between the cases and the controls was possible by employing the means and SDs to estimate the SMD with a random-effects model in a meta-analysis (Figure 9). Even though a high level of heterogeneity was present ($I^2 =77$), a large negative effect size of -0.62 (95% CI, -0.95:0.28) was determined, favoring the cases.

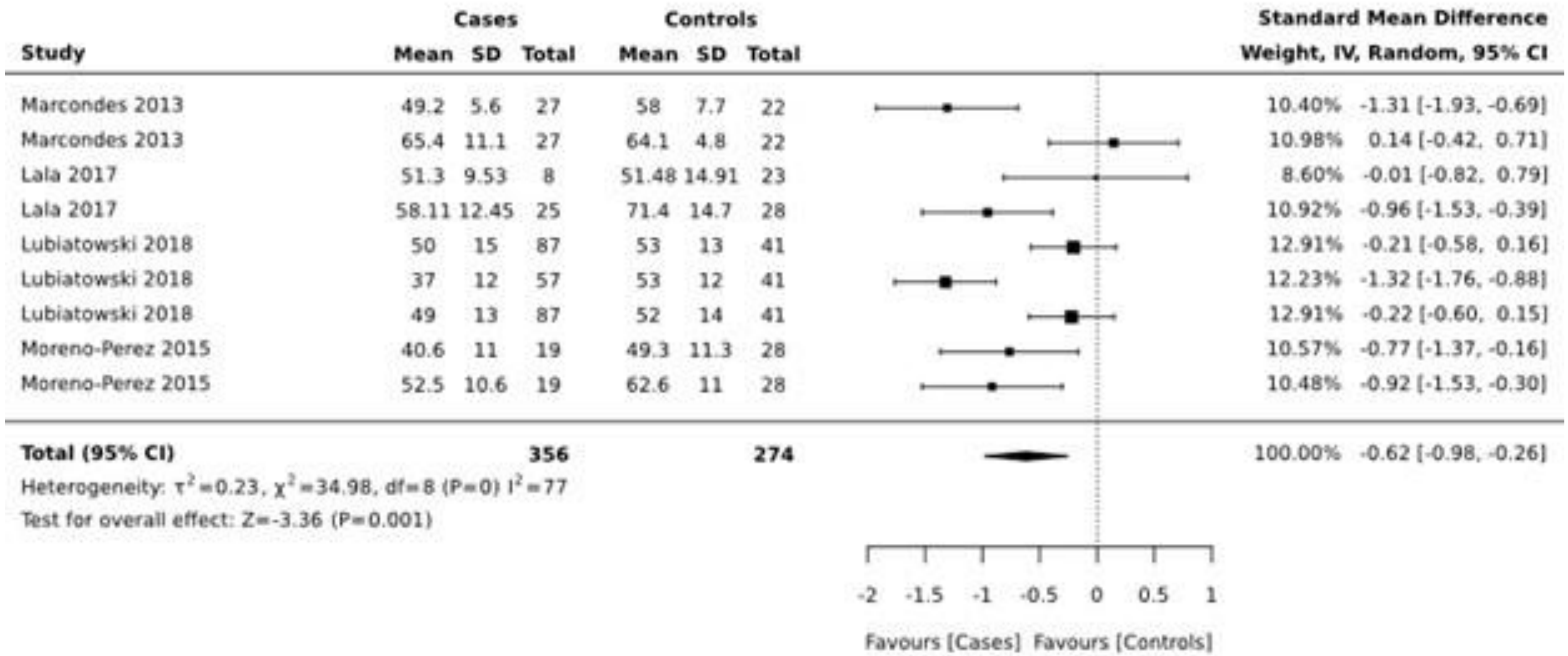


Figure 9: Meta-analysis of IR between the cases and the controls for IR ROM.

Study	Cases Mean	Cases SD	Cases Total	Controls Mean	Controls SD	Controls Total	Weight	Standard Mean Difference IV, Random, 95% CI
Marcondes 2013	49.2	5.6	27	58	7.7	22	23.50%	-1.31 [-1.93, -0.69]
Moreno-Perez 2015	40.6	11	19	49.3	11.3	28	24.83%	-0.77 [-1.37, -0.16]
Moreno-Perez 2015	52.5	10.6	19	62.6	11	28	24.14%	-0.92 [-1.53, -0.30]
Rosa 2019	57.4	12.4	25	71.4	14.7	28	27.52%	-1.01 [-1.58, -0.44]
Total (95% CI)			**90**			**106**	100.00%	-1.00 [-1.30, -0.70]

Heterogeneity: $\tau^2=0$, $\chi^2=1.6$, df=3 (P=0.658) $I^2=0$

Test for overall effect: Z=-6.5 (P=0)

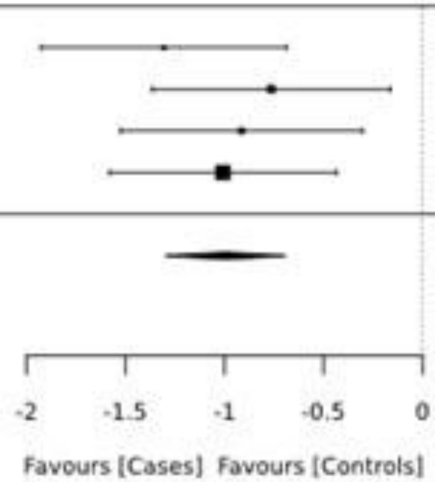


Figure 10: Sensitivity analysis for reducing heterogeneity in IR ROM.

According to the sensitivity analysis (Figure 10), after removing participants from larger sample sizes and grouping similar subgroups, such as tennis players together, less heterogeneity was demonstrated (I^2 =0), with a large negative effect size of -1.00 (95% CI, -1.30: -0.70). The results still favored the cases [55,60,85].

7.7 GIRD

Meta-analysis (5) explored the GIRD of the cases (Figure 11). When the means and SDs were pooled with the random effects model to determine the SMD, heterogeneity was not detected (I^2 =0), with a small negative effect size of -0.10 (95% CI, -0.36:0.16) favoring the cases.

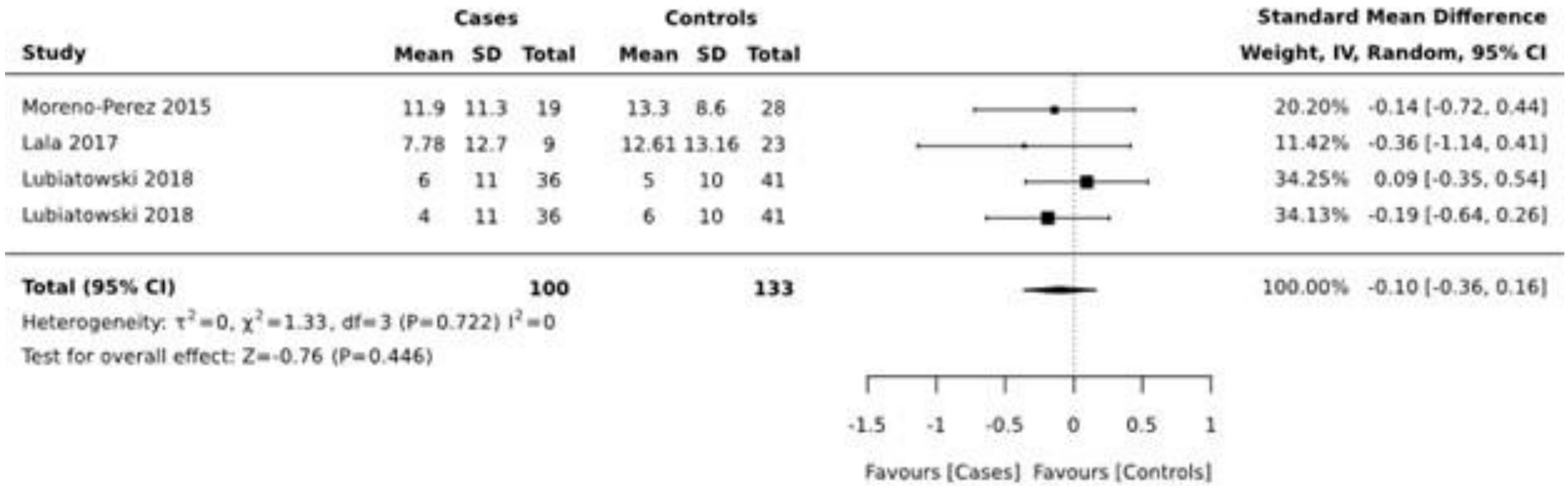


Figure 11: Meta-analysis (5): Forrest plot depicting the mean difference in GIRD between the cases and the controls.

7.8 Muscle flexibility of the cases and the controls

7.9 Pectoralis minor

The muscle length of the pectoralis minor muscle (PMm) was investigated in terms of the muscle indices; muscle shortening; muscle lengthening; muscle activity; muscle rest; and muscle length in different testing positions [64,71,74,77,79,82,89-98].

Two main physical examination-based measurements for the pectoralis minor muscle were identified and used by various authors in the study of both cases and controls: the pectoralis minor index (PMI) test described by Borstad [100] and the pectoralis minor length test (PMLT) described by Kendall [101]. Full details are available in (SoF) (Online Resource I) (Appendix M) and (Table of Characteristics) (Online Resource 2) (Appendix M).

The results of the studies that investigated PMm flexibility could not be pooled into a meta-analysis due to heterogeneity in the measurement methods used. The characteristics of pectoralis minor were pooled together, and the results are summarized in tabular formats (Table of Characteristics) (Online Resource 2) (Appendix M) and in (SoF) (Online Resource I) (Appendix M). A positive trend between changes in PMm flexibility and the cases has been established with the current systematic review. The derivation results are fully discussed in the discussion section.

7.10 Scapular kinematics

Scapular kinematics, dyskinesis and EMG studies of the scapular stabilizers were performed by the following authors: [37,55,68,83,91,93,95-96,102-104]. The results are highlighted, discussed and tabularized in the “SoF” section (Online Resource I) (Appendix M) and in the “Table of Characteristics” section (Online Resource 2) (Appendix M). Weaknesses of both lower trapezius and serratus anterior were present in the cases [32,91,105]. This in turn led to decreased upward rotation of the scapula [95,96,127]. Increased internal rotation and anterior tilt of the scapula were concluded in the presence of a shortened PMm [105,125]. Increased upper trapezius activity was present in the cases leading to more elevation than upward rotation of the scapula [53]. The altered scapular stabilizers activity concluded in the primary studies negatively influenced the scapular position and led to dyskinesis.

8 Discussion

8.1 Association between modifiable musculoskeletal risk factors and the development of shoulder dysfunction

The association of musculoskeletal factors leading to the development of shoulder dysfunction in an adult population was the main objective of the current systematic review. This was the first systematic review, to the authors' knowledge, to investigate multiple known modifiable musculoskeletal factors and their association with the development of shoulder dysfunction at one point in time. All currently available evidence was summarized, analyzed and methodologically appraised (Online Resources I, 2). The current systematic review included cross-sectional and longitudinal studies investigating numerous sporting populations (swimming, rugby, weightlifting, wheelchair sports, volleyball and baseball (1003 participants)) and members of the general population (4651). The studies included both females (2441) and males (3117).

An increased risk of developing shoulder dysfunction in the presence of modifiable musculoskeletal factors was determined with the RR and OR analysis of the present systematic review (Table I). Risk analysis revealed that the incidence of both ROM and strength changes in the presence of modifiable musculoskeletal factors in dysfunctional shoulders [77,65]. The strength of the association between exposure and outcome was tested by pooling studies into several meta-analyses (Figures 4, 5, 8, 9, 11).

Very little bony support is provided to the glenohumeral and scapulothoracic joints, which are mainly controlled by contractile and noncontractile muscular forces [28,105]. Participants studied with EMG analysis and presented with subacromial impingement demonstrated decreased activation of the subscapularis-infraspinatus and supraspinatus-infraspinatus force couples and increased middle deltoid activation at the start of elevation (0°–30°) [106]. Recent research by Millet [107] proposed that in (SIS), the force vector of the supraspinatus that counterbalances the upward directed force of the deltoid might be disrupted. Weakness and thus decreased proprioception of the infraspinatus disrupt the force couple of the rotator cuff and destabilize the glenohumeral joint on the glenoid [108]. These historical results will be discussed next considering the conclusions drawn from the current systematic review.

8.2 Strength

Numerous authors [61,65,67,73] of the included primary studies used for the generation of strength meta-analyses agree that stronger (ERs) contribute to shoulder stability and, in their opinion, lessen the chances of developing shoulder dysfunction. In primary studies conducted on the strength differences of non-dysfunctional shoulders of overhead athletes and in a convenience sample of members of the general population, no difference in side-to-side strength was found [44,56-58,67,109].

Considering the overall conclusions reached from the strength meta-analyses (Figure 5, 8), strengthening the (ERs), especially through eccentric control of the (ERs) in overhead athletes, might be advisable to offset strong (IRs). This prevents the development of (ERs) fatigue with repetitive overhead throwing motions, predisposing an athlete to injury. Hence, it could be hypothesized that a stronger (ERs) may be beneficial for shoulder stability in all healthy shoulders regardless of the activity performed.

Lajtai [110] determined that atrophy of the infraspinatus was present in the painful shoulders of beachball volleyball players, an incidence as high as 30 % in the painful hitting shoulder. The difference in strength was a mean of 2.3 kg between the painful and nonpainful sides. No correlation between suprascapular nerve neuropathy and the decreased strength observed was found [110]. However, in a review by Bozzi (2020) [111] of overhead athletes a clear association between decreased strength of the supraspinatus and the infraspinatus muscle complex and the incidence of suprascapular neuropathy was concluded. A decrease in the cross-sectional area of the supraspinatus in the presence of painful shoulders was observed by Benitez-Martinez [112]. Therefore, the authors of the present study believe that the decreased muscle (ERs) strength observed in the affected tissues (infraspinatus and supraspinatus) may be a precursor to the development of pain observed in the participants with painful shoulders.

Furthermore, the observed differences in strength may not be solely due to pain inhibition but to muscle atrophy of the affected muscles. The phenomena of suprascapular neuropathy were not mentioned in any of the primary articles researched, but it should be kept in mind as a potential cause of muscle weakness of supraspinatus and infraspinatus in overhead athletes presenting with shoulder pain. Technique change in the case of suspected suprascapular neuropathy in combination with (ERs) strengthening may therefore be advisable particularly in volleyball players Young (2023) [113].

8.3 Ratio of the ER:IR strength

In the present systematic review, strength ratios were explored in most populations, including members of the general population. The results of the primary studies [60,65,67,114,122] reflected higher strength ratios to favor the controls in both overhead, underhand and members of the general population (Figure 8). Even though some caution should be given to the conclusions, given the presence of a statistically significant (p=0.002) medium effect size, a higher ER:IR ratio was found in favor of the controls. Although not pooled into a meta-analysis, the results obtained in another systematic review [116], which was not pooled into a meta-analysis and was conducted on an overhead athletic population, concurred with the results of the current systematic review, which showed that a low strength ratio ER:IR is predictive of the development of shoulder dysfunction. These findings were reiterated in previous studies of overhead athletes by Saccol [116]**,** who concluded that no significant difference in strength was present in the isometric ER:IR strength ratios in asymptomatic athletes.

McDonough [65] investigated the dynamic control ratio (DCR) of the IR:ER in rugby league players. McDonough [65] tested the eccentric internal (Ecc/IR) and concentric external (Conn/ER) rotator cuff strengths in the 90-degree abducted position via isotonic testing of the inferior rotator cuff. Their main conclusion was that the (Ecc/IR: Conn/ER) ratio of the injured to the non-injured shoulder was lower (IR:ER) (1.84:1.71) on the left side than on the right side (IR:ER) (1.97:1.69) [65]. McDonough [65] recommended strengthening the (IRs) cuff to prevent injury which contrasts with most other studies investigating ER:IR ratios, that recommended strengthening of the (ERs) muscles to prevent injury [57-58,67,116].

Some consideration should be given to where in range the strength measurements are taken. In the presence of decreased IR ROM and increased ER ROM, the muscle length could be a factor influencing the muscle strength values. The force-length relationship may come into play with strength assessments [117]. It is therefore known in literature that a shorter muscle length may yield stronger muscle strength values and a longer muscle length may provide weaker strength values [117]. The study of Marcondes (2013) [60] conducted on the dominant painful side in comparison to the non-dominant non-painful side, concluded weaker (ERs) strength values and decreased ER:IR ratios in the presence of increased ER ROM and decreased IR ROM. The force-length relationship may thus have influenced the derived results.

The nature of overhead sports requires the player's dominant arm to generate higher strength values of the (IRs) for execution of the sporting motion. Increased (IRs) strength values leading to different ER:IR ratios were determined in handball players [58,67]. Therefore, functional ratios lower than the ER:IR (1.00:1.00) ratio recommended in the literature have been observed [58,67]. Isotonic measurements were conducted comparing the dominant side to the non-dominant side [58,67]. Statistically, significant differences of the eccentric IRs (eccIRs) were concluded to be stronger than the eccentric ERs (eccERs) in the dominant versus the non-dominant shoulder ($p<0.001$) [58]. It is suggested that (eccERs) should be stronger than (connIRs) to compensate for the deceleration and control of the glenohumeral head (GH) in the throwing motion in overhead sports [58,67].

Dos Santos Andrade [58] suggested functional (eccERs) exercises for the improvement of the eccentric ER's strength. In their opinion it may be preventative for pain development [58]. Numerous authors of the included primary studies agree that a higher ER:IR strength ratio prevents the development of shoulder dysfunction [57,58,67,116]. Strengthening of the (ERs) regardless of the mode being isometric or isotonic should therefore be beneficial to pain prevention.

A decrease in the subacromial space (SAS) was observed in the presence of a stronger (IRs). A stronger (IRs) resulted in a decreased ER:IR agonistic-antagonistic force couple ratio. A decreased SAS leads to impingement of the rotator cuff (RC) in the abduction motion from 0° to 60° [54]. This decreased ER:IR ratio had a knock-on effect on destabilizing the dynamic control of the humeral head on the glenoid in overhead sports, such as softball, leading to (SIS) [54].

Regardless of the shoulder motion required or strength of evidence provided, strengthening and restoring the ER:IR force couple to a better strength ratio is deemed advisable for improved shoulder stability in both athletes and members of the general population.

8.4 ROM

Decreased internal rotation has been identified as a precursor to developing shoulder dysfunction by various authors of the included primary studies pooled into a meta-analysis (4) (Figure 9) [60,79,84-85]. The population included overhead sports such as cricket, handball and tennis, as well as members of the general population [55,60,79,84-85]. IR ROM must not be measured in isolation; however, ER ROM and TROM should be measured and considered at the same time. In overhead sports, particularly baseball, a symmetrical loss of IR ROM is often offset by a symmetrical gain in ER ROM [81]. However, in a recent comprehensive systemic review by Garett (2024) [118] of tennis players of comparisons between the dominant and the non-dominant side revealed decreased IR ROM of the dominant side compared to the non-dominant side (53.0 ° vs. 62.4 °, $p<0.1$), and increased ER ROM of the dominant versus the non-dominant side of (105.4 °vs. 100.8 °, $p<0.01$). Therefore, the same phenomena as in baseball of the symmetrical loss of IR ROM being offset by the symmetrical gain in ER ROM were thus observed.

It was noted that the presence of IR ROM was less pronounced, even though still present, in a sample of the general public than in sporting populations, such as in overhead sports, tennis, handball, cricket, swimming, and underhand sports (rugby) [44,55,79,84-85] (Figure 9). Several studies have shown that players complaining of shoulder pain from posterosuperior internal impingement present with decreased IR ROM and ER ROM and a decreased total arch of movement (TAM) [79 84].

With an overall side-to-side comparison of the included primary studies of the present systematic review, a general decrease in TROM was determined, even though ER ROM are increased, and IR ROM decreased (Online resource 1). This was found in populations such as cricket, handball, tennis, swimming and underhand (rugby) [44,65,79,84,118,120-121] and in members of the general public [55].

GIRD has been linked to an increased risk of developing shoulder dysfunction by several of the authors of the included primary studies of the present systematic review in overhead sports such as tennis and handball at a professional level [79,85-86]. The pooled results are summarized in the meta-analysis (5) (Figure 11). Even though not covered in the present systematic review, when considering limited IR, osseous adaptation should also be considered a contributing factor to the limitation of IR. This approach is especially applicable in overhead sports, such as baseball [81]. Reuther [81] observed that if humeral retroversion is corrected in the presence of the measured GIRD, the GIRD disappears; thus, soft tissue changes are not solely responsible for the GIRD.

Lubiatowski [84] reported that a greater incidence of shoulder pain was present in patients with internal deficits of more than 20 degrees. A GIRD of up to 41 degrees has been determined in the symptomatic shoulders of individuals in a general population group [122]. A greater incidence of internal impingement was present when both internal deficits of more than 25 degrees and a total arch of motion of more than 20 degrees coexisted [84]. TAMDs of between 6 degrees to 16.7 have been found in pathological shoulders [84-85] (Online Resource 1). This is more than the 5-degree results obtained in the original study proposed by Wilk [121].

Posterosuperior internal impingement was associated with GIRD higher than 20°-25° and coexisted with TAMDs of 20° [60]. The study was conducted between the dominant painful shoulder and the dominant non-painful shoulder of skilled amateur tennis players [60].

Structures that can cause a decrease in IR ROM are the posterior inferior cuff (infraspinatus and teres minor) and the posterior capsule [19,123-124]. Posteroinferior shortening of the abovementioned structures results in a posterosuperior shift of the humerus, causing internal impingement [19,123,125]. This phenomenon can potentially maximize the peel-back forces of the long head of the biceps and predispose an athlete to developing SLAP lesions [19,126]. GIRD not only occurs in baseball players, as originally described by Pappas [124] and Burkhart [127] but also occurs in other overhead disciples, such as skilled amateur tennis players [60,123], handball players [84] and cricket players [64].

External rotation gain (ERG) was concluded and linked to shoulder dysfunction in various overhead sporting populations, such as cricket, tennis and handball [44,60,79,84]. Results could not be synthesized in a meta-analysis, but the Swim approach was utilized (Online resource 1). Partial rotator cuff tears (RCTs) were accompanied by greater ER ROM and TAMG in a study of professional handball players [84]. The findings are described in detail in the online supplement (Online Resource I).

No difference was observed in either ROM or strength during the preseason on gymnasts between athletes sustaining an injury and injury-free athletes [61]. The bilateral nature of the sport may provide a link to the lack of observed differences [61].

8.5 Pectoralis minor

Shortening of the pectoralis minor has been identified as contributing to scapula dyskinesis [21,103,129]. The results of the primary studies included in the current systematic review revealed that a shortened PMm can cause anterior tilt, protraction and internal rotation of the scapula [105, 129]. This places the scapular stabilizing muscles, particularly the lower fibers of the trapezius and the serratus anterior lower fibers, in a biomechanically altered position with reduced posterior tilt of the scapula [105].

Decreased flexibility of the PMm and ER ROM was noted after a bout of swimming in the painful group of swimmers [71]. Increased PMm activity occurred in a painful group of participants who presented with SIS in a laboratory-controlled group [91]. Decreased IR ROM and ER ROM as well as decreased flexibility of the PMm and weakness of the serratus anterior were determined in their study of cricket players [64]. Decreased flexibility of the PMm was observed in wheelchair users [74].

Decreased flexibility of the pectoralis minor and the latissimus dorsi was associated with an increase in pain in competitive swimmers [129]. The presence of scapular dyskinesis has also been observed with alterations in the PMm using different measurement methods [37,51,92-97,130]. See (SoF) (Online Resource I) and Table of Characteristics (Online Resource 2).

8.6 Scapular dyskinesis

Numerous authors have investigated the presence of scapular dyskinesis and its relevance [32,53,68,83,131-132] in both athletic and nonathletic population groups. Heterogeneity within the measurement properties used for scapular kinematics prevented pooling of studies. The SWiM approach was used, and the results of the identified studies are summarized in the Table of Characteristics (Online Resource 2) [48].

In their text and opinion study, Saini [132] highlighted the importance of the early identification and correction of observed scapular dyskinesis in tennis players. The control and position of the scapula are dependent mainly on scapular stabilizers due to an inherent lack of bony stability. Therefore, the abovementioned imbalance in the scapular stabilizers of the included studies may be clinically relevant. Phadke [32] concluded that decreased strength of the lower trapezius leads to less upward rotation of the scapula. Huang [83] observed increased upper trapezius activity in the presence of scapular inferior angle prominence in symptomatic shoulders.

Moreover, Kolber [53] reported the presence of increased strength of the upper trapezius in weightlifters with (SIS). Borstad and Ludwig [131] investigated scapular kinematics with a motion sensor (Fastrak) and concluded that less upward rotation was present at lower angles and more anterior tipping of the scapula was present at greater angles of elevation in symptomatic shoulders. The positioning of the scapula is mainly controlled by scapular stabilizers and imbalances in muscle strength, and more important force couples in these muscles may lead to abnormal positioning of the scapula, which has a negative impact on the functioning of the glenohumeral joint.

The previously mentioned imbalances in scapular stabilizers, as highlighted by various researchers, can hence lead to scapular dyskinesis or dyskinesia. However, an interesting observation of decreased muscle strength of the rotator cuff was made by [68]. According to the authors, this was a more frequent finding than the presence of scapular dyskinesis and limitation of active ROM in painful shoulders.

9. Conclusion

The present systematic review identified seven modifiable musculoskeletal factors among both athletic and nonathletic population groups. Decreased (ERs) strength, a decreased ER:IR strength ratio, decreased IR ROM, GIRD, ER ROM gain, PMm shortness and scapular dyskinesis were associated with shoulder dysfunction. Modifiable musculoskeletal factors synthesized into several meta-analyses provided strong evidence for the presence of decreased (ERs) strength, decreased ER:IR strength force couple ratios and decreased IR ROM being associated with shoulder dysfunction. Weaker evidence of GIRD being associated with shoulder dysfunction and of a shortened PMm and scapular dyskinesis in the presence of shoulder dysfunction was determined. Regardless of the level of evidence, the presence of the abovementioned modifiable musculoskeletal factors was determined to be associated with shoulder dysfunction.

Evaluation of musculoskeletal factors such as IR ROM, ER ROM, IR strength, ER strength, ER:IR strength ratios, GIRD, PMm length and scapular dyskinesis in isolation may not provide a clear and strong association between pain development and being precursors to the development of shoulder dysfunction. However, combining all the identified musculoskeletal factors at one point in time to a participant with a painful shoulder may provide clearer guidance to the solution. Early identification of biomechanical dysfunctions associated with any particular movement pattern of the shoulder can aid in preventing the development of shoulder pathology.

10. Recommendations

The etiology of shoulder dysfunction is multifactorial and complex in nature. All the identified modifiable musculoskeletal factors of the present systematic review should be considered in the comprehensive assessment and rehabilitation of the shoulder joint.

Moreover, correcting for the identified modifiable musculoskeletal factors, normalizing all the affected force–couple ratios of the modifiable musculoskeletal factors and increasing the flexibility of identified modifiable musculoskeletal factors should in theory lead to improved biomechanics of the scapulohumeral complex. In overhead athletes a change in technique as well as correction of the altered (ERs) strength and ER:IR ratio balance should be considered and not only ER strength correction. In underhand athletes and members of the general population correction of only the altered (ERs) strength and ER:IR strength ratio may be sufficient to altered pain symptoms.

11. Limitations

However, additional primary longitudinal studies should be conducted on the association between modifiable risk factors and the development of shoulder dysfunction. Due to the heterogeneity of the included primary studies, only a few studies reporting on the RR and OR could be pooled into a meta-analysis. Not all the included primary observational studies reported on RRs and ORs, and additional research in this area is needed.

No data could be found on the role of the latissimus dorsi or the subscapularis in either primary observational or longitudinal studies on the risk of developing shoulder dysfunction. Rehabilitation may need to be tailored to different age and population groups. Therefore, even though the methodological quality of the studies included in this review was fair overall, namely, at levels 3 and 4, meaningful information was collected.

12. Statements and declarations

Competing Interest

All the authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or nonfinancial interest in the subject matter or materials discussed in this manuscript.

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Availability of data

The authors declare that the data supporting the findings of this study are available within the paper and in the supplementary online information files.

Online supplements

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Chapter 5 Strength profile of the superior and inferior rotator cuff: A comparison of painful and nonpainful shoulders in an adult nonathletic population aged between 18 and 75 years.

The aims and objectives of this chapter is presented in Chapter one, page 21. This study is under peer review at Clinical Biomechanics.

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Abstract

Background

The ideal force couple ratio of the superior cuff, supraspinatus versus anterior deltoid, has yet to be determined in both athletic and nonathletic populations.

Objective

To determine the muscle force and muscle force couple ratios of the superior cuff, between the supraspinatus and the anterior deltoid and of the inferior cuff, between the external rotators and the internal rotators in painful and nonpainful shoulders in an adult nonathletic population.

Methods

This was an observational cross-sectional study. The shoulders of both painful and nonpainful shoulders of adults, women and men were tested. Isometric muscle force was collected with a handheld dynamometer. The ratios of the superior cuff (supraspinatus versus anterior deltoid) and inferior cuff (external versus internal rotators) were determined.

Findings

A statistically significant force–couple ratio of the supraspinatus versus the anterior deltoid was determined ($p = 0.001$), with a small effect size (0.21) in the nonpainful shoulders. Statistically significant differences (p = 0.001) in the external rotator force values between the nonpainful and painful sides of participants with painful shoulders were determined.

Interpretations

The study found an association between decreased force couple ratios and painful shoulders. All force couple-ratios may need to be considered in the assessment and rehabilitation process. Strengthening the weakened external rotators and supraspinatus and restoring all affected force couple ratios of both the superior cuff and the inferior cuff in painful shoulders among all age groups may be beneficial for pain and symptom relief.

Keywords

Force couple ratios, supraspinatus, anterior deltoid, external, internal rotators

1. Introduction

The shoulder is the most mobile joint of the human body and is a good example of controlled mobility and stability induced predominantly by muscular forces [1-3]. The shoulder joint can perform a large range of motion despite incongruent joint surfaces [4,5]. The interplay between osseous structures (scapula, clavicle and humeral head), muscular, capsular, ligamentous, and labral structures is finely coordinated and balanced to ensure a large range of motion of the shoulder joint [4,5]. The prevalence of shoulder pain in the general population is as high as 16% [6]. Through extensive research conducted by numerous authors, the association between decreased external rotator force and the development of shoulder pain has been established [7-9]. An increased risk of developing shoulder pain has also been identified as a decrease in the ratio of the external rotator force to the internal rotator force [7-9]. These studies have been conducted primarily in athletes, specifically in overhead athletes [10-12]. The deficits previously mentioned have not been explored extensively in nonathletic populations. This raises the question of whether these deficits are adaptive or protective phenomena specific to athletic populations and/or whether they also occur in nonathletic populations. Inman [13] initially proposed a force couple between the supraspinatus and deltoid. There is a paucity of evidence in the literature on the role and ideal force balance ratio of the superior force couple between the supraspinatus and anterior deltoid in both athletic and nonathletic populations in the development of shoulder pain.

The rotator cuff pathology contributing to shoulder dysfunction is complex and multifaceted and is often difficult to diagnose [14]. The rotator cuff has been implicated in the development of shoulder dysfunction by numerous authors [15,16,17]. An imbalance in the rotator cuff's musculature can result from altered force couple vectors. Instability of the glenohumeral head on the glenoid cavity can occur if the balanced rotator force couples are disturbed, and in total disruption of the rotator cuff, anterior dislocation of the humeral head can result [5]. Furthermore, if the centering of the humeral head on the glenoid fossa is lost due to imbalanced force couples of the rotator cuff, abnormal joint kinematics will follow [18,19]. A disturbed balance of the force couple of the rotator cuff can result in upward migration of the humeral head and can have a knock effect on the loading of the long head of the biceps (LHB) with increased labral tissue strain [20].

The anterior–posterior force couple of the inferior cuff comprises the anteriorly placed subscapularis (internal rotator) and the posteriorly placed infraspinatus and teres minor (external rotators). The infraspinatus, subscapularis, and teres minor force couples act synergistically, creating a compressive force in the coronal plane and directing the head of the humerus into the glenoid cavity [19,21,22]. This force coupling counterbalances the superiorly directed force coupling of the supraspinatus (SS) and deltoid [23]. The general consensus among numerous authors is that stronger external rotators contribute to shoulder stability and decrease the development of shoulder pain [10,24]. Moreover, several authors agree that no real left-to-right-sided force difference in the rotator cuff musculature exists in nonpainful shoulders [9,11,12].

To our knowledge, no studies have been conducted on the force couple between the supraspinatus and anterior deltoid in either athletic or nonathlete populations. The purpose of the present study was therefore to investigate the force couples between the SS and anterior deltoid (AD) and the external rotators versus the internal rotators and the associated changes in both nonpainful and painful shoulders. We hypothesized that a relationship would exist between the force couple ratios of the SS and the AD, as well as the ratio of the external and internal rotators, within the left and right sides of the participants with nonpainful shoulders, as well as between painful and nonpainful shoulders.

2. Methods

2.1 Study design and setting

This was an analytical cross-sectional study, and data were collected in the South and North of Johannesburg area. Ethical approval was obtained from the University of the Witwatersrand, the Human Research Ethics Committee (Medical).

2.2 Participants

Sampling method

A convenience sample was used, and potential participants were invited from the South and North of the Johannesburg area. Participants were recruited via adverts on bulletin boards of schools, churches and sports clubs. A priori sample size calculation, with rotator cuff muscle strength as the variable, using inferential statistics with a medium effect (0.50), standard deviation (SD) of 1.0, alpha of 0.05, and power of 80% yielded a sample of (n=60). A sample of 85 participants was recruited and tested to provide for any fallout.

The inclusion and exclusion criteria were as follows:

The study included 45 participants with nonpainful shoulders and 40 participants with painful shoulders, both females and males, aged between 18 and 75 years (Table 1, 2) (Fig. 1).

Table 1 Demographics of the participants with and without painful shoulders.

	Mean	SD	n
Participants with painful shoulders			
Age P	51,74	11,95	40

Height	168,81	10,67	
BMI	22,93	4,88	
Gender Age F	50.94	15,17	17
Gender Age M	50,83	11,2	23
Dom L			2
Dom R			38
Participants with nonpainful shoulders			
Age NP	41,17	12,87	45
Height	168,23	16,93	
BMI	26,01	32,72	
Gender Age F	40,93	11,9	22
Gender Age M	39,64	12,77	23
Dom L			10
Dom R			35

P = painful; NP = nonpainful; F = female; M = male; L = left; R = right.

For the group of participants with painful shoulders, the recruitment criteria were as follows: participants with shoulder pain (antero- and antero-lateral) present for longer than a month and shoulder pain with active flexion and/or abduction; but without any previous shoulder dislocation; and without any previous shoulder or cervical surgery; without shoulder pain elicited with cervical movements and without referred pins and needles down the arm. For the group of participants with non- painful shoulders, the recruitment criteria were as follows: participants without shoulder pain present for longer than three months and without any previous shoulder dislocation and without any previous shoulder or cervical surgery.

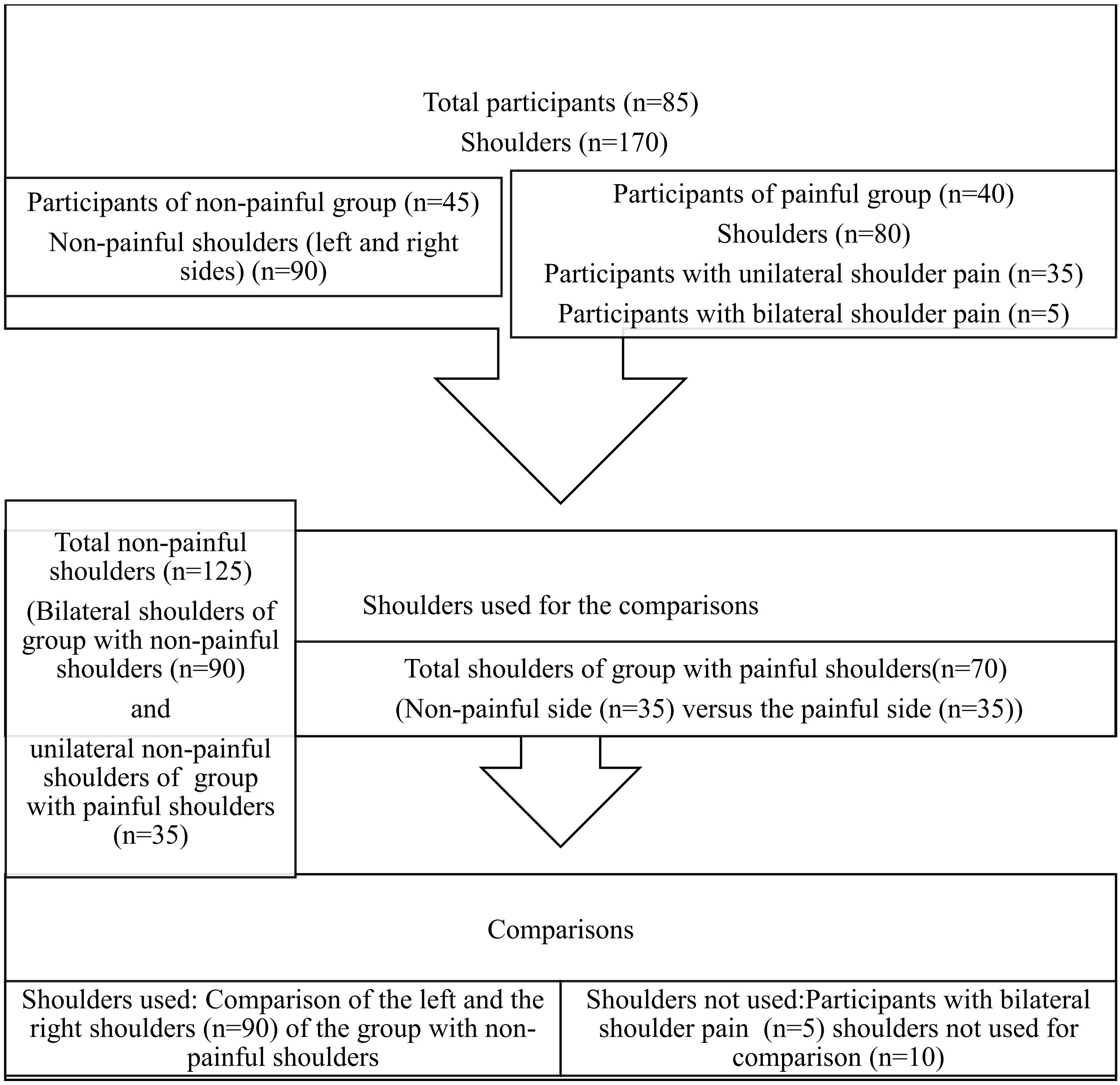

Figure 1 Flow diagram reflecting participants (n = 45) with nonpainful shoulders (n = 90) and participants (n = 40) participants with painful shoulders (n = 35) used for the data analysis.

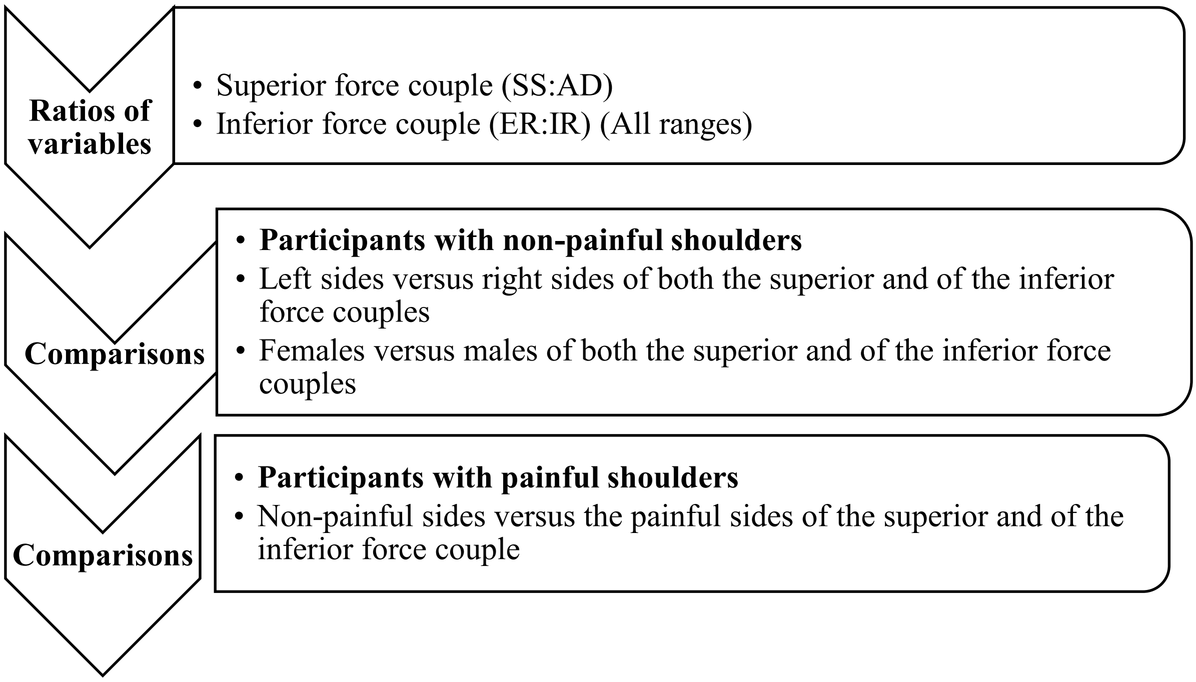

Figure 2 The ratios of the superior focce couple (supraspinatus versus anterior deltoid) and the inferior force couple (external versus internal rotators) were determined.

SS: AD = supraspinatus versus anterior deltoid; ER: IR = external rotator versus internal rotator.

The investigation and determination of both the force values and ratios of the supraspinatus and the anterior deltoid of the superior force pair, the SS versus the AD and the inferior force pair, between the subscapularis and the infraspinatus/teres minor were conducted. To draw clinical conclusions from these results, the force–couple ratios were determined in participants with both nonpainful and painful shoulders. The force couple values in the group of participants with nonpainful shoulders were used for comparisons between females and males to determine side-to-side differences (Fig. 2). The relationship between the force couples on the nonpainful side and painful sides of participants with painful shoulders was explored to help clarify the role that disruption of these force couples may play in the development of pain.

Testing procedure

Instruments and data collection

A handheld dynamometer (HHD Micro-FET3) was used to measure the force of the shoulder muscles (Health Industries Inc., West Jordan, UT, USA). The reliability and validity of HHD have been demonstrated clinically by various researchers [8,24,25,26]. The participants were weighed via a commercially available electronic bath scale (Camry, Loot.co.za) and measured via a statue meter (Hi Care Height Measure/Stature Meter, The Paramedic Shop cc). To collect isometric force measurements from the pain-free shoulders, the “make test” was used. Resistance slowly increased until maximum voluntary effort was achieved and then until the participant matched the force applied by the primary researcher. The force was maintained for five seconds prior to movement occurred [27,28].

Resistance was applied to the painful shoulders just prior to the onset of discomfort. The range of movement was limited to the onset of discomfort experienced in the painful shoulder. To avoid potentially increasing pain, full strength was not applied to the painful shoulders. Bias was limited when self-reported pain was used as the guiding factor. The use of maximal voluntary isometric strength testing, in which the muscle-tendon unit remains at a constant length, is a recognized technique in testing participants with rotator cuff pathology [24,26]. Force is applied at specific joint angles and is better controlled than are isotonic contractions. High reliability has been demonstrated [24,26].

2.3 Data collection procedure

A pilot study comprising eight participants (four participants with pain-free and four with painful shoulders) was conducted. The aim of the pilot study was to estimate the time needed to collect data. The results obtained reflected the first testing procedure to produce the best force value for nonpainful participants. Only one testing procedure could be performed on the participants with painful shoulders, as they became more tender after only one testing procedure. The same procedure described in the main study was followed, and no changes were implemented following the pilot.

The main study procedures were as follows. The participants read the information sheet and completed and signed the consent form to participate in the study. The participants were weighed and measured, and demographic and anthropometric information were collected and recorded by the primary researcher**.** Force measurement data were collected and recorded on the data collection sheets by the primary researcher (Online supplement 1) (Appendix M).

The testing sequence and measurements were explained to the participants before the onset of the actual testing to ensure that they fully understood the testing procedure. A familiarisation process demonstrating the force measurements procedure and explaining the force measurements (positions and way of applying the force), were conducted prior to the testing session. Measurements were performed once on both the painful and nonpainful shoulders. One testing procedure has been established in the literature to be adequate for data collection [28,29].

