Factors influencing the Acromio-Humeral distance in elite athletes

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I dedicate this thesis to my grandfather, ‘Morfar’, Charles Martin.

List of abbreviations

AHD	Acromio-Humeral distance
AGT	Acromion-Greater Tuberosity distance
C7	Cervical Vertebra seven
CI	confidence interval
GERG	Glenohumeral external rotation gain
GHJ	Glenohumeral joint
GIRD	Glenohumeral internal rotation deficit
IAS	Inferior Angle of Scapula
IAS-Sp	distance of Inferior Angle of Scapula to Spinous Process
ICC	intraclass correlation coefficient
IS	Impingement Syndrome
$MDC_{95\%}$	minimal detectable change
PALM	palpation meter
RSS	Root Spine of Scapula
RSS-IAS	distance of Root Spine of Scapula to Inferior Angle of Scapula
RSS-Sp	distance of Root Spine of Scapula to Spinous Process
RTUS	real time ultrasound
SAIS	Subacromial Impingement Syndrome
SEM	standard error of the measure
Sp	Spinous Process
STD	standard deviation
SR	Scapular rotation
TROM	total rotational range of motion
US	ultrasound

Abstract

Shoulder Impingement Syndrome is prevalent in sportsmen and can end sporting careers. The Acromio-Humeral distance (AHD) is a measure taken with ultrasound (US) and used to quantify the space in which structures in the shoulder become impinged. This space is normally reduced as the arm elevates. Factors identified in the literature that could further reduce this space, are explored in this thesis. Correlation analysis between factors (Scapula rotation in the coronal plane, Pectoralis Minor length, Thoracic kyphosis, Glenohumeral rotation and load) with the AHD was done to confirm or refute some of these associations. To accomplish the research: a) reliability of tools and stability of the measure was established; b) data was collected in elite sportsmen and controls to verify variance in the independent variables; c) correlation analysis between independent variables and the AHD was carried out to determine association. In summary, the results of this thesis demonstrated that factors influencing the Acromio-Humeral distance are multifactorial, including Pectoralis Minor length, Glenohumeral rotation ranges, and load. The strength of the association between variables is population dependant. Scapula rotation in the coronal plane, and Thoracic kyphosis were not found to influence the AHD when modified in isolation.

Chapter 1. General introduction – outline and aims of the thesis

List of abbreviations

AHD	Acromio-Humeral distance
GHJ	Glenohumeral joint
IS	Impingement Syndrome
PALM	palpation meter
SAIS	Subacromial Impingement Syndrome

1.1 The first aim of this thesis is to undertake an evidence-based review of current perceptions with regard to Impingement Syndrome and the role of AHD in Impingement Syndrome; why is AHD important and what influences it?

The purposes of the literature review are: to provide a broad perspective on the current perceptions with regard to the pathology and pathomechanics of subacromial and Internal Impingement Syndrome, describe the intrinsic and extrinsic mechanisms considered to contribute to these syndromes, and critique the level of evidence supporting these concepts, and then to draw up an algorithm to provide structure for this thesis. From this it was concluded that one of the factors considered to be part of the pathological process is size of the AHD and in turn that variables considered to influence AHD include, Scapula rotation in the coronal plane, Pectoralis Minor length, Thoracic curvature, Glenohumeral joint (GHJ) rotation and load. Chapter 2. An evidence-based review of current perceptions with regard to Subacromial Impingement Syndrome and the role of the AHD; why AHD is important and what influences it covers this topic.

Additional literature reviews were undertaken to identify portable, inexpensive, clinically applicable tools to quantify Scapula position and Glenohumeral range and incorporated into Chapter 3. Methods. Literature quantifying Scapula rotation in the coronal plane is descriptively covered in Chapter 3.1. The palpation meter (PALM) is reliable and valid for measuring Scapula upward rotation. The current literature on real time ultrasound to quantify Acromio-Humeral distance is incorporated into Chapter 3.2. Interrater reliability of real time ultrasound to measure Acromio-humeral distance. Previous literature on further instrumentation used is incorporated into Chapter 3.3. Intra-rater inter-session reliability of further instrumentation.