A brief warm-up session on the shoulder, including free arm movements in the sagittal and frontal planes of movement, was performed before testing. The principal researcher verbally counted “1-2-3-go” before the measurement started and then encouraged the participant verbally with a “push-push-push-keep-pushing and relax” command. This process was repeated for all the tested positions.

For the force production measurements, the participants stood with their legs spread apart, with their arm on the side and the elbow flexed at 90° for internal and external rotation testing [30] (Appendix 3). The HHD was positioned 2 cm proximal to the ulnar styloid process on the dorsal and volar surfaces of the forearm [8,31] (Appendix 3). The elbow was kept straight for SS and AD testing (Appendix 1). A novel test position for the testing of the supraspinatus was used; the arm was 30° of scaption, with external rotation of the arm and the thumb pointing up (Appendix 1). Based on the electromyographic (EMG) study of Kijkunasathian [32], which was conducted at the best position to isolate the SS from the AD, we proposed the position of abduction in 30° scaption with external rotation of the arm to best isolate the SS muscle. The testing position proposed by Daniel and Worthingham was used for AD [33]. The HHD was positioned laterally to the radius of the forearm 2 cm above the wrist line (Appendix 1). The left side was tested first, followed by the right side.

Force measurements were collected from the external rotators (ER) and internal rotators (IR) (neutral rotation, 45° rotation, abduction external rotation (ABDER), and external rotation in the flexion (ERF) positions) (Appendix 3). Force measurements of the SS at 30° of scaption and the AD at 90° of sagittal flexion were collected (Appendix 1). The ratio of external: internal rotators ER:IR and SS:AD forces were calculated.

Active range of motion measurements were taken and recorded via a digital goniometer namely, the EasyAngle® inclinometer (https://meloqdevices.com/pages/easyangle-digital-goniometer). For the range of motion measurements of active sagittal flexion and active frontal abduction, the participants stood with their arms hanging by their sides, and their legs were spread comfortably apart (Appendix 2). The inclinometer was placed along the lateral surface of the humerus for sagittal flexion measurements and along the posterior surface of the humerus for frontal plane measurements (Appendix 2). The range of motion was taken from neutral to the end of range in both sagittal flexion and frontal abduction (Appendix 2). The reliability and validity of digital goniometers have been reported by numerous authors in clinical practice [34-36].

3. Statistical analyses

Statistical analysis was performed via the Statistical Package for the Social Sciences (SPSS Statistics 240 28.01.1.1, (15) IBM Corp., Armonk, NY, USA) package. The normality of the data was tested with the Shapiro–Wilk test ($p< 0.05$). Some data were concluded to be skew distributed, and some data were normally distributed. For descriptive statistics, the means and standard deviations (SDs) for normally distributed data and the medians and interquartile ranges (IQRs) for skew data were calculated and reported for all continuous variables. The confidence interval (CI) was set at 95%, and statistical significance was set at $p < 0.05$. Using Cohen's d effect size where d = 0.2 (small), d = 0.5 (medium), and d ≥ 0.8 (large) effect sizes were calculated. The effect size in clinical terms indicate the strength of the relationship between two variables.

The isometric force measurements were normalized to body weight (force/kg*100) for all force measurements with allometric normalization to account for anthropometric differences between participants [37]. The normalized data can then be used for comparisons among different participants. For paired skew distributed data, the Friedman Two Way Analysis of

Variance (ANOVA) was used. The *t* test was used for normally distributed data for comparisons. For paired non-normal distributed data, the Friedman's two-way analysis of variance by ranks (ANOVA) was used to compare the within groups variables. This was followed by a post hoc test, the Wilcoxon-sign-rank test, to determine which specific pairs of measurements of the variables were different.

Correlation analysis was used to quantify the degree of linear association between the variables, whether positive or negative and then simple linear regression analysis was used to quantify the change brought about in the dependent variable (muscle force) due to the independent variable (age, gender and between the NP and P groups).

For the correlations within participants with nonpainful shoulders and those with painful shoulders, the Spearman correlation test was used for skew distributed data. The Pearson correlation test was used for normally distributed data.

4. Results

4.1 Force measurements

The demographic data of participants with both nonpainful and painful shoulders are presented in Table 2.

Table 2 Demographic data of the participants with nonpainful shoulders (n = 45) and participants with painful shoulders (n = 40).

Painful				**Non-painful**		
	n	Mean	SD	n	Mean	SD
Age (years)	40	51.74	11.9	45	41.17	12.87
Height (cm)		168.81	10.67		168.23	16.93

Mass (kg)	77.72	16.56		78.26	17.20
BMI	22.93	4.88		26.01	32.72

P = painful; NP = nonpainful; SD = standard deviation; BMI = body mass index; L = left; R = right; SD = standard deviation.

Levene's test indicated that the variances between the two groups NP versus P were homogeneous (F 1.1.39, p=.288). Using a simple linear regression model a weak positive linear effect of age on muscle force was determined (Appendix A). The results of the age as a predictor of muscle force revealed to be a weak predictor of muscle force.

The force measures of the left and the right sides of the group with nonpainful shoulders (n=90) are summarized in the Online supplement 1 (Appendix M). Some differences were detected between the left and right sides of participants with bilateral nonpainful shoulders (n= 45) with Related- Sample Friedman Two Way of Analysis of Variance by Ranks (ANOVA). A strong positive correlation was determined between the left and right sides' force values via Spearman's rank correlation coefficient, ranging from r = 0.84-0.93 (p=0001). (Online supplement 3) (Appendix M). Using simple linear regression analyses the results indicated dominance to be a weak predictor of muscle force.

Table 3 Means (SD) CI (95%), standard error of measurement and effect sizes of all variables for nonpainful shoulders (n = 125) participants (n=45).

Ratios	**N**	**Mean**	**SD**	**SE**	**d**	**p**
SS: AD	45	1.20	0.21	0.02	0.21	0.001

ER: IR0	45	1.24	0.47	0.04	0.47	0.001
ER: IR45	45	1.29	0.23	0.02	0.23	0.001
ER: IRABD	45	1.25	0.25	0.02	0.25	0.001
ER: IRF	45	1.17	0.21	0.02	0.21	0.001

SS = supraspinatus; AD = anterior deltoid; ER0 = external rotation in neutral, ER45 = external rotation at 45°; ERABD/ER = external rotation in abduction at external rotation; ERF = external rotation in flexion; IR0 = internal rotation in neutral; IR45 = internal rotation at 45 degrees; IRABD/ER = internal rotation abduction in external rotation; IR F = internal rotation during flexion, SD = standard deviation. SE = standard measurement of error, d = effect size.

Statistically significant differences (p=0.001) between the muscle force values of all the muscle force variables of the females and males were determined via Friedman Two-Way-Analysis by Ranks (ANOVA) (Online supplement 3) (Appendix M). Force measures were trending stronger for male participants compared to female participants in the nonpainful group (Online supplement 1) (Appendix M).

Using Spearman correlation analysis to determine the correlation direction, weak negative (r = -0.03) to weak positive correlations (r = 0.07) were detected between females and males for the muscle force variables (Online supplement 3) (Appendix M). Using a simple linear regression model to determine the effect of gender on muscle force, a moderate positive linear association of all the force variables of gender on muscle force were determined. Cohen's d calculation between the female and male groups revealed a small effect size of d = 0.27 for the SS:AD ratio and a large effect size of d = 0.67 for the ER:IR ratio (neutral).

Table 4 Means (SD) CI (95%), correlation, and effect sizes of the ratios between the nonpainful sides (n = 35) and painful sides (n = 35) of participants with painful shoulders (n = 70).

Ratios	N	Mean	SD	r	Significance: p	d
NP SS/AD	35	1.26	0.20	-0.14	0.45	0.31
P SS/AD	35	1.20	0.25			
NP ER/IR0	35	1.23	0.21	0.04	0.83	0.29
P ER/IR0	35	1.15	0.21			
NP ER/IR45	35	1.32	0.21	0.22	0.25	0.78
P ER/IR45	35	1.05	0.24			
NP ERABD/IR	35	1.21	0.21	0.08	0.67	1.70
P ERABD/IR	35	0.99	0.27			
NP ERF/IRF	35	1.18	0.21	0.01	0.94	0.31
P ERF/IRF	35	0.99	0.22			

SS = supraspinatus; AD = anterior deltoid; NP = nonpainful; P = painful; ER0 = external rotation in neutral, ER45 = external rotation at 45°; ERABD/IR = external rotation in abduction versus internal rotation; ERF = external rotation in flexion; IR0 = internal rotation in neutral; IR45 = internal rotation at 45 degrees; IRF = internal rotation in flexion, SD = standard deviation, d = effect size, r = correlation.

Pairwise comparisons of the muscle force values between the nonpainful sides (n=35) and painful sides (n=35) of the participants (n=70) with shoulder pain were conducted via related-samples Friedman-Two-Way Analysis of Variance by ranks (ANOVA). There was a statistically significant difference (p=0.001) between the nonpainful sides and the painful sides of the participants with painful shoulders for the variables SS, AD, and ER, but not for the IR force measurements (Online supplement 1) (Appendix M). Weak negative (r= -0.14) to weak positive (r= 0.22) correlations between the nonpainful and painful sides' ratios of the participants with painful shoulders were determined via Pearson's correlation coefficient. A small correlation (r=0.22) with a large effect size (d=0.78) was observed for the ER:IR (45-degree position) between participants with nonpainful and painful shoulders.

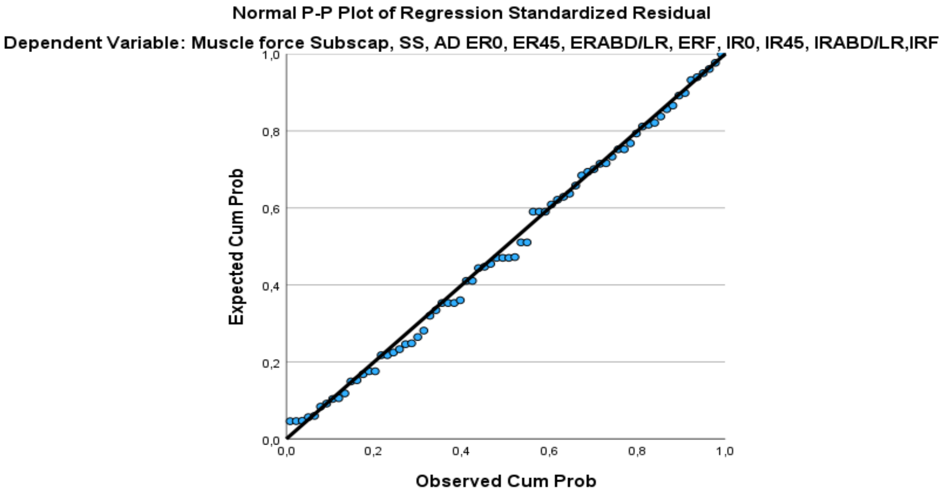

Figure 3 Regression analysis between the dependent variable (muscle force on the y-axis) and the independent variable (pain on the x-axis).

A simple linear regression analyses was conducted to determine the effect of pain on muscle force. A strong positive linear was determined with a significant statistical (p<0.001) for all the variables of Subscap, SS, AD, ER0, ER45, ERABD/LR, IR0, IR45, IRABD, IRABD/LR. Pain was determined to be a strong predictor of decreased muscle force (Appendix A).

The results of age as a predictor of muscle force revealed to be a weak positive predictor of muscle force. No significant effect of age on muscle force was detected when the force measurements were normalized to the body weight.

Table 5 Median (IQR) range of motion (in degrees) of both painful shoulders (n = 45) (unilateral pain = 35, bilateral pain n = 10 and nonpainful shoulders (n = 125) (unilateral pain n = 35, bilateral no pain n = 90). Total number of shoulders (n = 170).

ARoM degrees		**SFNP**	**FABDNP**	**SFP**	**FABDP**
N		45	45	40	40
Percentiles	25	160	163	119	85
	50	168	170	152	156
	75	173	176	164	170

ARoM = active range of motion; SFNP = sagittal plane flexion; NP = not painful; FABD = frontal plane abduction; P = painful.

A decreased range of motion was present in both the sagittal plane of flexion and the frontal plane of abduction in the painful shoulders, but the decreased range of motion was greater in the frontal plane of abduction in the painful shoulders. This finding was most noticeable in the first 25% of the IQRs, where decreased sagittal plane flexion of 119° in the painful shoulders compared with 160° in the nonpainful shoulders was present. A decrease in frontal plane abduction of 85° was observed in painful shoulders, compared to 163° observed in nonpainful shoulders.

5. Discussion

A fine balance between shoulder musculature mobility and stability must coexist to provide stable shoulder function [2]. Monitoring of all the muscle forces and force couple ratios as investigated in our study may prove meaningful in the evaluation process. The new evidence added to literature on the force couple ratio between the SS and the AD fills a research gap and may provide a more complete picture of the rotator cuff functioning. Monitoring all the ranges, as in our study, of the external rotation in neutral, 45-degrees, 90-degrees ABD/ER and SFER, incorporated the transverse and the oblique fibers of the infraspinatus. By means of internal rotation in neutral, 45-degrees, 90-degrees ABD/IR SFIR, both the upper and lower fibers of subscapularis were monitored. A more complete picture of the inferior rotator cuff is hence provided. Monitoring the rotator cuff via isometric force measurements has proven useful in the clinical setting, as supported by published clinical guidelines [38,39].

Age and gender

The results of the age as a predictor of muscle force revealed to be a slight positive predictor. This may be reflected in our study as older patients presented with nonpainful shoulders (Table 1). A key to lack of pain in older patients with nonpainful shoulders may, therefore, be preserved force couple ratios, rather than increased age.

Research on HHD in overhead athletes has revealed that sex differences are absent once force measurements are normalized to body weight [8]. In contrast, our study still revealed differences between genders with a normalized weight of males versus females (Online supplement 1) (Appendix M). A simple linear regression analysis yielded gender to be a moderate positive predictor of muscle force. Males presented with higher muscle force compared to females (Online supplement 2) (Appendix M). This finding of higher muscle force values has also been reiterated by other authors [40,41]. Possible explanations have been linked to the presence of different muscle morphologies and lean body masses, which are more pronounced in the upper body of males than in females [40,41].

SS: AD force couple ratio

Historically, Inman [13] proposed a force couple between the SS and AD. Our study was the first, to the authors' knowledge, to explore the force measures of the SS and AD via isometric dynamometry.

The specific force couple ratios were determined for both participants with nonpainful shoulders (SS:AD 1.25, ±0.20) and participants with painful shoulders (SS:AD 1.20, ±0.23), with a weak negative correlation (r = - 0.142) between the SS and AD values (Tables 3,4). The results indicate that the SS force significantly decreased when correlated with the AD force. In essence, this could translate into a decreased compressive force provided by the SS and a potentially increased superior anterior translation force provided by the AD.

Increased deltoid activation has been demonstrated in shoulders with compromised supraspinatus and infraspinatus muscle forces [42,43,44]. This in turn led to increased cranial migration of the humeral head and painful subacromial impingement [42,43,44]. Furthermore, the unopposed action of the deltoid caused cranial migration to occur [45,46]. Proximal migration of the humerus has been confirmed previously by radiology, and increased loading of the arm has been shown to increase this migration [45,46]. This phenomenon is not age-related and occurs in all age groups [43].

It can therefore be surmised that combined with the observed decreased strength of the external rotators versus the internal rotators in the group with pain, as reflected in our study, the action of the deltoid may be amplified, and increased cranial migration of the humeral head may result in subacromial impingement. The known values of all the variables can be used to tailor rehabilitation protocols to correct the affected variables.

External rotators

Our study revealed that the ER of participants with painful shoulders was weaker than that of participants with nonpainful shoulders, with a statistically significant difference (p = 0.001)

(Online supplement 3). The results of Lang [47] emphasized the importance of the known values of the ER, not only in neutral ranges but also in higher ranges. The authors concluded that increased external rotator activity with increased degrees of elevation was present but not increased internal rotator activity [47]. The finding of decreased external but not internal rotator cuff strength in painful shoulders in our study might therefore confirm their findings [47]. The results obtained for the weaker ER rotators but not for the IR rotators may accelerate the decentering of the humeral head and lead to pain or secondary pathology.

Weaker ER strength was detected in participants with painful shoulders compared to those with nonpainful shoulders (Online supplement 3). They also presented with a lower ER:IR strength ratio (Table 4). These findings are in agreement with the results of Maestroni's study [31]. Their study was also conducted on a nonathlete population, with strength normalized to body weight. However, the test was conducted in the prone position, potentially limiting gravitational scapular control. In our study, the participants stood in a more functional position that required more scapular control. In Maestroni's [31] study, testing was conducted in the 90°-abducted shoulder position, and in our study, different angles were incorporated into the measurement (neutral, 45°, ABD/ER, ER/F).

Decreased external rotation strength is linked to shoulder pathology in both athletic and nonathletic populations [7,48,49]. Furthermore, previous studies have shown that stronger external rotators can enhance shoulder stability [7,48,49]. It is believed that stronger external rotators and a higher ER:IR ratio can decrease the development of shoulder dysfunction.

ER:IR force couple ratios

Lower ER:IR ratios were detected in participants with painful shoulders (Table 4). This finding indicates that the balance between the external rotator muscle strength and the internal rotator muscle strength was compromised. This result agrees with other authors' findings of decreased strength ratios of the ER:IR forces [12,31,48]. Studies conducted on the asymptomatic shoulders of both athletes and nonathletes have not revealed any real differences in strength between the sides [8,9,24,50]. Similar results were expressed in our study, with no statistically significant difference between sides in the nonpainful group regardless of arm dominance (Online supplement 1). Given the previously mentioned results of lower ER force values and lower ER:IR strength ratios in painful shoulders, we postulate that the presence of these altered variables may predispose shoulders to dysfunction. Therefore, theoretically, correction of these altered variables, decreased external rotation strength, and decreased ER:IR strength ratios should lead to less shoulder dysfunction.

The same trend of decreased ER force compared with that of the IR force was observed in neutral and higher ranges of movement (Online supplement 1,3). A decrease in the strength ratio was also observed for the ER:IR force couple ratio, which was not just in neutral (Table 4). Therefore, disruption of the subscapularis/infraspinatus and teres minor force couple may produce an anterior or posterior shearing force that destabilizes humeral head articulation on the glenoid fossa and perhaps contributes to shoulder dysfunction.

Internal rotators

Another interesting finding was that the IR force values (Online supplement 1,3) did not significantly decrease in the painful shoulders. This finding is reiterated by several authors [12,31,48]. The practical application of the proposed method can therefore be that strengthening should focus more on the weakened ERs and not be applied with equal importance to both the strength components of the ER and the IR, until the balance is restored.

With the presence of decreased ER strength, unchanged IR strength, and a decreased ER:IR ratio, disruption of the inferior anterior–posterior force couple can be anticipated. Theoretically, this imbalance can lead to destabilization of the humeral head on the glenoid surface due to increased translatory shear forces across the glenoid. This finding perhaps echoes the viewpoint of Ellenbecker and Rotert [51] that the strength of individual muscles in the rotator cuff is important, but more so the external versus the internal rotator strength ratio for balanced joint motion.

Comparison between left and right sides of participants with nonpainful shoulders

In the nonpainful group, no statistically significant difference was observed between the left and right sides of the participants without shoulder pain (Online supplement 3). This was confirmed with a positive correlation analyses determined between the left and right sides of participants without shoulder pain and results yielding a weak positive linear association (Online supplement 1) (Appendix M). Arm dominance is, therefore, not a strong predictor of muscle force. Hence, in practice, comparisons may be made of the same individual's left and right sides for assessment and rehabilitation purposes. This finding was also reflected in other studies among asymptomatic participants in both athletic and nonathletic populations [7-9, 24, 50].

Strength differences

Differences in the observed strength of participants with painful shoulders (Online supplement.1) (Appendix M) cannot be attributed solely to pain inhibition [52]. Ellenbecker [52] visually observed infraspinatus atrophy in the dominant arm of male tennis players. The presence of infraspinatus atrophy is correlated with ER weakness [52]. Manske [53] used musculoskeletal ultrasound (MSK-US) to visually confirm that atrophy was linked to decreased cross-sectional muscle volume of the infraspinatus. Lajtai [54] also reported atrophy in the painful shoulders of beach volleyball players, and Benitez-Martinez [55] reported a decrease in the cross-sectional area of the supraspinatus in the presence of painful shoulders in their respective studies. The conclusion drawn from these observations therefore casts doubt on the decreased muscle force resulting from only pain inhibition. Decreased cross-sectional volume of the infraspinatus and the supraspinatus may result in the presence of decreased muscle force and therefore a weaker muscle.

Furthermore, disruption of both the anterior–posterior (ER:IR) and superior (SS:AD) force couples can potentially predispose the shoulder to dysfunction. In lieu of the findings of Werner [56], who reported that isolated induced palsy of the SS muscle does not lead to superior migration of the humeral head, all muscles and force couples of the rotator cuff should be considered, not just the supraspinatus muscle in isolation. It is known in the current literature that the whole cuff contributes to elevation; therefore, the description of the role of all force couples can lead to better informed diagnosis and treatment strategies for the shoulder [23,56-58].

Evidence-based Practice (EBP)

EBPs are becoming increasingly important in all spheres of medical practice. The use of isometric evaluation for strength testing and rehabilitation program progression is recommended for practice [38, 39]. Approaching shoulder evaluation and treatment with an objective evaluation measurement is meaningful for both patients and clinicians. To echo the viewpoint of Ellenbecker and Roetert [51], the strength of the individual muscles of the rotator cuff is important, but more so, for balanced joint motion, the external versus internal rotator cuff strength ratio is important. Adding information on all the concluded force couples provides a more comprehensive overview of the biomechanics and kinematics of the glenohumeral joint.

6. Implications, Limitations and recommendations

Our study was an observational cross-sectional study, and the cause of pain was not determined. Only the muscle force and force couple ratios of the SS and AD were determined. However, investigating the force–couple ratios between the supraspinatus and middle deltoid and between the supraspinatus and posterior deltoid is recommended in all population groups. An investigation of the abovementioned factors, with observational, cross-sectional, and longitudinal cohort study designs, should therefore be further researched. In addition, the development of pathology in the presence of altered force–couple ratios should be explored in larger randomized control trials and larger longitudinal cohort studies. The principal researcher was not blinded to the strength testing, to avoid increasing muscle pain in participants with shoulder pain. This might have introduced bias. Muscle force was conducted to point of discomfort in the participants with painful shoulders, therefore sub-maximal strength, and not full strength as in the participants without shoulder pain, was measured.

Clinically, rotator cuff strength should not be considered in isolation; the range of motion and flexibility of the periscapular musculature should also be considered and integrated into interpretation of findings.

7. Data availability statement

The authors Sonia Briel and Corlia Brandt declare that the data supporting the findings of this study are available within the paper and in the supplementary online information files.

8. Funding

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9. Disclosure of interest

All authors as above-mentioned declare that they have no affiliations with or involvement in any organization or entity with any financial interest or nonfinancial interest in the subject matter or materials discussed in this manuscript.

10. Ethics declaration

Ethical approval was obtained from the Approval Committee of Medical Internal Review Board: Human Research Ethics Committee (Medical) number M190984.

11. Acknowledgements

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Consent to participate

Voluntary signed consent was obtained from all participants prior to the testing session.

Consent to publish

Written informed consent for publication was obtained from the participants used for the use of the images that will be freely available on the internet and may be seen by the public.

Online supplements

Available on pages 383-388.

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Appendix A

Table: Regression analyses (CI 95%) of the non-painful and painful sides of participants with shoulder pain (n=35).

Variables	n	R Square	F	Sig p	Coefficients Standardized Beta	df
Subscap	35	0,00	1.035	<,001	-1,21	1
SS	35	-0,01	0,00	<00,1	0,00	1
AD	35	-0,01	0,19	<,001	0,05	1
ER0	35	-0,01	0,48	<,001	0,83	1
ER45	35	0,00	0,68	<,001	0,10	1
ERABD/LR	35	-0,01	0,47	<,001	0,08	1
ERF	35	0,01	1.50	<,001	0,14	1
IR0	35	0,03	2.87	<,001	0,20	1
IR45	35	0,12	10.92	<,001	0,36	1
IRABD/LR	35	0,06	5.23	<,001	0,26	1
IRF	35	0,06	5.61	<,001	0,27	1

Chapter 6 Shoulder Soft tissue Flexibility in an Adult Population: Differences within Participants with Non-painful and Painful shoulders.

The aims and objectives of this chapter is available in Chapter one, page 21.

This study is under peer review at the Physical Therapy Reviews Journal.

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Abstract

Background

Limited information on the correlation of the flexibility of the modifiable musculoskeletal factors, such as the latissimus dorsi (LD), the subscapularis, the short head of biceps (SHB), the pectoralis minor (PMm) muscles and the posterior capsule (PC), in terms of range of motion (ROM), in the presence of pain in shoulders are available in a non-athletic population group.

Objective

To investigate the flexibility alterations in the LD, the subscapularis, the SHB, the PMm and the PC in a non-athletic population, at one point in time, in terms of ROM within both non-painful and painful shoulders.

Methods

This observational cross-sectional study assessed eighty-five participants, forty with painful and forty-five with non-painful shoulders in an adult female and male population aged between 18 and 75 years. External rotation (ER) of ROM, internal rotation (IR) ROM, flexibility of the LD, the subscapularis, the SHB, the PMm length and the PC were assessed. Descriptive and inferential statistical analyses were conducted.

Results

Statistically significant correlation coefficients were concluded between loss of ROM and painful shoulders of; LD ($r = 0.94$) ($p = 0.01$) with a large effect size of 0.95, of ER0 ($r = 0.98$) ($p = 0.003$) with a large effect size of 1.41.

Conclusions

This study emphasised that the loss of ER ROM (0°and 90°) and LD ROM are correlated with the presence of painful shoulders in a non-athletic population group.

Clinical implication

All identified modifiable musculoskeletal factors should simultaneously be evaluated in shoulder dysfunction.

Keywords: Flexibility, subscapularis, latissimus dorsi, posterior capsule

1 Introduction

Shoulder stability depends on an ideal compromise between periscapular musculature flexibility, rotator cuff force and force couple ratio (Borstad & Ludewig 2005; Briel et al. 2024; Sebastiaan, Chovvath & Malladi, 2017). The flexibility of the PMm and of the PC have been thoroughly investigated in the athletic community, mainly in overhead athletes (Burkhart, Morgan & Kibler, 2003; Finley & Ebaugh, 2017; Olivier, Lala & Gillion, 2020; Young, Briner & Dines, 2023). Limited information on the concurrent presence of PMm and the PC in a non-athletic population is available (Rosa et al. 2019). An anterior tilted, protracted and internally rotated scapula can be the result of a shortened PMm (Kinsella et al. 2014; Morais & Cruz, 2016; Thomas et al. 2011; Sebastiaan et al. 2017). Reciprocal inhibition of the muscles of the scapular stabilizers, in particular the serratus anterior lower fibers and the lower trapezius, due to a shortened PMm will cause decreased posterior tilt of the scapula (Sebastiaan et al. 2017; Yeşilyaprak Yüksel & Kalkan, 2014).

It is, therefore, well known in the literature that shortening of the PMm can contribute to scapular dyskinesis (Dutton, et al. 2019; Finley & Ebaugh, 2017; Olivier et al. 2020; Reeser et al. 2010; Sebastiaan et al. 2017).

Decreased IR ROM in pain full shoulders has been well established in overhead sport; cricket, tennis, handball, swimming and underhand sport; as well as rugby (Lala, 2017; Lubiatowski et al. 2018; Moreno-Pérez et al. 2015; Peckitt & McCaig, 2019). The occurrence of decreased IR ROM and glenohumeral internal rotation deficit (GIRD) are seen in numerous overhead sporting population groups, such as baseball, tennis, handball and cricket populations and have been linked to the development of shoulder pain (Cools et al. 2016; Lubiatowski et al. 2018; Olivier et al. 2020; Park et al. 2021; Turgut & Baltaci, 2018; Young, Briner & Dines, 2023). In addition, shortening of the posterior capsule and of the posterior inferior musculature can cause decreased IR ROM (Burkhart et al. 2003; Evans and Guyver, 2015; Manske et al.2013). The development of internal impingement may be the result of shortening of the postero-inferior structures (posterior capsule and posterior inferior rotator cuff), causing a posterosuperior shift of the humeral head (Burkhart et al. 2003; Glousman, 1993). Predisposition to development of superior labrum anteroposterior (SLAP) lesions can occur due to traction created on the long head of the biceps (Burkhart et al. 2003; Saccol, Almeida & de Souza, 2016). This phenomenon occurs because of the posterosuperior shift of the head of the humerus (Burkhart et al. 2003; Saccol et al. 2016).

Little is known about the role of the short head of the biceps in shoulder pain. Theoretically, the attachment to the anterior tip of the coracoid process can cause anterior tilt of the scapula and, therefore, contribute to dyskinesis of the scapula (eds Travell & Simons, 1992). The influence of LD has been minimally investigated and mainly in the swimming community (Feijen et al. 2020; Herrington & Horsley, 2014). Individuals with a shortened LD may have decreased shoulder flexion, with the arm in external rotation, leading to the development of shoulder dysfunction (Herington & Horsey, 2014). A correlation between the influence of a shortened LD and shoulder pain has been established in the swimming population (Feijen et al. 2020; Herrington & Horsley, 2014).

Limited studies have been conducted on the role of the subscapularis muscle in all population groups (Rosa et al. 2019). The subscapularis muscle is believed to shorten during active glenohumeral internal rotation and to lengthen during active external rotation (Inman & Abbott, 1996; Kuechle, 2000). Hypertrophy of the subscapularis muscle with resultant shortening has been implicated in coracoid impingement syndrome (Schöffl, Schneider & Küpper, 2011). Shortening of both the muscle belly and the tendon of the subscapularis muscles following repeated microtrauma may limit external rotation in patients (Kelly et al. 2013; Morag et al. 2011; Turkel, et al. 1981). Tears of the subscapularis muscle are often a part of the anterior-superior cuff disruption and rarely occur on its own (Gerber & Krushell, 1991).

Pain free shoulder function is essential not just in an athletic population, but the ability to work, to perform activities of daily living, recreational hobbies and enjoy a pain free lifestyle are dependent on pain free shoulders (MacDermid, Solomon & Prkachin, 2006). Shortened muscles present with a loss of sarcomeres in series and a greater amount of connective tissue (Goldspink et al. 1974; Weppler & Magnusson, 2010). The presence of increased connective tissue in shortened muscles, has been proposed as a cause of perceived pain in musculoskeletal disorders (Alter, 2004; Rassier, MacIntosh & Herzog, 1999). Taking the biopsychological model into consideration, central sensitization may also play a role in participants presenting with painful shoulders. However, our study only investigated the passive ROM of the musculoskeletal factors (the LD, the subscapularis, the SHB, the PMm and the PC) and the resultant altered musculoskeletal factors potentially due to nociceptive soft tissue input.

Very few studies on the concurrent presence and the influence of modifiable musculoskeletal factors, in terms of ROM, such as the LD, the subscapularis, the SHB, the PMm and the PC have been conducted in non-athletic populations. Rosa et al. (2019) investigated only the variables of external rotation of the glenohumeral joint and the PMm flexibility in a study of non-athletic participants. Soft tissue flexibility alterations observed in athletes, such as PMm and PC changes, are known in the literature. The observed changes of these deficits are mostly associated with painful shoulders in athletes. Therefore, to clarify the concurrent presence of altered musculoskeletal factors in shoulders, such as the flexibility (ROM) in the LD, the subscapularis, the SHB, the PMm and the PC, our study investigated these musculoskeletal factors at one point in time in a non-athletic population. The correlation of altered modifiable musculoskeletal factors and painful shoulders will be closely investigated in terms of ROM measurements.

2 Methods and Materials

2.1 Study design and setting

This was an analytical cross-sectional study, and data were collected in South and North of Johannesburg. Ethical approval was obtained from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand. Modifiable musculoskeletal factors (LD, subscapularis, SHB, PMm and the PC) were explored within participants presenting with painful shoulders and within participants presenting without shoulder pain.

The correlation between flexibility alternations in terms of ROM and pain were sought. The collective term modifiable musculoskeletal factors were used because only soft tissue and not bony factors were investigated. Correlation analysis was conducted between the same sides of participants, between the non-painful and the painful sides of participants with painful shoulders and between the left and right sides of participants without shoulder pain. This decision was reached because unlike in strength measurements where values can be normalised to compare results between participants, due to different body morphology, flexibility measurements cannot be normalised to compare differences between participants to gain meaningful results.

2.2 Participants

2.2.1 Inclusion and exclusion criteria

Participants were invited from the South and North of Johannesburg. A sample of convenience from the public was used. A sample of 85 participants were recruited and tested. Participants, both females and males (n=85) aged between 18 and 75 years of age, were included. For the group with non-painful shoulders, females (n = 22), males (n = 23) and both left- and right-hand dominant (L = 10, R = 35) were included. For the group with painful shoulders, females (n = 17, males (n = 23), left- and right-hand dominant (L = 2, R = 38) were included. Participants were included in the pain-free group if they met the following criteria: no previous shoulder or cervical surgery, no previous dislocation of the shoulder, had not experienced shoulder pain for a three-month period prior to testing and absence of cervical pathology or symptoms (numbness or pins and needles down the arm). Participants were included in the painful group if the following criteria were met, shoulder pain (anteriorly or anterolateral) (Alburquerque-Sendín, et al. 2013; Ludewig & Borstad, 2003; Michener & Kardun, 2006) and/or pain with active elevation of the arm (Hung et al. 2010). and pain not elicited with neck movements. Pain present for longer than a month, no previous dislocation, or shoulder surgery received. No labelling of pain was done. Many diagnostic labels are given to shoulder pain, quite often misleading. Diagnostic validity of many standardized orthopaedic shoulder tests is questioned in current literature (Hughes, Taylor & Green, 2008; Lasbleiz et al. 2014)

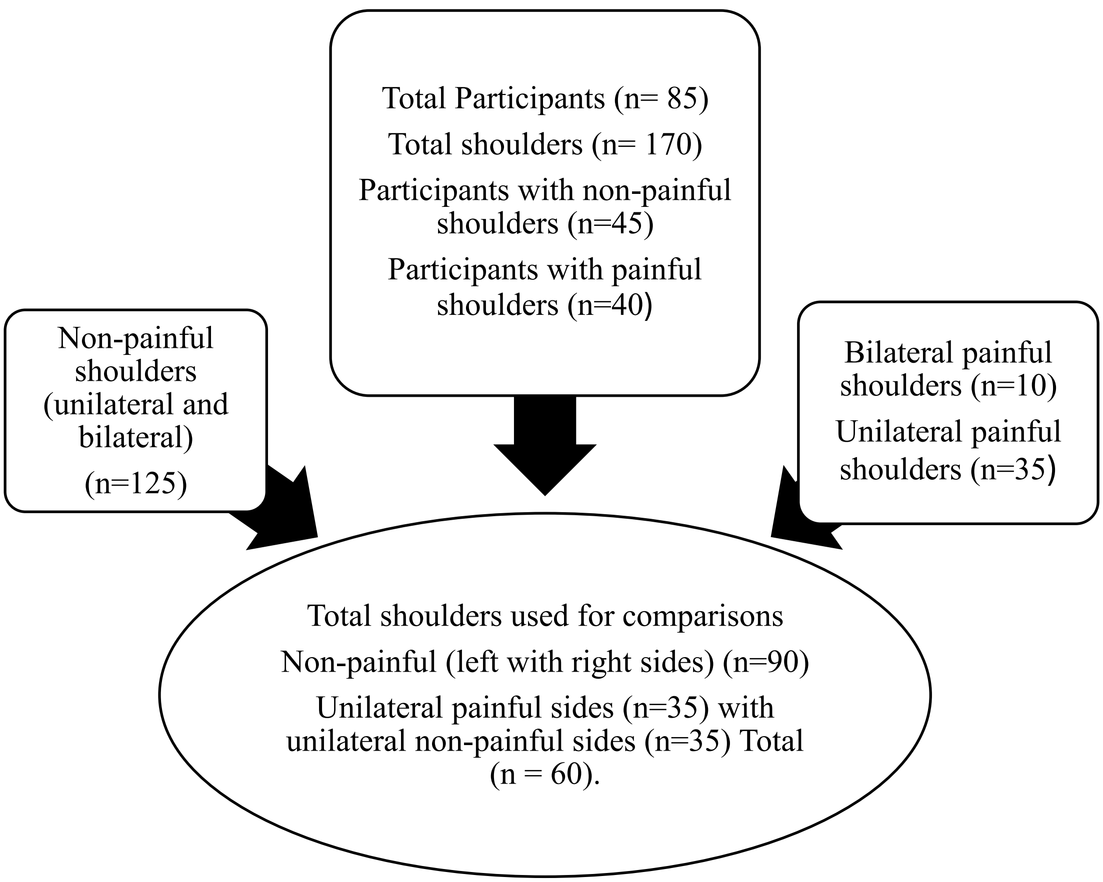


Figure 1 A flow diagram of participants tested, including participants with non-painful and painful shoulders.

Comparisons were made within the non-painful and the painful side of participants with painful shoulders (n = 35 + 35 = 60) and within the left and right sides of participants without shoulder pain (n = 45+45 = 90).

2.2.2 Testing procedure

Instruments and data collection

Passive range-of-motion measurements were taken and recorded with a digital goniometer, the EasyAngle® inclinometer (https://meloqdevices.com/pages/easyangle-digital-goniometer). Reliability and validity have been confirmed by numerous authors in clinical practice namely, intrarater reliability Intraclass Correlation Coefficient (ICC (3.1) = 0.89 – 0.96] and interrater reliability (ICC (3.1) = 0.91] (Silverson et al., 2021, Duffy, 2024).

Data collection procedure

A pilot study was conducted to determine the time needed for the data collection. Eight participants (four with non-painful shoulders and four with painful shoulders) were tested (Figure 1). No changes were made to the protocol following the pilot study and the data was included for final analysis. The steps followed during the pilot study were the same as those described in the main study.

The procedure for the main study was as follows: upon reading the information sheet, the consent form was completed and signed. The participants were then weighed, measured& anthropometric information was collected and recorded by the principal investigator (Table 3).

For the passive range of ER and IR ROM of participants without shoulder pain, passive range of movement was conducted to end of the range of movement (Table1, 2). For the measurements of E (0 and 90) the participants were in supine (lying on their backs) the scapula was hence stabilised by their body weight. For the measurements of PCSL (IR) the participants were in side-lying therefore, the weight of the body stabilised the scapula. For participants with painful shoulders, who had a limitation of either or both the ER and IR ROM and F, movement was conducted to the onset of discomfort (p = 2) experienced in the painful shoulder. To protect participants from flare-up of pain, during the testing session, the primary researcher was aware of which participants had painful shoulders before testing.

ROM measurements were performed once only on the periscapular musculature (SHB, PM, LD, ER0°, ER90°, PCSL) for both the non-painful and painful shoulders (Table 1, 2). The participants were verbally asked if they had a painful or non-painful shoulder before onset of testing. The numerical rating pain scale was used (Wilkie et al. 1990). Pain scale was from 0-10, where 0 was no pain and 10 was severe pain. One testing procedure has been established in the literature to be adequate for data collection (Turner et al. 2009; Bohannon & Saunders, 1990).

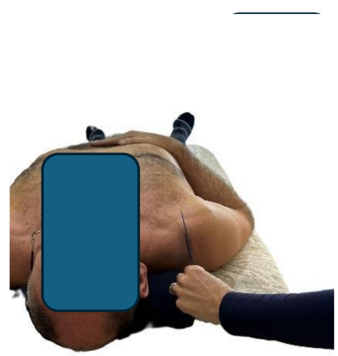
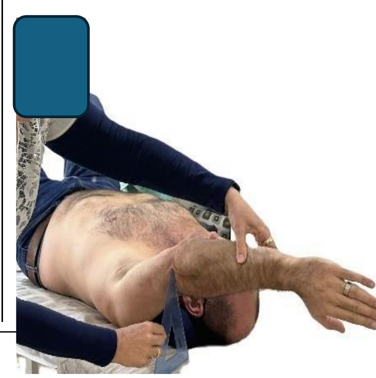
The measurement positions for the subscapularis, PMm, LD and PC positions were based on existing literature: Subscapularis flexibility was measured in the 0° position for the upper fibres (Donatelli et al. 2012; Ekstrom & Osborn, 2011; Muraki et al. 2007) and in the 90° position for the middle and lower fibres (Muraki et al. 2007; Evjenth & Hamberg 1984) (Table 1) (Appendix B).

The PMm was measured in the 90° ABD/ER position (Borstad & Ludewig, 2006; Umehara et al. 2017) (Table 1). LD was measured with the LDF Kendall's position (Conroy et al. 2022; Herington & Horsley, 2012) (Table 1) (Appendix B). PC was measured using the PCSL position (Cieminski et al. 2015; Lunden, 2010) (Table 1) (Appendix B).

The intra-rater ICC values for rater 1 for the flexibility measures, ranged from slight to almost perfect (0.04-0.83) (Appendix A). The ICC for rater 2, for the flexibility measurements, ranged from slight to almost perfect (0.00-0.93) (Appendix B).

A pilot reliability study was conducted of all the flexibility measurements used (Appendix A).

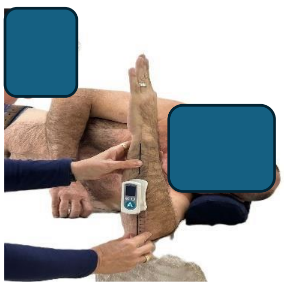
Table 1 Testing positions for LD, SHB and PMm.

Position and test	Test description	Visual depiction
Supine	SHB: Supine and arm straight beside you Measurement from the posterior aspect of the acromion process to the bed Measurements taken with a square ruler	
Supine Kendall McCreary & Provance, (1993);mLewis & Valentine (2007)	PM: Supine and elbow bent and relaxed on the stomach. Measurement from the posterior aspect of the acromion process to the bed Measurements taken with a square ruler	
Supine LDF Kendal, McCreary& Provance (1993), Herington and Horsley (2012)	LD: Supine and the knees bent up and the arm straight with the thumb pointing down Measurement from the lateral epicondyle to the bed Measurements taken with a square ruler	

SHB= short head of biceps, PM= pectoralis minor, LD= latissimus dorsi.

Table 2 Testing positions for ROM of ER and IR.

Starting position	End position	Position and test
		Supine
ER is neutral. Elbow bent to 90 degrees. Inclinometer placed in line with the forearm	ER is neutral. Elbow bent to 90 degrees and rotated to the end of range. Inclinometer placed in line with forearm	Supine
		Supine
ER at 90: 90 degrees of shoulder abduction and	ER at 90: 90 degrees of shoulder abduction and	Supine

elbow flexed at 90 degrees. Inclinometer placed in line with the forearm	elbow flexed at 90 degrees and arm rotated to the end of range. Inclinometer placed in line with the forearm	
		Side lying Lunden (2010), Cieminski et al. (2015)
PCSL: Side lying elbow bent at 90 degrees. Inclinometer placed in line with the forearm	PCSL: Arm rotated to end of the range. Inclinometer placed in line with the forearm	Side lying

ER= external rotation, PCSL= posterior capsule side lying.

3 Statistical analyses

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS Statistics 240 28.01.1.1, (15) IBM Corp, Armonk, NY, USA). Normality of data was tested with the Shapiro- Wilk test (p< 0.05). Data had a non-normal distribution, and nonparametric tests were used to calculate the median and the inter-quartile range (IQR) for all continuous variables. The confidence level (Cl) was set at 95% and statistical significance at ($p<0.05$). For paired non-normal distributed data, the Friedman's two-way analysis of variance by ranks (ANOVA) was used to compare the within groups variables.

This was followed by a post hoc test, the Wilcoxon-signed-rank test, to determine which specific pairs of measurements of the variables were different. Correlation analysis was used to quantify the degree of linear association between the variables, whether positive or negative.

For the correlation within non-painful and painful participants of participants with painful shoulders, the Spearman correlation test was employed for non-normally distributed data. Correlations were ranked as minimal or no relationship ($0.00 < r < 0.25$), fair ($0.25 < r < 0.50$), moderate ($0.50 < r <0.75$) and excellent ($r > 0.75$) ($p<0.050$ (Portney & Watkins 2009). To quantify measurement error, the standard error of measurement (SEM) was calculated (SD X 2√n). The minimal detectable change (MDC) was calculated as the (SEM x 1.96) to define the minimal difference that must occur within the participants with painful shoulders non-painful shoulders, for the results to be 95% confident of true difference (Table 6). The Wilcoxon Signed Rank Test was used to compare variables within participants with and without painful shoulders (Table 5). The z-score in Eq. (1) was used to calculate the effect size (r=z/ 2√n) (Pautz, Olivier & Steyn, 2018). A pilot intra-rater (2 raters) reliability study was conducted of all the flexibility measures (Appendix A). The intra-rater ICC values for rater 1 for the flexibility measures, ranged from slight to almost perfect (0.03-0.83) (Table 2) (Appendix A). The ICC for rater 2, for the flexibility measurements, ranged from slight to almost perfect (0.00-0.93) (Table 3) (Appendix A).

4 Results

The demographics of the participant will be presented next (Table 3). Correlations coefficient results of the left and right sides within the non-painful shoulders and within the painful and non-painful sides of participants presenting with shoulder pain are presented in Table 5. The correlation coefficients between the presence of pain and the decreased flexibility (ROM) of the modifiable musculoskeletal factors are presented in Table 5. The standard error of measurement (SEM) and minimal detectable change (MDC_{95}) of ROM within participants with painful shoulders of the non-painful side (n=35) and the painful side (n=35) are presented in Table 6.

Table 3 Demographics of both the participants without (n=45) and with (n=40) painful shoulders.

	n	Mean	SD		n	Mean	SD
Age P Years	40	51.74	11.95	**Age NP Years**	45	41.17	12.87
Height (cm)		168.81	10.67	**Height (cm)**		168.23	16.93
Weight (kg)		77.72	16.56	**Weight (kg)**		78.26	17.2
BMI		22.93	4.88	**BMI**		26.01	3.72

P = painful, NP = non-painful, SD = standard deviation, BMI = body mass index.

Levene's test shows that the variances are homogeneous (F 1.1.39, p=.288).

Table 4 Median, correlations and effect size of ROM between the left sides and right sides of the participants with non-painful shoulders (n=90).

Variables	n	Median	*r*	*p*	*d*
SHBR	45	9.2	0.87	0.001*	0.57
and					
SHBL (cm)	45	9.5			
PMR	45	9.6	0.92	0.001*	0.59
And					
PML	45	9.8			
(cm)					
LDR	45	10.5	0.88	0.23	0.47
and					
LDL	45	10.2			
(cm)					
ER0R	45	79	0.55	0.006*	0.41
and					
ER0L	45	82			
(°)					

ER90R and	45	83.5	1.0	0.11	0.52
ER90L (°)	45	80			
IR PCSLR	45	64.5	0.99	0.61	0.61
IR PCSLL (°)	45	65			

SHB = short head of the biceps, NP = L= left, R= right, PM = pectoralis minor, LD = latissimus dorsi, ER0 = external rotation in neutral, ER90 = external rotation in 90 degrees, PCSL = posterior capsule side-lying, IR = internal rotation.

High positive correlations of fairly symmetrical ROM were present between the left and the right sides of participants with non-painful shoulders, ranging from (0.55-1.00) with large effect sizes ranging from (0.41-0.57) (Table 4).

Table 5 Median, correlation and effect size of ROM between the non-painful sides (n=35) and painful sides (n=35) of participants with painful shoulders.

	N	Median	*r*	*p*	*d*
SHBNP	35	7.2	0.87		
and				0.002 *	0.32
SHBP	35	8.5	0.87		
(cm)					
PMNP	35	8.3	0.89		
and				0.002*	0.95
PMP	35	9.6	0.89		
(cm)					
LDNP	35	9.3	0.94		
and				0.01*	0.95
LDP	35	13.8	0.94		
(cm)					
ER0NP	35	78	0.98		

and				0.003*	1.41
ER0P (°)	35	64	0.98		
			0.89		
ER90NP	35	75			
and				0.04*	1.42
ER90P	35	64	0.89		
(°)					
IR PCSLNP	35	62	0.88		
and				0.05*	1.41
IR PCSLP	35	43	0.88		
(°)					

SHB = short head of the biceps, NP = non-painful, P= painful, PM = pectoralis minor, LD = latissimus dorsi, ER0 = external rotation in neutral, ER90 = external rotation in 90 degrees, IR = internal rotation, PCSL = posterior capsule side-lying.

Effect size was determined using the Wilcoxon Signed Ranks test and the Spearman's correlation test for the correlation coefficient. The correlation is significant at the 0.01 level (2-tailed) with the Spearman's correlation coefficient.

Statistical significance ($p < 0.05$) was determined for all the altered modifiable musculoskeletal factors in terms of decreased ROM in the presence of pain in the painful sides of the painful shoulders (Online supplement 1) (Appendix M). Statistically significant ($p<0.05$) with high correlation coefficients associated with decreased ROM were determined for all the flexibility variables ranging from (0.87-0.98) with large effect sizes ranging from (0.95-1.42) (Table 5). Spearman's correlation was used for the correlation within the painful sides and non-painful sides of the variables of participants with painful shoulders (Table 5).

Table 6 Standard error of measurement (SEM) and minimal detectable change (MDC_{95}) of ROM within participants with painful shoulders of the non-painful side (n=35) and the painful side (n=35).

Variables	SEM	MDC_{95}
SHBNP (cm)	0.52	0.78
SHBP (cm)		
PMNP (cm)	0.62	0.87
PMP (cm)		
LDNP (cm)	0,52	0.73
LDP (cm)	0.38	

ER0NP (°)	5.81	8.13
ER0P (°)		
ER90NP (°)	5.95	8.33
ER90P (°)		
IR PCSLNP (°)	4.49	6.29
IR PCSLP (°)		

SHB = short head of the biceps, NP = non-painful, P= painful, PM = pectoralis minor, LD = latissimus dorsi, ER0 = external rotation in neutral, ER90 = external rotation in 90 degrees, PCSL = posterior capsule side-lying.

Estimates of measurement error were smaller for flexibility measurements of LD, SHB and PM, ranging from (0.52% to 0.38%), but larger for ROM of ER and PC, ranging from (1,.5 % to 5.81 %) (Table 6).

Table 7 Total range of motion of participants with and without shoulder pain.

Variable	N	Minimum	Maximum	Mean	SD	*r*	*d*	*p*
TROMNP								
(°)	35.00	100.00	174.00	137.38	19.32	0.25	1.22	0.16
TROMP								
(°)	35.00	22.00	172.00	104.75	38.19	0.25		

TROMNP = total range of motion non-painful; TROMP = total range of motion painful, SD = standard deviation.

Total range of motion was calculated by adding ER ROM and IR ROM. (TROM = ER ROM + IR ROM). Overall, TROM was decreased in the painful side of participants with painful shoulders with a large effect size of 1.22 (Table 7).

Table 8: GIRD of the non-painful and painful sides of the participants with painful shoulders.

	N	Minimum	Maximum	Mean	SD
GIRD (°)	35.00	-2.00	51.00	19.41	14.24

GIRD = glenohumeral internal range of motion deficits.

A mean GIRD of 19.41 degrees was present between the non-painful and painful sides of the participants with painful shoulders.

5 Discussion

Our study is a first of its kind investigating the flexibility of all the modifiable musculoskeletal variables of the SHB, the PMm, the LD, the subscapularis and the PCSL (IR) at one point in time in a non-athletic population in terms of ROM. In our study, we evaluated passive ROM ER (0-degrees and 90-degrees), IR (90-degrees) and active and passive sagittal flexion. A high correlation with a large effect size was noted between the left and right sides in symmetrical ROM in the non-painful shoulders (Table 4). A high correlation with decreased ROM, were concluded in our study (Table 5). These were present in all the variables of SHB, PMm, LD, the subscapularis and PCSL (IR) (Table 5). The medium to large effect sizes reached may be due to; the sensitivity of the measurement instrument used; and the homogenous population investigated.

5.1 Flexibility and ROM

External rotation range of movement

In our study a large positive correlation with a medium to large effect size between decreased ROM of ER were observed in the painful sides in participants with painful shoulders in both the ER 0°-

position and the ABD/ER 90°-position (Table 5). In contrast to our findings a study by Rosa et al. (2019) conducted on a similar non-athletic population group found that PMm flexibility was not strongly associated with ER ROM. However, their study compared participants with shoulder pain and participants without shoulder pain, they did not do within group comparisons (Rosa et al. 2019). No significant differences in the ER ROM have been observed in other studies in sporting populations (Olivier et al. 2020; Stuelken et al. 2008). However, these authors compared uninjured and injured athletes. This led to their conclusion that comparisons should be made on an individual basis, comparing obtained values within the same athletes (Olivier et al. 2020). Based on the recommendation in the study of Olivier et al. (2020), our study therefore compared expressed values only within the non-painful and painful sides of participants presenting with painful shoulders.

The MDC_{95} results (Table 6) can be used to check if the results determined for both the nonpainful shoulders and painful shoulders is not due to inter-trial variability or measurement error. For example; in Table 6 the expressed MDC_{95} value of for ER0 is 11.53, this can be applied to ER0NP of 78 degrees and to ER0P of 64 degrees. A difference of ≥11.53 degrees is needed to rule out that the observed value was due to change or measurement error, therefore (64 ER0P + 11.53 MDC_{95} =75.53) is less than the ER0NP 78 degrees value determined. Moreover, the expressed MDC_{95} value of 0.78 for SHBNP was determined, this can be applied to the SHBNP value of 7.2cm and the SHBP of 8.5cm. A value of equal to 0.78 or greater would be needed to be 95% certain that the observed change is not due to measurement error or inter-trial variability. Adding (0.78 to 9.2cm = 7.98cm), therefore, the observed difference between SHBNP and SHBP cannot be due to chance or measurement error. This principle can be applied to all the variables values determined. In our study ROM was assessed only to discomfort in the participants with painful shoulders to prevent flare-up of pain the participants.

In participants presenting with ER ROM limitation, several musculoskeletal factors should be considered (Table 9). It has been shown that shortening of the upper fibres of subscapularis limits ER in the 0-degrees position (Donatelli et al. 2014; Ekstrom & Osborn, 2011). Shortening of both the middle and lower fibres of subscapularis and the medial and lateral fibres of PMm limits ABD/ER ROM in the 90-degree position (Borstad & Ludewig, 2006; Evjenth & Hamberg, 1984;

Muraki et al. 2007; Umehara et al. 2017). Adaptive shortening of both the muscle belly and tendons of the subscapularis muscle may clinically limit ER ROM (Donatelli et al. 2014; Ekstrom & Osborn, 2011, Kelley et al. 2013).

Considering the above-mentioned, measurements of both the 0-degree and ABD/ ER 90-degree positions are therefore advised in the evaluation process for testing the flexibility of the subscapularis (upper, middle and lower fibers). Furthermore, shortening of the subscapularis both upper, middle and lower fibres may have been a contributing factor to the limitation observed in ER (0°and 90°) in the painful shoulders in the present study. In our study only ROM was assessed and not the cause of the loss of flexibility, which should be explored in longitudinal studies.

Pectoralis minor muscle

A statistically significant positive correlation with a large effect size was observed with the painful sides presenting with decreased ROM and a shorter muscle length with the measurement of the PMm length distance test (McCreary & Provance, 1993; Lewis & Valentine, 2007) (Table 5). Furthermore, the ABD/ER 90-degree position revealed a statistically significant positive correlation with a large effect size with decreased ER ROM present in the painful sides. Decreased ROM of PMm were thus present in both tests, alluding to decreased flexibility of both the medial and lateral fibres of the PMm. However, a study conducted in a non-athletic population comparing the non-painful side of asymptomatic participants with the painful side of symptomatic participants found no real difference between the participants for both the ER and the PMm measurements (Rosa et al. 2019). Furthermore, the comparisons were made between different participants and not within participants (Rosa et al. 2019).

Due to a lack of current literature in non-athletic populations, comparisons were made with the sporting population. In a study of elite cricketers measuring only the flexibility of PMm using the Kendall length distance test (Conroy et al. 2022; Lewis & Valentine, 2007), PMm tested shorter on the dominant uninjured side (Olivier et al. 2020). This contrasted with the study of swimmers, who presented with shortened PMm on the painful side (Higson et al. 2014; Harrington, Meisel &

Tate, 2014). The fact that cricket is a unilateral asymmetrical sport and in swimming both arms are used, similar to members of the general population where both arms are used, could be a potential reason for the differences observed.

Conflicting evidence on the best stretching positions for the PMm has been presented in the literature (Borstad & Ludewig, 2006; Muraki et al. 2009; Umehara et al. 2017). Taking the above-mentioned into consideration it was thought best to evaluate ER in neutral (0-degree) and the 90-degree position to draw meaningful conclusions from the derived results. Therefore, to increase the sensitivity of measurement for PMm flexibility, a combination of the ABD /ER-90° position and the PMm Kendall's length test (Conroy et al. 2022; Lewis & Valentine, 2007) are suggested in the evaluation process. In our present study participants with painful shoulders had decreased ROM of both components. Decreased ROM above 90°of shoulder flexion/ abduction is often present in painful shoulders, therefore the 150-degrees flexion position as suggested by Muraki et al. (2009), can potentially be added later in the rehabilitation process to improve on the flexibility of PMm.

In the participants without shoulder pain a statistically significant positive correlation between the left and right sides of PMm length (ROM) was determined (Table 4). Most participants were right dominance (Table 3).

Internal range of motion

A high positive correlation between decreased IR ROM with a large effect size in the presence of painful shoulders was reached (Table 5). The IR was noticeably decreased in the painful sides of participants with painful shoulders (Table 5). The limitation of IR ROM observed in our study in the painful side of participants with painful shoulders agrees with results observed in other sporting populations, with painful shoulders, of decreased IR ROM (Duzgun et al. 2017; Ishigaki et al. 2015**).** Decreased IR ROM was also observed in a general population presenting with painful shoulders (Rosa et al. 2019). The phenomena of decreased IR ROM in painful shoulders is not restricted to overhead sport but has also been determined in underhand sport such as rugby (McDonough et al. 2014). The risk for the development of pain has been explored and determined to be 1.26% higher in the presence of decreased IR ROM in their systematic review with meta-analysis (Chapter 4, Study 1). The PCSL test position proposed by Cieminski et al. (2015) was used for the measurement of IR ROM in our study. This position allows for better scapula control.

Different pathophysiology may play a role in and cause posterior capsule tightness in different populations (Burkhart et al. 2003; Manske et al. 2013; Evans & Guyver, 2015). In overhead athletes, micro-trauma to the posterior structures of the glenohumeral joint with repetitive overhead motion results in scar tissue formation. Shortening of the posterior capsule and the posterior inferior cuff (infraspinatus and teres minor) can lead to a reduced IR ROM motion. (Burkhart et al. 2003; Manske et al. 2013). In adhesive capsulitis (frozen shoulder), capsule fibroses occurs (Evans & Guyver, 2015). In SIS, inappropriate biomechanics leading to increased strain and inflammation of the posterior rotator cuff and capsule may lead to shortening of the posterior capsule (Amin et al. 2015). In our study participants with painful shoulders had undiagnosed pathology therefore, participants could have fallen into either of the above-mentioned categories. It can therefore be concluded that IR ROM limitation regardless of cause occurs in painful shoulders in both non-athletic and athletic populations.

Latissimus dorsi

A statistically high positive correlation with a large effect size with decreased ROM of LD was noted in the painful sides of the participants with painful shoulders (Table 5). The LD was substantially shortened in the painful side of participants with painful shoulders. Research conducted on the LD in asymptomatic athletes by Herrington & Horsley (2014), concluded significant decreased flexion in the ER position, between swimmers, canoeist and controls and to a lesser extent between rugby players and controls. Comparisons of the results of our study to existing literature could not be made due to scarcity of available literature on the LD length and flexibility in painful shoulders.

It can hence be seen that stiffness of the LD can limit full scapular elevation. Overuse of the LD, as seen especially in swimming, may result in hypertrophy of the LD with the resultant shortening and an inability to fully lengthen (Feijen et al. 2020; Herrington & Horsley, 2014). The full flexibility of the LD allows for full scapular elevation and external rotation of the humerus in an elevated position (Feijen et al. 2020; Herrington & Horsley, 2014; Laudner & Williams**,** 2013). (Table 9). Individuals may be predisposed to shoulder dysfunction if LD restriction is present (Feijen et al. 2020; Tate et al. 2012; Laudner & Willimas, 2013). The LD may, therefore, be more affected in painful shoulders, in everyday use, than anticipated& not just in a sporting population as can be seen from the results of our study.

Furthermore, full passive flexion of the arm is not only dependent on the flexibility of LD, but PMm shortening, of especially the medial and lateral fibers of PMm, should also be considered as a limiting factor (Borstad, 2008; Evjenth & Hamberg, 1984; Herrington & Horsley, 2014; Muraki et al. 2009) (Table 9).

Short head of biceps

A statistically significant positive correlation with a large effect size between decreased SHB ROM in the presence of the painful sides were determined (Tables 4, 5). Furthermore, the muscle length value of the median between the non-painful and the painful sides within the participants with painful shoulders was increased, with the painful sides having a shorter resting muscle length of SHB (Table 5). No comparison to existing literature could be made due to unavailability of literature.

Glenohumeral internal rotation deficit

Our study concluded GIRD means = 19.41° to be present when comparing the non-painful and the painful sides of participants with painful shoulders (Table 5). This conclusion agrees with GIRD present in athletes presenting with painful shoulders (Dutton et al. 2019; Lubiatowski et al. 2018; Manske et al. 2013). Marcondes et al. (2013) determined GIRD of 20° to 25° to be present in amateur tennis players, their results concurs with our study's findings. The GIRD deficits in our study were slightly less that the conclusions reached in the study of Jacome-Perez et al. (2023), who determined a GIRD of 41°. Their study was conducted in a general population group, similar to our study.

The phenomenon of GIRD originally highlighted by Papas et al. (1985) and Burkhart, Morgan & Kibler (2003) and thought to be isolated to baseball players, is also present in other overhead disciplines, such as amateur tennis players (Manske et al. 2013; Marcondes et al. 2013), handball players (Lubiatowsli et al. 2018), cricket players (Dutton et al. 2019) and in general population groups (Jácome-López et al. 2023). The findings of our study of the presence of GIRD reiterate the findings in the general population.

Non-painful shoulders

Overall, a large positive correlation with a medium to large effect size was determined in the ROM of all the variables (SHB, PMm, LD, ER0, ER90, PCSL) between the left and right sides of the participants with non-painful shoulders (Table 4). ROM was fairly symmetrical between the left and right sides in participants with non-painful shoulders (Table 4)

Total range of motion

The results of our study reflected a TROM decrease of 32.63° between the non-painful side and the painful side of participants with painful shoulders (Table 7). Overall, the TROM was decreased in the painful sides of the participants with painful shoulders in our study (Table 7). The finding in our study agrees with the results of the study of Marcondes et al. (2013). A TROM of > 20° was observed in overhead athletes with painful shoulders in their study. Unlike baseball where an increase in ER ROM is compensated for by a concomitant decrease in IR ROM Reuther et al. (2018) the same was not observed in our study.

Overall, the IR, ER and TROM were decreased in the painful side of participants with painful shoulders in our study (Tables 5). Considering the above mentioned, shortening of the subscapularis (upper, middle, lower fibers), PMm (medial and lateral fibers) PC and LD, may be responsible for these changes and may be linked to the development of pain in participants presenting with painful shoulders. Changes in the biomechanical functioning of the glenohumeral joint, with subsequent pain development, can be a result of altered musculoskeletal changes, such as changes in flexibility or range of motion (Edmonds & Dengerink, 2014; Kinsella et al. 2014).

It may be postulated that shortness of both the subscapularis muscle and the posterior capsule, as observed in our study, may ultimately contribute to intra-articular decentering of the humeral head in the glenoid cavity, resulting in shoulder dysfunction (Table 5). Significant loss of IR ROM in the presence of decreased posterior capsule flexibility has been reported in different population groups (Duzgun et al. 2017; Ishigaki et al. 2015; Tyler et al. 2000). Biomechanical alteration of the superior translation of the humeral head and decreased posterior translation of the humeral head on the glenoid were concluded to be present (Lin et al. 2006). This phenomenon placed the humeral head in closer proximity to the rotator cuff tendons, resulting in impingement (Lin et al. 2006).

A shortened LD and/or PMm can potentially contribute to extra-articular shoulder dysfunction. Anterior tilt and downward and internal rotation of the scapula are associated with a shortened PMm (Borstad et al. 2006; Edmonds & Dengerink, 2014; Umehara et al. 2017). Scapular dyskinesis occurs due to reciprocal inhibition of the scapular stabilizers, especially the serratus anterior lower fibers (Finley & Ebaugh 2017; Reeser et al. 2020). The inability to fully posterior tilt the scapula with resultant scapular dyskinesis was observed by numerous researchers (Timmons et al. 2012; Huang et al. 2015). This, in turn, may lead to subacromial impingement and shoulder dysfunction (Reeser et al. 2020, Finley & Ebaugh, 2017). The normal biomechanical homeostasis of the scapulohumeral complex is hence disturbed.

Shoulder pathology involves many musculoskeletal factors and flexibility of various musculoskeletal components is involved (Hegedus et al. 2012; Michener et al. 2009), this was reiterated in the findings of our present study (Table 5). Furthermore, evaluation of different movement planes during assessment can, therefore, provide differential diagnoses and tailor the rehabilitation process (Kelley et al. 2013).

An interesting finding was that regardless of age (Table 3) decreased ROM (Table 5) was present in painful shoulders and in the non-painful shoulders, regardless of age, and ROM was symmetrical (Table 4). Alteration in ROM can hence not necessarily be linked to older age groups, but rather to pathology.

Limitations

A limitation of our current study is that we only investigated ROM measurements. However, the necessary muscle ROM needs to be balanced with muscle strength and co-ordination, to ensure optimal shoulder function. ROM was assessed only to tolerance of discomfort to avoid increasing pain in the painful sides of shoulders. This may have influenced the ROM measurements in that measured ROM could potentially have been greater than determined. Only musculoskeletal factors and not bony factors were considered in our study as contributors to limitation of the concluded ROM measurements.

Recommendations

In painful shoulders all the modifiable musculoskeletal variables (SHB, PMm, LD, subscapularis, ER0, ER90 and PCSL) should ideally be assessed. Moreover, evaluation of PMm shortness could therefore include not only the known PMm flexibility length measures, but also ER ROM in the 90°-ABD position. Evaluation of shortness of the subscapularis muscle may include ER ROM in both the (0-degree and 90-degree) positions. In individuals presenting with limited full passive flexion flexibility, deficits in both the LD and PMm could be suspected. More research is needed to clarify the role of LD, SHB and subscapularis in shoulder pathology, ideally through longitudinal cohort study designs.

Conclusions

Decreased ROM (IR, ER, TROM), GIRD and shortness of subscapularis, LD and PMm positively correlated with the presence of pain in painful shoulders in the present study. Therefore, evaluation of all the identified musculoskeletal components (the LD, the subscapularis, the SHB, the PMm and the PC), as highlighted in our study and not only individual musculoskeletal factors, should ideally be incorporated in baseline evaluation to draw meaningful conclusions from the derived results.

Statements and declarations

Funding

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Conflict of interest

All authors Sonia Briel and Corlia Brandt declare that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Availability of data

The authors declare that the data supporting the findings of this study are available within the paper and in the supplementary online information files.

Ethics

Ethical approval was obtained from the Human Research Ethics (Medical).

Consent to participate

Voluntary informed signed consent was obtained from all participants prior to the testing session.

Consent to publish

Signed consent was obtained from the model used in Table 1 and in Table 2 for the photographs to be used in the publication.

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Appendices

Appendix A

Table: The intra-rater (rater 1) reliability ICC (95% CI) values for the flexibility variables. A pilot reliability study conducted on the flexibility (ROM) measures of LD, PMm, SHB, subscapularis and PC.

Intra-rater reliability for Rater 1				
Variables	SEM	MDC	ICC 95% CI (SD)	P-value
PMm	2,46	4,8	0,47 (-0,56-0,93)	0,17
SHB	1,79	3,50	0,58 (-0,433-0,95)	0,11
LD	7,34	14,38	0,76 (-0,13-0,97),	0,03*
ER0	15,65	30,67	0,07 (-0,78-0,83)	0,44
ER90	46,28	90,70	0,83 (0,05-0,98)	0,02*
PCSL (IR)	19,23	37,69	0,04 (-0,80-0,82)	0,47

*PMm = pectoralis minor, SHB = short head of biceps, LD = latissimus dorsi, ER0 = external rotation in neutral, ER90 = external rotation in 90 degrees, PCSL = posterior capsule, CI = 95% confidence interval, ICC = Interclass correlation coefficients, SEM = standard error of measurement, MDC = minimal detectable change, statistical significance denoted by *.*

Table: The intra-rater (rater 2) reliability ICC (95% CI) values for the flexibility variables.

Intra-rater reliability for Rater 2				
Variables	SEM	MDC	ICC 95% CI (SD)	P-value
PMm2	1,36	2,6	0,00 (-0,81-0,81)	0,5
SHB2	3,19	6,25	0,54 (-0,79-0,82)	0,003*
LD2	10,64	20,85	0,93 (0,53-0,99)	0,46
ER02	28,96	56,7616	0,82 (0,02-0,98)	0,02*
ER902	49,46	96,9416	0,06 (0,83-0,78)	0,59
PCSL (IR)2	21,04	41,2384	0,52 (-0,50-0,93)	0,15

*PMm = pectoralis minor, SHB = short head of biceps, LD = latissimus dorsi, ER0 = external rotation in neutral, ER90 = external rotation in 90 degrees, PCSL = posterior capsule, CI = 95% confidence interval, ICC = Interclass correlation coefficients, SEM = standard error of measurement, MDC = minimal detectable change, statistical significance denoted by *.*

Appendix B

Table: Limitation of the range of movements in current literature, ER, IR and F

Limitation of the range of motion	Musculoskeletal factors	Literature
ER neutral - 0 degrees	Subscapularis-upper fibers	Ekstrom & Osborn 2004; Donatelli et al. 2012; Thurner et al. 2013
ER 90- ABD/ER degrees	Subscapularis middle and lower fibers Pectoralis minor medial and lateral fibers	Muraki et al. 2007; Muraki et al. 2009; Evjenth & Hamberg, 1984.
IR 90-degrees	Shortness of the posterior capsule and of the posterior inferior musculature (infraspinatus, teres minor)	Pappas et al. 1985; Burkhart et al. 2003; Manske et al. 2013

Sagittal plane flexion	Latissimus dorsi Pectoralis minor medial and lateral fibers	Herrington & Horsley 2014; Muraki et al. 2009.

ER =external rotation; ABD = abduction; IR = internal rotation, F = flexion.

Table: The intra-rater (rater 2) reliability ICC (95% CI) values for the flexibility variables.

Intra-rater reliability for Rater 2				
Variables	SEM	MDC	ICC 95% CI (SD)	P-value
PMm2	1,36	2,6656	0,00 (-0,81-0,81)	0,5
SHB2	3,19	6,2524	0,54 (-0,79-0,82)	0,003*

LD2	10,64	20,8544	0,93 (0,53-0,99)	0,46
ER02	28,96	56,7616	0,82 (0,02-0,98)	0,02*
ER902	49,46	96,9416	0,06 (0,83-0,78)	0,59
PCSL (IR)2	21,04	41,2384	0,52 (-0,50-0,93)	0,15

*PMm = pectoralis minor, SHB = short head of biceps, LD = latissimus dorsi, ER0 = external rotation in neutral, ER90 = external rotation in 90 degrees, PCSL = posterior capsule, CI = 95% confidence interval, ICC = Interclass correlation coefficients, SEM = standard error of measurement, MDC = minimal detectable change, statistical significance denoted by *.*

The intra-rater ICC values for rater 1 for the flexibility measures, ranged from slight to almost perfect (0.03-0.83) (Table 2). The ICC for rater 2, for the flexibility measurements, ranged from slight to almost perfect (0.00-0.93) (Table 3).

Table 1: Demographic data of the participants.

Participants	**Gender**	**Mass**	**Height**	**Age**	**Dominance**

		(kg)	(cm)	(years)	
1	M	67,35	186	23	R
2	F	52,8	172	20	R
3	F	59,65	162	22	R
4	F	65,55	165	21	R
5	F	64,3	163	21	R

M = male, F = female, R = right.

Capter 7 Exploring a clinically relevant Physiotherapy Shoulder Assessment Model - A Pilot Study.

The aim and objectives of this study are available in Chapter one, page22.

Authors: Sonia Briel, Corlia Brandt.

Conceptualisation and first draft: Sonia Briel, conceptualisation, editing and final draft: Sonia Briel and Corlia Brandt. This manuscript was edited according to the guidelines of the journal of submission.

Submitted to International Biomechanics.

Abstract

Background

Shoulder assessment models often fail to address the complexity of shoulder dysfunction as many modifiable musculoskeletal factors influence shoulder dysfunction. A clinically applicable physiotherapy shoulder assessment model is currently lacking.

Aim

This study aimed to explore a comprehensive and evidence-based shoulder assessment model, applicable to Physiotherapists.

Setting

Online nominal group technique.

Methods

Practicing Physiotherapists (n = 4) with a special interest in shoulder conditions, both women and men (aged between 32- 47 years of age) were selected, based on predetermined inclusion criteria, to participate in a nominal discussion group (NGT). Ordering and ranking of novel findings of what factors should be included in a shoulder evaluation model were done. Qualitative thematic analysis was performed.

Results

Physiotherapists' experience ranged from 4-25 years of clinical and academic work experience. Postgraduate qualifications included PhD, MSc, MPhysT degrees, and Orthopaedic Manipulative Therapist (OMT1) and Sports Physiotherapist (SPT1) certification. The top three concepts for inclusion into shoulder assessment were; (a) scapular force couple ratios (b) cervical spine evaluation (c) modifiable musculoskeletal factors; differentiation between pectoralis minor (PMm) and the subscapularis muscle length, and consideration of the ratios of the rotator cuff instead of individual muscle forces of the rotator cuff muscles.

Conclusions

Inclusion of force couple ratios of both the rotator cuff and the scapular stabilisers, the flexibility of pectoralis minor and subscapularis and differentiation of pain originating from the cervical pain and the shoulders, were factors deemed important for inclusion into a shoulder assessment model.

Relevance to clinical practice

The development of a comprehensive shoulder assessment model applicable to clinical practice using evidence-based outcomes was the end goal.

1 Introduction

Shoulder pain affects all age groups and is a common musculoskeletal complaint seen often in medical practices (Nichols, 2012). Shoulder pain ranks third on the list of musculoskeletal conditions needing health care from primary practitioners (Lucas et al. 2022; Hsiao et al., 2015; Roldán-Ruiz et al. 2025). The one-year prevalence of shoulder pain occurring in adult populations has been estimated to be between 20% to 51% (Van Heijden et al. 1999). A more recent systematic review concluded the one-year prevalence of shoulder pain in a general population to be between

5% to 51% (Luime et al. 2004). The occurrence of shoulder pain over a patient's lifetime varied between 7% to 67% (Luime et al. 2004; Nichols et al. 2012).

Pain free shoulder function is needed for functional activities of daily living by all individuals (Linaker and Walker-Bone, 2015). Time away from work, loss of income, lack of sleep and even losing jobs are linked to shoulder pain (Borstad and Woeste, 2015; Linaker Walker-Bone, 2015).

Many altered musculoskeletal factors are present in painful shoulders, such as imbalance in strength ratios (Chapter 4, Study 1) (McDonough et al. 2014; Maestroni et al. 2020) weakness of specific muscle groups (Rosa et al. 2019; Marcondes et al. 2013) and shortening of specific musculoskeletal structures (Dutton et al. 2019; Tate et al. 2014). Standard orthopaedic shoulder tests are mainly used in physiotherapy practices in the evaluation of shoulder conditions. Different views are however expressed in literature on the use of standardized orthopaedic shoulder tests used in clinical practice. In their systematic review, Hughes et al. (2008), investigated the diagnostic accuracy of the Hawkins-Kennedy, Infraspinatus, Napoleon, Lift-off, Belly Press or Drop Arm and Empty Can test. Their overall conclusion was that these tests were inaccurate in diagnosing subacromial impingement syndrome (SIS) (Hughes et al., (2008). In the recent study of Baigent et al. (2023) the diagnostic validity of standardised orthopaedic shoulder tests was again questioned. The authors concluded that these tests were inaccurate in diagnosing either subacromial syndrome or acromioclavicular pathology (Baigent et al. 2023).

Diagnosing shoulder pain therefore still remains challenging today and the pathophysiology of it is still unclear. Different labelling is used interchangeably by clinicians adding to the confusion of shoulder related pain (Bron et al. 2011; Schellingerhout et al. 2008; Roldàn-Ruiz et al. 2025). Musculoskeletal factors such as the supraspinatus (SS) muscle (Empty- Can Test) is often evaluated in isolation and a skewed diagnostic picture may be portrayed. Diagnosing and effective treatment of shoulder pain therefore remains very challenging even today and adds to the difficulty in patient management (Baigent et al. 2023; Bron et al., 2011; Schellingerhout et al. 2008; Roldàn-Ruiz et al. 2025). The positive benefits of receiving early physiotherapy at first contact has however been established in primary care settings (Hon et al. 2021; Virta et al. 2012).

This study aimed to generate perspectives in clinical practice regarding an evidence-based shoulder assessment model, based on the key findings identified in three recent studies; a systematic review (SR) conducted on modifiable musculoskeletal factors and two analytical studies conducted on modifiable musculoskeletal factors in painful shoulders (Briel et al. 2024).

2. Materials and Methods

A qualitative consensus design using the NGT technique (Van de Ven and Delbecq, 1972) to inform the use of an integrated shoulder assessment model was conducted. The opinions of different Physiotherapists were gauged on the inclusion of applicable information into an assessment model for the shoulder. The NGT was originally developed by Van de Ven and Delbecq (1972) to assist in healthcare planning. It has since been used successfully in research prioritising (Wilkes et al. 2013) and in education (Cunningham 2017). Ethical approval was obtained from the University of Witwatersrand Human Research Ethics (Medical) (M190984). Voluntary written informed consent was obtained from all participants for the audio recording and use of their information.

Physiotherapists (clinicians as well as academics) practicing/ lecturing in the shoulder field were purposively sampled through an online questionnaire (Appendix 1). The questionnaire, using Research Electronic Data Capture system (REDCap) (Harris et al. 2009), was sent to one-hundred practicing Physiotherapists in South Africa. Of the one-hundred participants recruited only twenty participants responded. From the twenty respondents, a shortlist was compiled consisting of eight participants, fulfilling the predetermined inclusion criteria of which only four participants could attend the online Teams meeting. These four participants were included in the final panel (McMillan et al. 2014). Inclusion criteria were Physiotherapists that treated more than five shoulder patients weekly (Table 2). Exclusion criteria were Physiotherapists that work in subdisciplines other than musculoskeletal practices and those who did not treat any shoulder patients monthly. Eligible participants were invited to participate in the nominal group discussion. The participants met in a face-to-face online group setting via the Teams online platform.

Table 1 Results of the systematic review and the observational cross-sectional studies used for the proposed statements employed in the nominal group discussion.

Modifiable musculoskeletal factors		Systematic review's findings (Chapter 4, Study 1)	Physical data's concluded findings (Chapter 5, Study 2; Chapter 6, Study 3)
3	**ER strength**	Increased strength in asymptomatic participants	Increased strength in asymptomatic participants
4	**ER: IR ratio**	Higher ratios of ER: IR in asymptomatic participants	Higher ratios of ER: IR in asymptomatic participants
5	**IR ROM**	Decreased IR ROM in symptomatic participants	Decreased IR ROM in symptomatic participants
6	**GIRD**	GIRD present in symptomatic participants	GIRD present in symptomatic participants
7	**Scapular dyskinesis**	Present in symptomatic participants	Not tested
8	**Weakened scapular stabilizers**	Present in symptomatic participants	Not tested
9	**Shortened PM**	Present in symptomatic participants	Present in symptomatic participants
10	**Shortened LD**	Shortened LD in symptomatic participants	Present in symptomatic participants

11	**Shortened PC**	Shortened PC in symptomatic participants	Present in symptomatic participants

ER = external rotator; IR = internal rotator; GIRD = gleno humeral internal rotation deficit; PM = pectoralis minor; LD = Latissimus dorsi; PC = posterior capsule.

An external facilitator was invited to serve as the facilitator, to protect against bias. The systematic approach followed in the discussion process allowed for meaningful information to be collected from participants in a relatively short time period (Figure 2) **(**Mullen et al. (2021). NGT has proven to be a reliable method in gaining clarity around identified statements in a group setting (Durkin et al. 2019).

Results of the global systematic review (SR) with meta-analyses conducted in a non-athlete and athletic population (Briel et al. 2024), identified the following musculoskeletal factors namely; weaker external rotators (ER), stronger internal rotators (IR), lower external (ER) versus internal rotators (IR) ratios, shortened posterior capsule (PC), decreased internal rotation (IR), increased external rotation (ER), decreased total range of motion (TROM), glenohumeral internal rotation deficit (GIRD), shortened Latissimus dorsi (LD) and pectoralis minor (PMm), to be associated with shoulder dysfunction (Table 1). Two studies conducted in a non-athletic population aged between 18 and 75 years of age determined weaker ER, stronger IR, lower ER:IR ratio, decreased TROM, GIRD, shortened LD, PMm, subscapularis and LHB to be associated with painful shoulders (Chapter 4, Study 1; Chapter 5, Study2, Chapter 6, Study 3) (Table1). The key concepts from the aforementioned studies were presented in the NGT discussion for discussion and ranking (Table 1).

2.1 Data collection

The group discussion was conducted and recorded on Teams (Figure 1). Silent generation (brainstorming for 20 minutes) was allowed for participants to reflect on the presented statements and/or to record their individual ideas (Van de Ven and Delbecq, 1972). This was followed by the facilitator asking one participant at a time in a ‘round robin’ way to verbally state their ideas (10 minutes) (Mullen et al.2021). No discussion was allowed at this stage (Harvey and Holmes, 2012). Only verbatim ideas were recorded on Teams (Perry and Linsley,2006).

Thirty minutes was then allowed for new ideas, grouping, and including or excluding ideas (Kennedy and McKay, 2011). No direction by the facilitator was provided at this stage. Ideas were discussed among the participants themselves. The three main ideas, as is commonly suggested in literature (McMillan et al. 2016; Wang et al. 2006), were selected. An open discussion was allowed, but the individual voting was kept confidential (Kennedy and McKay, 2011). Participants were allowed ten minutes to make their final decision and vote (Dening et al. 2013).

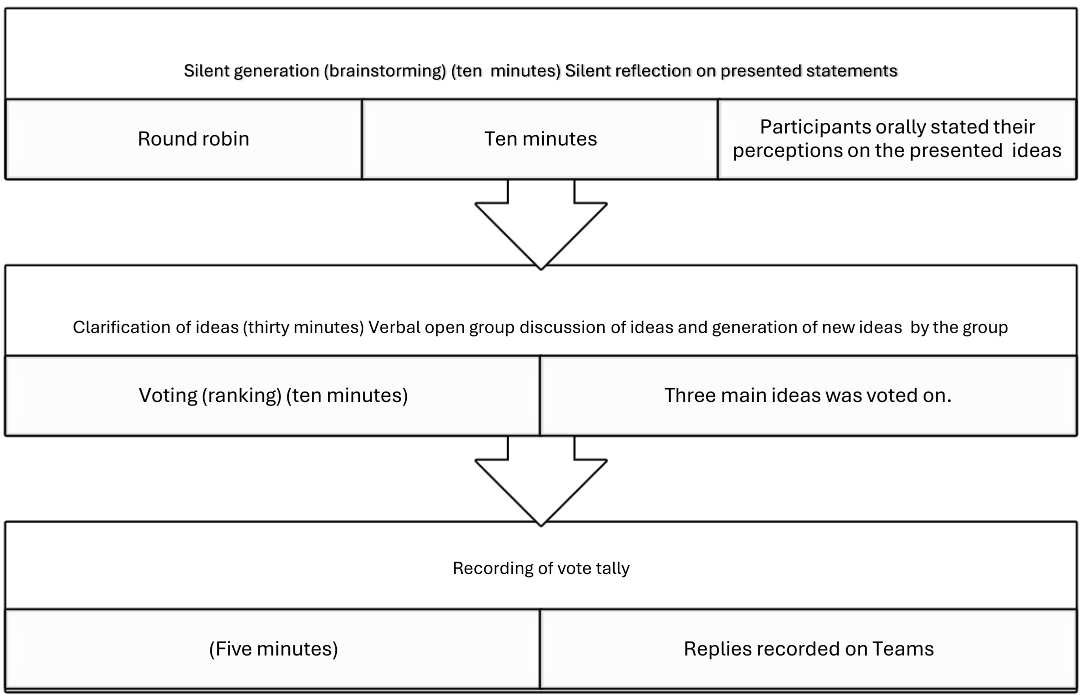

Figure 1 Schematic diagram of NGT process.

The participants' viewpoints were given through as accurately as possible to increase the truth value of the derived findings. To increase the trustworthiness of the findings the audio recordings and the transcribed copy were consulted repeatedly and thoroughly to reflect the expressed views of all participants.

2.2 Data analysis

Transcribing of the audio recording was done using Microsoft One Note function, an independent scribe and cross-checked with the facilitator. Coding of data was conducted and broadly labelled into three main codes of “scapular muscles”, “muscle force”, and “ROM”. Thematic analysis was then used for the clearer identification of specific themes and patterns of the coded collected data (Figure 3). A latent approach rather than a sematic approach was followed, to identify the underlying ideas and assumptions in the collected data. Similar ideas were grouped (Table 1 and Figure 3) and three key concepts arose from the group discussion and voting (Figure 3). For the scoring and ranking of data, a quantitative approach was utilized. The use of tables and mind-maps were employed in the description of the results (Figure 1and Table 3).

3. Results

The demographic data of the participants and the results of the NGT discussion will be presented next.

Table 2 Demographics of the participants.

Participant	Gender	Age	Years of clinical experience	Post graduate qualifications	Shoulders treated weekly
1	F	47	25	OMT1, MPhysT	>5
2	M	32	4	MSc	>5
3	F	41	19	MSc, PhD	>5

4	F	40	18	OMT1, SPT1	>5

F = female, M = male, OMT1 = orthopaedic manipulative therapy level 1, SPT1 = sports Physiotherapy level 1.

Three factors were identified with grouping of the primary themes from the proposed statements used in the NGT discussion group namely; (A) the evaluation of the scapular stabilizers and in particular the force couple ratios of the scapula stabilizers. (B)The modifiable muscular factors; such as the ROM in different movement planes (muscle length of the peri-scapular muscles) in particular differentiation between the PMm and the subscapularis muscle was deemed very relevant to the evaluation plan; the strength ratio of ER:IR of the rotator cuff rather than measuring the individual muscle strength. (C) Differentiation between shoulder pain and cervical referred pain should include evaluation of the upper quarter e.g. the cervical spine (Figure 2).

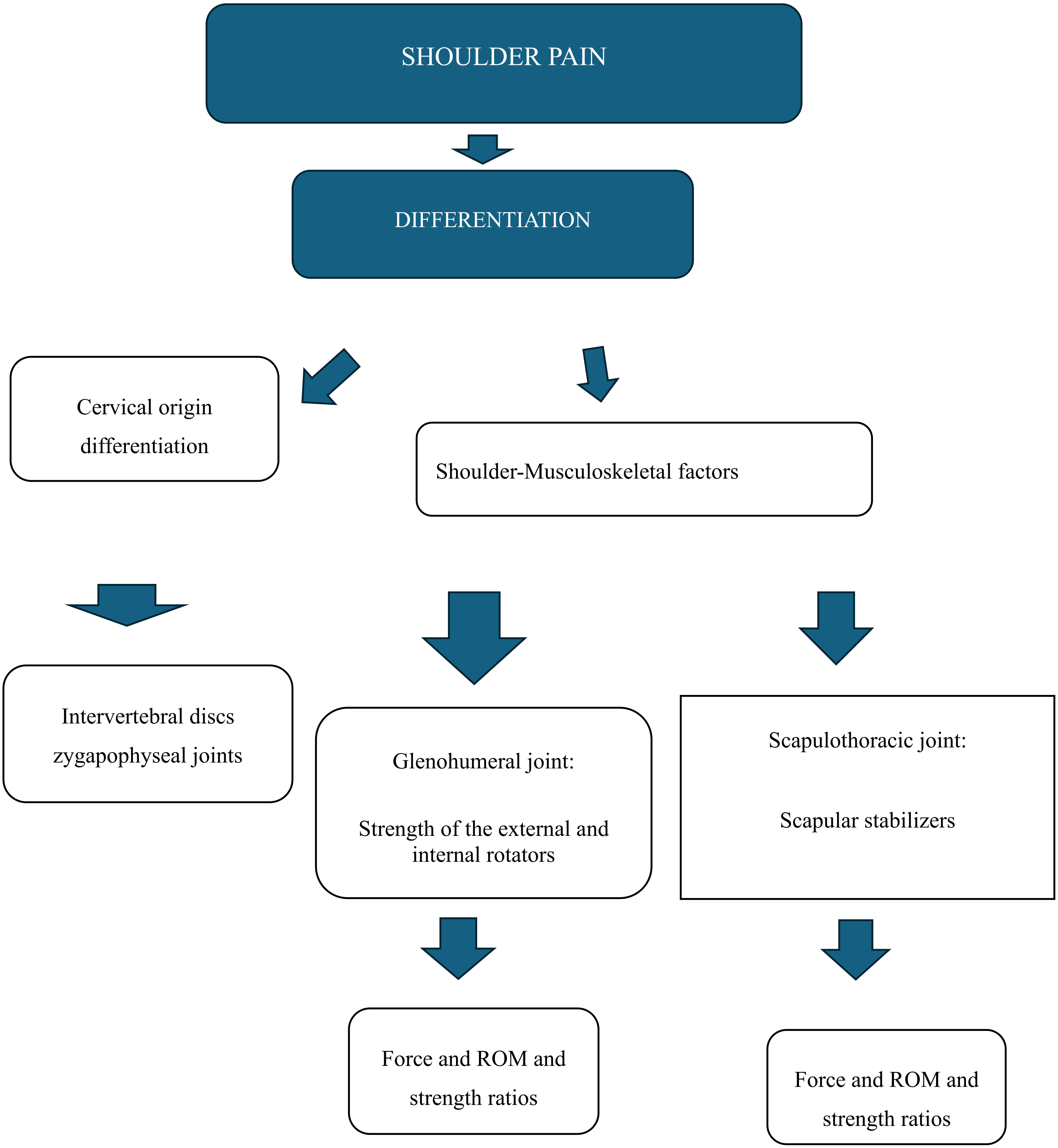

Figure 2 A flow diagram of the proposed assessment model.