1.2 The second aim of this thesis is to establish reliability of procedures and tools.

Methods were devised to quantify AHD and the variables considered to influence AHD and control for confounding variables which were not investigated in this study. Tools had to be field based in order screen the desired population. Reliability of methods and tools was established and reported in Chapter 3. Methods: reliability of procedures and tools.

A literature review was conducted to search for appropriate tools to quantify the variables of AHD, Scapular rotation, Glenohumeral joint rotation, Pectoralis Minor length, and thoracic rotation. Tools had to be field based in order to screen the desired population, therefore, the use of radiological methods other than RTUS were not appropriate to quantify AHD. Under the introduction in section 3.1, of this chapter, headed 'Inter-rater reliability of real time ultra sound to measure Acromio-Humeral distance' is a review and appraisal of the literature with respect to the use of RTUS to quantify AHD. Considering the need for a field based portable and reliable method to quantify Scapular upward rotation the use of EMT was not an option. As a result clinical measurements had to be used to determine Scapular rotation in the coronal plane. Either an inclinometer or lateral measures of the distance of the Scapular from the spine (used in the sin rule) were deemed appropriate. Since the later was a novel method to explore it was chosen and the two methods compared. Under the introduction in section 3.2, of this chapter, headed 'The palpation meter (PALM) is reliable and valid for measuring Scapular upward rotation' is a review and appraisal of the literature with respect to the use of various instrumentation reported in the literature to quantify lateral distance of the Scapular from the Spine the inclinometer to quantify Scapular upward rotation. A comparison of the two tools and methods is reported in the method and results section of 3.2 in this chapter. Further tools were required to quantify Glenohumeral joint rotation, Pectoralis Minor length, and thoracic rotation. The review and appraisal of the various tools appropriate for this are summarized under the heading 3.3, in this chapter, headed 'Intra-rater 24 hours apart inter-session reliability of further instrumentation' under the subheadings: *Appraisal of tools and methods to assess GHJ range of motion; Appraisal of tools and methods to assess Thoracic curve; Appraisal of tools and methods to assess Pectoralis Minor length.*

Measures of the Acromio-Humeral distance are used to quantify the Subacromial Space. Real time ultrasound has been suggested as a reliable measure of the Acromio-Humeral distance. To date, no rigorous assessment and reporting of inter-rater reliability of this method has been done in shoulder neutral or in active and passive arm abduction. This study assesses inter-rater intra-session reliability of real time ultrasound to capture and analyse images of the Acromio-Humeral distance in healthy participants in shoulder neutral, and in 60° of both active and passive arm abduction .This is reported in Chapter 3.1. Inter-rater reliability of real time ultrasound to measure Acromio-Humeral distance.

The Palmmeter (PALM) was chosen to quantify Scapular rotation. This study assesses a new method of quantifying Scapula rotation in the coronal plane and so set out to establish intra-rater and inter-rater reliability of the PALM to assess Scapular position. Chapter 3.2 The palpation meter (PALM) is reliable and valid for measuring Scapular upward rotation, covers this topic.

From the literature review other variables were considered to influence AHD also included, Pectoralis Minor length, Thoracic curvature, GHJ rotation and load. Methods for the screening of these in elite athletes are reported in Chapter 3.3. Intra-rater inter-session reliability of further instrumentation. Intra-rater inter-session reliability 24 hours apart is established for the procedures and instruments.

1.3 The third aim of this thesis is to explore sport specific adaptation in the elite athlete's shoulder

An elite sport population was chosen to investigate what factors influence AHD, because there is limited data in the literature on these variables in elite sportsmen and it is know that sportsmen suffer from SAIS which has impact on their sporting careers. In addition, they represent a population whose shoulders are exposed to the extremes of load. To confirm the hypothesis that the sportsperson adapts to enhance sporting performance and that this adaptation will influence the AHD, descriptive profiling of sportspersons shoulders in varying disciplines was done and reported in Chapter 4.1.Profilling the athletes shoulder; within and between sports comparison. Further to this detailed inferential and comparative statistic results between controls and male golfers is reported in Chapter 4.2. Sport specific adaptation in the elite golfer's shoulder. Conflicting results exist in the literature with regards to whether the AHD is indeed greater in athletes compared to non-sports populations. The results found in this study are summarised in Chapter 4.3. AHD in the athlete's shoulder.

1.4 The fourth aim of this thesis is to establish an association between factors (Scapula rotation in the coronal plane, Pectoralis Minor length, Thoracic curvature, GHJ rotation and load) and the AHD.

Factors affecting AHD are noted to be multifactorial. The strength of the influence of the variable affecting AHD is population specific differing between genders and sport disciplines. The results of the correlations between the variables investigated and the AHD are reported in <u>Chapter 5. Association between factors influencing the AHD.</u>

Chapter 2 An evidence-based review of current perceptions with regard to impingement syndrome and the role of AHD in Impingement Syndrome: why is AHD important and what influences it?

List of abbreviations

AHD	Acromio-Humeral distance
GHJ	Glenohumeral joint
IS	Impingement Syndrome
SAIS	Subacromial Impingement Syndrome

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Chapter overview

The purposes of this chapter are to: provide a broad perspective on the current perceptions with regard to the pathology and pathomechanics of subacromial and Internal Impingement Syndrome, consider the role of the Subacromial Space, quantified in this thesis by the AHD, in SAIS and describe the intrinsic and extrinsic mechanisms considered to contribute to AHD, and critique the level of evidence supporting these concepts, and finally to draw up an algorithm to provide structure for this thesis.

Note on terminology

- Dysfunction of Scapular patterning, Scapular timing, Scapular humeral rhythm and Scapular dyskinesis will be collectively referred to in this chapter as alterations in Scapular kinematics**.**
- The Subacromial Space is a three dimensional space. The Acromio-Humeral distance is a two dimensional measure used in this research to quantify this space.
- Subacromial Impingement Syndrome is a broad term used to cover numerous types of pathology originating from the soft tissues housed in the subacromial space of which the aetiology is not completely understood (Ratcliffe, Pickering, McLean, & Lewis, 2014). Typically, patients clinically present with Rotator Cuff Tendinopathy. This too is a broad term used to cover pathology in the Tendon without assuming specific knowledge of the underlying mechanism causing the condition (Seitz, McClure, Finucane, Boardman III, & Michener, 2011). Other anatomical structures also housed in the subacromial space which can undergo compressive and shear forces in SAIS are: the Long Head of Biceps and the Subacromial Bursa. This chapter debates impingement as a syndrome because by referring to the condition as impingement syndrome incorporates the

combination of signs, symptoms, and pathomechanics that are indicative of the disorder.

2.1 Anatomy of the Subacromial Space and pathogenesis of impingement syndrome

One of the most common musculoskeletal complaints of patients seeking medical advice is shoulder pain, with shoulder Impingement Syndrome being the most commonly diagnosed shoulder disorder in the primary health care in the USA (de Witte et al., 2011; Michener, McClure, & Karduna, 2003). In America it is reported that Rotator Cuff disorders are the most common of shoulder diagnoses made (Seitz et al., 2011). In the UK three in ten patients experience shoulder pain in their life time (Choices, 2013; Parsons et al., 2007). Despite the commonality of shoulder Impingement Syndrome, aetiology is still unclear and much debated.

> Rehabilitation of the patient with Subacromial Impingement Syndrome requires complete understanding of the anatomical structures involved and the underlying mechanisms (Ellenbecker & Cools, 2010).