Grouping of key factors (modifiable musculoskeletal factors) and proposed factors namely, the upper quarter (cervical spine), is represented in Figure 3.

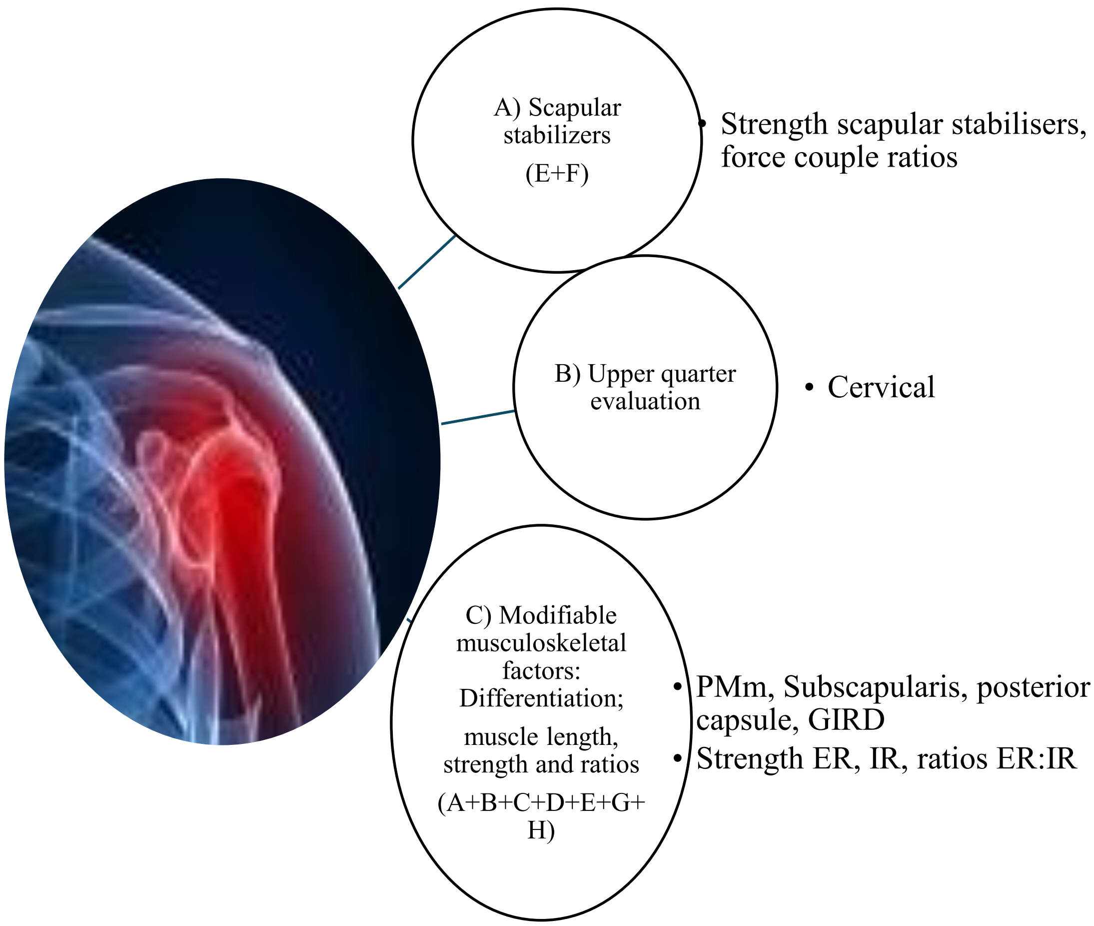

Figure 3 Mind map of key concepts generated during the NGT discussion.

Table 3 Statements and ranking of presented ideas.

Statement	Participants	Group ranking
2 Testing of the scapular stabilizer and stabilizer ratios and/ or scapular dyskinesis test.	4	2nd
3 Upper quarter evaluation: cervical spine	3 1	1st 3rd
4 Modifiable musculoskeletal factors: **1) Differentiation of muscle length, PMm, subscapularis, posterior capsule flexibility.** **2) Muscle strength testing, ER, IR, muscle force couple ratios ER: IR,.** **3) GIRD.**	1 3	1st 3rd

ER = external rotator; IR = internal rotator; GIRD = glenohumeral internal rotation deficit. The 1st, 2nd, 3rd portrays the position ranked by the participants of the presented grouping of key concepts. The 1, 3 and 4 portray the number of participants voting for a specific item.

“Scapular stabilisers strength” were deemed important by all four participants (*P1-P4*) but “force couple ratios” was deemed more important by one participant (P3), and all agreed on the inclusion of these factors into the assessment model (*P1- 4*). (Table 3).

“So, did they look at the scapula stabilizing muscles at all? I would definitely include the scapular stabilisers” (P2).

“It is more important for me to look at the known force couple ratios of the scapular stabilisers when looking at the shoulder.” (P3).

All four participants (P1-P4) agreed that assessment must include “motion measurement in different planes”. *Differentiation between “PMm and the subscapularis” was deemed important by all four participants (P1-P3). One participant in particular emphasized this concept.*

“It is important to differentiate between the decreased range coming from the PMm or the subscapularis muscle” (P1).

It was the overall opinion of most (three) participants (P1-P3) that *“the upper quarter, hence the “cervical spine” should be included in the assessment process.*

“And the one thing that I would definitely include, and I might be throwing a spanner in the works here is to actually assess the upper quarter, so to include the cervical range of motion because it can implicate the shoulder” (P3).

“Referred pain can originate from the neck, so to rule out the neck it must be examined in patients with shoulder pain” (P2).

Therefore, the whole upper kinetic chain should be considered in the thorough assessment of the shoulder joint.

“Now the evaluation of the external rotators and the internal rotators is important to me “(P4).

Most participants (three) (P1-P3) agreed that the strength of the rotator cuff is important, but one participant (P3*) thought that the "force couple ratios*" of the rotator cuff is more important than isolated muscle strength.

"It is more important for me to look at the force couple ratios of the rotator cuff than individual muscle strength" (P3).

4. Discussion

The drive for evidence-based practices (EBP) is increasingly becoming important in all spheres of medical practices (Hopman et al. 2018). Physiotherapists currently base their assessment of the musculoskeletal system, in this instance the shoulder complex, on standardised orthopaedic shoulder tests, leaving them with an unclear, perhaps unreliable, guide as to what to treat. An alternative to the currently used standardised orthopaedic shoulder tests is therefore proposed to be used in shoulder assessments. All the participants were in agreement on three main concepts derived from the thematic analyses that must be present in the comprehensive assessment of the scapulohumeral complex, the evaluation of; the scapular stabilizers; the modifiable muscular factors; such as the ROM in different movement planes; the strength ratio of ER:IR of the rotator cuff ; differentiation between shoulder pain and cervical referred pain should include evaluation of the upper quarter e.g. the cervical spine (Figure 2).

Scapular control by the scapular stabilizers are known in literature to play a role in healthy shoulders (Du et al. 2020; Kibler and Sciascia 2019; Kibler et al. 2013; Michener et al. 2016; Sahrmann, 2001). One of the conclusions agreed upon by all the participants of the current study, was that the inclusion of evaluation of the scapular stabilisers and in particular the force couple ratios of the scapular stabilisers is needed (Figure 2,3). It is widely accepted that the force couples of the scapular stabilisers must be in synchrony for the optimal execution of the scapular motion (Cools et al. 2004; Inman et al. 1944; Ludewig and Reynolds 2009; Vanderstukken et al. 2020). The assessment and interpretation of specific force couples of the scapular stabilizers present in both females and males were concluded in the study of Briel et al. (2022). Testing only individual muscles and not taking the muscle strength of the force couples and especially the force couple ratio into consideration, may be misleading (Magery and Jones, 2003; Briel, et al. 2022).

Many periscapular structures can have an influence on shoulder function including, PMm, LD, Subscapularis, and PC (Dutton et al. 2019; Harrington et al. 2014; Rosa et al. 2019). Differentiation between various musculoskeletal factors causing loss of flexibility can lead to rehabilitation programs being more effective. Loss of ER ROM may be from shortness of both subscapularis and PMm (Ekstrom and Osborn 2004; Donatelli et al. 2012; Thurner et al. 2013, Muraki et al. 2007; Evjenth and Hamberg, 1984). Loss of flexibility of IR ROM may be from shortness of the posterior inferior cuff (infraspinatus, teres minor and the posterior capsule), (Pappas et al, 1985; Burkhart et al. 2003; Manske et al, 2013). Loss of sagittal flexion may be from shortness of LD and PMm (Higson et al. 2018; Muraki et al. 2009). Glenohumeral internal rotation deficit (GIRD) should also be considered in all populations (Jácome-López, 2023). Posterosuperior internal impingement occurs with GIRD of more than 20°-25° (Heck et al. 2021).

Following a more holistic approach, evaluation of the upper quarter, incorporating the cervical spine is suggested to be included in shoulder evaluation. This was reiterated in the study of Roldán-Ruiz et al. (2025). Poor patient management may result from not differentiating between symptoms originating from the cervical spine compared to originating from the shoulder (Roldán-Ruiz et al. (2025).

Overlap of the musculature (originating from the cervical spine area) namely the levator scapula and especially the upper trapezius, also plays a direct role in shoulder function (Donnelly et al., 2019). Following a nociceptive neurophysiological approach the cervical spine and related structures, the zygapophyseal joints, C4–T1 (Cooper et al. 2007; Bogduk et al. 2002) and the intervertebral discs (C4–C7) (Grubb and Kelly, 2000; Ito and Creemers, 2013) can be a driver of pain experienced in the shoulder area. False positives can be gained from shoulder specific orthopaedic tests in these instances (Abady et al. 2018) and this may provide clinicians with inaccurate information leading to ineffective management of the patient (Rosedale et al. 2019).

Standard orthopaedic shoulder tests often fail to address the complexity of the shoulder joint (Bron et al. 2011; Schellingerhout et al. 2008; Roldán-Ruiz, 2025). Many modifiable musculoskeletal factors influence the functioning of the shoulder joint (Chapter 4, Study 1) and it is the aim of physical therapists to identify and address these factors to restore normal function. Dutton et al. (2019) in their study voiced the need to identify a cluster of tests for the comprehensive assessment of the shoulder joint. This statement was reiterated in the study of Thoomes et al. (2018) stating that using a cluster of identified tests can aid decision making in shoulder pain.

5. Limitations

The proposed inclusion of factors into an assessment model was explored in only one pilot NGT discussion session, potentially paving the way for more in-depth investigations into evidence-based shoulder assessment models. The views expressed in the current study may therefore not be generalised to the global physiotherapy community.

6. Recommendations

The findings of this study could be a starting point for more discussion and investigation around the inclusion of key factors into shoulder assessment models. NGT or Delphi discussion techniques including a larger group of participants and physiotherapists from around the globe can be used to further explore the findings of the present study. More research is needed in the development of more applicable clinical guidelines for shoulder assessment specific to the physiotherapy profession.

7. Conclusion

Consideration of all musculoskeletal factors influencing the shoulder joint, including periscapular muscle flexibility and strength, both individual muscles, but more so the force couple ratios of the scapular stabilizers and of the rotator cuff, might need to form part of the evidence-based assessment of the shoulder joint.

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Chapter 8 An Evidence-based Assessment Model for the Comprehensive Assessment of the Scapulohumeral Complex: A Pilot Reliability Study

The aims and objectives of this chapter is available in Chapter one, page 21.

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Abstract

Background

The establishment of scientifically sound assessment models are needed for the screening of the scapulohumeral complex. A proposed scapulohumeral complex model (incorporating both flexibility and force measurements) was tested with a reliability study to examine the applicability to clinical practice.

Objectives

To determine the intra- and inter-tester reliability of the two testing sessions of the modifiable musculoskeletal factors.

Design

A quantitative reliability study.

Methods

A reliability study was conducted on measurement of key modifiable musculoskeletal factors included in a scapulohumeral complex assessment model. The flexibility of pectoralis minor

(PMm), short head of biceps (SHB), latissimus dorsi (LD), subscapularis, posterior capsule (PC) and the force measurements (17) of all the rotator cuff musculature and the scapular stabilisers were included. The intra-rater and inter-rater reliability was assessed using the intraclass correlation coefficients (ICC) for all the continuous variables. Statistical significance was set at 95%.

Results

Intra-rater reliability ICC (95% CI) ranked from moderate to almost perfect for the flexibility measures for PMm 0,47 (-0,56-0,93), SHB 0,58 (-0,433-0,95), LD 0,76 (-0,13-0,97) for rater 1. For rater 2 moderate to almost perfect reliability was found for SHB 0,54 (-0,79-0,82), LD 0,93 (0,53-0,99), ER (neutral) 0,82 (0,02-0,98), and PCSL (IR) 0,52 (-0,50-0,93). For the scapular stabilisers, the intra-rater reliability was moderate to almost perfect for both raters.

Conclusions

Measurement of most of the key musculoskeletal factors, produced moderate to high reliability values, when tested by the same rater (intra-rater).

Keywords:

Assessment; shoulder; musculoskeletal; evidence based.

1 Introduction

The prevalence of shoulder pain has been estimated to range from 0.7% to 55.2% (Monrad et al., 2018). Lucas et al. (2002) in their epidemiological systematic review determined that the vast majority of people will experience shoulder pain either or both daily, yearly, monthly and recurrently throughout their lives. There is a worldwide shift to later retirement, therefore the average working age is getting older and the reported shoulder pain episodes more (Hodgetts et al. 2021). The impact of both occupational and physical recreational activities as well as sporting activities on the development of shoulder pain are more pronounced as we age (Hodgetts et al.

2021). The socio-economic burden as well as psychological impact of shoulder pain on the general population may still increase in time (Vincent et al. 2017; Hodgetts et al. 2021).

Shoulder symptoms can be prevented by the early identification of biomechanical dysfunctions of any particular movement pattern of the shoulder (Hess, 2000). Standardised orthopaedic shoulder tests are mainly used in practice to diagnose shoulder pain. However, the diagnostic validity of these tests is questioned in practice. Numerous authors have questioned the use of tests such as; the Hawkins-Kennedy, Infraspinatus, Napoleon, Drop Arm, Empty Can, Yergason, Jobe's, Full Can tests in practice (Hughes et al. 2008 Lasbleiz et al. 2014). Symptoms elicited with these tests have a poor correlation with the anatomy of the shoulder (Hughes et al. 2008). Furthermore, using standardised orthopaedic tests in practice to diagnose shoulder pain frequently still leaves the physiotherapy practitioner with unanswered questions as to the objective of the treatment. For example, diagnosing supraspinatus pathology in isolation provides a skew picture of the origin of shoulder pain. Shoulder pain can originate from many shoulder structures (Hughes et al. 2008; Taylor and Green, 2008; Baigent et al. 2023). Even with known standardised orthopaedic shoulder tests, uncertainty remains in the diagnoses and treatment of shoulder pain.

Many modifiable musculoskeletal factors have been identified in patients presenting with shoulder dysfunction. The presence of modifiable factors such as decreased external (ER) rotator cuff strength, ratio imbalances between the ER versus the IR, loss of flexibility of subscapularis, LD, PC, PMm; differences in range of motion (ROM) in ER, IR, total range of motion (TROM), glenohumeral internal rotation deficit (GIRD) have been indicated in shoulder dysfunction (Briel et al. 2024). Several authors in individual primary studies have determined musculoskeletal factors such as increased ER strength (Rosa et al. 2019, Marcondes et al. 2013, Moreno-Perez et al. 2015) and higher ER:IR strength ratio (Marcondes et al. 2013; McDonough and Funk, 2014; Forthomme et al. 2018; Maestroni et al. 2020; Bagordo et al. 2020) to be present in shoulders without dysfunction. Decreased IR ROM (Lala, 2017, Lubiatowski et al. 2018; Moreno-Perez et al. 2015); GIRD (Lala, 2017; Moreno-Perez et al. 2015; Turgut and Baltaci, 2018), and PMm shortness (Phadke et al. 2009; Kolber et al. 2017; Nordqvist et al. 2021) were concluded to be present in participants with shoulder dysfunction.

In the systematic review on etiology and risk with meta-analyses (chapter 4, Study 1) the authors identified modifiable musculoskeletal factors putting a patient at risk of developing shoulder dysfunction to be: decreased ER strength, decreased ER:IR strength ratios, decreased IR, GIRD, decreased TROM, decreased flexibility of the PC and PMm. The risk ratio (RR) for developing shoulder dysfunction in the presence of decreased IR were 1.21-fold and in the presence of GIRD there was a 1.026-fold increased risk (Chapter 4, Study 1). A positive association between decreased ER strength and decreased ER:IR strength balance ratio and decreased flexibility of the PMm. were determined. The odds ratio (OR) yielded an increased risk of 1.29-fold in the presence of decreased ER strength and a supraspinatus tear Chapter 4, study 1).

Dutton et al. (2019) advocated for the identification of a cluster of tests to investigate the modifiable musculoskeletal factors and their influence on shoulder dysfunction. Potential incorporation of all known musculoskeletal factors into an assessment tool may help simplify and clarify diagnoses and focused treatment strategies for the shoulder joint.

It is important for clinicians and researchers to establish reliable and accurate tests and tools that can be applied to clinical practice as effective outcome measures in the assessment of the scapulohumeral complex. Drawing on the results obtained with previous studies, a systematic review and physical data collection (Chapter 4, Study 1) by the author, as well as existing literature, a novel assessment scapulohumeral complex model was proposed. The standardisation of clinical tests is however important to reduce variation and to obtain a standardised outcome. In the development of assessment tools, several factors need to be considered, such as the scientific value (reliability and validity) and the clinical application thereof (Castro-Piñero et al. 2009). In order for an assessment model to be clinically relevant it must be reliable and easily reproducible. The reliability of the proposed assessment model was hence tested in a clinical setting using ICC values to determine the intra-rater and inter-rater reliability of the tests included in the model.

2 Methods

Ethical approval was obtained from the University of the Witwatersrand to conduct the pilot reliability study.

Participants without shoulder pain or cervical pathology were conveniently sampled from the South and North of the Johannesburg area. Two independent raters, rater 1 and rater 2, conducted the measurements. Both raters received training in the assessment model, with one more experienced rater and one less experienced rater in the applied testing procedures. Testing took place seven days apart (Coinceicao et al. 2018). The participants were asked to not change their routine in terms of work and/or sporting habits between the two measurement sessions. No participant reported any injuries between the two testing sessions. Measurements were collected once only on both days by each of the two raters.

Prior to testing the participants signed voluntary informed consent. The demographics of the recruited participants were collected on a data collection form. The participants were weighed via a commercially available electronic bath scale (Camry, Loot.co.za) and measured via a statue meter (Hi Care Height Measure/Stature Meter, The Paramedic Shop cc). The testing positions was explained and demonstrated to the participants prior to the testing session. The right, dominant shoulder of five participants was tested. The flexibility measurements were collected first, second the scapular stabiliser force measurements and lastly the force measurements of the anterior deltoid and the rotator cuff (in all ranges) were collected (Appendix 1). Rater 1 tested the participants first and then rater 2 repeated the testing independently. Testing was conducted in the same way on both days.

2.1 Measurements

The range of motion measurements was conducted using an electronic inclinometer (Micro-FET 3, Health Industries Inc., West Jordan, UT, USA). Flexibility measurement of the PMm was measured in the 90° abduction external rotation (ABD/ER) position (Borstad and Ludewig, 2006; Umehara et al. 2017) (Table 1). LD was measured with the LDF Kendall's position (Conroy et al. 2022; Herington and Horsley, 2012) (Table 1) and PC was measured using the PCSL position (Cieminski et al. 2015; Lunden, 2010) (Table 1). External rotation in neutral (ER0) and external rotation ER in 90° was conducted in supine. A full description of the measurement positions are provided in Appendix 1.

2.1.1 Strength measurements

A handheld dynamometer (HHD Micro-FET3) was used to measure the force of the shoulder muscles (Health Industries Inc., West Jordan, UT, USA). The reliability and validity of the HHD have been demonstrated clinically by various researchers (Cools et al. 2016; Rieman et al. 2010; Bagordo et al. 2020; McLain et al. 2019). The "make test" was used with the force measurements collection. The force was maintained for a count of five (Cools et al. 2014; Turner et al. 2009). Supraspinatus was tested in 30 degrees of scaption (a novel position) (Kijkunasathian et al. (2023) (Table 2). AD testing position was based on Brown et al. (2013). The ER rotation positions, for testing of both the oblique fibers and transverse fibers of infraspinatus were based on Hughes et al. (2014) (Appendix 1).

For the scapular stabilisers strength testing the testing positions used for upper trapezius, middle trapezius and lower trapezius and serratus anterior were based on the descriptions of Brown et al. (2013). The full description of all the strength testing positions are described in Appendix 1.

3 Statistical analyses

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS Statistics 240 28.01.1.1, (15) IBM Corp, Armonk, NY, USA). The confidence level (Cl) was set at 95%, and statistical significance was set at $p < 0.05$. The Consensus-based Standards for the selection of health Measurement Instruments (COSMIN) guidelines were used for the calculation of the intra-rater and inter-rater calculations (De Vet et al. 2006; Mokkink et al. 2010).

To quantify measurement error, the standard error of measurement (SEM) was calculated (SD X $2\sqrt{n}$). The minimal detectable change (MDC_{95}) was calculated as the (SEM x 1.96 X $2\sqrt{n}$) to determine the minimal detectable difference between the two raters (inter-rater) and between the two data collection sessions of the same rater (intra-rater). The ICC was used to analyse the intra-rater and inter-rater reliability of the clinical tests. The ICC takes both systematic and random errors into account (De Vet et al. 2006). The ICC agreement values were interpreted as follows:

slight (r = 0.00-0.19); fair (r = 0.20-0.39); moderate (r = 0.40-0.59); substantial (r = 0.60-0.79); and almost perfect (r = 0.80-1.0) (Landis et al. 1977).

4 Results

The demographic data and the intra-and-inter-rater reliability ICC (95% CI) results of all the variables will be presented next.

Table 1 Demographic data of the participants.

Participants	Gender	Mass (kg)	Height (cm)	Age (years)	Dominance
1	M	67,35	186	23	R
2	F	52,8	172	20	R
3	F	59,65	162	22	R
4	F	65,55	165	21	R
5	F	64,3	163	21	R

M = male, F = female, R = right.

The intra-rater ICC values for rater 1 for the flexibility measures, ranged from slight to almost perfect (0.03-0.83) (Table 2). Similar intra-rater reliability was found for the strength measurements of rater 1 (0.05- 0.99) (Table 3). The ICC for rater 2, for the flexibility measurements, ranged from slight to almost perfect (0.00-0.93) (Table 6), and also for the strength measurements (0.18-0.98) (Table 7). The reliability for the force couple ratios of both the scapular stabilisers and the rotator cuff ranged from moderate to almost perfect for intra-rater reliability for both raters (Tables 5,7).

Table 2 The intra-rater (rater 1) reliability ICC (95% CI) values for the flexibility variables.

Intra-rater reliability				
Variables	**SEM**	**MDC_{95}**	**ICC (95% CI)**	**P-value**
PMm	0,31	1,09	0,47 (-0,56-0,93)	0,17
SHB	0,16	0,78	0,58 (-0,433-0,95)	0,11
LD	3,41	3,6	0,76 (-0,13-0,97),	0,03*
ER0	4,58	4,17	0,07 (-0,78-0,83)	0,44
ER90	25,68	9,88	0,83 (0,05-0,98)	0,02*
PCSL (IR)	1,79	2,61	0,036 (-0,80-0,82)	0,47

*PMm = pectoralis minor, SHB = short head of biceps, LD = Latissimus dorsi, ER0 = external rotation in neutral, ER90 = external rotation in 90 degrees, PCSL = posterior capsule, CI = 95% confidence interval, ICC = Interclass correlation coefficients, SEM = standard error of measurement, MDC_{95} = minimal detectable change, statistical significance denoted by *.*

The inter-rater reliability ICC (95% CI) of the flexibility measures ranged from slight to moderate (0.04-0.4) (Table 7), and for the strength measurements from slight to substantial (0.1-0.88) (Table

9). The force couple ratios' reliability for both the scapular stabilisers and the rotator cuff ranged from fair to substantial (0.02-0.63) (Tables 10).

Table 3 The intra-rater (rater 2) reliability ICC (95% CI) values for the flexibility variables.

Intra-rater reliability for Rater 2				
Variables	**SEM**	**MDC_{95}**	**ICC (95% CI)**	**P-value**
PMm2	0,99	1,94	0,00 (-0,81-0,81)	0,5
SHB2	0,56	1,46	0,54 (-0,79-0,82)	0,003*
LD2	5,48	4,56	0,93 (0,53-0,99)	0,46
ER02	4,27	4,03	0,82 (0,02-0,98)	0,02*
ER902	4,41	4,09	0,06 (0,83-0,78)	0,59
PCSL (IR)2	7,44	5,32	0,52 (-0,50-0,93)	0,15

*PMm = pectoralis minor, SHB = short head of biceps, LD = Latissimus dorsi, ER0 = external rotation in neutral, ER90 = external rotation in 90 degrees, PCSL = posterior capsule, CI = 95% confidence interval, ICC = Interclass correlation coefficients, SEM = standard error of measurement, MDC = minimal detectable change, statistical significance denoted by *.*

Table 4 The intra-rater reliability ICC (95% CI) values for the force measurements of both the scapular stabilisers and the rotator cuff.

Intra-rater 1				
Variables	**SEM**	**MDC_{95}**	**ICC (95% CI)**	**P-value**
SAU	0,84	1,79	0,5 (-0,53-0,93)	0,15
RH	0,63	1,55	0,68 (-0,30-0,96)	0,07
MT	0,78	1,87	0,87 (0,2-0,97)	0,01*
LT	0,92	1,92	0,90 (0,32-0,99)	0,007*
UT	0,97	2,46	0,76 (-0,13-0,97)	0,04*
SAL	1,59	2,79	0,70 (-0,25-0,96)	0,06
SS	2,05	2,72	0,76 (-0,13-0,97)	0,03*
AD	1,95	2,18	0,77 (-0,12-0,97)	0,03*
ER0	1,25	1,97	0,77 (-0,12-0,97)	0,03*
IR0	1,06	1,97	0,75 (-0,15-0,97)	0,04*
ER45	1,03	1,98	0,98(0,81-0,99)	0,001*
IR45	1,03	1,98	0,78 (-0,08-0,97)	0,03*
ERABD	0,77	1,71	0,92 (0,47-0,99)	0,004
IRABD	0,76	1,67	0,65 (-0,34-0,96)	0,08

ERF	0,8	1,74	0,94 (0,57-0,99)	0,002*
IRF	1,31	2,23	0,99 (0,86-0,99)	0,001*
HBB (IR)	1,88	2,67	0,99 (0,86-0,99)	0,001*

*SAU = serratus anterior upper fibers, RH = rhomboids, MT = middle trapezius, LT = lower trapezius, SS = supraspinatus, AD = anterior deltoid, ER0 = external rotation in neutral, ER45 = external rotation at 45 degrees, IR45 = internal rotation at 45 degrees, ABDER = external rotation at abduction, ABDIR = internal rotation abduction, ERF = external rotation at frontal flexion, IRF = internal rotation at frontal flexion. CI = 95% confidence interval, ICC agreement = Inter class correlation coefficients. Meandiff_1,2 = mean difference between examiner 1 and 2, SDdiff_AB = standard deviation of the mean difference between examiner 1 and 2. SEM = standard error of measurement, MDC = minimal detectable change, statistical significance donated by *.*

Table 5 The intra-rater reliability ICC (95% CI) values for the force couple ratios (rater 1).

Variables	Minimum	Maximum	Mean	95%CI	ICC (95% CI)	P value
SAU/MT	1,83	3,21	2,49	0,51	0,48	0,48
SAU/MT	2,54	3,95	3,24	0,60		
SAL/RH	0,74	1,30	0,99	0,23	0,81	0,06
SAL/RH	0,64	1,51	1,03	0,32		
UT/LT	2,08	5,29	3,06	1,29	0,96	0,001*
UT/LT	2,30	5,16	3,26	1,18		
SS/AD	1,05	1,13	1,09	0,03	0,11	0,46
SS/AD	1,12	1,16	1,13	0,02		
ER/IR0	0,94	1,11	1,04	0,07	0,79	0,70
ER/IR0	0,75	1,28	1,04	0,20		
ER/IR45	0,96	1,41	1,18	0,16	0,50	0,26
ER/IR45	0,86	1,56	1,16	0,31		
ABDER/ABDIR	1,05	1,77	1,31	0,28	0,46	0,64
ABDER/ABDIR	1,00	1,94	1,43	0,48		
ERF	0,82	1,16	0,99	0,14	0,49	0,27

IRF	2,00	7,10	3,46	2,07

*SAU = serratus anterior upper fibers, RH = rhomboids, MT = middle trapezius, LT = lower trapezius, SS = supraspinatus, AD = anterior deltoid, ER0 = external rotation in neutral, ER45 = external rotation at 45 degrees, IR45 = internal rotation at 45 degrees, ABDER = external rotation at abduction, ABDIR = internal rotation at abduction, ERF = external rotation at frontal flexion, IRF = internal rotation at frontal flexion. CI = 95% confidence interval, ICC agreement = Inter class correlation coefficients. Meandiff_1,2 = mean difference between examiner 1 and 2, SDdiff_AB = standard deviation of the mean difference between examiner 1 and 2. SEM = standard error of measurement, MDC = minimal detectable change, statistical significance donated by *.*

Table 6 The intra-rater (rater 2) reliability values ICC (95% CI) for the force variables.

Intra-rater rater 2				
Variables	SEM	MDC_{95}	ICC (95% CI)	P-value
SAU2	1,8	2,61	0,58 (-0,43)	0,11
RH	0,95	1,9	0,90 (0,35-0,99)	0,007*
MT	0,64	1,56	0,93 (0,53-0,99)	0,003*
LT	0,76	1,7	0,98 (0,79-0,98)	0,001*
UT	0,39	1,22	0,18 (-0,74-0,86)	0,37
SAL	0,74	1,68	0,89 (0,27-0,99)	0,009*
SS	0,85	1,8	0,98 (0,82-0,99)	0,001*
AD	0,95	1,9	0,98 (0,80-0,99)	0,001*
ER0	0,74	1,68	0,74 (-0,17-0,97)	0,04*

IR0	0,99	1,96	0,93 (0,48-0,99)	0,004*
ER45	0,72	1,65	0,70 (-0,26-0,96)	0,06
IR45	0,82	1,77	0,64 (-0,36-0,96)	0,08
ERABD	0,48	1,35	0,74 (-0,18-0,97)	0,49
IRABD	0,97	1,92	0,73 (-0,2-0,97)	0,05
ERF	0,8	1,74	0,86 (0,15-0,98)	0,05
IRF	1,55	2,43	0,94 (0,52-0,99)	0,003*
HBB (IR)	1,16	2,1	0,95 (0,57-0,99)	0,002*

*SAU = serratus anterior upper fibers, RH = rhomboids, MT = middle trapezius, LT = lower trapezius, SS = supraspinatus, AD = anterior deltoid, ER0 = external rotation in neutral, ER45 = external rotation at 45 degrees, IR45 = internal rotation at 45 degrees, ABDER = external rotation at abduction, ABDIR = internal rotation at abduction, ERF = external rotation at frontal flexion, IRF = internal rotation at frontal flexion. CI = 95% confidence interval, ICC agreement = Inter class correlation coefficients. statistical significance donated by *, CI = 95% confidence interval, ICC agreement = Inter class correlation coefficients. Meandiff_AB = mean difference between examiner 1 and 2, SDdiff_1,2 = standard deviation of the mean difference between examiner 1 and 2. SEM = standard error of measurement, MDC = minimal detectable change.*

Table 7 The intra-rater (rater 2) reliability values ICC (95% CI) for the force couple ratios of the variables.

Variables	Minimum	Maximum	Mean	95%CI	ICC	P value
SAU/MT1	1,39	2,65	2,06	0,56	0,33	0,36
SAU/MT	1,83	3,21	2,49	0,51		
SAL/RH1	0,77	1,17	0,98	0,17	0,59	0,21
SAL/RH	0,74	1,30	0,99	0,23		
UT/LT1	1,45	1,84	1,63	0,17	0,83	0,05
UT/LT	2,08	5,29	3,06	1,29		
SS/AD1	0,74	1,19	0,99	0,19	0,41	0,31
SS/AD	1,05	1,13	1,09	0,03		
ER/IR01	0,80	1,16	0,93	0,14	0,37	0,34
ER/IR0	0,94	1,11	1,04	0,07		
ER/IR451	0,71	0,98	0,82	0,11	0,59	0,21
ER/IR45	0,96	1,41	1,18	0,16		
ABDER/ABDIR1	0,69	1,08	0,89	0,14	0,33	0,35
ABDER/ABDIR	1,05	1,77	1,31	0,28		
ERF/IRF1	0,62	0,93	0,72	0,13	0,10	0,47

ERF/IRF	0,82	1,16	0,99	0,14

SAU= serratus anterior upper fibers, MT = middle trapezius, SAL = serratus anterior lower fibers, UT = upper trapezius, LT = lower trapezius, SS = supraspinatus, AD = anterior deltoid, ER = external rotation, IR = internal rotation, ABD = abduction, F = frontal. 1 = rater one, 2 = rater 2, ICC = intra class coefficient.

Table 8 The inter-rater reliability ICC (95% CI) values for the flexibility measurements between rater 1 and 2.

Variable	ICC (95%CI)	P-value	SEM	MDC_{95}	Mean (1-2)	SD (-2)
PMm2	0.04 (-0.80-0.81)	0.05	0,22	0,28	0.79	0.45
SHB2	0,05 (0,73-0,82)	0,44	0,19	0,84	0,8	0,64
LD2	0,40 (-0,88-0,61)	0,78	2,05	2,79	0,8	0,34
ER02	0,31 (-0,58-1,9)	0,25	3,91	3,86	0,9	0,64
ER (90)2	0,33 (-0,58-0,90)	0,24	11,91	6,73	1,2	10,29
PCSL (IR)2	0,04 (-0,78-0,93)	0,52	1,72	6,14	5,39	5,39

CI = 95% confidence interval, ICC agreement = Inter class correlation coefficients. Meandiff_1,2 =mean difference between examiner 1 and 2, SDdiff_1,2 = standard deviation of the mean difference between examiner 1 and 2. SEM = standard error of

measurement, MDC = minimal detectable change.

Table 9 The inter-rater reliability ICC (95% CI) for the force variables.

Variables	ICC (95% CI)	P value	SEM	MDC	SD 1-2	Mean 1-2
SAU	0,32 (-0,87-0,65)	0,73	0.68	1.60	-1,1611	2,860
RH	0,28 (-0,86-0,68)	0,7	0.91	1.86	0,6377	0,880
MT	0,12 (-,81-0,75)	0,6	0.18	0.83	0,5145	0,920
LT	0,16 (-0,82-0,74)	0,61	0.17	0.80	0,1988	0,640
UT	0,84 (0,98-1,11)	0,98	0.46	1.32	0,1941	5,100
SAL	0,88 (-0,88-0,63)	0,76	0.80	1.74	1,1485	1,020
SS	0,56 (-0,93--0,45)	0,88	0.79	1.60	1,4969	1,960
AD	0,22 (-0,84-0,71)	0,66	0.68	1.20	1,2778	1,560
ER0	0,37 (-0,88-0,62)	0,77	0.38	0.83	0,5781	1,500
IR0	0,1 (-0,77-0,580)	0,49	0.25	0.97	0,7212	1,000
ER45	0,12 (-0,81-0,76)	0,58	0.18	0.83	0,3141	0,760
IR45	0,16 (-0,23-0,74)	0,62	0.16	0.40	-0,1310	-0,640
ERABD	0,15 (-0,81-0,75)	0,6	0.14	0.72	0,2463	0,6440
IRABD	0,28 (-0,86-0,68)	0,7	0.22	0.91	-0,1101	-0,600
ERF	0,43 (-0,90-0,58)	0,8	0.39	1.14	-0,0308	0,480
IRF	0,36 (-0,86-0,68)	0,75	0.35	1.15	-0,2694	-0,740
HBB (IR)	0,29 (-0,86-0,68)	0,71	0.004	0.12	0,7049	4,380

SAU= serratus anterior upper fibers, MT = middle trapezius, SAL = serratus anterior lower fibers, UT = upper trapezius, LT = lower trapezius, SS = supraspinatus, AD = anterior deltoid, Er = external rotation, IR = internal rotation, ABD = abduction, F = frontal, CI = 95% confidence interval, ICC agreement = Inter class correlation coefficients. Meandiff_1,2 = mean difference between examiner 1and 2, SDdiff_1 and 2 = standard deviation of the mean difference between examiner 1 and 2. SEM = standard error of measurement, MDC = minimal detectable change.

Table 10 The inter-rater reliability ICC (95% CI) values of the force couple ratios of both the scapular stabilisers and of the rotator cuff musculature.

Ratios	Minimum	Maximum	Mean	95%CI	ICC	SIG
SAU/MT1	1,39	2,65	2,06	0,56	0,49	0,65
SAU/MT	1,83	3,21	2,49	0,51		
SAL/RH1	0,77	1,17	0,98	0,17	0,63	0,18
SAL/RH	0,74	1,30	0,99	0,23		
UT/LT1	1,45	1,84	1,63	0,17	0,05	0,66
UT/LT	2,08	5,29	3,06	1,29		
SS/AD1	0,74	1,19	0,99	0,19	0,02	0,51
SS/AD	1,05	1,13	1,09	0,03		
ER/IR01	0,80	1,16	0,93	0,14	0,51	0,25
ER/IR0	0,94	1,11	1,04	0,07		
ER/IR451	0,71	0,98	0,82	0,11	0,48	0,28
ER/IR45	0,96	1,41	1,18	0,16		
ABDER/ABDIR1	0,69	1,08	0,89	0,14	0,39	0,62
ABDER/ABDIR	1,05	1,77	1,31	0,28		
ERF/IRF1	0,62	0,93	0,72	0,13	0,29	0,60

ERF/IRF	0,82	1,16	0,99	0,14

SAU= serratus anterior upper fibers, MT = middle trapezius, SAL = serratus anterior lower fibers, UT = upper trapezius, LT = lower trapezius, SS = supraspinatus, AD = anterior deltoid, ER = external rotation, IR = internal rotation, ABD = abduction, F = frontal. 1 = rater one, 2 = rater 2, ICC = intra class coefficient.

5 Discussion

The aim of the study was to determine the reliability of a proposed assessment model incorporating both flexibility and strength measurements of the scapulohumeral complex. Assessment models for the musculoskeletal system need to be reliable, cost effective, time-effective and easily reproducible in the clinical setting (Bruton et al. 2000). Currently used standardised orthopaedic shoulder tests are mainly used in practice to diagnose shoulder pain. However, the diagnostic validity of these tests is questioned in practice as they correlate poorly with anatomy (Hughes et al. 2008). Even after arriving at a diagnosis using standardised orthopaedic shoulder tests, the practitioner is still left with unanswered questions, as to what structures should be rehabilitated. Shoulder pain can be driven by many shoulder structures (Taylor and Green, 2008; Baigent et al. 2023). Many modifiable musculoskeletal factors have been identified in patients presenting with shoulder dysfunction in current literature (Chapter 4, Study 1). Using our proposed model for the identification of the specific modifiable musculoskeletal factors affected rehabilitation can be tailored to address those factors.

The MDC_{95} results (Table 2) can be used to check if the results determined between measurements (day 1 and day2) of rater 1 (intrarater) reliability analysis is not due to inter-trial variability or measurement error. Measurement of ER0 on day 1 was (68.60) degrees and on day 2 (80.20) degrees (Appendix A). A MDC_{95} of $\geq$ 4.17 degrees, therefore, reflects no measurement error. The same principles can be applied to the strength measurements e.g. of Table 4 with MDC_{95} value of UT of 2.46 and measures of rater 1 of (4.16 and 9.52) on the two separate days; therefore, a MDC_{95} 2.46 reflects no measurement error.

In the clinical setting muscle tests are normally applied only once due to time constraints or risking producing muscle fatigue and flaring up injured tissue. Therefore, in our study the tests were conducted once on the two separate days by each rater. The analysis of both the flexibility and strength measures indicated that the intra-rater reliability was overall high (Tables 2-7). High intra-rater ICC values of the strength values were found in our study (Tables 4,6). The intra-rater reliability was also high for the majority of the strength measurements except for the UT force reliability value of rater one (Table 4). Paying more attention to the measurement positions and increased training of the assessment positions may lead to higher reliability values.

The ER and IR force reliability measurement values were high for both raters (Tables 4,6). This finding concurs with previous researchers measuring the ER and IR either in the seated, standing or supine positions (Cools et al. 2014; Roman et al. 2022; Balalha et al. 2014; Eduard et al. 2011) or the prone positions (Hopkins et al. 2000; Cools et al. 2014) where high reliability ICC values of >.80 were concluded.

The force couple ratios were calculated for both the scapular stabilisers and the rotator cuff (Tables 5,7,10). Most reliability values were high, except for the force couple ratio of SS/AD for rater 1 (Table 5). The position of testing for both the SS and the AD may have played in role in the lower reliability values of these tested force couple ratios. More practice may improve the reliability values. For rater 2 the ERF/IRF ratio was slight (Table 6). Once again the testing position may have been difficult for the testing and more practice should improve the reliability values. The intra-rater (rater 1 and rater 2) reliability for the force couple ratios of the both the scapular stabilisers and the rotator cuff were higher than the individual force measurements and ranged from moderate to high for most values except for the force couple between the SS/AD that was slight (Table 5,7). The reliability value for the force couple ratio of the UT/LT was statistically significant $p=0.001$ for rater one (Table 5). The inter-rater reliability, however, was only slight to fair for the flexibility measurements, and only slight to substantial for the strength measurements (Tables 8-10). The inter-rater reliability was also better for the force couple ratios than for the individual muscle force values and reliability ranged from fair to substantial for all force couple ratios, except for the force couple ratios between the UT/LT and SS/AD that was slight for both (Tables 8-10). It may therefore be more meaningful to use not only the force measurements but also the force couple ratios in the assessment process.

Consistency in HHD placement and/or clarity of instruction to the participant may have impacted the inter-rater reliability. There is a lack of intra-and-inter rater reliability studies on force couple ratios of the scapular stabiliser and comparisons are therefore difficult to make.

In our study the ER:IR strength ratios of the rotator cuff demonstrated moderate to excellent intra-rater reliability in all ranges (Table 5, 7). This concur with ER:IR ratio findings of other studies of Abdullah et al. (2023) where ICC 95% CI (0.83-0.82) reliability values for intra-rater reliability was investigated. In the study of Cools et al. (2014) the concluded ICC 95% CI high reliability values of (0.83-0.82) for the ER:IR ratios was determined.

It may, therefore, be more meaningful to assess both the individual muscle force as well as the force couple ratios of both the scapular stabilisers and of the rotator cuff in practice. Our findings can hence be seen as a confirmation of the statement of Labriola et al. (2005). In the biomechanical functioning of both the scapular stabilisers and of the rotator cuff the known force couples are important for rehabilitation and to improve joint stability (Labriola, et al. 2005). The whole cuff contributes to shoulder movement, as it is well known that the force couples, the agonistic/ antagonist and synergistic working of the force couples is important for optimal rotator cuff functioning (Abboud et al. 2002; David et al. 2000; Kuhlman et al. 2002; Werner et al. 2006). The evaluation of all ranges as suggested in the assessment model can hence lead to the known values of force couples. Monitoring and correction of these force couples can lead to better informed treatment strategies. Rehabilitation may be guided by the restoration of both the force and the balance of forces (force couple ratios). In the clinical situation where two individual raters may need to compare results, looking at the force couple ratios may be more meaningful than the individual force values.