Modern advances in anatomy, biomechanics, and research have gone some way in improving the understanding of Impingement Syndrome (Ellenbecker & Cools, 2010), but despite this, it is still a debated topic. Typically, patients present with Rotator Cuff tendinopathy. This is the term used broadly to cover pathology in the Tendon without assuming specific knowledge of the underlying mechanism causing the condition (Seitz et al., 2011). The Long Head of Biceps and Rotator Cuff (Supraspinatus, Infraspinatus, and Teres Minor) Tendons are housed in the Subacromial Space, which also cases the

Subacromial Bursa. It is these mentioned structures that undergo compressive and shear forces in SAIS (Neer, 1983).

The superior boundary of the Subacromial Space is formed by the Acromion and the Coracoacromial Ligament (Figure 1.). The Acromion, the Coracoacromial Ligament and the Coracoid together form the Coracoacromial Arch. Posteriorly the Coracoacromial Ligament is continuous with the fascia of the Supraspinatus muscle, which runs under the Coracoacromial Ligament and is protected in its superior aspect by the Subacromial Bursa. On its anterior aspect the Coracoacromial Ligament has a sharp free edge that can impinge on underlying structures in arm elevation if joint kinematics dysfunction. The anterior Acromion and superior boundary of the Subacromial Space have to move superiorly for the Humeral Head to elevate during arm elevation (Flatow et al., 1994). Should this not occur, it is the anterior Acromion that has been identified as the site at which compression on the bursal side of the Rotator Cuff Tendon occurs (Brossmann et al., 1996; Flatow et al., 1994; Lee, Itoi, O'Driscoll, & An, 2001).

The inferior Subacromial Space is defined by the humeral head, superior Glenohumeral joint, and the Coraco-Humeral Ligament, which runs from the lateral border of the Coracoid process to the Humerus (Figure 1.). The Glenohumeral joint, consisting of the Humeral Head and the Glenoid of the Scapular, is inherently unstable as it requires large ranges of motion for function and sporting performance. Only 25% to 30% of the surface of the Head of Humerus is said to be in contact with the Glenoid at one time (Hurov, 2009). Stability is provided by the osseous configuration, Glenoid Labrum, neuromuscular system, and negative articular pressure (Wilk et al., 2009).The instant centre of rotation (axis of rotation) of the humeral head, although movable, has to be controlled with in this limited surface contact. Failure to control the instant centre of rotation in the Glenohumeral joint compromises the integrity of the inferior surface of the Subacromial Space.

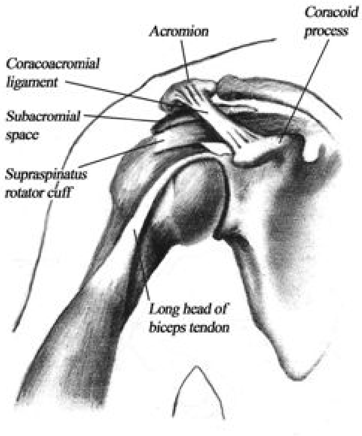

Figure 1. Anatomy of the Subacromial Space

SAIS, involving tendinopathy of the Rotator Cuff Tendons, can be divided into two broad groups defined according to anatomical site (articular or bursal side) of the Tendon being impinged upon, and by the pathomechanics involved. These two broad groups are referred to as SAIS and Internal Impingement Syndrome.

2.1.1 *Pathogenesis of Subacromial Impingement Syndrome*

In 1972, Neer (Neer, 1983) coined the term subacromial impingement and proposed a pathomechanical process in which mechanical compression of the soft tissues in the Subacromial Space occurred due to a narrowing of the Subacromial Space (Neer & Welsh, 1977). He asserted that the soft tissues most commonly involved was the bursal side of the Supraspinatus and Long Head of Biceps Tendons, which compress against the anterior and lateral edge of the Acromion and Coracoacromial Ligament . Since contact occurs between the upper surface of the Supraspinatus Tendon and the Coracoacromial Ligament during arm elevation, Neer (Neer, 1983) proposed that any reduction of the Subacromial Space would lead to Impingement Syndrome. When the arm is elevated, internally rotated, and flexed the Greater Tuberosity of the Humerus applies pressure towards the anterior inferior Acromion and the, hence placing pressure on the Supraspinatus Tendon and Subacromial Bursa.

Contact between the Supraspinatus Tendon and the Biceps Tendon with the Coracoacromial Ligament has been confirmed in cadaveric studies to occur between 45° and 60° of abduction (Burns & Whipple, 2013). Converging evidence from radiographs and MRI, determined that the distal Supraspinatus Tendon was engaged between the Greater Tuberosity and the Acromion as early as 30° of flexion and abduction (Brossmann et al., 1996). It has been suggested via x-ray determination that at rest the distance between the Acromion and Humerus is on average 11mm , and at 90° abduction this distance is reduced to 5.7mm on average (Flatow et al., 1994). Thus, AHD is reduced with arm elevation. The pathogenesis of SAIS is described due to a reduction in the height of the Subacromial Space and referred to this as Congenital Subacromial Stenosis (Burkhart, 1995). In the study, a reduction in the Acromio-Humeral distance correlated to the incidence of Impingement Syndrome in subjects (Burkhart, 1995). The same study concluded that this reduction in Acromio-Humeral distance was not due to proximal migration of the Humerus (Burkhart, 1995). Further evidence to support the notion that decreases in the Acromio-Humeral distance (Acromio-Humeral interval) is responsible for SAIS was reported in a study on 206 shoulders with Rotator Cuff tears (Werner et al., 2008). In the study, AP radiograph and computed tomogram were used to measure the Acromio-Humeral interval; a decrease in Acromio-Humeral interval directly correlated to multiple Rotator Cuff Tendon tears and fatty degeneration in the infraspinatus and Supraspinatus muscles (Werner et al., 2008). Recently, (Maenhout, Eessel, Dyck, Vanraes, & Cools, 2012) a reduction in Acromio-Humeral interval was identified using ultrasound to quantify this distance, during arm abduction.

2.1.2 *Pathogenesis of Internal Impingement Syndrome*

An Impingement Syndrome, commonly considered to be prevalent in overhead sportsmen, has been identified and named Internal Impingement Syndrome (Jobe & Pink, 1996; Kibler & Sciascia, 2009). This Impingement Syndrome occurs when the arm is in the abducted, extended, and externally rotated position. In sportsmen, this is the throwing position. However, the area of compression on the Rotator Cuff Tendon is the articular side as opposed to the bursal side of the Tendon as in SAIS (Seitz et al., 2011)(Figure 2.). Internal Impingement Syndrome, a result of repetitive micro trauma to the articular side of the Rotator Cuff, is also referred to as posterior Impingement Syndrome in the literature. The Tendon becomes compressed between the superior posterior Glenoid Rim and the Humeral Head (Ellenbecker & Cools, 2010). This Impingement Syndrome typically occurs with increased capsule laxity or instability of the Glenohumeral joint, (Brukner & Khan, 2010). Capsule laxity or instability of the Glenohumeral joint results in an un-centred Humeral Head in the Glenoid, which can impose on the Subacromial Space and lead to a decrease in (Azzoni, Cabitza, & Parrini, 2004) the Acromio-Humeral space, and subsequently to this pathological process.