The intra-rater reliability was high for most of the flexibility tests except for the ER0 for rater one and for rater two the PMm and ER90 (Tables 2,3). More familiarisation with the testing positions may increase the reliability values. The inter-rater reliability for both the flexibility and force measurements was generally low (Tables 8-9). It has been shown in literature that many factors can influence muscle strength testing, for example the strength of the rater (Bohannon, 2019; Cools et al. 2014; Stark et al. 2011) This may have been the case in our study. Only one study could be located that evaluated the inter-tester reliability of force measurement. The study of Dollings et al. (2012), took the mean of three different testing sessions and concluded a good inter-rater reliability with an ICC value of (0.52 to 0.94). However, it can be argued that if the mean of the different combined readings is used, a true patient individual force measurement value is not represented. In contrast to our study, MacMillan ‘s et al. (2021) study, investigating muscle strength using manual muscle testing, determined a high intra-and inter-rater reliability. However, using handheld dynamometry is more objective and measurable and can distinguish smaller changes in muscle force, unlike manual muscle testing (Cools et al. 2014). It may, therefore, be postulated that using handheld dynamometry may produce lower inter-rater reliability than manual muscle testing. The HHD values are more sensitive to change and may therefore show wider variances between and within raters.

Inter-rater reliability of the flexibility testing may be improved by more focused training sessions in the assessment model. In has been shown in literature than increased number of testing trials, a minimum of five trials, increases the test's reliability, through reducing measurement error and increasing the ICC values (Pinsault et al. 2008; Swait et al. 2007). Investigating the reliability of both the flexibility and strength assessment in non-painful versus painful shoulders may also yield different reliability scores. This has been proven in the study of Cuthbert and Goodheart (2007) where both inter-rater reliability of 82.00% – 97.00% and intra-rater reliability of 96.00% – 98.00% were determined when measuring the symptomatic and asymptomatic participants respectively of a non-sporting population. Therefore, to improve both the intra-rater and inter-rater reliability scores with the flexibility measures, more intensive training to closer correlate the testing positions, and to identify compensatory mechanisms, could be implemented.

Testing a battery of musculoskeletal tests, as in our study incorporating both flexibility and strength assessments, have been proven reliable in both intra-and inter-rater values amongst collegial athletes (Haitz et al. 2014). One reason provided is that superior physical fit athletes are used to batteries of tests applied to them on a regular basis. Physiologically they may be able to respond and recover better than non-athlete populations exposed to a battery of tests on the same and different days; explaining some of the poorer reliability findings in our study (Haitz et al. 2014).

Strengths and limitations

All the modifiable musculoskeletal factors identified in the global systematic review to be present in painful shoulders (Chapter 4, Study 1) were incorporated in the current proposed model. The battery of test proposed in our assessment model can be seen as clinically relevant as the musculoskeletal factors identified and tested with the reliability study yielded valid results for both the intra and interrater results. Comparing assessment results from an increased number of raters, may yield more valid findings for interpretation. Despite only a short training period of 30 minutes, the second rater, not familiar with the assessment model, produced good overall intra-rater reliability values. Both raters achieved overall good intra-rater reliability values in both the flexibility and strength measurements. Good inter and intra rater values could have been influenced by the homogenous participant population. The assessment model was only tested on young participants with non-painful shoulders which present a homogeneous sample. This might be a limitation and may yield different findings when tested on a different population. This was the first pilot of the proposed assessment model and future research should consider making the necessary adjustments in testing procedures.

Recommendations

The assessment model should be tested on larger sample sizes, in different population groups and preferably amongst participants with non-painful and painful shoulders. Raters should receive more intensive training in the assessment model, since it involves different positions and measurements. This may yield different results.

Conclusions

The current study examined both the intra-rater and inter-rater reliability of the musculoskeletal tests of a scapulohumeral complex assessment model. The intra-rater reliability of most tests remained high overall which is promising for implementation into clinical practice. Continuous efforts to improve the reliability of the scapulohumeral complex assessment model should however be sought, before implementation as a clinical tool.

Data availability statements

The authors Sonia Briel and Corlia Brandt declare that the data supporting the findings of this study are available within the paper and in the supplementary online information files.

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Disclosure of interest

All authors as above-mentioned declare that they have no affiliations with or involvement in any organization or entity with any financial interest or nonfinancial interest in the subject matter or materials discussed in this manuscript.

Ethics declaration

Ethical approval was obtained from the Approval Committee of the Human Internal Review Board: Human Research Ethics Committee (Medical) number M190984.

Voluntary signed consent was obtained from all participants prior to the testing session.

Consent to publish

Written informed consent for publication was obtained from the participant for the use of the images that will be freely available on the internet and may be seen by the public.

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Appendices

Appendix A

Table: Mean (SD) of the flexibility variables participants (n=5) (95%CI)

Variables		**Mean**	**N**	**Std. Deviation**
Pair 1	PMm	6,300	5	0,45
	PMm	6,500	5	0,61
Pair 2	SHB	6,500	5	0,50
	SHB	6,100	5	1,43
Pair 3	LD	7,700	5	3,91
	LD	9,700	5	4,76
Pair 4	ER0	80,20	5	17,31
	ER0	68,60	5	12,10
Pair 5	ER90	219,20	5	28,19
	ER90	95,00	5	22,12
Pair 6	PCSL (IR)	63,00	5	10,63

	PCSL (IR)	61,80	5	9,42

Appendix B

Variables		**Mean**	**N**	**SD**
Pair 1	SAU1	7,92	5,00	1,21
	SAU	8,26	5,00	2,15
Pair 2	RH1	4,58	5,00	1,72
	RH	4,86	5,00	1,90
Pair 3	MT1	3,34	5,00	1,17
	MT	2,66	5,00	1,09
Pair 4	LT1	3,40	5,00	0,97
	LT	3,16	5,00	0,91
Pair 5	UT1	9,52	5,00	1,11
	UT	4,16	5,00	0,91
Pair 6	SAL1	4,56	5,00	1,93
	SAL	4,80	5,00	1,69
Pair 7	SS1	5,32	5,00	2,35

	SS	4,96	5,00	2,55
Pair 8	AD1	4,92	5,00	2,24
	AD	4,36	5,00	2,21
Pair 9	ER01	5,72	5,00	1,43
	ER0	5,38	5,00	2,36
Pair 10	ER451	4,20	5,00	1,18
	ER45	4,12	5,00	1,14
Pair 11	ERABD1	3,58	5,00	0,80
	ERABD	3,58	5,00	1,06
Pair 12	IRABD1	2,82	5,00	0,94
	IRABD	2,80	5,00	1,52
Pair 13	ERF1	3,60	5,00	0,83
	ERF	3,68	5,00	1,42
Pair 14	IRF1	3,76	5,00	1,33
	IRF	3,46	5,00	2,07
Pair 15	HBB (IR)1	3,22	5,00	1,90
	HBB (IR	3,38	5,00	2,30

Chapter 9 Discussion

The discussion in Chapter 9 highlights and brings into context all the findings of the individual Studies (1, 2, 3, 4, and 5). The culmination of the findings led to the development of an assessment model for the scapulohumeral complex, Study 5 (Chapter 8). In Chapter 2 an overview of globally available current literature on the presence of modifiable musculoskeletal factors in non-athlete and athletic population groups was collected and analysed. This was followed with a physical data collection study on the presence of modifiable musculoskeletal factors in a general non-athlete population group. The second Study (Chapter 5) researched the superior force couple between the SS and the AD, and the inferior force couple between the ER and the IR rotators. The third study (Chapter 6) investigated the periscapular musculature flexibility. The opinions of physiotherapists working in the shoulder field were sought in a NGT discussion group on the key identified findings of Studies 1, 2, and 3. (Chapter 7). The developed scapulohumeral complex assessment model was introduced in Study 5 (Chapter 8).

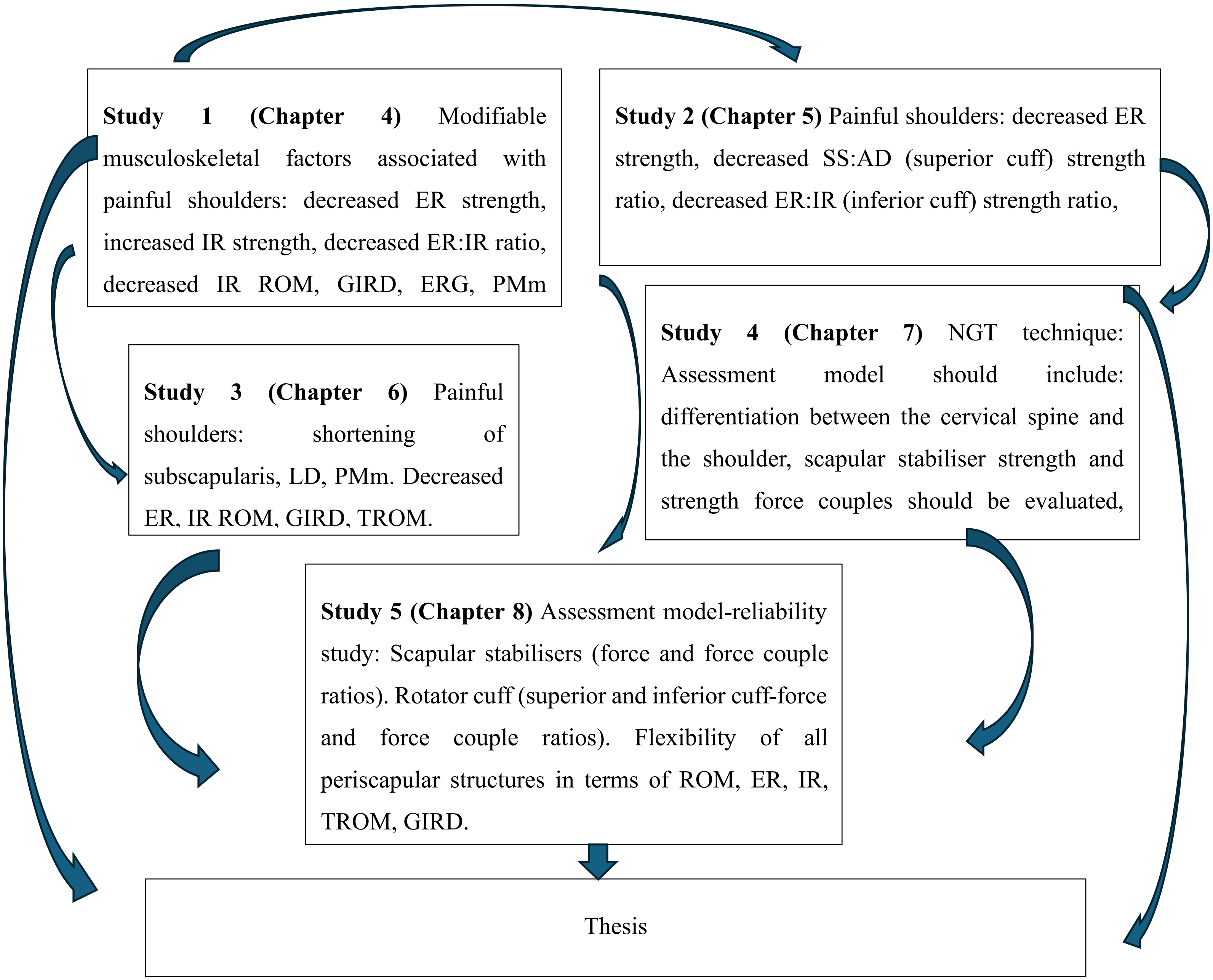


Figure 1 An updated flow diagram of informed results of the present thesis.

9.1 Intra-articular glenohumeral joint centering

Evidence on the force values of the rotator cuff and of the scapular stabilisers were explored in the first study through a systematic review and meta-analyses (Chapter 4). The rotator cuff force couples were also investigated in the second paper (Chapters 5). Known force couple ratios of the rotator cuff is the inferior force couple between the external and the internal forces of the anteriorly placed subscapularis and the posteriorly placed infraspinatus and teres minor as yielded by the first study (Chapter 4). The other force couple ratio between the supraspinatus and the anterior deltoid as originally proposed by Inman et al 1944 was investigated in the second study (Chapter 5). The proposed and concluded SS:AD force couple ratio was a first of its kind to be proposed with isometric muscle force testing. The concluded results of the inferior force couple ratio revealed a higher ER:IR strength ratio to be present in the non-painful shoulders of participants in the SR. This concurred with the results found in the non-painful shoulders in Study 2, conducted in a general population group, concluding higher force couple values to be present in the ER:IR force couples' ratio in the non-painful shoulders compared to the painful shoulders. The discussion will focus on the musculoskeletal factors influencing the intraarticular centring and the extraarticular centring of the scapulohumeral complex (Figure 1 and 2).

The optimal functioning of the scapulohumeral complex is dependent on an intricate interplay between the static stabilisers (ligaments, the bony and labral structures, the negative intraarticular pressure) and all the dynamic stabilisers (the rotator cuff, the scapular stabilisers and the long head of biceps) (Goetti et al 2020; Halder et al. 2000; Lugo et al. 2008). Only musculoskeletal factors were however, researched for the purpose of the current project. Goetti et al. 2020 reiterated the concept of balanced scapular and rotator cuff force couples and their importance for the optimal functioning of the scapulohumeral complex.

Higher force values of the external rotators of the rotator cuff were found in the SR to be present in participants without shoulder pain (Chapter 4, Study 1). The findings of our study concur with findings of studies done on athletes namely, higher ER strength values that is present in non-painful shoulders (Cools et al. 2016; Maestroni et al. 2020; Marcondes et al. 2013.) The findings of our study also concur with the findings in a general population group similar to our group (Rosa et al.

2019). An interesting finding was that the IR was not weakened in participants with shoulder pain in Study 2 (Chapter 5). Similar conclusions were drawn in previous studies of participants with painful shoulders (Skazalski et al. 2021). A possible reason for this finding may be that only the ER weaken in participants with painful shoulders. The cause hereof, should be explored with longitudinal study designs. The effect of age on muscle force proved to be minimal, with muscle force determined to be a weak positive predictor of muscle strength (Chapter 5). The answer, therefore, to maintaining pain free shoulders may perhaps lie in the preservation of ideal force couple ratios rather than the effect of age. These phenomena should be explored in longitudinal cohort studies.

To our knowledge, our study was a first if its kind to investigate the isometric force couple between the supraspinatus and the anterior deltoid (superior force couple) (Chapter 5, Study 2). Inman et al. (1996) originally proposed the force couple between the supraspinatus and the deltoid. Specific force couple ratios were determined of the superior force couple with the force of the SS decreased compared to the force of the AD in painful shoulders (Chapter 5, Study 2, Table 4). Decreased activity of SS may potentially lead to a decreased compression force into the glenoid cavity and an increased cranially directed force by the AD.

The force of the rotator cuff can be classified as a three-component force vector (Yanagawa et al. 2008). A compressive force to aid the stability of the glenohumeral head into the glenoid cavity provided by the simultaneous action of the SS, IS, TM and subscapularis Yanagawa et al.2008). A shear force in an antero-posterior direction caused by the agonistic or antagonistic force of either the subscapularis or the infraspinatus/ teres minor. The imbalance of this force couple can potentially cause destabilisation of the glenohumeral joint (Yanagawa et al. 2008). The humeral head can translate up to 6mm in the glenoid cavity (Apreleva et al. 2000; Poppen and Walker, 1978). Previous studies have shown that the whole cuff (SS, IS, TM, subscapularis) contributes to normal elevation of the arm (Labriola, 2004; Huegel et al. 2015; Hwang et al. 2014, Oh et al. 2014). The concluded decreased ER:IR strength balance ratio in painful shoulders and the decreased SS:AD force couple ratio may hence in essence translate into increased upward migration of the humeral head due to the unopposed AD force, which may promote subacromial impingement (Graichen et al. 2000; Steenbrink et al. 2010; Keener et al. 2009). Theoretically, the decreased ER:IR force couple ratio can contribute to the antero-postero shear force translation and the decreased SS:AD force couple ratio, as concluded in our study, may increase the upward migration of the humeral head. The combined disrupted force couple effect of both the superior and the inferior force couples may contribute to shoulder dysfunction (Figure 2).

In Study 3 (Chapter 6) the flexibility of the modifiable musculoskeletal factors were investigated such as the LD, subscapularis, SHB, PMm and the PC. Decreased flexibility of the PC with resulted decreased IR was concluded in participants with painful shoulders in both the SR, Study1 and in Study 2. It is known that PC shortening may cause an antero-superior translation of the humeral head (Burkhart et al. 2003; Noonan et al. 2016). Therefore, the combined antero-superior force created by the PC shortening and the imbalanced humeral centering caused by the ER:IR and the SS:AD ratio imbalances may lead to intraarticular glenohumeral decentering with resultant subacromial impingement. It is known that decreased flexibility of both the upper and lower fibres of subscapularis decrease ER ROM in neutral and in 90 degrees (Thurner et al. 2013; Muraki et al. 2009). Theoretically decreased flexibility of the subscapularis can also add to the decentering of the humeral head. However, no studies could be located that investigated this relationship (Figure 2).

The SR (Chapter 4, Study 1) determined that decreased IR was present in the painful shoulders of participants. This finding concurred with the findings in Study 3 (Chapter 6) namely, the presence of decreased IR in the painful shoulders of participants. Possible structures responsible for decreased IR have been linked to the posterior capsule (Burkhart et al. 2003; Manske et al. 2013). Literature has indicated that a shortened posterior capsule can lead to anterior superior migration of the humeral head. This phenomenon can potentially predispose to subacromial impingement (Burkhart et al. 2003; Manske et al. 2013; Evans and Guyver, 2015). Furthermore, the combined effect of the decreased ER strength, decreased ER:IR force couple ratio coupled with a shortened PC, can increase humeral head decentring (Figure 2). The combined effect of the above-mentioned may result in increased upward migration of the humeral head and promote subacromial impingement and consequent shoulder pain. Pain might therefore be experienced with active movement of the arm in all planes of movement as normal arthrokinematics are disrupted.

9.2 Extra-articular centering of the scapulothoracic joint

The SR (Chapter 4, Study 1) concluded that scapular dyskinesis exists in a patient with shoulder pain. Weakness of lower trapezius and serratus anterior have been determined in the presence of scapular dyskinesis (Phadke et al. 2009; Solem-Bertoft et al. 1993). Optimal positioning and control, static and dynamic, of the scapula is mainly through the combined actions of the scapular stabilisers, the upper, middle and lower trapezius, the upper fibers and lower fibers of serratus anterior and the rhomboids (Bagg and Forrest, 1988; Inman et al. 1944; Kiber, 1998; Cools et al. 2004). In our study the muscle force of the scapular stabilisers were not determined, however the primary researcher has previously investigated the force and the force couple ratios of the scapular stabilisers and the electromyographic activity of the serratus anterior lower fibers and the lower trapezius (Briel et al. 2020; Briel et al. 2022). Briel, et al. 2022 determined the presence of specific force and force couple ratios to be present in healthy participants. Even though anatomically one muscle, the serratus anterior muscle consists of different parts, the upper and lower fibers (Smith et al. 2003). The trapezius muscle consists of the upper, middle and lower fibers, even though anatomically one muscle (Johnson et al. 1994). However different functions are shown of the individual parts of the serratus anterior (upper and lower fibers) (Ekstrom et al. 2004) and the trapezius (upper, middle and lower fibers) (Wiedenbauer and Mortenson, 1952; Fey et al. 2007) musculature. The serratus anterior upper fibers are more active in protraction of the scapula, and the serratus anterior lower fibers are more involved with upward and posterior tilting of the scapula (Ekstrom et al. 2004). The upper fibers of the trapezius muscle is more active in elevation of the scapula (Fey et al. 2007; Johnson et al. 1994) , the middle fibers more involved in retraction of the scapula (Johnson et al. 1994) and the lower fibers more involved in upward rotation of the scapula (Johnson et al. 1994; Phadke et al. 2009.Specific force couple ratios were determined of the UT:LT, MT: SAU, SAL:RH in both female and males (Briel et al. 2022) without shoulder pain (Briel et al. 2022) (Figure 2). Individual muscle strength is important, but more imperative is the balanced force couple ratios of all the scapular stabilisers in controlling balanced scapular motion (Bagg and Forrest, 1988; Cools et al. 2004; Ludewig and Reynolds, 2009). The individual strength of muscles are important, but the force couple ratio made up of the agonistic/ antagonistic and synergistic musculature overshadows the individual muscle strength (Kibler, 1998; Magarey and Jones, 2003). This phenomenon is illustrated when good muscle strength is reported with individual muscle testing, but execution of functional movements is poor (Kibler and Chandler, 1994; Magarey and Jones, 2003). Several authors have determined that the serratus anterior lower fibres and the lower trapezius are the only upward rotators of the scapula (Ekstrom et al. 2004; Phadke et al. 2009). In the EMG study of Briel et al. (2020) the serratus anterior lower fibres demonstrated increased activity in the frontal plane of abduction and the lower trapezius and serratus anterior lower fibres were both active in the sagittal plane of movement (Briel et al. 2020). In EMG studies decreased ratios of the UT:LT have been demonstrated with increased activation of UT (Cools et al. 2007). Historically, the trapezius (upper, middle and lower) demonstrated increased activity in abduction versus flexion ((Bagg and Forrest 1986; Inman et al. 1944). However, other more recent studies differed from these findings and concluded that increased activity of serratus anterior lower fibres versus trapezius activity was present in abduction compared to flexion (Briel et al. 2020; Ludewig and Reynolds 2009; McClure et al. 2001; Smith et al. 2003).

It was determined that in injured shoulders of population groups presenting with shoulder pain, altered EMG ratios of the lower trapezius, the middle trapezius and the serratus anterior lower fibers were present (Cools et al. 2007; Karduna et al. 2005; Myers et al. 2005). Numerous EMG studies have determined decreased lower trapezius, serratus anterior lower fibers and increased upper trapezius activity in patients with shoulder pain (Cools et al. 2004, 2005, 2007; Ludewig and Cook 2000). Increased EMG UT:LT ratios have also been concluded in participants with shoulder pain (Cools et al. 2007). Due to limited isokinetic or isometric information available on the scapula force couple ratios comparisons are made to available EMG studies. Even though not homogeneous some information can be inferred from the EMG studies. The isometric force measurement study of Briel et al. (2020) was conducted on a younger and on non-painful shoulders in a younger population aged between 18-35 years of age. Notwithstanding, the conclusions reached may serve as a guideline to be used in clinical practice. Clinically, the known values of all the scapular stabilisers (UT, MT, LT, RH, SAU, SAL) and of all the proposed scapular stabilisers ratios (UT: LT, MT: SAU, SAL: RH) (Briel et al. 2020) may lead to better assessment strategies. Correction of these identified altered force couple ratios may lead to correction of scapular dyskinesis. It is might therefore be important to monitor the force couple ratios for assessment and rehabilitation purposes (Figure 2).

PMm length plays a role in the scapula's position (Saine et al. 2020; Turgut and Baltaci, 2018). A shortened PMm can cause anterior tilt and protraction of the scapula due to its anatomical attachment to the scapula (Kisner et al. 2017; Kibler et al. 2013). The presence of a shortened PMm in painful shoulders has been concluded in numerous studies in different populations groups Harrington et al., 2014; Dutton et al. 2019; Ebaugh et al. 2017). A shortened PMm has also been linked to the presence of scapular dyskinesis (Saine et al. 2020; Bond, 2016). A shortened PMm has been identified as an associated factor of shoulder dysfunction in the present SR (Chapter 4, Study 1) in mainly athletic populations (Briel et al. 2024). Study 3 (Chapter 6) determined the presence of a shortened PMm in the painful shoulder of participants (Briel et al. 2024 b).

In Study 3 (Chapter 6) a shortened LD was determined in the painful shoulders of participants. Anatomically, due to the attachment of the LD to the inferior angle of the scapula, a shortened LD can limit elevation of the scapula (Feijen et al. 2020; Herrington and Horsley, 2014; Laudner and Williams, 2013).

In Study 3 (Chapter 6) the painful shoulders presented with decreased IR. Contributing factors to decreased IR were determined to be a shortened PC (Burkhart et al. 2003; Manske et al. 2013). A shortened PC has also been linked to scapula dyskinesis (Turgut and Baltaci, 2018). In Study 3 a shorthand SHB was concluded in the painful shoulders of participants. Theoretically, due to the anatomical attachment of the SHB, if shortened, it can cause an anterior tilted scapula. Due to scarcity of research on the SHB, no comparisons could be made. More research in this area is needed in both non-athlete and athletic populations.

Therefore, monitoring all of these variables in scapular force couple ratios and the flexibility of PMm, LD and the PC, can help with identification of altered variables at baseline in painful shoulders (Figure 2). None of these variables (scapular force couple ratios, PMm, LD and PC flexibility) should however be considered in isolation as it has been highlighted that all the variables play a role in shoulder pain. Incorporation of these altered variables early in the rehabilitation process may lead to a more meaningful assessment of the shoulder and potentially speed up the rehabilitation process. Correcting the unbalanced scapular stabilisers forces around the scapula will ensure better kinematics of the scapula for articulation with the humeral head and pain free shoulder movements should result. Considering that the beforementioned modifiable musculoskeletal factors, the imbalance of the scapular stabilisers and the shortened PMm and LD may play a role in scapular dyskinesis and shoulder pain, monitoring of these factors routinely at baseline, and throughout the rehabilitation process, could lead to more effective management.

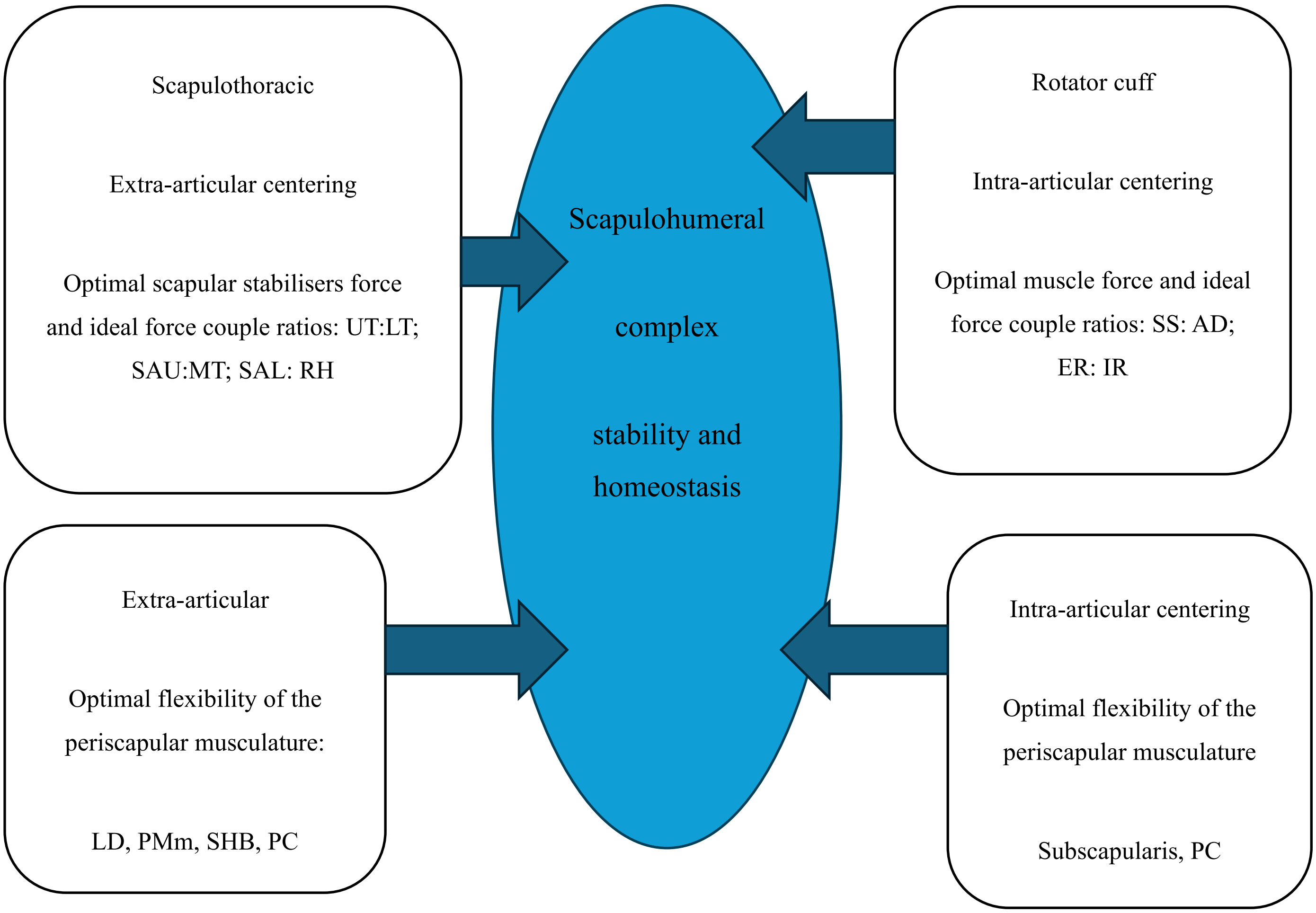


Figure 2 Updated conceptual framework of informed results of the scapulohumeral complex.

9.3 Summary

A recent study by Moor et al. 2016, investigated the critical shoulder angle/ the glenoid inclination. Their study concluded that an increased cranially orientated glenoid can lead increased shear joint reaction forces of the rotator cuff with higher compensatory activity of the rotator cuff and may lead to degenerative changes (Moor et al. 2016). Another interesting finding was that an EMG ratio of 1:1 of the SS:AD compared to a deltoid dominant ratio of 2:1, protected the glenohumeral head from cranial subluxation Kijkunasathian et al. (2023). It is well known that the positioning of the glenoid is mainly controlled by the optimal scapular stabilisers balanced actions (Mottram, 1997; Ekstrom et al. 2004; Fey et al. 2007; Phadke et al. 2009). Measurements and monitoring of the force couple ratios of the scapular stabilisers, may hence detect imbalance if monitored and can be corrected early on in the rehabilitation process. In Study 2 (Chapter 5), we determined the SS:AD force couple ratio in non-painful shoulders to be 1.25:1.0 ±0.20, concurring with the findings of the EMG study by E Kijkunasathian et al. (2023) even though the study of Kijkunasathian et al. (2023) was an EMG study and direct comparisons cannot be made due to different measurement models; some inferences can be drawn from this. No other studies on the proposed isometric force of SS:AD force couple or force couple ratios is available in current research.

In Study 2 (Chapter 5) an increased ER:IR force couple ratio was determined in the painful shoulders of participants compared to the non-painful shoulders of participants in neutral (1.23 versus 1.15); in 45 degrees scaption (1.32 versus 1.05), in ABDER (1.21:0.99), in sagittal flexion (1.18 versus 0.99). As elevation increases the ER:IR ratio steadily decreases. Authors have reported on a decrease in supraspinatus and infraspinatus muscle activity, linked with an increase in deltoid activity (Grachen et al. 2000; Steenbrink et al. 2010; Keener et al. 2009). It can hence be surmised that increased deltoid activity may lead to increased cranial migration of the humeral head and subacromial impingent will follow with resultant shoulder pain. Assessment of both the superior and inferior rotator cuff force (all ranges) couples should in theory detect imbalances and can be addressed during the rehabilitation process. However, if muscle force and force couple ratios are not assessed in an objective and measurable way, subtle changes would not be detected.

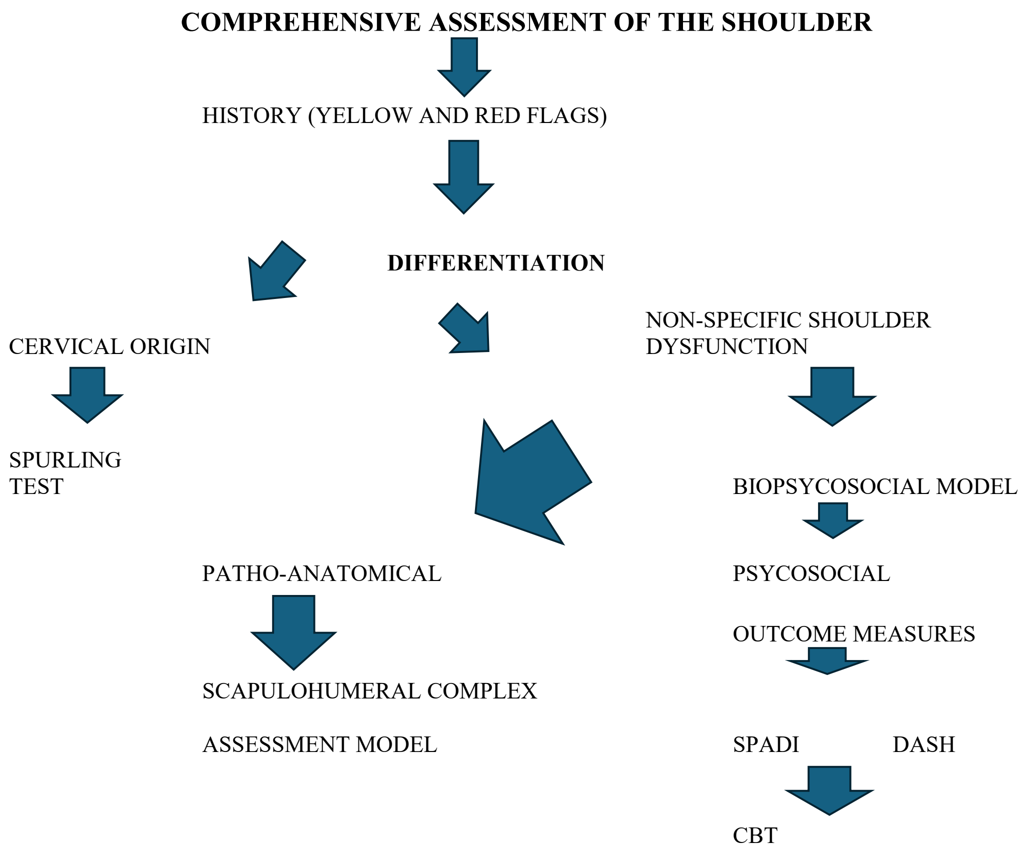
The results reached with Studies 1-3 (Chapters 4-6) were presented to Physiotherapists on the possible inclusion thereof into a shoulder assessment model, specific to the Physiotherapy profession. They were also consulted on any other factors applicable for inclusion into the assessment model. The results reached in Study 4 (Chapter 7), confirmed that physiotherapists feel the need for an easily reproducible cluster of tests incorporating the musculoskeletal factors in a shoulder assessment model.

Taking all the information and determined results of Studies 1-4 (Chapter 4-7) into consideration an assessment model was proposed. A reliability Study 5 (Chapter 8) was conducted on the proposed modifiable factors. Intra-rater reliability ICC (95% CI) ranked from moderate to almost perfect for the flexibility measures for PMm 0,47 (-0,56-0,93), SHB 0,58 (-0,433-0,95), LD 0,76 (-0,13-0,97) for rater 1. For rater 2 moderate to almost perfect reliability was found for SHB 0,54 (-0,79-0,82), LD 0,93 (0,53-0,99), ER (neutral) 0,82 (0,02-0,98), and PCSL (IR) 0,52 (-0,50-0,93). For the force measurements of the rotator cuff and the scapular stabilisers, the intra-rater reliability was moderate to almost perfect for both raters.

Previous researchers also concluded high intra-rater reliability of force measurements using a HHD, in their studies (Cools et al. 2014; Roman et al. 2022; Balalha et al. 2014; Eduard et al. 2011). The inter-rater reliability however rated from fair to poor. Many factors can influence the strength measurements, such as the strength of the tester (Bohannon, 2019; Cools et al. 2014; Stark et al. 2011), this may have happened in our study.

Assessment of all the identified modifiable musculoskeletal factors, the scapular stabiliser force and force couple ratios of the scapular stabilisers, the force and force couple ratios of both the superior and inferior cuff, the flexibility of PMm, LD, subscapularis, PC and ER (neutral and 90 degrees) and IR ROM, were incorporated into a proposed shoulder assessment model (Study 5, Chapter 8).

Providing a comprehensive holistic overview of a shoulder assessment pathway, the following should however, be considered; full detailed history taking; differentiation of cervical referred shoulder pain and non-specific shoulder pain; the biopsychosocial pain model; the patho-anatomical model (explored in the current thesis) (Figure 9.3).



SPADI = shoulder pain and disability index; DASH = disability of the arm, shoulder and hand; CBT = cognitive behaviour therapy.

Figure 9.3: Comprehensive holistic shoulder assessment pathway.

9.4 Strengths of the thesis

Study one (Chapter 4) is the first SR of its kind investigating not only the etiology but also the risk factors of developing shoulder dysfunction in the presence of altered modifiable musculoskeletal factors.

The physical data collection studies (Study 2 and 3) were conducted using objective measurements namely, the HHD for the isometric testing of the musculature and the inclinometer for gathering the ROM kinematic data. Mass was normalised to body weight for comparing findings across participants. New areas identified with the SR such as the force couple ratios and the flexibility of the LD; subscapularis were investigated and new information gathered with Studies 2 and 3. The NGT was a first of its kind probing the opinion of physiotherapists on factors they thought must be included in an assessment model for the shoulder. A novel scapulohumeral assessment model is proposed with the culmination of evidence gathered. The robustness of the assessment model was tested with a pilot reliability study, and positive results were yielded.

9.5 Limitations of the study

Some limitations must however be acknowledged. The cross-sectional design of Studies 2 and 3, only determined the association of shoulder pain in the presence of altered modifiable musculoskeletal factors. The cause and effect of modifiable musculoskeletal factors on shoulder function or pathology should be explored with longitudinal cohort studies.

Only pilot studies were conducted with both the NGT group discussion and the reliability studies. The NGT study was confined to one geological area, and the findings cannot necessarily be generalised. More global NGT studies across different geological areas of the physiotherapy profession are encouraged to build on the current findings.

The pilot reliability study was only conducted on a small sample size; more studies are encouraged to include bigger sample sizes and to include patients with healthy shoulders and shoulder pathology. Our study was conducted on healthy younger participants.

In the comprehensive assessment of a patient, it is of cardinal importance to conduct a thorough medical examination to identify potential yellow (e.g. metabolic) and red (e.g. cancer or pain from internal organ referral) flags and address these and refer to other specialities, if needed. Taking the biopsychosocial model into consideration, especially with chronic pain (pain of longer than 3 months duration) where cortical neuroplastic changes have occurred, the psychosocial aspect must be considered. Outcome measures such as the SPADI or DASH questionnaires can be used to gauge the subjective pain picture of a patient. These psychosocial and work/sport related factors should be considered in the holistic overview of the patient presenting with shoulder pain. The pain matric model must always be kept in mind since it is well known that pain is not always nociceptive in nature.

The bidirectional nociception-motor interaction is still far from clearly understood, despite increased research into this area. An integrated classification system that will allow rational assessment of shoulder pain from biomedical, psychological and social constructs will be the ideal assessment of the shoulder complex. The current study however only researched the biomechanical factors that could potentially influenced shoulder pain. The psychosocial factors fall outside the scope of the present thesis. It is recommended that these factors be explored in future cohort longitudinal studies.

10 Conclusions

The thesis present an evidence-based novel scapulohumeral complex assessment model for physiotherapists. Known and new information on the modifiable musculoskeletal factors associated with shoulder dysfunction have been incorporated into the scapulohumeral complex assessment model. The concluded presence of altered modifiable musculoskeletal factors associated with shoulder dysfunction in athletes but also in a non-athletic population contributes to fill the identified gaps in the literature. The shoulder assessment model was proposed in a NGT group discussion, gaining physiotherapists' perspective on the model. The robustness of the assessment model was tested with a pilot reliability study. Further research on the clinical use of the model should ideally be tested with longitudinal cohort studies and comparisons be made between patients with shoulder pathology and those with healthy shoulders.

11 Application to clinical practice

Physiotherapists treat the musculoskeletal system, therefore, using an assessment model identifying the affected modifiable musculoskeletal factors may prove clinically more appropriate. The early identification of affected musculoskeletal factors of the scapulohumeral complex and targeting the affected variables can lead to shorter and more effective treatment strategies, and therefore, quicker return to either sport or everyday life of all individuals. Using a measurable and objective assessment model for the scapulohumeral complex can prove clinically useful in numerous ways such as; collecting baseline values of all variables; progression and monitoring of these variables. This can result in a better-informed rehabilitation model. Better objective feedback can be provided to a patient and to other health professional colleagues involved in the rehabilitation process of the shoulder patient.

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Appendices

Appendix A Foundation keywords of the systematic review.

Chapter 4 Study 1

Foundation keywords

Foundation Keywords		
Foundation Keywords and Index Terms		
Keyword	Text*	Mesh*
Body area**	shoulder*	scapula*
	glenohumeral	shoulder*
	gleno-humeral	rotator cuff
	subacromial	pectoralis minor
	sis	subscapularis
	rotator cuff	
	scapula*	
	upper limb	
	scapulothoracic	
	pectoralis minor	
	Latissimus dorsi	
	posterior capsule	

	GIRD subscapularis strength ratio* upper limb acromioclavicular	
Symptom **	pain syndrome impingement dysfunction kinematic* dyskinesi* injur* range of motion rom imbalance	pain risk factor*

	risk factor* stretch “Shoulder pain” “Shoulder strain”	
Syndrome**	“Subacromial impingement syndrome” “Rotator cuff syndrome” “Impingement syndrome”	

* Text words and MeSH on each level connected with “OR” ** Each level connected by “AND.”

I was unable to use a “human” filter.

Filters applied:

Free full text

Observational studies

Systematic reviews

Appendix B Search strategy of data bases.

5. PUBMED Advanced

- PUBMED Advanced. The search was conducted on 01/08/2022.

Search	Query	Retrieved records
#1	shoulder*[Text Word]) OR glenohumeral[Text Word]) OR gleno-humeral[Text Word]) OR subacromial[Text Word]) OR sis[Text Word]) OR rotator cuff[Text Word]) OR scapula*[Text Word]) OR upper limb[Text Word]) OR scapulothoracic[Text Word]) OR scapula*[MeSH Terms]) OR shoulder*[MeSH Terms]) OR rotator cuff[MeSH Terms]) OR pectoralis minor[Text Word]) OR Latissimus dorsi[Text Word]) OR posterior capsule[Text Word]) OR GIRD[Text Word]) OR subscapularis[Text Word]) OR strength[Text Word]) OR ratio*[Text Word]) OR pectoralis minor[MeSH Terms]) OR subscapularis[MeSH Terms]	3389505
#2	pain [Text Word]) OR syndrome [Text Word]) OR impingement [Text Word]) OR dysfunction [Text Word]) OR kinematic*[Text Word]) OR dyskinesi*[Text Word]) OR injur*[Text Word]) OR range of motion [Text Word]) OR rom [Text Word]) OR imbalance [Text Word]) OR risk factor*[Text Word]) OR pain [MeSH Terms]) OR risk factor*[MeSH Terms]	3288230
#3	shoulder*[Text Word]) OR subacromial impingement syndrome [Text Word]	166741

#4	(non-operative [Text word]) OR subacromial impingement syndrome [Text word]	2000
#5	1 AND 2 AND 3 AND 4	221

I was unable to use a "human" filter.

Filters applied:

Free full text

Observational studies

Systematic reviews

Boolean/phrases applied

EBSCOhost

Search conducted on: 01/04/2021.

The following databases are affiliated with the platform EBSCOhost, allowing for a combined search:

Cumulative Index to Nursing and Allied Health Literature (CINAHL) Full Text complete.

SPORTDiscus with Full Text.

MEDLINE COMPLETE, MEDLINE.

MasterFile.