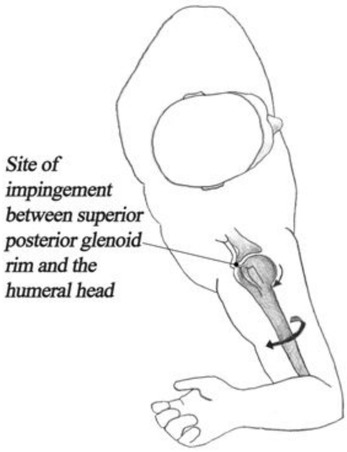

Figure 2. Pathogenesis of Internal Impingement Syndrome

2.2 Biomechanical influences on AHD

There is controversy with regard to the exact pathomechanics and biomechanics responsible for SAIS. Possibly, causes are multifactorial (Wilk et al., 2009). Pathological factors that are considered to contribute to shoulder Impingement Syndrome can be divided into extrinsic and intrinsic categories. Extrinsic factors are considered to be those that compress the structures with in the Subacromial Space (extra-tendinous), and intrinsic factors are those associated with degeneration with in the Rotator Cuff Tendons themselves (intra-tendinous) (Seitz et al., 2011). Extrinsic factors that encroach upon the Subacromial Space and contribute to bursal side compression of the Rotator Cuff Tendons have been broadly grouped by the author into: postural dysfunction, alterations in Glenohumeral or Scapular kinematics, muscular extensibility, anatomical/osseous factors, deficits in muscle performance as well as ergonomic and sport-specific adaptations and are expanded on in this chapter. Intrinsic factors that contribute to Rotator Cuff Tendon degradation with tensile/shear overload include: alterations in biology, mechanical properties, morphology, and vascularity within the Tendon.

The diverse nature of these speculated mechanisms indicates that SAIS is not a homogenous entity, and thus may require different treatment interventions. Treatment aimed at addressing mechanical factors appears to be beneficial for patients with SAIS but not for all patients (Ludewig & Borstad, 2003; C. H. Wang, McClure, Pratt, & Nobilini, 1999). It has been proposed that classification of SAIS into subgroups based on underlying mechanism may improve treatment outcomes and could assist in prevention of the syndrome (de Witte et al., 2011; Seitz et al., 2011). In reality, it is unlikely that only intrinsic or extrinsic factors are responsible for SAIS. It is more likely that a combination of the two contribute to SAIS and that, the longer the syndrome is present, both intrinsic and extrinsic causes become meshed and provocative of each other.

2.2.1 Intrinsic causes of subacromial impingement syndrome

Reduction in AHD is not the only mechanism considered to cause Rotator Cuff tendinopathies (Seitz et al., 2011). Although the above argument supports the notion that reduction in Acromio-Humeral interval is thought to cause Tendon degeneration due to repetitive shear and compressive forces, it is also postulated that cuff degeneration precedes Subacromial Space reduction (Neagle & Bennett, 1994).

In 1972, Neer postulated that there were three stages to SAIS: during stage one, oedema and haemorrhage of the bursa and Rotator Cuff Tendons occurs, commonly in the population under the age of 25 years; during stage two, irreversible changes occur in the Tendon resulting in fibrosis and Tendonitis of the Rotator Cuff Tendon, commonly in the population between the ages of 25-40 years; and lastly, stage three comprises of chronic changes in the Rotator Cuff, resulting in partial and complete tears, typically occurring in the population over the age of 40 years. This was later linked with the notion of outlet (restriction in the outlet or Subacromial Space size) and non-outlet (a result of space occupancy of the Subacromial Space by fibrous degenerative tissues) SAIS (Bigliani & Levine, 1997). Histological changes within the Tendons are considered responsible for intrinsic causes of Rotator Cuff tendinopathy. Degenerative changes are considered to start from as young as 40 years of age (Girish et al., 2012). It is postulated that the following intrinsic factors compromise the Subacromial Space due to tensile and shear overload: alterations in biology, mechanical properties, morphology, and vascularity of the Tendon."

Degeneration of the Rotator Cuff Tendons could be due to progressive Tendon failure and a part of the normal aging process, as has been shown to be the case in numerous studies (Frost, Andersen, & Lundorf, 1999; Girish et al., 2012; Milgrom, Schaffler, Gilbert, & Holsbeeck, 1995). These reports concur with Ernest Codman's 1937(Codman, 1937) description of the partial articular tear of the Rotator Cuff, in which he proposed that an atraumatic Tendon degeneration leads to a partial thickness tear on the articular surface of the Tendon due to fibre failure, a pre-determined process of aging and hence genetically determined. Since tenocyte levels drop in the aged Tendon, so too does reparability, and the Tendon become susceptible to intrinsic shear failure(Seitz et al., 2011). Tendon properties have been shown to change with age as the Tendon becomes less elastic and loses tensile strength (Seitz et al., 2011). Histological studies have shown the following features in the Tendons of asymptomatic elderly subjects which are not present in the younger Tendon: calcification, fibro vascular changes, decrease in glycosaminglycan and proteglycans content, reduction in collagen content, and an increase in irregular type III collagen. Type III collagen is thinner, weaker, and has irregular fibres compared with collagen II fibres (Seitz et al., 2011).

Histological evidence shows that Type III collagen fibres, which are more extensible than the type II fibres, are more profuse in the region of the insertional fibrocartilage(Lake, Miller, Elliott, & Soslowsky, 2009). The disadvantage of these fibres is that they have decreased mechanical properties in the matrix of the Tendon in the area of the Tendon closest to the bony insertion. Histological evidence proves that this same inferior tissue organisation is present in the mid substance or articular side of the Supraspinatus Tendon compared with the bursal side (Seitz et al., 2011). Cholewinski et al. 2008 (Cholewinski, Kusz, Wojciechowski, Cielinski, & Zoladz, 2008a), via ultrasound examination found thinner Rotator Cuff Tendons in patients with SAIS (Cholewinski, Kusz, Wojciechowski, Cielinski, & Zoladz, 2008b). In contrast to this, with the same methods and population Scott el al. 2007, reported thickening of the Rotator Cuff Tendons in symptomatic subjects. It must be borne in mind that these may not be contrasting results: morphology of the Tendon may relate to the duration of the disease; in both of these studies the period which subjects had presented with SAIS signs did vary. It is possible that thicker Tendons will be more evident in the early stages of the process and thinner in later stages(Seitz et al., 2011). Controversy exists as to whether these observed histological changes are due to the effect of age or are secondary to the compressive and shear forces of external Impingement Syndrome, and hence are the result of inferior healing after micro trauma (Seitz et al., 2011).

Genetic predisposition is considered to be a factor in Rotator Cuff disease. A study conducted in Utah combining genealogical and health data of over 2 million residences, identified 3091 patients with Rotator Cuff disease; a sub group of those younger than 40 years of age identified 652 patients (Tashjian, Farnham, Albright, Teerlink, & Cannon-Albright, 2009). Of this sub group, a significant familial connection was proven ($p=0.01$), supporting the theory that genetic predisposition is a risk factor in Rotator Cuff disease (Tashjian et al., 2009).

The area that is most commonly torn in the Supraspinatus Tendon (1cm from the insertion on to the Greater Tuberosity of the Humerus) was referred to as the critical zone by Codman 1937 (Bigliani & Levine, 1997; Codman, 1937), who proposed that this area is avascular and so most susceptible to reduced healing and tearing. In vivo studies have not confirmed this postulated area of decreased vascularity. In fact, studies reporting on hyper- or hypo-vascularisation and relating this to the stages of pathology of rotator tendinopathy are conflicting (Seitz et al., 2011).

Jeremy Lewis, 2010 (J. S. Lewis, 2010), defined a model of continuum of Tendon pathology which is based on radiological findings. This is based on the theory that the Tendon intrinsic properties response to demand. The continuum defines the under loaded to the over loaded Tendon with the normal Tendon in between the two extremes of the continuum. Too little demand causes Tendon degeneration due to lack of exposure to tensile loads. But the intrinsic response to demand within the Tendon requires an adaptation period to histologically respond favourably. If the intensity of demand and time ratio is disproportionate the Tendon undergoes disrepair. He proposed a staged treatment model which takes into account staged loading of the Tendon with care to avoid the extremes of under or over loading that is graduated over time.

To further add to the debate, Girometti et al. 2006, used RTUS to examine the morphology of the Supraspinatus Tendon in ten professional baseball players and compared these to ten non-athlete controls. Eco texture, Supraspinatus and Subacromial Bursa thickness, and AHD were all measured. No differences were reported in the morphology of the Tendon between the groups. A decrease in the AHD was reported in the athletes (Girometti et al., 2006), thus bringing the debate of intrinsic versus extrinsic cause and effect to a full circle.