Search	Query	Records retrieved
S1	TX (subacromial impingement syndrome or subacromial pain syndrome or shoulder pain or subacromial) OR TX (rotator cuff tendinopathy or rotator cuff tendonitis) AND TX (pain management or pain relief or pain control or pain reduction) AND TX human AND TX (musculoskeletal disorders or musculoskeletal pain or	2, 559, 834

	musculoskeletal injuries) OR TX (shoulder injury or shoulder pain or shoulder impingement or shoulder tendinopathy) NOT TX (randomized controlled trials or rtc or randomised control	
S2	TX (subacromial impingement syndrome or subacromial pain syndrome or shoulder pain or subacromial) OR TX (rotator cuff tendinopathy or rotator cuff tendonitis) AND TX (pain management or pain relief or pain control or pain reduction) AND TX human AND TX (musculoskeletal disorders or musculoskeletal pain or musculoskeletal injuries) OR TX (shoulder injury or shoulder pain or shoulder impingement or shoulder tendinopathy) NOT TX (randomized controlled trials	69,991

	or rtc or randomised control	
S3	TX (subacromial impingement syndrome or subacromial pain syndrome or shoulder pain or subacromial) OR TX (rotator cuff tendinopathy or rotator cuff tendonitis) AND TX (pain management or pain relief or pain control or pain reduction) AND TX human AND TX (musculoskeletal disorders or musculoskeletal pain or musculoskeletal injuries) OR TX (shoulder injury or shoulder pain or shoulder impingement or shoulder tendinopathy) NOT TX (randomized controlled trials	66,711

	or rtc or randomised control ...	
S4	TX (subacromial impingement syndrome or subacromial pain syndrome or shoulder pain or subacromial) OR TX (rotator cuff tendinopathy or rotator cuff tendonitis) AND TX (pain management or pain relief or pain control or pain reduction) AND TX human AND TX (musculoskeletal disorders or musculoskeletal pain or	40,085

	musculoskeletal injuries) OR TX (shoulder injury or shoulder pain or shoulder impingement or shoulder tendinopathy) NOT TX (randomized controlled trials or rtc or randomised control	
S5	TX (subacromial impingement syndrome or subacromial pain syndrome or shoulder pain or subacromial) OR TX (rotator cuff tendinopathy or rotator cuff tendonitis) AND TX (pain management or pain relief or pain control or pain reduction) AND TX human AND TX (musculoskeletal disorders or musculoskeletal pain or musculoskeletal injuries) OR TX (shoulder injury or	110,624

	shoulder pain or shoulder impingement or shoulder tendinopathy) NOT TX (randomized controlled trials or rtc or randomised control ...	
S6	AB (subacromial impingement syndrome or subacromial pain syndrome or shoulder pain or subacromial) OR TX (rotator cuff tendinopathy or rotator cuff tendonitis) AND TX (pain management or pain relief or pain control or pain reduction) AND TX human OR TX (musculoskeletal disorders or musculoskeletal pain or	21,478

	musculoskeletal injuries) OR TX (shoulder injury or shoulder pain or shoulder impingement or shoulder tendinopathy) NOT TX (randomized controlled trials or rtc or randomised control	
S7	S1 AND S2 AND S3 AND S4 AND S5 AND S6	2,847

Conducted on:08/01/2022.

Searches in the abstract (AB) and text (TX)

Limiters applied: Observational studies and systematic reviews.

Limiter applied: Full text.

Narrow by Subject Age: - all adult: 19+ years

Narrow by Subject Major: - shoulder

Narrow by Subject Major: - shoulder pain

Expanders selected - Apply equivalent subjects.

Search modes selected - Boolean/phrase

6. Physiotherapy Evidence Database (PEDro)

Conducted on: 02/02/2022.

I was unable to perform a complex "Boolean" search.

An advanced search with "drop down bars" under the following subheadings was performed:

Abstract and title: shoulder pain/dyskinesis (keywords used)

Abstract and title	Shoulder pain or dyskinesis (drop down bar)
Therapy	Strength training
Problem	Muscle weakness
Body part	Shoulder or shoulder girdle (drop down bar)
Subdiscipline	Physiotherapy
Topic	Shoulder
Method	Practice guideline/systematic review (drop down bar)
Published since	1900
New records added since	1/09/2022

Results yielded=1.

8. Web of Science (Clarivate Analytics)

Conducted on 01/10/2022.

Articles (Document type), reviews (Document type), medicine (Subject area), and health profession

(Subject area)

Search word variations selected.

Titles, abstracts and keywords were searched.

TITLE-ABS-KEY (advanced search) shoulder AND subacromial OR glenohumeral AND observational studies AND pain OR dysfunction AND sis NOT post-operative AND no intervention OR “gleno-humeral” OR “rotator cuff” OR scapulothoracic OR scapula* OR GIRD OR “Latissimus dorsi” OR subscapularis OR “posterior capsule” OR “upper limb” OR acromioclavicular AND pain OR syndrome OR impingement OR kinematic* OR “risk factor*” dyskinesi* OR imbalance OR “range of motion” OR “shoulder pain” OR “shoulder strain” AND “subacromial impingement syndrome” OR “rotator cuff syndrome” OR “impingement syndrome”

Search	Query	Records retrieved
#1	**shoulder** (Title) and **subacromial** (Title) or **glenohumeral** (Title) and **observational studies** (All Fields) and **pain** (Title) or **dysfunction** (Title) and **sis** (Title) not **post-operative** (Title) not **no intervention** (Title)	292

#2	**shoulder** (Title) and **subacromial** (Title) or **glenohumeral** (Title) and **observational studies** (All Fields) and **pain** (Title) or **dysfunction** (Title) and **sis** (Title) not **post-operative** (Title) not **no intervention** (Title) and **Human** (Search within all fields)	16
#3	**shoulder** (Title) and **subacromial** (Title) or **glenohumeral** (Title) and **observational studies** (All Fields) and **pain** (Title) or **dysfunction** (Abstract) and **sis** (Abstract) not **post-operative** (Abstract) not **no intervention** (Abstract)	388
#4	((((((((TI=(shoulder)) AND TI=(subacromial)) OR TI=(glenohumeral)) AND TI=(observational studies)) AND TI=(pain)) OR TI=(dysfunction)) OR TI=(sis)) NOT TI=(post-operative)) NOT TI= (no intervention)	149,177
#5	#4 AND #3 AND #2 AND #1	0
#6	#1 OR #3	389
#7	#2 OR #4	149194

#8	((((((((((((((((TI=(shoulder)) AND TI=(subacromial)) OR TI=(glenohumeral)) AND TI=(observational studies)) AND TI=(pain)) OR TI=(dysfunction)) OR TI=(sis)) NOT TI=(post-operative)) NOT TI=(no intervention)) AND ALL=(shoulder)) AND ALL=(subacromial)) OR ALL=(glenohumeral)) AND ALL=(observational studies)) AND ALL=(pain)) OR ALL=(dysfunction)) AND ALL=(sis)) NOT ALL=(post-operative)) NOT ALL=(no intervention)	16
#9	#1 OR #2 OR #3 OR #8	399

Records retrieved 399.

9. Scopus (Elsevier)

Search conducted on 01/11/2021.

TITLE-ABS-TEXT-KEY

Shoulder* OR glenohumeral OR “gleno-humeral” OR subacromial OR subacromial OR sis OR “rotator cuff” OR scapula* OR “upper limb” OR scapulothoracic OR “pectoralis minor” OR “Latissimus dorsi” OR “posterior capsule” OR GIRD OR subscapularis OR strength Or ratio* OR “upper limb” OR acromioclavicular OR musculoskeletal AND pain OR syndrome OR impingement OR dysfunction OR kinematic*OR dyskinesi* OR injur* OR range of motion OR rom OR “range of motion” OR imbalance OR “risk factor*” OR “shoulder pain” OR “shoulder strain” AND ‘subacromial impingement syndrome” OR ‘Rotator cuff syndrome” OR “impingement syndrome” AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"re"

)) AND (LIMIT-TO (SUBJAREA,"MEDI") OR LIMIT-TO (SUBJAREA,"HEAL")) AND (LIMIT-TO (EXACTKEYWORD,"Human") OR LIMIT-TO EXACTKEYWORD,"Humans")

Filters applied: Human/s (Keyword), Articles (Document type), Reviews (Document type), Medicine (Subject area), Health profession (Subject area)

Search word variations selected.

Titles, abstracts and keywords were searched.

The search on Scopus yielded 2097 results.

Appendix C Excluded studies of systematic review.

Excluded studies.

Astolfi MM, Struminger AH, Royer TD, Kaminski TW, Swanik CB. Adaptations of the Shoulder to Overhead Throwing in Youth Athletes. Journal of Athletic Training (Allen Press) [Internet]. 2015;50(7):726–32. Available from: http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=s3h&AN=108527026&site=ehost-live&scope=site

Reason for exclusion: Ineligible participant characteristics

Bhakti Lala. Shoulder injury in cricketers: The role of shoulder rotation range of movement, throwing arc range of movement and pectoralis minor muscle length. 2017;

Reason for exclusion: Postgraduate dissertation from which the publication Olivier et al… emanating. Olivier et al… was included in this review.

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Reason for exclusion: Ineligible study design

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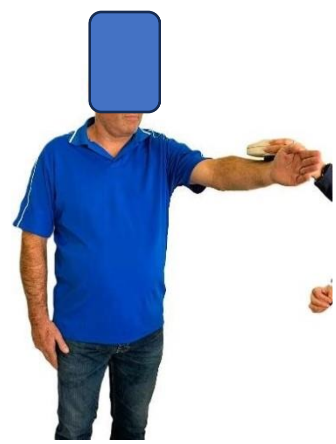
Reason for exclusion: Ineligible participant characteristics

Appendix D Strength measurements of the SS and AD.

Chapter 5 Study 2

Strength measurements of the SS and AD.

Muscle	Description of the muscle test	Visual presentation of the muscle test
Supraspinatus	Straight arm. In the scapular plane (30° anterior to the frontal plane of movement). Dynamometer force applied to the radius of the forearm 2 cm above the wrist line in the downward direction.	
Anterior deltoid	Straight arm. Flexion of 90° in the sagittal plane of movement. Dynamometer force applied to the radius of the forearm 2 cm above the wrist line in the downward direction.	

Appendix E Range of motion measurements in sagittal flexion and frontal abduction.

Description of the movements	**Range of motion starting position**	**Range of motion end position**
Active frontal abduction. Inclinometer placed posteriorly on the humerus		
Active sagittal flexion Inclinometer placed laterally on the humerus		

Appendix F Testing positions for the ER rotation and the IR rotation positions.

Description/Visual	Description/Visual
 ER° External rotation in neutral. The arm is beside the body, arm is in the scaption plane, the elbow bend to 90 degrees. The thumb pointing up. Resistance is given in the inward	 IR° Internal rotation in neutral. The arm besides the body in the scaption plane with the elbow bend to 90 degrees with thumb

direction until maximum resistance is reached.	pointing up. Resistance is given in the outwards direction until maximum resistance is reached.
 ER45 External rotation 45 degrees in the scaption plane. The arm is in the scaption plane, the upper arm is 45 degrees away from the body, the elbow bend to 90 degrees with the thumb pointing up. Inwards directed resistance is given until maximum	 IR45 Internal rotation 45 degrees in the scaption plane. The arm is in the scaption plane, the upper arm is 45 degrees away from the body, the elbow bend to 90 degrees with the thumb pointing up. Outwards directed resistance is given until maximum

resistance is reached.	resistance is reached.
 ERSF External rotation and flexion in the sagittal plane. The arm is in the sagittal plane, with the elbow bend to 90 degrees the thumb pointing toward the body. Resistance is given inwards until maximum resistance is reached.	 IRSF Internal rotation and flexion in the sagittal plane. The arm is in the sagittal plane, with the elbow bend to 90 degrees the thumb pointing toward the body. Resistance is given outwards until maximum resistance is reached.
For the force measurements, the participants stood with their legs spread comfortably apart. The HHD was placed 2cm above the wrist line on the volar side for the IR and on the dorsal surface	

for the ER. The ER positions were based on Hughes et al. 2014.

Appendix G Informed concent form for the NGT group discussion.

Chapter 7 Study 4

Dear participant. I am Sonia Briel a PhD student at the Physiotherapy Department. Thank you for agreeing to participate in this NGT technique study, which will take place on the 7th of March 2024. Ethical clearance has been granted by the University of the Witwatersrand Human Research Ethics Committee (Medical). The concluded results of the group discussion will be utilised to develop a clinical tool for the comprehensive evaluation of the shoulder joint.

The NGT discussion will take more or less 60 minutes.

This form details the purpose of this study, a description of the involvement required and your rights as a participant.

The purpose of this study is:

2 to gain insight into the functioning of the shoulder joint.

The benefits of the research will be:

3 To better understand the biomechanics of the shoulder joint.

4 To identify significant components that could help in the evaluation and treatment of the shoulder joint.

5 The methods that will be used to meet this purpose include:

6 A Nominal group technique, mini discussion groups.

You are free to raise questions and make your concerns known at any time if you are unsure of the purpose of the study or the methods I am using.. Please contact me anytime at the e-mail address or telephone number listed below.

The group discussion will be audio taped, this will make it easier to interpret and to accurately report on your thoughts. The tapes will only be heard by me the primary researcher and the facilitator of the session, for the purpose of this study. The recorder may be turned off at any stage if you do not feel comfortable with it.

You also have the right to withdraw from the study at any time. In the event you choose to withdraw from the study all information you provide (including tapes) will be destroyed and omitted from the final paper.

Insights gathered by you and other participants will be used in writing a qualitative research report, in partial fulfilment of my PhD thesis. Though direct quotes from you may be used in the thesis and any publications that might arises thereof, your name and other identifying information will be kept anonymous.

Demographic information:

2 Work environment:

…………………………………………………………………………………

3 Qualifications:

…………………………………………………………………

4 Professional capacity:

………………………………………………………………………………….

5 Expertise/ area of interest:

………………………………………………………………………………….

6 Years of practising

…………………………………………………………………………………..

7 Gender:

…………………………………………………………………………………..

8 Age:

……………………………………………………………………………………

Steps of the NGT technique

1.1 Silent generation (brainstorming)–20 minutes will be allowed to silently reflect on and/or record their individual ideas.

2.1 Round robin–the facilitator will ask one participant at s time in a ‘round robin’ way to orally state their ideas (10 minutes). No discussion will be allowed at this stage. Only verbatim ideas will be recorded on a flipchart.

3.1 Clarification of ideas–30 minutes will be allowed for new ideas, grouping and including or excluding ideas. No direction by the facilitator will be is provided at this stage. Ideas will be discussed by the participants themselves.

4.1 Voting (Ranking)–Top ideas, five, as is commonly used in literature (Campbell *et al*., 2003; Wang *et al*., 2006) will be selected. An open discussion will be allowed, but the individual voting will be kept confidential. Voting time, ten minutes as suggested in literature will be allowed. Ranking cards will be used.

5.1 Recording of vote tally sheet.

By signing this consent form, I certify that I ______________________________ agree to

(Print full name here)

the terms of this agreement.

______________________________   _______________

(Signature)   (Date)

Primary researcher Sonia Briel

Signature Date

Contact details:

sonia@miphysio.co.za

083 379 3726

Contact details of my supervisor:

Prof Corlia Brandt

E-mail: Corlia.Brandt@wits.ac.za

Appendix HAssessment sheets of the scapulohumeral complex.

Chapter 8 Study 5

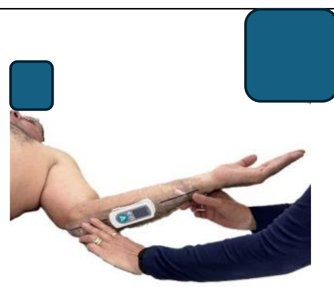
Variables	Right side		Demographics
Flexibility			Age
SHB (CM)			Height

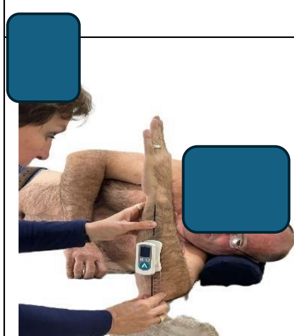
PMm (cm)			Mass
LD (cm)			
ER 0 (degrees)			
ER 90 (degrees)			
PCSL (degrees)			
Scapular stabilisers			
Kg/f			
SAU supine			
RH prone			
MT prone			

LT prone			
UT (seated)			
SAL (130) seated			

Variables	Right side		Demographics
Rotator cuff and anterior deltoid (Kg/f)			Age
SS			
			Height
AD			
			Mass
ER 0			
IR 0			
ER 45			
IR 45			
ER ABD/ER			
ER ABD/IR			
ERF			
IRF			
HBB (IR)			

Appendix I Flexibility assessment positions.

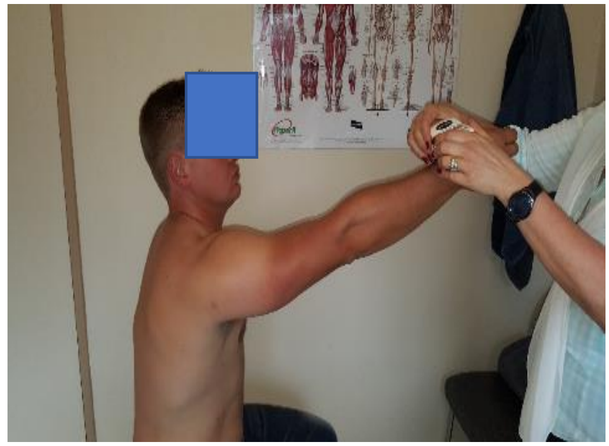
Starting position	End position	Position and test
		Supine
ER is neutral. Elbow bent to 90 degrees. Inclinometer placed in line with the forearm	ER is neutral. Elbow bent to 90 degrees and rotated to the end of range. Inclinometer placed in line with forearm	Supine

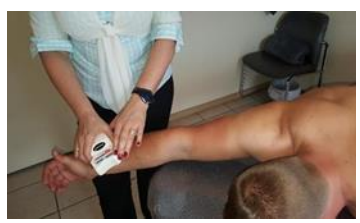
		Supine
ER at 90 degrees and elbow flexed at 90 degrees. Inclinometer placed in line with the forearm	ER at 90 degrees elbow flexed at 90 degrees and arm rotated to the end of range. Inclinometer placed in line with the forearm	Supine
		Side lying Lunden (2010), Cieminski (2015)
PCSL: Side lying elbow bent at 90 degrees. Inclinometer placed in line with the forearm	PCSL: Arm rotated to end of the range. Inclinometer placed in line with the forearm	Side lying

Appendix J Strength assessment positions of both the scapular stabilisers and the rotator cuff.

Muscle descriptions and testing positions for the scapular stabilisers.

Muscle	Description of muscle test	Visual presentation of muscle test
Upper trapezius	Seated, shrug the shoulder. Maximum isometric hold for a count of 10. Position: on the lateral part of the shoulder over the acromio-clavicular joint	

Serratus anterior lower fibres	Maximum protraction in 130º of sagittal flexion. Downward pressure to 'break' hold of the scapula. Position: on the inferior distal radius, just above the styloid process	
Muscle	Description of muscle test	Visual presentation of muscle test
Rhomboids	Arm in frontal plane, 45° of abduction, thumb pointing down. Maximum downward force applied to 'break' hold of the scapula. Position: on the inferior ulna, just above the styloid process	

Middle trapezius	Arm in frontal plane, 90º of flexion, thumb pointing up. Maximum isometric hold, and downward pressure applied to 'break' hold of the scapula. Position: on the inferior radius, just above the styloid process)	
Muscle	Description of muscle test	Visual presentation of muscle test
Lower trapezius	Arm in 145° of flexion in the frontal plane, thumb pointing up. Maximum isometric hold, and downward pressure applied to 'break' hold of the scapula. Position: on the	

	inferior radius, just above the styloid process)	

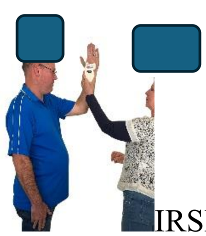
Testing positions for SS and AD

Muscle	Description of the muscle test	Visual presentation of the muscle test
Supraspinatus	Straight arm. In the scapular plane (30° anterior to the frontal plane of movement). Dynamometer force applied to the radius of the forearm 2 cm above the wrist line in the downward direction.	

Anterior deltoid	Straight arm. Flexion of 90° in the sagittal plane of movement. Dynamometer force applied to the radius of the forearm 2 cm above the wrist line in the downward direction.	

Testing positions for the ER rotation and IR rotation positions.

Description/Visual	Description/Visual
 ER° External rotation in neutral. The arm is beside the body, arm is in the scaption plane, the elbow bend to 90 degrees. The thumb pointing up. Resistance is given in the inward direction until maximum resistance is reached.	 IR° Internal rotation in neutral. The arm besides the body in the scaption plane with the elbow bend to 90 degrees with thumb pointing up. Resistance is given in the outwards direction until maximum resistance is reached.

	
ER45 External rotation 45 degrees in the scaption plane. The arm is in the scaption plane, the upper arm is 45 degrees away from the body, the elbow bend to 90 degrees with the thumb pointing up. Inwards directed resistance is given until maximum resistance is reached.	IR45 Internal rotation 45 degrees in the scaption plane. The arm is in the scaption plane, the upper arm is 45 degrees away from the body, the elbow bend to 90 degrees with the thumb pointing up. Outwards directed resistance is given until maximum resistance is reached.
 ERSF	 IRSF

External rotation and flexion in the sagittal plane. The arm is in the sagittal plane, with the elbow bend to 90 degrees the thumb pointing toward the body. Resistance is given inwards until maximum resistance is reached.	Internal rotation and flexion in the sagittal plane. The arm is in the sagittal plane, with the elbow bend to 90 degrees the thumb pointing toward the body. Resistance is given outwards until maximum resistance is reached.

For the force production measurements, the participants stood with their legs spread apart. The HHD was positioned 2 cm above the wrist line, on the dorsal surface (for the ER testing) and on the volar surface (for the IR testing) of the forearm.

Appendix K Ethical certificate.

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

Office of the Deputy Vice-Chancellor (Research and Postgraduate Affairs)

TO:	Ms S Briel School of Therapeutic Sciences Department of Physiotherapy Medical School University E-mail: sonia@miphysio.co.za
CC:	Supervisor: Dr C Brandt and Professor B Olivier <Corlia.Brandt@wits.ac.za> and <HREC-Medical Research Office@wits.ac.za>
FROM:	Mr Iain Burns Human Research Ethics Committee (Medical) Tel: 011 717 1252 E-mail: Iain.Burns@wits.ac.za
DATE:	2021/04/29
REF:	R14/49
PROTOCOL NO:	**M190984** (This is your ethics application reference number. Please quote it in all enquiries, oral or written, relating to this study.)
PROJECT TITLE:	*Shoulder stability: A novel biomechenical assessment approach*

Please find attached the Clearance Certificate for the above project. I hope it goes well and that an article in a recognized publication comes out of it. This will reflect well on your professional standing and contribute to Government funding of the University.

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An Evidence-based Assessment Model for the Comprehensive Assessment of the Scapulohumeral Complex

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Appendix M Online supplements

Study 1 Online supplement 1

Chapter 4 Study 1

SoF: a) Isometric and isotonic external and internal rotator strength values reported of the cases.

Study	LOE	Sport	Sample size	Age *	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
Cools et al., 2016. Observational study	3	Handball athletes and healthy controls	N=100	18-25	F=19	Isom ER Position (90/0) 0.91 (kg/f) (0.14) SD	Isom ER Position (90/0) 0.94 (kg/f) (0.12)	11.34 %	-0.23 (-0.60. 0.14)

Study	LOE	Sport	Sample size	Age*	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
							SD		
		Tennis	N=100	26-33	F=10	ECC ER Position (90/90) 2.1	ECC ER Position (90/90) 2.0	21.29 %	0.18 (-0.19. 0.55)

Study	LOE	Sport	Sample size	Age *	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
						(Nm kg) (0.5) SD	(Nm kg) (0.6) SD		
		Volleyball	100	34-50	F=20	Isom ER Position (90/0) 1.9 (Kg//f) 0.4	Isom ER Position (90/0) 1.9 (Kg/f)	4.69%	0.00 (-0.58. 0.58)

Study	LOE	Sport	Sample size	Age*	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
						(SD)	0.4 (SD)		
						ECC ER Position (90/90) 2.5 (Nm kg) 0.7 (SD)	ECC ER Position (90/90) 2.3 (Nm kg) 0.5 (SD)	21.09 %	0.33 (-0.05. 0.70)

Study	LOE	Sport	Sample size	Age*	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
		Handball		18-25	M=22	Isom ER Position (90/0) 1.6 (kg/f) 0.4 (SD)	Isom ER Position (90/0) 1.5 (kg/f) 0.4 (SD)	4.25%	0.25 (-0.36. 0.85)
						ECC ER Position (90/90)	ECC ER Position (90/90)		0.18 9-0.19. 0.55)

Study	LOE	Sport	Sample size	Age*	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
						2.2 (Nm kg) 0.5 (SD)	2.0 (Nm kg) 0.6 (SD)	21.29 %	
		Tennis		26-33	M=11	Isom ER (90/0) 0.91 (kg/f)	ER Position (90/0) 0.94 (kg/f) 0.12	11.34 %	

Study	LOE	Sport	Sample size	Age *	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
						0.14 (SD)	(SD)		-0.23 (-0.61. 0.15)
						ECC ER Position (90/90) 0.92 (kg/f) 0.22 (SD)	ECC ER Position (90/90) 0.94 (kg/f) 0.18 (SD)	8.01%	-0.10 (-0.70. 0.51)
		Volleyball		34-50	M=	Isom ER	Isom ER		

Study	LOE	Sport	Sample size	Age *	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
						Position (90/0) 0.87 (kg/f) 0.15 (SD)	Position (90/0) 0.89 (kg/f) 0.19 \(SD)	4.68%	-0.11 (-0.69. 0.46)
						ECC ER Position (90/90) 1.02	ECC ER Position (90/90) 1.11	8.53%	-0.49 (-1.07. 0.10)

Study	LOE	Sport	Sample size	Age*	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
						(Nm kg) 0.20 (SD)	(Nm kg) 0.16 (SD)		
Dos Santos De Andradeet al., 2010. Observational	3	Handball players female and males	27	23.0-34	27	Ecc ER Position (90/0) 33.7 (Nm kg) 8.0 (SD)	ECC ER Position (90/0) 32.2 (Nm kg) 4.9 (SD)	5.47%	0.22 (-0.31. 0.76)

Study	LOE	Sport	Sample size	Age *	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
Study	LOE		Sample size	Age, Mean/ (SD)	F Sample	Isom ER Position (90/0)	Isom ER Position (90/0)		SMD CL 95%
Riemann et al., 2010 Observational	3	Healthy volunteers	181 180	23.4 4.1 F	91 90	9.9 (kg/f) 3.0 (SD) 17.8 (kg/f) 5.2 (SD)	9.6 (kg/f) 4.1 (SD) 17.8 (kg/f) 5.2 (SD)	18.54 % 18.35 %	0.08 (-0.2. 0.37) 0.00 (-0.29. 0.29)

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Study	LOE	Sport	Sample size	Age *	Gender F=female; M=male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
Peckitt et al., 2019 Observational cohort	3	Cricketers	36	20.-28.0	4	155.0 (kg/f) 27.8 (SD)	147.2 (kg/f) 22.5 (SD)	N/A	N/A
Forthomme et al., 2018.	3		108	24 4		Ecc ER Position (90/90) 0.63 (Nm kg) 0.11	Ecc ER Position (90/90) 0.61 (Nm kg) 0.13	21.94 %	0.17 (-0.10. 0.43)

Study	LOE	Sport	Sample size	Age *	Gender F=female; M= male	Strength Dominant	Strength Non-Dominant	Weight	SMD (95%CI)
						(SD)	(SD)		
Furness et al., 2018 Cohort.	2	Surfacing athletes	13	24.1 6.9	4	Isom ER (90/0) 1.81 (kg/f) 0.40 (SD)	Isom ER Position (90/0) 1.65 (kg/f) 0.34 (SD)	N/A	N/A

F=female; M= male; D= dominant; ND= non-dominant; ecc= eccentric; isom= isometric; ER= external rotation.

Age*= years in mean (SD); SD= standard deviation; D= dominant' ND= non-dominant.

Level of Evidence (LOE): OCEBM Levels of Evidence Working Group*. "The Oxford 2011 Levels of Evidence". Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653 * OCEBM Table of Evidence.

F=female; M= male; D= dominant; ND= non-dominant; ecc= eccentric; isom= isometric; ER= external rotation.

Age*= years in mean (SD); SD= standard deviation; D= dominant' ND= non-dominant.

Level of Evidence (LOE): OCEBM Levels of Evidence Working Group*. "The Oxford 2011 Levels of Evidence". Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653 * OCEBM Table of Evidence Working Group = Jeremy Howick, Iain Chalmers (James Lind Library), Paul Glasziou, Trish Greenhalgh, Carl Heneghan, Alessandro Liberati, Ivan Moschetti, Bob Phillips, Hazel Thornton, Olive Goddard and Mary Hodgkinson

SoF: b) Eccentric external rotator strength of the cases.

Study	**LOE**	**Sample size**	**Sport**	**Age***	**S**	**AS**	**Study**			**Weight**	**SMD (95%CI)**
							M F	S	AS		

McDonough et al., 2014 **Cohort**	2	20	Rugby league	19.6 (1.77)	8	14	M=20	56.9 (Nm kg) 18.39 (SD) 54.1 (Nm kg) 12.28 (SD)	62.3 (Nm kg) 19.32 (SD) 64.5 (Nm kg) 25.4 (SD)	6.53 % 6.47 %	0.27 (-0.60. 1.15) 0.46 (-0.42. 1.34)
Laudner, 2004 **Observational study**	3	22	Baseball league	22.9 3.45		11	M=22	-0.60 (Nm kg) 6.16	0.17 (Nm kg) 4.90 (SD)	6.80 %	0.13 (-0.70. 0.97)

								(SD)			
Heck et al., 2021. **Cohort**	2	15	Gymnasts	20.5 0.9	12	19	F=15	10.2 (Nm kg) 2.9 (SD) 9..8 (Nm kg) 2.2 (SD)	10.9 (Nm kg) 3.9 (SD) 10.2 (Nm kg) 3.5 (SD)	7.75 %	0.19 (-0.53. 0.92)
Forthomme et al., 2018 **Cross sectional**	3	108	Handball	24 4	51	57	M=108	0.62 (Nm kg) 0.10	0.63 (Nm kg) 0.12	11.12 %	-0.09 (-0.47. 0.29)

								(SD)	(SD)		

S= symptomatic; AS= asymptomatic; ER= external rotators; ER= external rotators; N=Newton, N-M= Newton-meters, iso= isokinetic; ecc= eccentric, Age*= mean in years (SD); SD= standard deviation. Level of Evidence (LOE): OCEBM Levels of Evidence Working Group*. "The Oxford 2011 Levels of Evidence". Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653 * OCEBM Table of Evidence Working Group = Jeremy Howick, Iain Chalmers (James Lind Library), Paul Glasziou, Trish Greenhalgh, Carl Heneghan, Alessandro Liberati, Ivan Moschetti, Bob Phillips, Hazel Thornton, Olive Goddard, and Mary Hodgkinson.

SoF: c) IR and GIRD of the cases.

Study	**LOE**	**Sample size**	**Sport**	**Age***	**S**	**AS**	**IR Position Supine (90/90)**	**Means (SD) Degrees**		**Weight %**	**SMD (95 %CI)**
								S	**AS** Values expressed as means and (SD)		
Lala., B 2017. Prospective Observational study.	3	36	Cricket professional league.	S= and AS= 23.56 (4.27)	8	23	D ND	51.30 (9.53) 58.11 (12.45)	51.48 (14.91) 64.09 (13.30)	8.94 % 10.50 %	-0.01 (0.82. 0.79) -0.44 (-1.26 -

Study	LOE	Sample size	Sport	Age*	S	AS	IR Position Supine (90/90)	Means (SD) Degrees S	AS Values expressed as means and (SD)	Weight %	SMD (95 %CI)
											0.37)
Rosa et al., 2019. Cross-sectional study	3	51	Members of the general public	S= 33.5(10.1) AS= 27.4 (6.6)	25	28	IR	57.4 (12.4)	71.4 (14.7)	11.11 %	-1.01 (-1.58. -0.44)

Study	**LOE**	**Sample size**	**Sport**	**Age***	**S**	**AS**	**IR Position Supine (90/90)**	**Means (SD) Degrees**		**Weight %**	**SMD (95 %CI)**
								S	**AS**		
								Values expressed as means and (SD)			
Lubiatowski1 et al., 2018. **Cross sectional**	3	128	Professional handball Player and asymptomatic control group	S= 25.0 (4.7) AS= 25.0 (1.0)	87 57 49	41 41 41	IR	50.0 (15) 37.0 (12.0) 49.0 (13)	53.0 (13.0) 53.0 (12.0) 52.0 (14.0)	13.79 % 12.86 % 13.79 %	-0.21 (-0.58 . 0.16) -1.32 (-1.76 .-

Study	LOE	Sample size	Sport	Age*	S	AS	IR Position Supine (90/90)	Means (SD) Degrees		Weight %	SMD (95 %CI)
								S	AS		
								Values expressed as means and (SD)			
											0.88) -0.22
Moreno-Perez et al., 2015 Analytical Cross sectional Study.	3	47	Tennis	S=25.6 (3.0) AS= 27.2 (4.3)	19	28	D ND	40.6 (11.6) 52.5	49.3 (11.3) 62.6	10.71 % 10.61 %	-0.77 (-1.37 .-0.16)

Study	LOE	Sample size	Sport	Age*	S	AS	IR Position Supine (90/90)	Means (SD) Degrees S AS Values expressed as means and (SD)		Weight %	SMD (95 %CI)
								(10.6)	(11.0)		-0.92 (-1.53 .-0.30)
Marcondes et al., 2013 **Analytical cross-sectional**	3	49	Tennis	S= 25.9 (4.1) AS= 26.5	27	22	D ND	49.2 (5.6) 65.4	58.0 (7.7) 64.1	10.50 %	-1.31 (1.93.-0.69)

Study	LOE	Sample size	Sport	Age*	S	AS	IR Position Supine (90/90)	Means (SD) Degrees		Weight %	SMD (95 %CI)
								S	AS Values expressed as means and (SD)		
				(3.6)				(11.1)	(4.8)		0.14 (-0.42 . 0.71)
								Degrees Means (SD)			
Moreno-Perez et al., 2015 **Observational**	3	47	Tennis professional players.	S= 25.6 (3.0)	19	28	GIRD	11.9 (10.5)	13.3 (8.6)	20.20 %	-0.14 (-0.72

Study	**LOE**	**Sample size**	**Sport**	**Age***	**S**	**AS**	**IR Position Supine (90/90)**	**Means (SD) Degrees**		**Weight %**	**SMD (95 %CI)**
								S	**AS**		
								Values expressed as means and (SD)			
cross-sectional				AS= 22.2 (4.3)							. 0.44)
Lala, 2017 Prospective observational study	3	36	Professional Cricketers	S and AS= 23.56 (4.27)	9	23	GIRD	7.78 (12.70)	12.61 (13.16)	11.42 %	-0.36 (-1.14 . 0.41)
Lubiatowski1 et al., 2018	3	128	Professional handball players	S=25 (4.7) AS=	36	41	GIRD	6.0 (11)	5 (10)	34.25 %	0.09 (-0.35 .

Study	**LOE**	**Sample size**	**Sport**	**Age***	**S**	**AS**	**IR Position Supine (90/90)**	**Means (SD) Degrees**		**Weight %**	**SMD (95 %CI)**
								S	**AS**		
								Values expressed as means and (SD)			
Cross sectional			and asymptomatic control	25 (1.0)				7 (11) 4 (11)	5 (10) 6 (10)	34.13 %	0.54) -0.19 (-0.64. 0.26)

IR= internal, GIRD= gleno humeral internal range deficit, age*= Age*= mean in years (SD); SD= standard deviation

Level of Evidence (LOE): OCEBM Levels of Evidence Working Group*. "The Oxford 2011 Levels of Evidence". Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653 * OCEBM Table of Evidence Working Group = Jeremy

Howick, Iain Chalmers (James Lind Library), Paul Glasziou, Trish Greenhalgh, Carl Heneghan, Alessandro Liberati, Ivan Moschetti, Bob Phillips, Hazel Thornton, Olive Goddard and Mary Hodgkinson.

SoF: d) ER:IR strength ratios of the cases.

SoF: d) ER:IR strength ratios of the cases.

Author	**Ratio ER: IR Values expressed as means (SD)**		**Isometric**	**DCR Isotonic**	**Sport/ Healthy individuals**	**No Participants**	**Pre-season**	**Post season**
	D	**ND**						
Riemann et al., 2010	0.87 (0.21)	0.88 (0.25)	X		Members of the general public	M=181		
Riemann et al., 2010	0.86 (0.37)	0.85 (0.30)	X		Members of the general public	F=181		
Peckitt and	0.87 (0.21)	0.92 (0.27)	X		Elite cricketers	M=18	X	

Author	**Ratio ER: IR Values expressed as means (SD)**		**Isometric**	**DCR Isotonic**	**Sport/ Healthy individuals**	**No Participants**	**Pre-season**	**Post season**
	D	**ND**						
McCaig 2019								
Peckitt and McCaig 2019	0.82 (0.17)	0.81 (0.24)	X		Elite cricketers.	M=18		X
Forthomme et al., 2018.	0.73 (0.12)	0.81 (0.13)		X Conn Er/conn IR at 60°/s	Hand ball players	M=108		
Forthomme et al., 2018.	1.20 (0.30)	1.30 (0.35)		X Mixed ratio Ecc ER/Conn IR	Handball players.	M=108		

Author	Ratio ER: IR Values expressed as means (SD)		Isometric	DCR Isotonic	Sport/ Healthy individuals	No Participants	Pre-season	Post season
	D	ND						
				at 60°/s.				
Author	Asymptomatic	Symptomatic	Isometric	Isotonic	Discipline			
McDonough et al., (L)	1.84 (0.5)	1.71 (0.26)		X	Rugby	M=20		
McDonough et al., 2014(R)	1.97 (0.29)	1.69 (0.44)		X	Rugby	M=20		
Maestroni et al.,	0.9 (0.2)	0.7 (0.2)	X		Members of the general public	67		
Marcondes et al., (D)	0.82 (0.1)	0.74 (0.2)	X		Tennis	49		
Marcondes et al (ND)	0.99 (0.1)	0.98 (0.1)	X		Tennis	49		

Author	**Ratio ER: IR Values expressed as means (SD)**		**Isometric**	**DCR Isotonic**	**Sport/ Healthy individuals**	**No Participants**	**Pre-season**	**Post season**
	D	**ND**						
Forthommme et al	0.74 (0.12)	0.73 (0.12)		Conn ER at 60°/s X	Handball	108		
Fortheomme et al.,	0.79 (0.16)	0.77 (0.13)		Conn ER at 60°/s X	Handball	108		
Fortheomm et al.,	1.21 (0.33)	1.19 (0.28)		Conn ER at 60°/s	Handball	108		
Skazalski et al	1.35 (0.18)	1.63 (0.53)		Conn ER at 60 °/s	Volleyball	81		

F=female; M= male; D= dominant; ND= non-dominant; ecc= eccentric; isom= isometric; ER= external rotation.

Age*= years in mean (SD); SD= standard deviation; D= dominant' ND= non-dominant, ER:IR = internal versus external ratio.

Level of Evidence (LOE): OCEBM Levels of Evidence Working Group*. "The Oxford 2011 Levels of Evidence". Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653 * OCEBM Table of Evidence Working Group = Jeremy Howick, Iain Chalmers (James Lind Library), Paul Glasziou, Trish Greenhalgh, Carl Heneghan, Alessandro Liberati, Ivan Moschetti, Bob Phillips, Hazel Thornton, Olive Goddard and Mary Hodgkinson

SoF: e) IR; ER; TROM; GIRD; TAMD of the cases.

Authors	IR ROM Means (SD)		GIRD Means (SD)	ER Means (SD)		ERG Means (SD)	TROM Means (SD)	TAMD Means (SD)		Discip
	D	ND	(ND-D)	D	ND	(ND-D)	D	(ND-D) ND		
Peckitt et al.,	185.4 (41.9)	172.1 (46.3)	-13.3	155.0 (27.8)	147.2 (22.5)	-7.8	177.8 (13.5)	183.0 (14.4)	5.6	Crick (Pre- seasor
Peckitt et al.,	172.8 (46.3)	169.1 (52.6)	-3.1	139.2 (32.7)	128.8 (27.3)	11.2	197.8 (16.9)	197.0 (10.3)	- 0.2	In sea
Lala, 2017	51.30 (9.53)	58.11 (12.45)	7.78 (12.70)	121.60 (18.10)	114 (20)	0 (-6-4)	172.90 (19.65)	178 (26)		Crick S

Authors	IR ROM Means (SD)		GIRD Means (SD)	ER Means (SD)		ERG Means (SD)	TROM Means (SD)	TAMD Means (SD)		Discip
	D	ND	(ND-D)	D	ND	(ND-D)	D	(ND-D) ND		
	51.48 (14.91)	64.09 (13.30)	12.61 (13.16)	122.0 (19)	Lala,2017	-2 (-16: -8)	173.09 (20.380	184.91 (19.53)		Cricke AS
Marcondes et al., 2013	49.2 (8.6)	65.4 (11.1)	8.8	107.1 (7.7)	90.5 (3.3)	-16.6	156.3	155.9	- 0.4	Tenni S
Marcondes et al., 2013	58.0 (7.7)	64.1 (4.8)	6.1	97.3 (4.6)	91.8 (2.9)	-5.5	155.3	155.9	0.6	Tenni AS
Moreno-Perez et al., 2015	40.6 (11.6)	49.3 (11.3)	8.7							Tenni S

Authors	IR ROM Means (SD)		GIRD Means (SD)	ER Means (SD)		ERG Means (SD)	TROM Means (SD)	TAMD Means (SD)		Discip
	D	ND	(ND-D)	D	ND	(ND-D)	D	(ND-D) ND		
Moreno-Perez et al., 2015	51.5 (10.6)	62.6 (11.0)	13.3							Tenni As
Rosa et al., 2019	71.4 (14.7)				102.6 (15.3)			174.0		(AS)

Author	IR Means (SD)	GIRD Means (SD)	ER Means (SD)	ERG Means (SD)	TAM Means (SD)	TAMD Means (SD)	Symptoms	Discipline
Lubiatowski et al., 2018	50 (15)	6 (11)	88 (21)	3 (11)	138 (32)	4 (14)	Shoulder pain	Handball (S)

Authors	IR ROM Means (SD)		GIRD Means (SD)	ER Means (SD)		ERG Means (SD)	TROM Means (SD)	TAMD Means (SD)	Discip
	D	ND	(ND-D)	D	ND	(ND-D)	D	(ND-D) ND	
Lubiatowski et al., 2018	53.0 (12.0)	5 (10)	94 (15)	5 (10)	146 (24)	1 (18)	Shoulder pain	Handball (AS)	
Lubiatowski et al., 2018 S	37 (12)	7 (11)	76 (26)	1 (17)	110 (34)	6 (20)	Internal impingement	Handball (AS)	
Lubiatowski et al., 2018	53 (12)	5 (10)	94 (14)	4 (10)	148 (22)	1 (11)	Internal impingement	Handball (AS)	
Lubiatowski et al., 2018 S	49 (13)	4 (11)	94 (16)	7 (7)	14(26)	-3 (9)	Partial rotator cuff tear	Handball (AS)	
Lubiatowski et al., 2018	52 (14)	6 (10)	9(18)	3 (12)	143 (28)	3 (13)	Partial rotator cuff tear	Handball (AS)	

Authors	IR ROM Means (SD)		GIRD Means (SD)	ER Means (SD)		ERG Means (SD)	TROM Means (SD)	TAMD Means (SD)	Discip
	D	ND	(ND-D)	D	ND	(ND-D)	D	(ND-D) ND	

F=female; M= male; D= dominant; ND= non-dominant; ecc= eccentric; isom= isometric; ER= external rotation.

Age*= years in mean (SD); SD= standard deviation; D= dominant’ ND= non-dominant. IR=internal rotation, TROM= total range of motion, GIRD, gleno humeral internal motion deficit, TAMD, total arch of motion deficit.

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SoF: f) Studies investigating pectoralis minor (PM) muscle of the cases and the controls.

Authors	**Sport/ Members of the general public**	**PML (pectoralis minor muscle length) (Kendall position)**	**PMI (pectoralis minor muscle index) (Borstad position)**	**Novel testing position**	**Symptomatic (S) Asymptomatic (AS) Dominant (D) Non-dominant (ND)**	**Other variables**
Lala, 2017	Cricket	X			S and AS	TROM, ER, GIRD
Olivier et al., 2020	Cricket	X			D and ND	TAROM, ER, GIRD
Olivier et al., 20148	Cricket	X			S and AS	ER, IR, TROM
De Souza, 2019	Swimming				AS	

Bhati et al., 2007	Competitive sportsmen				S	Pectoralis minor enthesis
Morais and Cruz, 2016	Overhead athletes				S	Scapula dyskinesis
Grimes et al., 2020	Soc		X		S and AS	Scapula dyskinesis Scapula assistance test (SAT)
Kim et al., 2020	Office workers			X		Shortness of PM
Reeser et al., 2010	Athletes			X		Scapula dyskinesis, GIRD, ER, IR strength
Finley et al., 2017	Soc		X		S and AS	Resting and activated length of PM during arm elevation

Ebaugh et al., 2018	Soc			X	S and AS	Resting and activated length of Pm during scapular plane elevation
Bond, 2016	Soc	X	X		S and AS	Difference between PM Length testing and PMI testing. Scapula dyskinesis.
Yeşilyaprak et al., 2016.	Soc		X		S and AS	Upper trapezius length and scapula dyskinesis test (SDT)
Lee et al., 2015	Soc		X		AS	Serratus anterior muscle

						strength, posterior capsule tightness and scapula dyskinesis
Turgut and Baltaci, 2018	Soc	X			S and AS	Scapula dyskinesis in elevation and posterior capsule tightness.
Navarro-Ledesma et al., 2019	Soc	X			S and AS	Scapula dyskinesis and posterior shoulder tightness And acromio-humeral distance (AHD)

Muhle et al., 2020	Soc		X		S and AS	Strength of lower trapezius
Struyf et al., 2014	Soc		X		S and AS	Intra -and inter -rater reliability
Sebastian et al., 2017	Soc	X			S and AS	Scapula backward s test (SBT)
Harrington et al., 2014	Swimming		X		S and AS and D and ND	IR, ER and joint position test JPS
Rosa et al., 2019	Soc		X		S and AS	Gleno-humeral (GHJ) and ER
Lee et al., 2020	Soc		X		S and AS	Scapular reposition test (SRT) VAS (Pain) and isometric

						elevation strength

F=female; M= male; D= dominant; ND= non-dominant; ecc= eccentric; isom= isometric; ER= external rotation.

Age*= years in mean (SD); SD= standard deviation; D= dominant' ND= non-dominant. IR=internal rotation, TROM= total range of motion, GIRD, gleno humeral internal motion deficit, TAMD, total arch of motion deficit.

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Online supplement 2

Table 1: Table of Characteristics of Included Studies.

Study	Country	Setting/context	Participant characteristics	Groups	Outcomes measured	Main description of results

Umehara et al., 2017.	Japan	University setting	Men (n=18). Age:26.2 (4.0) years. Height: 171.1 (5.0) cm. Weight: 67.4 (7.8) kg.	One group.	(PM) length applying shear elastic modulus, used as the index of muscle elongation, was computed using ultrasonic shear wave elastography.	The most effective stretching position for PM was determined to be horizontal abduction at an elevation of 90 degrees and horizontal abduction at 150 degrees.
Harrington et al., 2014	Brittan.	British Swimming World Class programme.	Female: (n = 37). Age = 19.5 (1.19) years. Height = 170 (7) cm. Weight = 64.7 (6.8) kg. Body-mass index = 22.5 (2.3) kg/m2, who were at	Two groups Painful versus non-painful group.	IR and ER ROM; PML; JPS 45-degree angle; lateral rotation.	Following swimming training shoulder external rotation range of motion and pectoralis minor length reduced significantly in the

			least 18 years old, currently participating in full team practices, and had no history of shoulder surgery in the past 12 months.			painful group.

Online Resources II

Table 1: Table of Characteristics of Included Studies

Study	Country	Setting/context	Participant characteristics	Groups	Outcomes measured	Main description of results
Umehara et al., 2017.	Japan	University setting	Men (n=18). Age:26.2 (4.0) years. Height: 171.1 (5.0) cm. Weight: 67.4 (7.8) kg.	One group.	(PM) length applying shear elastic modulus, used as the index of muscle elongation, was computed using ultrasonic shear wave elastography.	The most effective stretching position for PM was determined to be horizontal abduction at an elevation of 90 degrees and horizontal abduction at 150 degrees.
Harrington et al., 2014	Brittan.	British Swimming World Class programme.	Female: (n = 37). Age = 19.5 (1.19) years. Height = 170 (7) cm. Weight = 64.7 (6.8) kg. Body-mass index = 22.5 (2.3) kg/m2, who were at least 18 years old, currently participating in full team practices, and had no history of shoulder surgery in the	Two groups Painful versus non-painful group.	IR and ER ROM; PML; JPS 45-degree angle; lateral rotation.	Following swimming training shoulder external rotation range of motion and pectoralis minor length reduced significantly in the painful group.

Critical appraisal of studies.

Table 2: Characteristics of Included Studies - Case Control Study Form

Study	Country	Setting/context	Participant characteristics	Group A description and sample	Group B description and sample	Exposures/variables measured	Description of main results

Verma et al., 2020.	Rohtak.	Sample of convenience.	N= 181. N= 90 (F), n= 91 (M). Patients aged between 30-70 years. Two groups age and gender matched control.	181 Randomly selected cases with shoulder pain, age and gender matched.	181 Cases without shoulder pain.	Hand dominance, activity level, working above shoulder level>1 hour, lifting heavy objects > 2 hours, sleep quality, sleep duration, distress, depression, somatisation, waist hip ratio, measures of serum lipid profile, (triglyceride, cholesterol, LDL and VLDL), C-reactive protein, diabetes, metabolic syndrome, pectoralis minor	The final prediction model showed that six out of nine principal components significantly predicted shoulder pain: 1. shoulder compromising work situations; 2. lipid profile I; 3. sleep function; 4. metabolic disorders; 5. antagonist strength

						tightness, thoracic kyphosis, antagonist strength ratio (flexion/extension, abduction/adduction, external rotation/internal rotation) and presence of neck pain.	ratio; and 6. thoracic posture.
Castelein et al., 2016.	Belgium.	Laboratory control study.	N= 37 (F). SIS group (n = 17) Control group (n = 20) Height: 167.4 (6.1) cm 170.1 (5.9) cm; Weight: 65.7 (9.4) kg 62.9 (7.1kg)	Two groups the SIS group and the asymptomatic group.	The healthy control group consisted of 20 participants.	EMG data was collected using a TeleMyo 2400 G2 Telemetry System (Noraxon Inc., Scottsdale, AZ) from 5 scapulothoracic muscles (Trapezius (UT, MT, LT) SA, LS, PM, RM).	During the elevation exercises, the PM was significantly more active in the SIS group in comparison with the healthy

			Age: 30.1 (10.3) years, 28.9 (11.5) years.				control group.

Table 3: Characteristics of Included Studies - Diagnostic Test Accuracy Form

Study	Country	Setting/context	Year/timeframe for data collection	Participant characteristics	Index test description and sample	Reference test descriptions and samples	Description of main results (including adverse events from tests)
Borstad et al., 2015	USA.	Overhead throwing sports and non-throwing sports.	Study 1: 13 participants: once off testing. Study 2: 18 participants: pre-post	Study 1 Throwers Age=22.2 (1.4) years.	LF-low flexion test. The LF measurement is performed	Horizontal adduction was measured inside lying as	Excellent intra-rater reliability for LF (low flexion)

			pitching testing. Study 3: 25 participants : once off testing.	Height= 1.79 (0.05) m. Weight=79.6 (9.9) kg. (n=13) M (n=4) F. Non-throwers Age=23.5 (1.3) years. Height=1.75 (0.06) m. Weight=72.4 (7.6) kg. (n= 13) M (n = 5) F. Study 2: Age=24.2	by passively flexing the patients' shoulder to 60 degrees in the sagittal plane, supporting the elbow, and allowing GHJ IR ROM to reach the end of passive motion. e (Borstad and Dashottar, 2011).	described by Tyler using a metal ruler marked in millimetres.	was concluded that all ICCs were greater than 0.90, indicating excellent intra-rater reliability for LFT. The Low Flexion (LF) test position generated high strain on the posterior capsule and was responsive to experimental tightenin

				(2.4) years. Height=1.82 (0.06) m. Weight= 88.9 (4.7) kg. (n=18) M. (n=0) F Study 3: Age=36.2 (11.3) years. Height= 1.76 (0.07) m. Weight= 79.3 (8.2) kg. (n=25) M. (n=12) F.				g of the capsule in a cadaver study, giving it strong construct validity as a capsule-specific measure

Lewis and Valentine, 2007.	London, UK	Orthopaedic and physical therapy out-patient department in a teaching hospital.	Once off data collection.	N= 90, n= 47 (F), n= 43 (M). Age= 32.1 (7.3) years. Height= 1.7 (0.1) m. Weight=70.4 (14.2) kg. Age=42.8 (16.6) years. Height=1.7 (0.1) m. Weight = 71.4 (11.8) kg.	Measurements were made with the subjects lying in supine. In this position the linear distance from the treatment table to the posterior aspect of the acromion was measured on two occasions (separated by a minimum of 30 minutes and additional	As described by Sahrmann the subjects placed their arms by their sides and the elbows were flexed and rested against the lateral wall of the abdomen. The subject's hands rested gently on the abdomen which would have	The pectoralis minor length test was found to have excellent intra-rater reliability for dominant and non-dominant side of the subjects without symptoms, and for the pain- free and painful side of the subjects with

					data collection on other subjects to reduce bias) by one rater.	placed the glenohumeral joint in slight internal rotation	symptoms.

Table 4: Characteristics of Included Studies - Cohort Study Form

Study	Country	Setting/context	Participant characteristics	Groups	Outcomes measured	Description of main results
Marcondes et al., 2013.	Brasil.	State Federation tennis championships in São Paulo, Brazil, during 2009 and 2011,	Forty-nine male amateur tennis players, between 19 and 33 years old. Age=26.2 (3.9) years. Height=177.3 0.1) cm.	Control group (n=22). Painful group (n=27).	Pain (VAS), internal and external rotation range of motion (ROM), posterior shoulder tightness.	When the strength analyses were performed, we only observed a significant difference

			Weight: 75.4 (5.4) kg.		Isometric HHD strength using a handheld dynamometer Lafayette dynamometer (Lafayette Instrument Company, Lafayette, IN, USA). ROM was collected using a rigid plastic goniometer.	(p<0.05) for the external rotation in the PG (dominant versus nondominant shoulders), indicating a weakness of the external rotators in the painful dominant shoulder. Painful Group presented lower internal rotation ROM and larger external

						rotation ROM than the other shoulders,
Heck et al., 2021	Florida, USA.	University of Florida University of Florida women's gymnastics team.	N = 15 (F). Age= 20.5 (0.9) years. Weight=62.1 (8.6) kg. Height=1.6 (0.06) m. BMI= kg/m2 24.27 ± 3.5 Hand dominance= Right 11 Left 4.	Non-injured arm of gymnast versus injured arm of gymnast.	Isokinetic shoulder internal and external rotation strength was collected using an isokinetic dynamometer. Isometric middle and lower trapezius strength was collected using a HHD (Hoggan Microfet 2). .	Preseason upper extremity ROM and strength were not different between gymnasts who sustained an in-season upper extremity overuse injury and those who did not.
Kolber et al., 2014.	Orlando, Florida.	Weight training fraternity.	N= 55 (M). Age=28.3 (6.5)	Two groups. SIS group	The painful arc sign and	Avoiding performance of

			years;29.0 (6.1); years; 27.9 (6.9) years.	and control group.	the Hawkins-Kennedy test.	lateral deltoid raises and upright rows beyond an angle of 90 degrees and efforts to strengthen the external rotators may serve as a useful means to mitigate characteristics associated with SIS.
Miller et al., 2016.	Nashville.	Orthopaedic and physiatry clinics at two academic	N= 179 Participants. N=86 (F), n= 93 (M). Age: 45 years and older and	Two groups. Symptomatic versus asymptomatic.	Isometric shoulder contraction strength was assessed in three planes -	Patients with supraspinatus tear had decreased

		medical centres.	shoulder symptoms for at least 4 weeks. The average age was 62.7 years in patients with tear versus 59.6 years without tear.		abduction, external rotation and internal rotation using an HHD. VAS collected for pain measurement.	abduction strength and decreased external rotation strength.
Dutton et al., 2019.	Cape Town, South Africa.	Elite South African cricketers.	Male: (n = 105). Injured (n = 18). Uninjured (n = 87). Age =27 (4.2) years, 27.5 (3.9) 26.5 (4.2). Dominance: Left= 17 2. Right=15.	Injured shoulders versus uninjured shoulders.	Shoulder function questionnaire specific to overhead athletes. Isometric muscle strength of the upper trapezius (UT), serratus anterior (SA), lower trapezius (LT), GH	The primary outcome of this study was that cricketers do not present with the classic “thrower's paradox.” Specifically, they exhibited no ERG;

					internal (GHIR) and external (GHER) rotators and gluteus medius (GM) muscles was collected using the (MicroFET 2, Hoggan Scientific, LCC., Salt Lake City, Utah, USA). A Digital inclinometer (Digi-Pas DWL80E, Digipas Technologies, Inc., Dundee, England) for collection of GH and hip rotation,	scapula downward rotation from rest to 90 degrees elevation; strong LT; and maintenance of the AHD. In addition, greater GIRD and loss of total GH rotational ROM; weaker SA, GHIR and GHER; and substantially shorter PSC and PML GH and hip rotation

					scapula upward rotation and GH horizontal adduction ROM (PSC stiffness), For PM length A calliper (Mastercraft Vernier Calliper, Mastercraft Tools, Johannesburg, South Africa) was used. Diagnostic US (M7, Shenzen Mindray Biomedical	GH horizontal adduction ROM (PSC).

					electronics Co., Ltd., Guangdong, China) was used to. measure AHD and supraspinatus tendon thickness (SsT).	
Lala. 2017.	South Africa.	Cricket players.	Thirty -six elite male cricketers, 18 years or older.	Injured: 9 cricket players sustained dominant shoulder injuries• Uninjured: 23 cricket players remained injury free• 3 excluded: 1 sustained	Shoulder external rotation ROM Shoulder internal rotation ROM Throwing arc ROM. GIRD and ERG using a bubble goniometer. Pectoralis minor length test distance	Significant asymmetries were present between four variables in the entire group (internal rotation ROM, external rotation ROM,

				a lumbar stress fracture, 1 sustained a non-dominant shoulder injury, 1 had a current shoulder injury during the preseason assessment and was not cleared to play	a right-angled ruler.	throwing arc ROM and pectoralis minor muscle length) and three variables in the uninjured group (internal rotation ROM, throwing arc ROM and pectoralis minor muscle length). These asymmetries may be involved in injury prevention whereas symmetri

						es observed in the injured group may play a role in injury development during the season
McDonough et al., 2014.	UK.	University Sports Science Laboratory and Professional Rugby League Club.	Twenty-two professional or semi-professional rugby league players Age= 19.6 (1.77) years; 19.2 (1.59) years. Weight=93.9 (9.37) kg; 91 (10.57) kg. Height =183.6 (3.5) cm; 183.3 (1.92) cm.	Non-injured group versus injured group.	Concentric (Con) and eccentric (Ecc) peak torque values; ratio of Ecc internal rotation IR to Con external rotation ER, also known as the dynamic control ratio (DCR), shoulder range of IR	Injury prevention strategies for rugby league players should include exercises to improve shoulder IR and possibly Ecc IR strength.

					and ER. An Isokinetic assessment was carried out. on a Biodex-System III Dynamometer (Biodex Medical, Shirley, New York). A bubble goniometer (model 12-1056, Fabrication Enterprises, White Plains, NY)) was used for ROM.	
Skazalskiet al., 2021.	Norway.	Professional volleyball players	81 Players various positions age= 23-26.	Players with baseline com	SAB thickness, and neovascularization assessments	Greater IR strength and greater IR:ER

				-plaints (n = 22) Developed season complaints (n = 16) No complaints group (n = 43).	internal and external strength HHD; ergoFET500, Hoggan Scientific LLC, Salt Lake City, UT, USA). IR:ER strength ratio calculated. ROM with an inclinometer. Humeral torsion was measured for both arms using a diagnostic. ultrasound device (MyLab25 Gold with LA523	strength ratios were observed in players with baseline complaints Having greater shoulder ER ROM increased a player's risk of developing complaints by 8% for every additional degree. Players presenting with neovessels. and/or increased

					transducer, Esaote, Genoa, Italy). A color Doppler was used to detect. the presence or absence of vessels within the supraspinatus	SAB thickness; are 48% more likely to develop. shoulder complaints.
Olivier et al., 2020.	South Africa.	Actively participating, provincial and club cricketers.	N=32. Male, provincial or premier league club cricketers, aged 18 years or older and exposed to a weekly cricket training workload.	Dominant arm versus non-dominant arm.	ROM, TA ROM, GIRD and ERG) was measured using manual inclinometer (Kolber & Hanney 2012). Pectoralis mnor muscle	Asymmetries in ROM and pectoralis minor muscle.

					length was measured using rigid plastic right angled. ruler (Lewis & Valentine 2007).	
Peckitt and McCaig, 2019.	Loughborough, UK.	Professional county cricket players.	18 male cricket players. Age=24.0 (4.3) years. Height=1.8 (0.1) m. Weight= 83.6 (7.7) kg.	One group, two testings, pre-season and in season.	Shoulder ROM elevation. Shoulder isometric Internal and external strength was collected using a Lafayette Manual Muscle Testing hand-held dynamometer Glenohumeral joint rotator total Arc	Those in the in-season 'playing, but with arm trouble' group had greater ER non-dominant ROM compared to the 'no arm trouble group,' whilst players who developed

					ROM was collected using a Solatronic digital inclinometer. (model EN17).	in-season 'arm trouble' had a tendency towards lower Preseason ER:IR DOM strength ratios.
Finley and Ebaugh 2017.	Philadelphia.	Laboratory setting.	Wheelchair users. N=22 Participants. n=18= (M). n=4 (F). Age=41.68 (4.62) Height=177.50 (8.59) m. Weight: 80.06 (15.51). BMI= 25.12 (6.76).	One group.18 men and 4 women.	PM length was defined as the distance between 2 bony landmarks: the coracoid process and inferior medial aspect of the fourth rib adjacent to the sternocostal junction using a	Association of reduced PMm extensibility with reduced shoulder girdle mobility, pain, and duration of wheelchair use in individual

					caliper (Palpation Metera).	s with SCI.
White et al., 2012.	Texas.	Local university sample of convenience	N= 58, n= 40 (F), n= 18 (M). Healthy adults with an average height (mean) (SD) of Age= 24.2 (5) years. Height=170 (9.3) cm). Weight=67 (12.6) kg.	Two groups.	Isometric Shoulder Internal and external rotation was measured using a tensiometer (Honeywell Sensotec Model GM, Columbus, OH, 500 lbs weight, accuracy of 0.02%Y1%). AHD measured using a MyLab. 25 grayscale ultrasound unit	In conclusion, submaximal isometric shoulder external rotation significantly decreased the AHD when compared with isometric shoulder internal rotation or no contraction at 45 degrees of shoulder abduction

					(Biosound Esaote, Indianapolis, IN).	, whereas at 30 degrees of shoulder abduction, the AHD tended to decrease with iso metric external rotation when compared with iso metric internal rotation or no contraction.
Miranda et al., 2001.	Finland.	Forestry company in Finland.	N=5250. Age between 35-55 years of age. Years 1992, 1993, 1994, 1995.	One group. Four consecutive years follow-up.	Shoulder pain modified Nordic questionnaire	Working with a hand above shoulder level increased the risk of

						developing shoulder pain

Table 5: Characteristics of Included Studies - Case Series Form

Study	Country	Setting/context	Participant characteristics	Groups	Outcomes measured	Description of main results
Duzgun et al., 2017.	Hacettepe University, Ankara, Turkey.	University Sports Physiotherapy Unit for rehabilitation.	N= 155 Participants. N= 104 (), n= 51 (M). Age=49 (9.1), 50.4 (10.7), 58.2 (10.5), 37.4 (12.5) years. BMI= (kg/m2) 26.9 (4.4), 7.6 (5.5), 28.7 (4.4), 24.8 (4.4).	4 groups.	Posterior capsule tightness was assessed in a side-lying position with a ruler from medial epicondyle to plinth position visual analogue scale was used for	Posterior capsule tightness was greatest in patients with frozen shoulder.

					assessing pain.	

Table 6: Characteristics of Included Studies - Case Reports Form

Study	Country	Setting/context	Participant characteristics	Patients	Description of main results
de Souza, 2019.	Brazil.	Swimming fraternity.	19-year-old male.	19-year-old male swimmer.	Elongation of the posterior inferior capsule and the pectoralis minor muscle is essential to achieve muscle balance.

Table 7: Characteristics of Included Studies - Prevalence Study Form

Study	Country	Year/timeframe for data collection	Participant characteristics	Conditions and measurement methods	Description of main results

Yamamoto et al., 2010.	Japan.	Once off data collection.	683 people (total of 1,366 shoulders), including n=229 (M) and n= 454 (F)with a mean age of 57.9 years (range, 22-87.)	Impingement sign was determined according to the Neer's procedure. The active range of motion was measured in forward elevation at the scapula plane with the subject standing upright, and the loss of muscle strength was examined in abduction and external rotation with manual muscle testing on a scale of 0-5. Ultrasonography was. used to examine both shoulders to diagnose rotator cuff tears.	The current results showed that the subjects with rotator cuff tears were positive for impingement sign, showed lesser active forward elevation and weaker muscle strength in abduction and external rotation.

				according to the technique described by Middleton et al,11 using. LOGIQ e (GE Health Care, USA) with linear-array probes at 12 MHz.	

Table 8: Characteristics of Included Studies - Text and Opinion Study Form

Study	Type of text	Population represented	Topic of interest	Setting/context/culture	Stated allegiance/position	Description of main argument(s)
Saini et al., 2020.	Literature review.	Tennis players.	Scapular Dyskinesis and the Kinetic Chain evaluation.	Tennis fraternity.	This article aims to provide a comprehensive understanding of the	Although shoulder pain in the overhead athletes is often multifacto

					evaluation, diagnosis, and management of scapular dyskinesis and its impact on the kinetic chain in tennis athletes.	rial, early recognition and treatment of scapular dyskinesis generally carry a favourable prognosis and result in improved patient outcomes.
Phadke et al., 2009.	Literature review.	Healthy subjects.	Scapula and rotator cuff musculature.	General population.	The rotator cuff plays a role not only in producing glenohumeral internal and external rotation, but more critically in stabilizing the humeral head on the glenoid.	Patients presenting either with excess scapular internal rotation or reduced scapular upward rotation may benefit from

					Thus, across studies, changes in the activity of the scapular muscles, especially trapezius and middle and lower serratus anterior, have been associated with various shoulder related pathologies including shoulder impingement.	incorporation of lower trapezius exercises into their rehabilitation. As noted above, this reduced rotator cuff activation may contribute to further shoulder impingement with excess superior translation of the humeral head.
Bhatia et al.,	Clinical case studies.	Three patients were competitive	Pectoralis minor muscle.	Overuse of the pectoralis minor muscle in a	This study describes the clinical	A simplified technique

2007.		sportsmen (rugby, swimming and body building) and four were non-competitive ones (recreational bodybuilding/fitness exercise).		young population.	features and management of a previously undescribed condition of pectoralis minor insertional tendinopathy, secondary to bench press type of weightlifting.	of ultrasound-guided injection of the pectoralis minor enthesis is described. A new pain site-based classification of shoulder pathology in weightlifters is suggested.
Morais and Cruz, 2016.	Masterclass review.	Overhead athletes.	PMm tightness.	Overhead athletes.	A rehabilitation approach focused on PMm stretching and simultaneous optimization of the	Given the possible interaction between PMm tightness and other biomechanical

					kinematic chain of arm elevation is also discussed, hoping to improve the management of shoulder movement-related impairments and pain.	mechanisms and components of the upper body quadrant, PMm length should be assessed along with the examination of scapular mobility, muscle strength of its antagonist muscles, and posture and mobility of the head, cervical and

						thoracic spines.

Table 9: Characteristics of Included Studies - Analytical Cross-Sectional Study Form

Study	Country	Setting/context	Participant characteristics	Groups	Outcomes measured	Main description of results
Fifolato et al., 2021.	Brazil.	Workers from a tertiary university hospital.	N=27. N= 11 (M), n= 16 (W). Unilateral or bilateral shoulder pain present for 0-12 months. Both sexes between 25 and 60 years of age.	Two groups. Symptomatic side versus asymptomatic side.	Numerical pain rating scale (NPRS). Work ability index. Quick disabilities of the arm, shoulder and hand (Quick International). Physical activity questionnaire (IPAQ)-short version DASH-Br) Nordic musculoskelet	No significant difference in strength between the upper extremities was concluded.

					al questionnaire Lateral preference inventory Isokinetic and isometric dynamometer testing Biodex System 4 Pro™ (Biodex Medical Systems, Inc., Shirley, NY, USA). Hand grip strength was assessed by a JAMAR™ isometric. Dynamometer.	
Maestroni et al., 2020.	Italy.	Sample of convenience from a private clinic.	n=67 Participants. N= 27 (F), n= 40 (M). Age (years).	Two groups, symptomatic and asymptomatic.	Isometric strength of shoulder external rotator and internal rotator muscles;	There was no significant difference in internal rotator strength

			Mean (SD) (min, max) Age 49.6 y (11.6). Height (1.71 m (0.08). Weight 68 kg.		external: internal rotators measured with a HHD (JTECH Commander, PowerTrack, Utah), strength ratio calculated. NPR for pain,	normalized to body weight between symptomatic and asymptomatic sides. Non-athletic people with rotator cuff related shoulder pain had external rotator strength deficits without pain interference during strength testing.

Ishigaki et al., 2015.	Japan.	Divisional collegial baseball team.	N=39 (M) Participants. Age, 20.0 (1.36) years; height, 174.59 (5.47) cm; weight, 71.89 (7.61) kg.	Thirty-nine collegiate baseball players, including 11 pitchers and 28 position players, painful shoulders. 16 Healthy collegiate baseball players (age, 19.4 ± 1.0 years; height, 169.0 ± 6.6 cm; weight, 62.3 ± 5.2 kg).	HAdd and IR ROM using a digital inclinometer (Survey Techno-Science, Nagoya, Japan). PCT measured by using a MyLab 25 ultrasound. unit (Biosound Esaote). Indianapolis, IN, USA).	The results of the present study indicates that posterior shoulder capsule tightness only relates to IR ROM, and that restricted HAdd ROM might reflect tightness of other tissue, such as the posterior deltoid.
Jain et al., 2018.	Nashville,	University controlled study at	N= 301 Participants, n= 144 (F),	Two groups, symptomat	External, internal rotation and	Presented is a model that can

	Tennessee, USA	Vanderbilt University Medical Center, Nashville, Tennessee, USA	n= 157 (M). 45 years of age and shoulder pain duration of at least 4 weeks.	ic versus asymptomatic.	abduction in neutral strength in neutral using a handheld dynamometer. Lift-off test,17 passive lift-off test,16 belly-press test,16 belly-off sign,53 and bear hug test6 for the subscapularis; the external rotation. lag sign at 0_,23 external rotation lag sign at 90_,23 Jobe test. (empty can test),32,33 full can test,36 Neer sign,48 Hawkins-	accurately predict the diagnosis of a rotator cuff tear with satisfactory discrimination and calibration based on 4 variables: sex, lift-off test, Jobe test, and external rotation strength ratio affected versus non-affected arm.

					Kennedy sign,20 and drop arm test60 for the infraspinatus. and supraspinatus; and the horn blower sign58 for the teres minor/infraspinatus.	
Reuther et al., 2018.	USA.	Professional baseball organization professional (both Major and Minor League).	N=30. Age: 22.5 (3.5) years. Weight: 96.1 (8.8) kg. Height: 190.8 (4.9 cm).	Dominant shoulder versus non-dominant shoulder.	HR-humeral retroversion PCT-posterior capsule thickness measured using a (SonoSite Titan Diagnostic Ultrasound Scanner; Fujifilm SonoSite,	When IR measurements were corrected by accounting for HR, GIRD was no longer present, indicating that soft-tissue tightness may not

					Bothell, WA, USA) using a digital inclinometer (Saunders Group Inc, Chaska, MN)) (Glenohumeral IR and ER= TM	be responsible for the reduced IR observed. When ER measurements were corrected by accounting for HR, ERG became a deficit instead of a gain. These findings suggest a paradigm shift in the current assumptions regarding soft tissue changes and their

						relationship to total clinical ROM.
Reeser et al., 2020.	USA.	University-based clinic orthopaedics.	N=60 Participants. N= 23 (F), n= 37 (M). Age=34.0 (15.3) 38.4 (14.6) 29.9 (12.7) 39.2 (15.0) years. Height= 1.71 (0.10) 1.74 (0.10) 1.75 (0.09) 1.72 (0.10) m. Weight= 77.2 (18.7) 84.4 (17.1) 79.6 (16.2) 82.1 (18.8) kg. BMI, kg/m2 26.2 (5.5)	Two groups.	Scapula assistance test (SAT). Penn Shoulder Score for Pain. Active shoulder elevation in the scapular plane, defined as 40 degrees anterior to the frontal plane using a goniometer. A HHD (microFET2; Hoggan Scientific, LLC, Salt Lake City, UT) was used for Ut, Mt, IT SA.	The only significant between group difference based on the result of the SAT was in pectoralis minor muscle length.

			27.9 (4.8) 25.9 (4.5) 27.7 (5.3).		Isometric assessment. PM muscle length was assessed using a tape measure.	
Kolber et al., 2017.	Florida.	Weightlifting fraternity university setting.	Fifty-five male adults, aged 21–56 (mean age 27) years, who participated in WT.	Participants included 24 individuals presenting with SIS. 31 individuals who did not have SIS.	Strength Testing: Internal and external rotation strength; Abduction strength; Upper and lower trapezius strength. With a HHD (micro- FET2_ digital handheld dynamometer Hoggan Health Industries,	Upper trapezius muscle strength was significantly greater in the SIS group. AROM was significantly less in the WT group with SIS; for shoulder internal and external rotations

					Draper, UT). Active flexion, abduction, and external and internal rotation ranges of motion were tested using a translucent plastic 12-inch goniometer.	group with SIS.
Jeon et al., 2019.	South Korea.	Office workers.	n=20 (F), (n=13) M. Age= 23.4 (2.2) years. Height = 176.7 (3.8) cm. Weight= 69.1 (7.1) kg. Hand dominancy 15 Left; 18 Right.	Mouse work shoulder versus non-mouse worker shoulder.	PM using a ruler (Johnson Level & Tool Mfg. Co, Inc., Mequon, WI), The examiner took pictures of each. worker's head and shoulders. IR and ER (ROM) was measured using a universal	The mouse shoulder showed more limited passive internal rotation (69.2% of the normal range) with pain (VAS 5.2) compared with the non-

					goniometer (Jamar, Jackson, MI, USA).	mouse shoulder (79.0% of normal range) without pain.
Ludewig and Cook, 2002.	Minnesota, Minneapolis, USA.	Construction workers in either sheet metal or carpentry trades.	N=52 (M). Age=39 13.3 39.7 12.0 Height (m) 1.80 0.08 1.81 0.06 Weight (kg) 85.7 12.7 90.9 14.0	Two groups. Asymptomatic versus Symptomatic shoulders.	Three-dimensional humeral translations were tracked with a 3-D motion sensor device (FASTRAK (Polhemus, Inc., Colchester, VT)) in symptomatic construction workers and an asymptomatic comparison group while elevating the arm in the	Persons with shoulder symptoms demonstrated small but significant changes in anterior-posterior translations of the humerus. These changes for the 90°–120° phase of humeral elevation were

					scapular plane under no-load, 2.3-kg, and 4.6-kg hand-load conditions. Between-group comparisons were made across 3 phases of motion (30°–60°, 60°–90°, and 90°–120°) and cross-body adduction and shoulder internal rotation ROM.	moderately negatively associated with available cross-body adduction ROM.
Reeser et al., 2010.	Utah, Salt Lake City, UT, USA.	National championship sporting event.	A total of 422 athletes returned questionnaires, of whom 276 also underwent a structured	Three groups, questionnaire, females and males.	SICK scapula score-Scapular malposition, Inferior medial border prominence; Coracoid pain and	A positive association between asymmetric coracoid tightness /pectoral shortening

			physical examination. N=286 (M) n= 136 (W). Mean age of participants, years 21.5 20.9 21.3.		malposition, and dyskinesis of scapular movement; GIRD; passive external glenohumeral rotation; isometric motor function of the shoulder external or internal rotators. Functional neuromuscular trunk control; PM tightness; apprehension at the extreme of passive glenohumeral external rotation. A carpenter's level, positioned across the	and shoulder pain was concluded .

					chest at the level of the coracoid, facilitated detection of any. gross asymmetry for PM.	
Celeste and Overbeek, 2019.	University Medical Centre.	Outpatient clinic between January 2016 and November 2016.	SAPS (n= 40) Controls (n = 30) Age, years (mean, SD) 50 (6) 51 y (6) Female (n=23) (58) 17 (57) Right-side dominance (n= 35 (88) 25 (83). Dominant side affected (n=25) (63) 17 (57)	Forty patients with SAPS and 30 asymptomatic controls were compared. The SAPS and control groups were not different with respect to age, sex,	Surface EMG (DelSys system Bagnoli-16, Boston, MA, USA) during rest and isometric abduction and adduction (using a one-dimensional force transducer).	Patients with SAPS showed an altered adductor co-contraction pattern with reduced teres major activation during abduction.

				and hand dominance.		
Huang et al., 2016.	Taipei, Taiwan	An outpatient clinic of a university hospital.	N=51 Participants, n=40 (M), n=11 (F). Age=22.5 y (2.4) height=171.4 (8.0) cm; weight= 64.9 (10.5) kg.	One group; unilateral shoulder pain around the glenohumeral joint while performing shoulder movement and had scapular dyskinesis.	EMG activity of upper/middle/lower trapezius (UT/MT/LT) and serratus anterior (SA); horizontal adduction range of motion (ROM) and horizontal abduction ROM were measured, respectively, in supine position. Passive ROM of shoulder internal and external rotation in supine.	Increased upper trapezius activity was the only factor associated with functional disability in patients with inferior angle prominence.
Finley et al., 2017.	Philadelphia, PA, USA	University campus.	N=35, n=18 F), n= 17 (M).	One group, free of current	Pectoralis minor muscle	A measuring method

			Between 18 and 35 years of age.	shoulder pain, and able to elevate their arms at least 130.	length resting and activated.	for obtaining PM muscle length extensibility.
Ebaugh et al., 2018.	Philadelphia, PA, USA	University setting.	N=30 One group: 6 males, 9 females. Second group: 3 males, 12 females. Age (years) 26 (4.26). Height (m) 1.70 (0.08); 1.67 (0.09). Mass (kg) 66.2 (10.3) 66.1 (10.4).	Two groups; One group; active pm length group-shelve reaching and scapular plane and elevation. Second group; Passive resting pm length.	Length of pectoralis minor using a PALM (Performance Attainment Associates, St. Paul, MN)	No differences were found in active (typical or passive, short PMm elongation between groups.
Bond C. 2016.	Wairaka.	Sample of convenience.	N=70. Healthy participants, between the	Two groups; Healthy	PMLT and PMI.	The findings of this study are

			age of 18 and 65 years with or without shoulder pain.	participants, Painful group.	4-Type System for monitoring of scapular dyskinesis.	indicative of a complex relationship between clinical measures of pectoralis minor muscle length, upward rotation, pain and observed scapular dyskinesis.
Gomes et al., 2020.	Brazil.	Surfing fraternity, male amateurs' surfers.	N=21 (M), aged between 18 and 42 years, surfing for at least two years. Age 28(5) Height 1.76 (0.7).	One group.	SD was evaluated through the methods slide lateral scapular test (SLST) (static evaluation) and filming (dynamic	Although the athletes had SD and some of them had pain, this does not seem to have

			Hand dominance L =90.5. R =9.5.		evaluation). The SLST consists of a bilateral measurement of the distance between scapula lower angle and corresponding spinous process, with shoulder in three distinct positions: 0°, 45° and 90° abduction. Life quality was assessed through the Western Ontario Shoulder Instability Index (WOSI) NPRS.	influenced their life quality and function.
Yeşilyapraket al., 2016.	Turkey	University setting.	N=148 participants,	Two groups;	Scapular Dyskinesis Test (SDT).	Having a shorter pectoralis

			n= 58 (F), n=90 (M). Age= 23.34 (3.94) years. Mean body mass index [BMI] 22.93 (3.10).	females and males.	Measurement of pectoralis minor resting length (PMI) (standing) And length of trapezius sitting.	minor and upper trapezius length substantially increased the likelihood of having visually observable scapular dyskinesis.
Lee et al., 2015.	South Korea.	Outpatient setting sample of convenience.	N=34 participants, n=22 (F), n= 12 (M). All subjects were at least 18 years of age and right side dominant. The mean and standard deviation of age, weight, and height	Two groups, long PM group and short PM group.	Pectoralis minor muscle length test (pectoralis minor index). Serratus anterior muscle strength test. Posterior shoulder tightness test (the amount of glenohumeral	All predictor variables, including posterior shoulder tightness, should be considered while assessing, managing, and preventin

			were Age; 33.78 (11.15) years; weight; 57.81 (9.10) kg, and Height; 1.64 (0.07) m.		internal rotation). Posterior shoulder tightness test (the amount of glenohumeral horizontal adduction.) Thoracic spine angle measurement in sagittal plane.	g forward scapular posture.
Lubiatowski P, et al., 2018.	Poland.	Male elite professional handball players.	Eighty-seven elite professional male handball players Forty-one healthy non-athlete volunteers were included in the control group based on the	Two groups. Forty-one healthy non-athlete volunteers were included in the control group.	Measurement of shoulder range of internal rotation (IR) and external rotation (ER) with a goniometer, visual analogue scale, Ultrasound scan.	Greater glenohumeral rotational deficits in throwing shoulders of handball players correlate with shoulder pain and internal

			following inclusion criteria: age 20–30; no history of shoulder injury, surgery, pain and/or dysfunction; and no history of professional sport participation. The average age in the players group was 25 years (SD 4.7, range 18–38), height was 188 cm (SD 6, range 175–202) and weight was 92 kg (SD 11, range 64–125 kg).			impingement, while increased external rotation with partial rotator cuff tears.

Benitez-Martinez et al., 2017.	Spain.	Overhead athletes.	Male n=81 age: 26.11 (8.4) y, height: 180 (6) cm, BMI: 24.6 (2.2) kg.	Two groups; pain full group and non-painful group.	Cross-sectional area (CSA), AHD, VAS using a portable Logic-e Ultrasound Scanner (GE HealthCare, Wauwatosa, WI, USA). Shoulder Rating Questionnaire.	Significant atrophy and reduction in the CSA of the supraspinatus muscle of the painful shoulder, compared with healthy controls.
Moreno-Perez et al., 2015.	Spain.	Professional male tennis players.	47 Male participants. Age (years) 23.2 ± 4.9 22.2 ± 4.3 25.6 ± 3.0 3.624 0.063 Height (cm) 183.6 ± 5.0 184.1 ± 5.8 182.7 ± 3.6 0.886 0.352 Mass (kg)	Two groups. 19 in the Painful group,28 in the non-painful group.	IR, TROM, ER. Photographs taken and digitally analysed.	In professional tennis players, limited IR ROM rather than a GIRD, seems to be associated with shoulder

			77.5 ± 6.5 77.60 ± 7.6 77.5 ± 4.8			pain history.
Wong 2020.	Hong Kong.	University laboratory.	56 participants. Age, y 26.0 (1.8) ;23.9 (4.5); 26.7 (4.9). Gender (M: F) 15:16; 11:3; 6:5. Height, m 1.7 (0.1); 1.7(0.1); 1.7(0.1). Weight, kg 58.9 (8.2); 68.9 (6.5);66.5 (12.6).	Two groups; twenty-five elite softball players and 31 asymptomatic sedentary controls.	Isokinetic concentric IR and ER peak torque and fatigue ratio were measured at 60°/s and at 180°/s, respectively; and ultrasound measurement of the SAS was measured during 0° and 60° of shoulder abduction.	Decreased strength ratio and fatigue ratio of ER/IR were related to reduction of the SAS.
Rosa et al., 2019.	Brazil	University setting, orthopaedic clinics, and surrounding community	N= 50, n= 26 (F), n= 24 (M). Age, y 27.4 ± 6.6 29.0 ± 8.0 32.2 ± 12.3 33.5 ± 10.1 2.48 (3) .06	Control group (n = 28) PCT group (n = 27) SIS group (n = 25), SIS + PCT group (n = 25	Scapular kinematics and humeral translations were quantified with an electromagnetic motion	Decreased ROM and lower pain thresholds were found in individuals with both

			Height, m 1.69 ± 0.08 1.70 ± 0.10 1.68 ± 0.12 1.68 ± 0.10 0.19 (3) .89 Weight, kg 67.98 ± 11.73 70.04 ± 12.28 71.46 ± 15.61 69.88 ± 10.77 0.12 (3)		capture system. Shoulder internal rotation and external rotation ROM, external rotation strength, and pain and Shoulder Pain and Disabilities Index score. PCT was estimated with the Low Flexion Test (LFT). ROM measured by a digital inclinometer (Acumar, Lafayette Instrument Co, Lafayette, IN, USA).	impingement symptoms and PCT. However, the combination of factors did not influence scapular and humeral kinematics

Turgut and Baltaci, 2018.	Turkey.	Sample of convenience.	N=58. 29 Symptomatic individuals. 29 Asymptomatic individuals.	Two groups.	Relationship between pectoralis minor (PMLT) posterior capsule flexibility (inside lying) deficits and scapular asymmetry in the resting position and during arm elevation in asymptomatic and symptomatic individuals.	Increased deficit in the pectoralis minor and posterior capsule flexibility were associated with increased scapular asymmetry.
Oyewole, 2019	South Africa.	Wheelchair basketball players.	Participants who were 18 and above. Two male clubs and one female club. 21 males and 4 females.	Two groups. 21 Males and 4Females.	Wheelchair User's Shoulder Pain Index Questionnaire for extrinsic risk factors. The Apprehension	The association between participants who reported shoulder pain prior to wheelchai

					test and relocation test. Sulcus sign test: Load and shift test: External rotation Internal rotation ROM. (12-inch plastic baseline goniometer model 12-1000) White Plains, New York). Association between shoulder pain history and range of motion.	r use and left external range of motion of the shoulder was significant.
Navarro-Ledesma et al., 2019.	Spain.	Primary-care centres.	108 participants aged between 18 and 45 years of age.	Two groups. Symptomatic versus	Scapula upward rotation (SUR) test. Pectoralis minor length (PMLT).	PML is poorly associated with AHD, as well as

			Age =46 (43.67-49.11) years. N=54 (F); n=54 (M). Height (cm) 164.42 (160.20-168.65). One group (54) with unilateral shoulder pain and the other group (54) without shoulder pain.	asymptomatic.	Shoulder pain and disability index (SPADI).	with shoulder pain and mobility, in people with chronic shoulder pain. SUR was greater in patients with chronic SAPS compared with controls at different angles of shoulder elevation.
Muhle et al., 2020.	South-Africa.	University setting.	N=144, between ages 18 and 24 from the Faculty of Health Sciences.	Two groups.	PML -index	The significant differences between the active and posterior

						tilt positions suggested that optimal muscle length of PM was affected by the inner range strength of the lower fibres of Trapezius.
Sarioglu and Pekyavas, 2021.	Turkey.	University Hospital's Physical Medicine and Rehabilitation Department.	30 Asymptomatic participants and 30 symptomatic participants aged 20 to 40.	Two groups. Asymptomatic versus symptomatic.	Trunk Flexibility- modified Schober test TLF Flexibility.	For the participants we studied, the flexibility of the TLF was not associated with SAIS.
Struyf et al., 2014.	Belgium	Outpatient based	N= 50. Age (y) Mean	25 patients with SIS	Intra-rater reliability and	Concluded Results:

		private setting.	(SD) 50.8 (16.3) 20.8 (1.5) Gender Male 8 (32%) 16 (64%) Female 17 (68%) 9 (36%) Height (cm) Mean (SD) 169.2 (9.9) 175.7 (9.8) Body weight Mean (SD) 74.5 (15.5) 72.6 (13.7)	and 25 pain-free controls	reliability of PMI test. The instruction was to palpate two anatomical reference points which in line represent the PMLI muscle: (1) the inferomedial aspect of the coracoid process and (2) the caudal edge of the fourth rib at the sternum.	the PMI measurement has good to excellent intra-rater reliability and poor to moderate inter-rater reliability.
Sebastian et al.,2017.	Livonia, USA	Outpatient clinic.	30 patients with shoulder pain.	Two groups: uni- lateral shoulder pain and	PML in supine.	The Scapula backward tipping test (SBTT) may be incorporated as a

				uni-lateral no pain shoulder.		simple yet effective test to determine the presence of PM tightness and subsequently scapula forward tipping.
Park et al., 2021.	Republic of Korea.	University setting.	58 Males, age, height, and body weight were 21 (1.1) years, 179 (5.4) cm, and 83.9 (9.7 kg), respectively.	29 college baseball players throwing arm, 29 college baseball players non -throwing arm.	External rotation (ER) and internal rotation (IR) of the shoulder using a digital inclinometer and PCT thickness using an ultrasound machine (Aplio i700 (Canon Medical Systems	SW (shear wave elastography velocity) is closely related to posterior shoulder capsular tightness.

					Co., Otawara, Japan).	
Harrington et al., 2014.	North Florida, Jacksonville, USA.	NCAA Division I swimmers in the state of Florida.	Female, (n = 37). age = 19.5 (1.19) y, height = 170 (7) cm, weight = 64.7 (6.8) kg, body-mass index = 22.5 (2.3) kg/m2.)	Dominant arm of swimmers and non-dominant arm of swimmers.	PMI (PALM's (Performance Attainment Assoc, St Paul, MN) shoulder pain and disability in dominant arm and non-dominant arm of swimmers were used.	Significant difference in dominant arm resting and stretched pectoralis minor muscle length between female swimmers with and without shoulder pain and disability.
Kara and Duzgun I. 2019.	Turkey.	Laboratory controlled study.	Twenty-two participants (11 females, 11 males) with a	Two groups SAIS versus	EMG activity of UT, MT, and LT were measured with electromyogra	The UT/LT ratio during scapular

			diagnosis of SAIS and 22 healthy controls (11 females and 11 males) matched with age and gender participated in this study.	healthy controls.	phic studies (Noraxon Telemyo DTS System, Scottsdale, USA).	retraction with external rotation at 0 degrees was significantly lower than all other exercises.
Borstad and Ludewig 2002.	Minneapolis, USA.	Construction workers in the sheet metal and carpentry trades.	Healthy and symptomatic, n=52. Mean SD Age (years) 39.9 (13.3) 39.7 1(2.0) Height (m) 1.80 (0.08) 1.81 (0.06) 1.67–1.93 Weight (kg) 85.7 (12.7) 90.9 (14.0)	Healthy group versus symptomatic group.	Scapular upward rotation, scapular internal rotation and scapular tipping FASTRAK electromagnetic motion capture system (Polhemus Inc., Colchester, VT, USA) was used to.	Averaged across phases, the symptomatic group. demonstrated significant reductions in upward rotation at lower humeral elevation angles, and significant

					track 3-D position and orientation of each subject. thorax, scapula, and humerus.	increases in anterior. tipping at higher elevation angles as compared to the healthy group.
Riemann et al., 2010.	USA.	Participants at a local university and local area fitness centers in Armstrong Atlantic State University, Savannah, GA, USA	Variable Men Women (n ¼ 90) (n ¼ 91) Age, years 23.3 4.8 23.4 4.1 Height, m) 1.79 .08 1.64 .08 Mass, kg) 81.4 14.0 64.7 16.9	181 healthy volunteers' sample of convenience Men (n= 90)181 healthy volunteers' sample of convenience Men (n= 91)	Shoulder internal and external rotator cuff strength were measured with a hand-held Baseline 250 hydraulic push-pull dynamometer (Baseline Corporation, Irvington, NY).	Because there are no differences between the seated at neutral and 30_-30_-30_ positions and the advantages it offers, we recommend the 30_-30_-30_ position

						for testing and the initiation of rehabilitation.
Rosa et al. 2019.	Brazil	local university setting and community	Asymptomatic group (n = 25) Symptomatic group (n = 25) Gender 13 women; 12 men 13 women; 12 men Age (years) 21.60 ± 2.50 22.48 ± 2.70 Height (m) 1.70 ± 0.08 1.72 ± 0.09 Weight (kg) 67.80 ± 12.18 69.66 ± 15.36	18 and 30 years of age convenience sample of 25 individuals asymptomatic group25 symptomatic group.	PMI was measured with a tape seated and in supine position. GHJ ER ROM measured with a digital inclinometer (Acumar™, Lafayette Instrument Company, Lafayette, Indiana).	A significant negative correlation between PMI resting length. and GHJ ER ROM in the seated position was noted in the asymptomatic group (r = −0.41; p = 0.04), but not in the

						symptomatic group.
Laudner, 2004.	University of Pittsburgh USA	Controlled laboratory setting at a university.	N=22. Impingement Group n=11. Healthy n=11. Group Mean ±SD Mean ±SD Age (yrs) 22.09 3.45 21.18 1.72 Height (m) 1.84 0.07 1.83 0.06 Mass (kg) 90.99 14.62 89.86 12.99.	Impingement Group The experimental subjects consisted of 6 pitchers and 5 position players, Healthy Group the control group consisted of 4 pitchers and 7 position players	Passive range of motion internal and external rom measured with a goniometer, posterior capsule tightness (Tyler et al,2002.) Biodex System 3 isokinetic Device used for isokinetic ER, Ir and ABD	Significantly decreased internal rotation and increased posterior capsule tightness among the impingement group compared to the healthy group.
Cools et al., 2016.	Belgium	Different sports disciplines : tennis, volleyball	Males (n = 101) Females (n = 100) Age (years) 27.3 ± 8.3 27.8 ± 8.5	Two groups. 101 Male healthy overhead athletes,	RC strength isometric ER and IR strength measured with a HHD (	ER, measured with a HHD, should be higher

		and handball.	Height (m)* 1.83 ± 0.06 1.69 ± 0.07 Mass (kg)* 80.4 ± 11.2 65.8 ± 9.3 BMI♦ 24 ± 2.8 22.9 ± 2.7	100 female healthy overhead athletes.	MicroFET 2, Hoggan Health Industries Inc., Biometrics, The Netherlands).	than the isometric IR strength, in both positions. In addition, side and gender difference s were apparent, with lower ER values for the male athletes on their dominant side. These results might reflect an increased risk of injury in these subjects,

						given the fact that weakness in the external rotator was established to be a risk factor for throwing related shoulder pain.
DOS SANTOS De Andrade et al., 2010.	Brazil	Brazil National Handball Team.	N= 27 (F). Age 23.0+3.4 years, weight 71.0+10.6 kg, and height¼1.73 +0.07 m.	Asymptomatic players.	Strength of internal and external rotators was tested through 120 degrees of range of motion between 60 degrees of internal and external rotation	Our results suggest that concentric strength exercises be used for internal and external rotators on the

					measured with a Biodex. System 3 dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA.)	nondominant side, and functional exercise that improves eccentric rotation strength for prevention programmes.
Kim et al., 2009.	Missouri.	Sample of convenience	Men and Women = 237. 144 men and ninety-three women.	Four groups. Subjects who were forty to forty-nine years subjects who were fifty to fifty-nine years subjects who were	Ultrasonography was performed. On the LHB, subscapularis, supraspinatusa and infraspinatus (scanner (Zonare Medical Systems,	When there is a substantial decrease in abduction strength in relation to external rotation strength, the presence of an

				sixty to sixty-nine years subjects who were seventy years old.	Mountain View, California) and a variable high-frequency linear array transducer (5 to 10MHz). Measurements for abduction in the scapular plane and external rotation with an Isobex dynamometer (Cursor AG, Bern, Switzerland) was. used to measure the isometric shoulder strength.	asymptomatic full thickness tear should be suspected in that shoulder.

Mankad and Jagad 2016.	Rajkot.	Physiotherapy college, RAJKOT.	N=200 participants, n= 176 (F); n=24 (M). Age 18-25 years.	One group. Healthy collegiate individuals.	PMI with a protractor.	There is prevalence of tightness of pectoralis minor in healthy collegiate individuals.
Lee et al., 2020.	Republic of Korea.	University setting.	Participants: n= 22 (F); n=12 (M). Short PM (n=18) Long PM (n=16) Gender Male 6 6 Female 12 10 Age (years) 23.77 (4.50); 21.93 (3.53) BMI (kg/m2) 21.85 (2.52); 20.73 (1.56).	Two groups. The inclusion criterion was reported pain intensity of at least 1.4 cm on a visual analogue scale (VAS) during one	Scapula reposition test (SRT), VAS, isometric shoulder elevation strength with a hand-held dynamometer (CommanderTM Muscle Tester; JTECH Medical, Midvale, UT, USA).	In the short pectoralis minor group, shoulder elevation strength was significantly improved by scapular reposition test.

				of three impingement tests (Neer, Hawkins-Kennedy, and the empty can test), which is the minimal clinically importance difference reported in shoulder pain participants assigned to the long PM group versus the short PM group.	PMI test.	
Forthomme. 2018.	France and Belgium	Male team handball senior divisions (the	108 male high level handball players (age ¼ 24 6 4	Two groups; dominant arm and non-	Internal rotators, Nm/kg External rotators,	For traumatic injuries, the concentric

		highest level) in France and Belgium.	years, height ¼ 189 6 6 cm, mass ¼ 87 6 11 kg)	dominant arm.	Nm/kg Ratio of external rotators: internal rotators Mixed ratio (external rotators in the eccentric mode at 60°/s to internal rotators in the concentric mode measured using an isokinetic dynamometer (model Cybex HUMAC NORM; Computer Sports Medicine, Inc, Stoughton, MA).	maximal strength developed by the internal rotators at high speed (2408/s) in the dominant shoulder was a protective factor against the risk of further injury
Nordqvist et al., 2021.	Sweden.	Swedish primary care unit in	Participants included in analyses (n =	Participants included in analyses	AROM, was measured with	Rotator cuff dysfunctio

		the county of Östergötland	164) n= 64 (F); N= 100 (M). Age in years: mean (SD) 52 (9); 52 (9).	(n = 164) Participants in RCT (n = 123) Participants in implementation study (n = 132) Participants with missing data (n = 91)	a handheld goniometer, included examination of flexion, abduction and external rotation, and was performed with the patient standing f resisted isometric manual resistance by the PT, testing in two different positions; approximately 30 degrees of abduction, as well as external rotation and internal rotation with the elbow	n, defined as pain during resisted isometric muscle-testing in one direction or more, is very frequent while limitation in AROM and scapular dyskinesia are more inconsistent findings. All three components are unique and not significantly correlated

					flexed to 90 degrees and the upper arm alongside the thorax scapular kinematics, was assessed according to the classification of Kibler	with each other which highlights their respective relevance.
Olivier et al.,2018	South Africa	Provincial and club cricketers.	32 Male, provincial or premier league club cricketers, aged 18 years or older and exposed to a weekly cricket training workload, a mean age of 23.56 years (4.27).	Two groups injured versus uninjured.	ER, IR, TROM PML. ER and IR measured with a plastic handheld goniometer.	Decreased combined. elevation, increased shoulder internal rotation ROM on the nondominant side and increased GIRD were associated

						with in - season. non-contact lower quarter injuries in domestic cricketers,

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Critical appraisal tables:

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score	Risk of Bias
Lewis and Valentine, 2007.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10/10	Low
Riley and Grimes 2020.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10/10	Low
Borstad et al., 2015.	Y	Y	Y	Y	U	Y	U	Y	U	Y	7/10	Low

%	100.0	100.0	100.0	100.0	66.6	100.0	66.6	100.0	66.6	100.0		

Table a): Critical Appraisal of Eligible Diagnostic Test Accuracy

1. Was a consecutive or random sample of patients enrolled?

Q2. Was a case control design avoided?

Q3. Did the study avoid inappropriate conclusions?

Q4. Were the index tests results interpreted without knowledge of the reference standard?

Q5. If a threshold was reached, was it pre-specified?

Q6. Is the reference standard likely to correctly classify the target condition?

Q7. Were the reference standard results interpreted without the knowledge of the results of the index test?

Q8. Was there an appropriate interval between the index test and the reference standard?

Q9. Did all patients receive the same reference standard?

Q10. Were all patients included in the analysis?

Table b): Critical appraisal of Eligible prevalence study.

Y=yes; N=no; U= unclear; NA= not applicable.

Q1. Was the sample frame appropriate to address the target population?

Q2. Were study participants sampled in an appropriate way?

Q3. Was the sample size adequate?

Citation	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Score**	**Risk of Bias**
Yamamoto et al., 2010.	Y	Y	U	Y	Y	Y	Y	Y	Y	8/9	Low
%	100.0	100.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0		

Q4. Were the study subjects and the setting described in detail?

Q5. Was the data analysis conducted with sufficient coverage of the identified sample?

Q6. Were valid methods used for the identification of the condition?

Q7. Was the condition measured in a standard, reliable way for all participants?

Q8. Was there appropriate statistical analysis?

Q 9. Was the response rate adequate, and if not, was the low response rate managed appropriately?

Table c): Critical appraisal of eligible case series

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score	Risk of Bias
Duszgun and Turgut 2017.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10/10	Low
Turgut And Baltaci 2018	U	Y	U	Y	N	N	N	N	N	U	2/10	High
%	50.0	100.0	50.0	100.0	50.0	50.0	50.0	50.0	50.0	50.0		

.

Y=yes; N=no; U= unclear; NA= not applicable.

Q1. Were there clear criteria for inclusion in the case series?

Q2. Was the condition measured in a standard, reliable way for all participants included in the case series?

Q3. Were valid methods used for identification of the condition for all participants included in the case series?

Q4. Did the case series have consecutive inclusion of participants?

Q5. Did the case series have complete inclusion of participants? Was there clear reporting of the demographics of the participants in the study?

Q6. Was there clear reporting of clinical information of the participants?

Q7. Were the outcomes or follow up results of cases clearly reported?

Q8. Was there clear reporting of the presenting site(s)/clinic(s) demographic information?

Q9. Was statistical analysis appropriate?

Table d): Critical Appraisal of cohort studies

Citation	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Score**	**Risk of bias**

Joffrey Drigny Vincent Gremeaux 2020.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11/11	Low
Dutton M, Tam N, Brown JC, Gray J. 2019.	Y	Y	Y	Y	Y	N	Y	Y	U	U	Y	8/11	Low
Bhakti Lala. 2017.	Y	Y	Y	Y	Y	U	U	Y	Y	Y	Y	9/11	Low
White CE, Dedrick GS, Apte GG, Sizer PS, Brismée J-M. 2012.	Y	Y	U	U	N	Y	Y	N/A	N/A	N/A	Y	8/11	Low
Earle Miller J, Higgins LD, Dong Y,	Y	Y	Y	Y	Y	N	Y	N/A	N/A	N/A	Y	10/11	Low

Collins JE, Bean JF, Seitz AL, et al. 2016.													
Kaysha Heck *† PT, Michael Moser § MD. 2021.	Y	Y	Y	Y	U	Y	U	Y	Y	U	Y	8/11	Low
Kolber MJ, Cheatham SW, Salamh PA, Hanney WJ. 2014.	Y	Y	U	Y	Y	Y	Y	N/A	N/A	N/A	Y	10/11	Low
Marcondes FB, de Jesus JF, Bryk FF, de Vasconcelos RA,	Y	Y	Y	Y	N	N	Y	N/A	N/A	N/A	Y	9/11	Low

Fukuda TY. 2013.												
McDonough A, Funk L. 2014.	Y	Y	Y	Y	U	Y	U	Y	Y	N/A	Y	9/11	Low
Skazalski C, Bahr R, Whiteley R. 2021.	Y	Y	U	Y	N	N	U	Y	Y	U	Y	6/11	Moderate
Olivier B, Lala B, Gillion N. 2020.	Y	U	U	Y	N	N	U	Y	Y	N/A	Y	6/11	Moderate
Peckitt J, McCaig S. 2019.	Y	Y	U	Y	U	N	U	Y	Y	U	Y	6/11	Moderate
Finley MA, Ebaugh D. 2017.	Y	Y	U	N	N	N	Y	N/A	N/A	N/A	Y	7/11	Low
H Miranda EV-J.2014	Y	Y	U	Y	Y	N	U	Y	Y	U	Y	7/11	Low

%	93.75	87.5	50.0	75.0	31.25	31.25	43.75	62.5	56.25	6.25	93.75		

Y=Yes; N=No; U=Unclear; N= Not applicable.

Q1. Were the two groups similar and recruited from the same population?

Q2. Were the exposures measured similarly to assign people to both exposed and unexposed?

groups?

Q3. Was the exposure measured in a valid and reliable way?

Q4. Were confounding factors identified?

Q5. Were strategies to deal with confounding factors stated?

Q6. Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?

Q7. Were the outcomes measured in a valid and reliable way?

Q8. Was the follow up time reported and sufficient to be long enough for outcomes to occur?

Q9. Was follow up complete, and if not, were the reasons to loss to follow up described and explored?

Q10. Were strategies to address incomplete follow-up utilized?

Q11. Was appropriate statistical analysis used.

Table e): Critical Appraisal of Eligible Case Control

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score	Risk of Bias
Castelein B, Cagnie B, Parlevliet T, Cools A. 2016.	Y	Y	Y	Y	U	Y	Y	Y	N/A	Y	9/10	Low
Verma B, Multani NK, Kundu ZS. 2020.	Y	Y	U	Y	U	N	N/A	Y	N/A	Y	7/10	Low
%	100.0	100.0	50.0	100.0	0.0	50.0	50.0	100.0	0.0	100.0		

Y=Yes; N=No; U=Unclear; NA=Not applicable.

Q1. Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?

Q2. Were cases and controls matched appropriately?

Q3. Were the same criteria used for identification of cases and controls?

Q4. Was exposure measured in a standard, valid and reliable way?

Q5. Was exposure measured in the same way for cases and controls?

Q6. Were confounding factors identified?

Q7. Were strategies to deal with confounding factors stated?

Q8. Were outcomes assessed in a standard, valid and reliable way for cases and controls?

Q9. Was the exposure period of interest long enough to be meaningful?

Q10. Was appropriate statistical analysis used?

Table f): Critical Appraisal of Eligible Analytical Cross-Sectional Study

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Score	Risk of Bias
Olivier et al., 2018	Y	Y	Y	Y	U	U	Y	Y	7/8	Low
Forthomme et al., 2018.	Y	U	U	Y	Y	N	U	Y	4/8	Moderate
Overbeek et al., 2019.	Y	Y	U	Y	Y	N	Y	Y	6/8	Low
Fifolato et al., 2021.	Y	Y	Y	Y	Y	N	Y	Y	7/8	Low
Grimes et al., 2020.	Y	U	Y	Y	Y	N	Y	Y	6/8	Low
Ishigaki et al. ,2015.	U	Y	Y	Y	Y	N	Y	Y	6/8	Low
Jain et al., 2018.	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low
Huang et al., 2016.	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low
Reeser et al., 2010.	N	Y	Y	Y	Y	U	Y	Y	6/8	Low
Gomes et al.,2020.	Y	Y	Y	Y	Y	N	Y	Y	7/8	Low

Benitez-Martinez et al., 2017.	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low
Bond C. 2016.	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low
Ebaugh et al., 2018.	Y	Y	U	Y	Y	Y	Y	Y	7/8	Low
Finley et al., 2017.	Y	N	Y	Y	Y	Y	N/A	Y	6/7	Low
Reuther et al., 2018.	Y	N	Y	Y	Y	U	Y	Y	6/8	Low
In-cheol et al., 2019.	Y	Y	U	Y	Y	N	U	Y	5/8	Moderate
Kolber et al., 2017.	Y	Y	U	Y	Y	Y	Y	Y	7/8	Low
Maestroni et al., 2020.	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low
Ludewig and Cook 2002.	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low
Yeşilyaprak et al., 2016.	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low

Lee et al., 2015.	Y	N	Y	Y	Y	Y	Y	Y	7/8	Low
Lubiatowski et al., 2018.	Y	Y	U	Y	Y	U	Y	Y	6/8	Low
Moreno-Perez et al., 2015.	Y	Y	U	U	Y	U	U	Y	4/8	Moderate
Wong 2020	Y	Y	Y	Y	Y	U	Y	Y	7/8	Low
Rosa et al., 2019.	Y	U	Y	Y	Y	Y	Y	Y	7/8	Low
Turgut and Baltaci 2018.	Y	Y	U	Y	Y	U	U	Y	5/8	Moderate
Oyewole Oluwayemisi Christiana. 2019	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low
Nordqvist et al., 2021.	Y	Y	U	Y	Y	U	Y	Y	6/8	Low
Navarro-Ledesma et al., 2020.	Y	Y	Y	Y	Y	N	Y	Y	7/8	Low

Navarro-Ledesma et al., 2019	Y	Y	U	Y	Y	N	Y	Y	6/8	Low
Navarro-Ledesma et al., 2018.	Y	Y	Y	Y	Y	N	Y	Y	7/8	Low
Muhle et al..	Y	Y	U	Y	Y	Y	U	Y	6/8	Low
Struyf et al., 2014.	Y	Y	Y	Y	Y	U	Y	Y	7/8	Low
Sebastian et al.,2017.	U	N	N	Y	Y	N	N/A	Y	3/7	High
Pekyavas, 2021.	Y	Y	Y	U	Y	N	U	Y	5/8	High
Park et al., 2021.	N	Y	Y	Y	Y	Y	Y	Y	7/8	Low
Harrington et al., 2014.	Y	Y	U	Y	Y	Y	U	Y	6/8	Low
Duzgun, 2019.	Y	U	Y	Y	Y	Y	Y	Y	7/8	Low
Borstad and Ludewig, 2002.	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low

Kim et al., 2009.	U	Y	U	Y	Y	Y	U	Y	5/8	Low
Mankad and Jagad, 2016.	Y	Y	U	N/A	Y	N	U	Y	4/7	Moderate
Lee I-G, Im S-C, Kim K. 2020.	U	Y	U	Y	Y	N	Y	Y	5/8	Low
Dos Santos De Andrade et al., 2020	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low
Cools et al., 2016.	Y	Y	Y	Y	Y	Y	N/A	Y	7/7	Low
Rosa et al., 2019.	Y	Y	Y	Y	Y	Y	Y	Y	8/8	Low
Laudner, 2004.	Y	Y	Y	Y	Y	N	Y	Y	7/7	Low
Riemann et al., 2010.	Y	Y	U	N/A	Y	Y	N/A	Y	7/8	Low
%	87.23	82.97	63.82	91.48	97.87	48.93	72.34	100.0		

Y=Yes; N=NO; U=Unclear; NA= Not applicable.

Q1. Were the criteria for inclusion in the sample clearly defined?

Q2. Were the study subjects and the setting described in detail?

Q3. Was the exposure measured in a valid and reliable way?

Q4. Were objective, standard criteria used for measurement of the condition?

Q5. Were confounding factors identified?

Q6. Were strategies to deal with confounding factors stated?

Q7. Were the outcomes measured in a valid and reliable way?

Q8. Was appropriate statistical analysis used?

Table g): Critical appraisal of Text and opinion studies.

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Score	Risk of bias
Morais N, Cruz J. 2016.	Y	U	Y	Y	Y	Y	5/6	Low
Phadke V, Camargo PR,	Y	U	Y	Y	Y	N	4/6	Low

Ludewig PM. 2009.								
Saini SS, Shah SS, Curtis AS. 2020.	Y	U	Y	Y	Y	U	4/6	Low
Bhatia DN, de Beer JF, van Rooyen KS, Lam F, du Toit DF. 2007.	Y	Y	Y	Y	Y	N/A	6/6	Low
%	100.0	25.0	100.0	100.0	100.0	25.0		

Y=yes; N=no; U= unclear; NA= not applicable.

Q1. Is the source of the opinion clearly identified?

Q2. Does the source of the opinion have standing in the field of expertise?

Q3. Is the interest of the relevant population the central focus of the opinion?

Q4. Is the stated position the result of an analytical process, and is there logic in the opinion expressed?

Q5. Is there reference to the exact literature?

Q6. Is any incongruency with the literature/sources logically defended?

Table h): Critical Appraisal of Eligible Case Reports

Citation	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Score**	**Risk of bias**
Ramos MRF, Junior YACS, de Souza LAB. 2019.	U	U	Y	Y	Y	Y	N	Y	5/8	Low
%	0.0	0.0	100.0	100.0	100.0	100.0	0.0	100.0		

Y=Yes; N=NO; U=Unclear; NA= Not applicable.

Q1. Were patient's demographic characteristics clearly described?

Q2. Was the patient's history clearly described and presented as a timeline?

Q3. Was the current clinical condition of the patient on presentation clearly described?

Q4. Were diagnostic tests or assessment methods and the results clearly described?

Q5. Was the intervention(s) or treatment procedure(s) clearly described?

Q6. Was the post-intervention clinical condition clearly described?

Q7. Were adverse events (harms) or unanticipated events identified and described?

Q8. Does the case report provide takeaway lessons?

Online supplement 1:

Table a) Median (IQR) of the force values measurements of the participants with non-painful shoulders.

NP		**Subscap (kg/f)**	**Supra (kg/f)**	**AD (kg/f)**	**ER0 (kg/f)**	**ER45 (kg/f)**	**ERABD/ER (kg/f)**	**ERF (kg/f)**	**IR0 (kg/f)**	**IR45 (kg/f)**	**IRABD/ER (kg/f)**	**IRF (kg/f)**
N			90	90	90	90	90	90	90	90	90	90
Median		4,55	10,59	8,64	8,64	6,33	5,27	5,75	7,50	4,92	4,25	4,91
Percentiles	25	3,48	8,31	6,88	6,88	5,00	4,17	4,68	5,76	3,92	3,26	3,84
	50	4,55	10,59	8,64	8,64	6,33	5,27	5,75	7,50	4,92	4,25	4,91
	75	6,03	13,71	11,46	11,46	7,80	6,67	7,08	9,81	6,35	5,24	6,52

NP = non-painful; Subscap = subscapularis; supra = supraspinatus; ER0 = external rotation in neutral, ER45 = external rotation at 45 degrees; ERABD/ER = external rotation in abduction at external rotation; ERF = external rotation in flexion; IR0 = internal rotation in neutral; IR45 = internal rotation at 45 degrees; IRABD/ER = internal rotation abduction in external rotation; IRF = internal rotation in flexion.

Table b) Median (IQR) of the force values of participants with painful shoulders (n=45). Participants with unilateral shoulder pain (n=35), participants with bilateral shoulder pain (n=10).

P		**Subscap** (kg/f)	**Supra** (kg/f)	**AD** (kg/f)	**ER0** (kg/f)	**ER45** (kg/f)	**ERABD/ER** (kg/f)	**ERF** (kg/f)	**IR0** (kg/f)	**IR45** (kg/f)	**IRABD/ER** (kg/f)	**IRF** (kg/f)
N		4	45	45	45	45	45	45	45	45	45	45
Median		2,64	8,13	7,17	7,82	5,00	4,71	5,25	7,19	5,24	4,21	5,00
Percentiles	25	0,99	5,77	4,16	5,13	3,09	2,73	3,25	4,99	3,17	2,71	3,11
	50	2,64	8,13	7,17	7,82	5,00	4,71	5,25	7,19	5,24	4,21	5,00
	75	4,00	12,04	9,88	10,56	6,84	5,75	6,14	8,93	6,02	5,70	6,34

P = painful; Subscap = subscapularis; supra = supraspinatus; ER0 = external rotation in neutral, ER45 = external rotation at 45 degrees; ERABD/ER = external rotation in abduction at external rotation; ERF = external rotation in flexion; IR0 = internal rotation in neutral; IR45 = internal rotation at 45 degrees; IRABD/ER = internal rotation abduction in external rotation; IRF = internal rotation in flexion.

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Table c) Median (IQR) of force values of the shoulders of the females (n=44) and males (n=46).

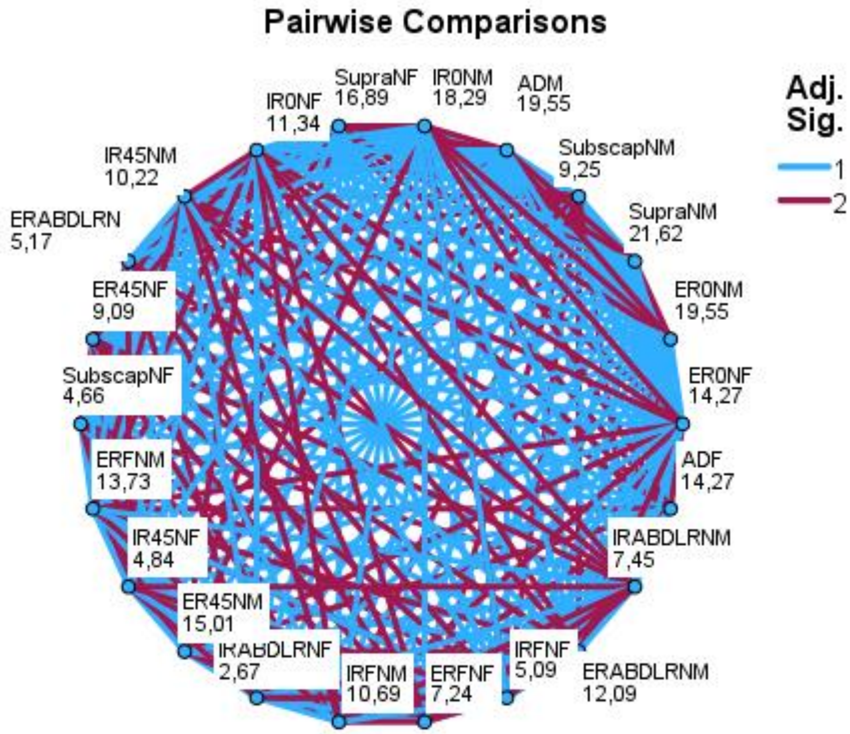
Measurements in (kg/f)		Subscap M	SS M	AD M	ER0 M	ER45 M	ERABD/LR M	ERF M	IR0 M	IR45 M	IRABD/LR M	IRF M	SFM	FABD M	Subscap F	SS F	AD F	ER0F	ER45 F	ERABD/LR	ERFF	IR0F	IR45 F	IRABD/LR F	IRF F	SFF	FABD F
N		46	46	46	46	46	46	46	46	46	46	46	46	46	44	44	44	44	44	44	44	44	44	44	44	44	44
Percentiles	25	3,80	11,41	8,90	8,90	6,45	5,48	5,77	7,70	4,76	4,15	4,79	161,00	163,00	3,09	6,71	6,21	6,21	4,69	3,62	3,87	5,05	3,45	2,93	3,32	158,75	166,25
	50	5,59	13,15	11,25	11,25	7,20	6,40	6,58	9,52	6,00	4,84	6,09	168,00	168,00	3,86	8,22	6,97	6,97	5,26	4,17	4,76	5,94	4,10	3,28	4,05	166,00	172,50
	75	6,79	15,40	13,01	13,01	8,80	7,38	8,08	11,15	7,46	5,93	7,19	172,00	174,00	5,02	9,69	7,94	7,94	6,16	4,85	5,70	7,07	4,89	4,27	5,10	174,00	177,00

Hypothesis Test Summary

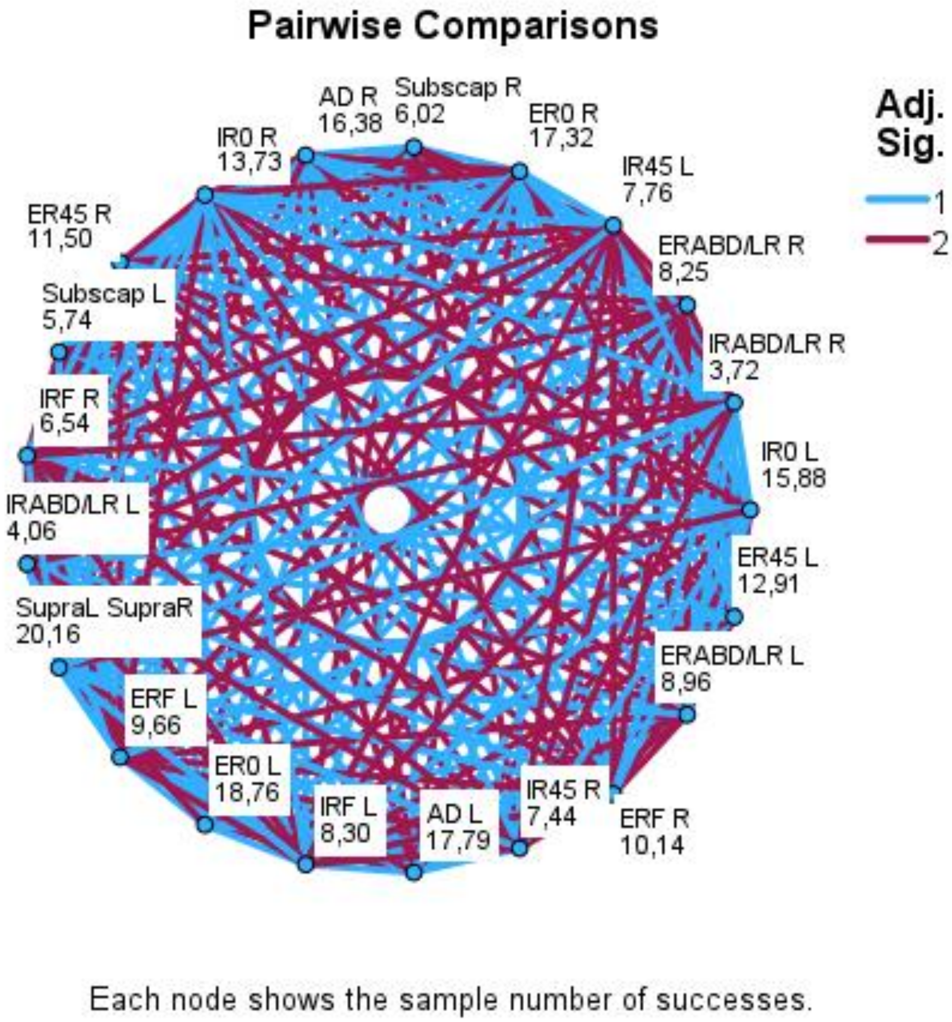
	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The distributions of SubscapNM, SubscapNF, SupraNM, SupraNF, ADM, ADF, ER0NM, ER0NF, ER45NM, ER45NF, ERABDLRNM, ERABDLRN, ERFNM, ERFNF, IR0NM, IR0NF, IR45NM, IR45NF, IRABDLRNM, IRABDLRNF, IRFNM and IRFNF are the same.	Related-Samples Friedman's Two-Way Analysis of Variance by Ranks	<,001	Reject the null hypothesis.

a. The significance level is ,050.

b. Asymptotic significance is displayed.



Each node shows the sample number of successes.



Related samples Friedman Two Way of Analysis of Variance (ANOVA).

Table b) Median (IQR) of the force values of participants with painful shoulders (n=45). Participants with unilateral shoulder pain (n=35), participants with bilateral shoulder pain (n=10).

P		**Subscap (kg/f)**	**Supra (kg/f)**	**AD (kg/f)**	**ER0 (kg/f)**	**ER45 (kg/f)**	**ERABD/ER (kg/f)**	**ERF (kg/f)**	**IR0 (kg/f)**	**IR45 (kg/f)**	**IRABD/ER (kg/f)**	**IRF (kg/f)**
N		4	45	45	45	45	45	45	45	45	45	45
Median		2,64	8,13	7,17	7,82	5,00	4,71	5,25	7,19	5,24	4,21	5,00
Percentiles	25	0,99	5,77	4,16	5,13	3,09	2,73	3,25	4,99	3,17	2,71	3,11
	50	2,64	8,13	7,17	7,82	5,00	4,71	5,25	7,19	5,24	4,21	5,00
	75	4,00	12,04	9,88	10,56	6,84	5,75	6,14	8,93	6,02	5,70	6,34

P = painful; Subscap = subscapularis; supra = supraspinatus; ER0 = external rotation in neutral, ER45 = external rotation at 45 degrees; ERABD/ER = external rotation in abduction at external rotation; ERF = external rotation in flexion; IR0 = internal rotation in neutral; IR45 = internal rotation at 45 degrees; IRABD/ER = internal rotation abduction in external rotation; IRF = internal rotation in flexion.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The distributions of ADP, ER0P, ER0NP, ER45P, ER45NP, ERABD/LRP, ERABD/LRNP, ERFP, ERFNP, IR0P, IR0NP, IR45P, IR45NP, IRABD/LRP, IRABD/LRNP, IRFP, IRFNP, SubscapP, SubscapNP, SupraP and SupraNP are the same.	Related-Samples Friedman's Two-Way Analysis of Variance by Ranks	<,001	Reject the null hypothesis.

a. The significance level is ,050.

b. Asymptotic significance is displayed.

Pairwise Comparisons

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
ADNP-SubscapP	9,931	1,629	6,095	<,001	,000
ADNP-IRABD/LRNP	7,431	1,629	4,560	<,001	,001
ADNP-IRABD/LRP	10,879	1,629	6,677	<,001	,000
ADNP-SubscapNP	-1,603	1,629	-,984	,325	1,000
ADNP-ERABD/LRP	7,914	1,629	4,857	<,001	,000
ADNP-IR45NP	9,983	1,629	6,126	<,001	,000
ADNP-IRFNP	13,362	1,629	8,200	<,001	,000
ADNP-ERABD/LRNP	7,638	1,629	4,687	<,001	,001
ADNP-ERFP	5,586	1,629	3,428	<,001	,128
ADNP-IRFP	8,017	1,629	4,920	<,001	,000
ADNP-IR45P	9,052	1,629	5,555	<,001	,000
ADNP-ER45P	3,828	1,629	2,349	,019	1,000
ADNP-ERFNP	1,103	1,629	,677	,498	1,000
ADNP-ER45NP	9,638	1,629	5,915	<,001	,000
ADNP-ADP	-1,155	1,629	-,709	,478	1,000
ADNP-IR0P	,638	1,629	,391	,695	1,000
ADNP-IR0NP	7,121	1,629	4,370	<,001	,003
ADNP-ER0P	-2,138	1,629	-1,312	,190	1,000
ADNP-SupraP	-3,793	1,629	-2,328	,020	1,000
ADNP-ER0NP	6,138	1,629	3,767	<,001	,035
SubscapP-IRABD/LRNP	2,500	1,629	1,534	,125	1,000
SubscapP-IRABD/LRP	-,948	1,629	-,582	,561	1,000
SubscapP-SubscapNP	-11,534	1,629	-7,079	<,001	,000
SubscapP-ERABD/LRP	2,017	1,629	1,238	,216	1,000
SubscapP-IR45NP	-,052	1,629	-,032	,975	1,000
SubscapP-IRFNP	-3,431	1,629	-2,106	,035	1,000
SubscapP-ERABD/LRNP	2,293	1,629	1,407	,159	1,000
SubscapP-ERFP	4,345	1,629	2,666	,008	1,000
SubscapP-IRFP	1,914	1,629	1,174	,240	1,000
SubscapP-IR45P	,879	1,629	,540	,589	1,000
SubscapP-ER45P	6,103	1,629	3,746	<,001	,038
SubscapP-ERFNP	8,828	1,629	5,417	<,001	,000
SubscapP-ER45NP	,293	1,629	,180	,857	1,000
SubscapP-ADP	8,776	1,629	5,386	<,001	,000
SubscapP-IR0P	9,293	1,629	5,703	<,001	,000
SubscapP-IR0NP	2,810	1,629	1,725	,085	1,000
SubscapP-ER0P	12,069	1,629	7,407	<,001	,000
SubscapP-SupraP	-13,724	1,629	-8,422	<,001	,000
SubscapP-ER0NP	3,793	1,629	2,328	,020	1,000
IRABD/LRNP-IRABD/LRP	-3,448	1,629	-2,116	,034	1,000
IRABD/LRNP-SubscapNP	-9,034	1,629	-5,544	<,001	,000
IRABD/LRNP-ERABD/LRP	-,483	1,629	-,296	,767	1,000
IRABD/LRNP-IR45NP	-2,552	1,629	-1,566	,117	1,000
IRABD/LRNP-IRFNP	5,931	1,629	3,640	<,001	,057

Table c) Median (IQR) of force values of the shoulders of the females (n=44) and males (n=46).

Measurements in (kg/f)		Subscap M	SS M	AD M	ER0 M	ER45 M	ERABD/LR M	ERF M	IR0 M	IR45 M	IRABD/LR M	IRF M	SF M	FABD M	Subscap F	SS F	AD F	ER0F	ER45 F	ERABD/LR	ERFF	IR0F	IR45 F	IRABD/LR F	IRF F	SF F	FABD F
N		46	46	46	46	46	46	46	46	46	46	46	46	46	44	44	44	44	44	44	44	44	44	44	44	44	44
Percentiles	25	3,80	11,41	8,90	8,90	6,45	5,48	5,77	7,70	4,76	4,15	4,79	161,00	163,00	3,09	6,71	6,21	6,21	4,69	3,62	3,87	5,05	3,45	2,93	3,32	158,75	166,25
	50	5,59	13,15	11,25	11,25	7,20	6,40	6,58	9,52	6,00	4,84	6,09	168,00	168,00	3,86	8,22	6,97	6,97	5,26	4,17	4,76	5,94	4,10	3,28	4,05	166,00	172,50
	75	6,79	15,40	13,01	13,01	8,80	7,38	8,08	11,15	7,46	5,93	7,19	172,00	174,00	5,02	9,69	7,94	7,94	6,16	4,85	5,70	7,07	4,89	4,27	5,10	174,00	177,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.^{a,b}	Decision
1	The distributions of SubscapNM, SubscapNF, SupraNM, SupraNF, ADM, ADF, ER0NM, ER0NF, ER45NM, ER45NF, ERABDLRNM, ERABDLRN, ERFNM, ERFNF, IR0NM, IR0NF, IR45NM, IR45NF, IRABDLRNM, IRABDLRNF, IRFNM and IRFNF are the same.	Related-Samples Friedman's Two-Way Analysis of Variance by Ranks	<,001	Reject the null hypothesis.

a. The significance level is ,050.

b. Asymptotic significance is displayed.

Online supplement 2

a) Data collection sheet.

NAME		**Name**		**Pain period**		**VPRS Pain**	
		Test 1	**Test 1**			**Test 1**	**Test 1**
		L	**R**			**L**	**R**
AROM	**degree**			**Position**	**cm**		
Sagittal flexion				SHB			
Frontal abduction				PM			
				LD			
HBB (IR)							
Isometric	**kg/f**			**PROM**	**degree**		
HBB lift-off				LR in neutral			
Supraspinatus				LR in 90 degrees			
Anterior deltoid				PC SL			
ER in neutral							

ER in 45 degrees							
ER in 90 ABD/ER							
ER Sagittal F							
IR in neutral							
IR in 45 degrees							
IR in 90 ABD/ER							
IR in sagittal F							
Demographics							
Age							
Sport/Hobbies							
Work							
Weight							
Height							
L/R dominance							
F/M							

Online Supplement 3

Supplement 3:

Table a) Median (IQR) force values of participants with nonpainful shoulders (n=125) and painful shoulders (n=35).

		SubscapNP	SubscapP	SSNP (kg/f)	SSP (kg/f)	ADNP (kg/f)	ADP (kg/f)	ER0NP (kg/f)	ER0P (kg/f)	ER45NP (kg/f)	ER45P (kg/f)	ERABD/ERNP (kg/f)	ERABD/ERP (kg/f)	ERFNP (kg/f)	ERFP (kg/f)	*P*=
n		125	45	125	35	125	35	125	35	125	35	125	35	125	35	0.001
Percentiles	25	3.46	0,99	8.22	5.77	6.88	4.16	7.05	5.13	5.00	3.09	4.17	2.69	4.68	3.25	0.001
	50	4.64	2.64	10.45	8.13	8.65	7.17	9.29	7.82	6.35	5.00	5.30	4.36	5.76	5.25	0.001
	75	6.06	4.00	13.70	12.04	11.50	9.68	11.44	10.56	7.92	6.70	6.67	5.79	7.07	6.14	0.001

The measurements were performed in kg/force. NP = nonpainful; P = painful; Subscap = subscapularis; ss = supraspinatus; ER0 = external rotation in neutral; ER45 = external rotation in 45°; ERABD/ER = external rotation in abduction at external rotation.

Table b: Means (SD), correlations, and effect sizes of the ratios of all variables between females (n=22) and males (23) of participants with nonpainful shoulders (n=90).

		N	Mean	SD	SE	*r* M and F	*Significance: p*	*d*
Pair 1	SS:ADM	23	1.25	0.19	0.03	0.11	0.39	0.27
	SS: ADF	22	1.16	0.21	0.03			
Pair 2	ER:IR0M	23	1.18	0.26	0.03	-0.03	0.85	0.67
	ER:IR0F	22	1.28	0.61	0.08			
Pair 3	ER:IR45M	23	1.30	0.22	0.03	0.07	0.58	0.34
	ER:IR45F	22	1.31	0.24	0.03			
Pair 4	ER: IRABDM	23	1.26	0.20	0.03	0.07	0.61	0.34
	ER: IRABDF	22	1.23	0.29	0.04			

Table c) Correlations for left and right side of the participants with non-painful shoulders

Variables		**N**	***r* =**	*p* =
Pair 1	Subscap L and R	88	0.819	0.001*
Pair 2	AD L and R	88	0.934	0.001*
Pair 3	ER 0 L and R	88	0.873	0.001*
Pair 4	ER45 L and R	88	0.872	0.001*
Pair 5	ERABD/LR L and R	88	0.894	0.001*
Pair 6	ERF L and R	88	0.925	0.001*
Pair 7	IR 0 L and R	88	0.846	0.001*