2.2.2 *Extrinsic mechanisms influencing AHD*

Anatomical/Osseous factors and the AHD

Morphology of the Acromion has been considered to contribute to narrowing of the Subacromial Space, hence reducing the outlet for the Rotator Cuff Tendons (Bigliani & Levine, 1997). Bigliani et al. 1997, (Bigliani & Levine, 1997) typed the shape of the Acromion into a flat type one, a curved type two, and a hooked type three. In one hundred and fourty cadavers, the incidence of each was: 17% flat Acromions, 43% curved Acromions, and 39% hooked Acromions (Bigliani & Levine, 1997). The third type was considered to predispose the Tendons to the greatest shear and compressive forces, and hence to have an association with Rotator Cuff tears. Equally, the shape of the Acromion was associated with response to treatment, with a less favourable outcome the higher up the classification type (Seitz et al., 2011; C. H. Wang et al., 1999). It has also been suggested that the slope of the Acromion predisposes to subacromial spur formation and Tendon compression, the more horizontal the Acromion slope, viewed on the Supraspinatus outlet view X-rays, the higher the proposed correlation to pathology (Edelson, 2000).

Contact geometry of the under surface of the Acromion was examined in fourty fresh cadavers by Lee et al. 2001 (Lee et al., 2001). Cadavers with and without Rotator Cuff tears were examined. In spite of the claims in previous reports, Lee et al. 2001 (Lee et al., 2001) found no difference in Acromion shape between the two groups of cadavers, and concluded that 'factors other than the Acromion shape may play a role in pathogenesis of Rotator Cuff tears'(Lee et al., 2001).

Interestingly, there are two centres of ossification on the Acromion, which only fuse between the ages of 18-25 (W. H. Lewis, 1902), and the shape type of the Acromion is considered to be congenital (Nicholson, Goodman, Flatow, & Bigliani, 1996). Os Acromiale (unfused Acromion) has been found to have an incidence of between 2.7% and 6% with full thickness Rotator Cuff tears (Neagle & Bennett, 1994).

Osseous changes can occur in the Acromioclavicular joint and in the Coraco-Acromial Ligament (Nicholson et al., 1996). Suenaga et al. 2002 (Suenaga, Minami, Fukuda, & Kaneda, 2002), investigated the histology of the Coracoacromial Ligament in overhead athletes' shoulders and found that there were hypertrophic fibrocartilagenous changes in this ligament. Spurs and osteophytes associated with arthritic changes in the Acromioclavicular joint have also been linked to Rotator Cuff pathology (Petersson & Redlund-Johnell, 2009). Yet research into subacromial decompression surgery in which the Subacromial Bursa is excised has shown that outcomes of this procedure, whether done with or without acromioplasty, are no different (Budoff, Rodin, Ochiai, & Nirschl, 2005; Henkus, Witte, Nelissen, Brand, & Arkel, 2009). This would support the notion that the morphology of the Acromion has no bearing on SAIS and this view is supported in numerous reports (Gill et al., 2002; Snow, Cheong, & Funk, 2009).

The contribution of Glenoid orientation to SAIS has been explored in research. Bishop et al. 2009 (Bishop, Kline, Aalderink, Zauel, & Bey, 2009) assessed the orientation of the Glenoid in 21 patients with one sided Rotator Cuff tears. Using computer tomography-based bone models they compared Glenoid inclination bilaterally. It was found that the side with the Rotator Cuff tears had significantly less Glenoid inclination (by 1.6°; p=0.04) when compared with the asymptomatic side. This did not correlate to a more superiorly translated Humerus, therefore 'failing to support the theory that Glenoid inclination was responsible for superior humeral translation and hence the development of SAIS'(Bishop et al., 2009). Opposing results reported in a study by Wong et al. 2003, tested the hypothesis that a superiorly inclined Glenoid would promote superior migration of the Humeral Head and hence the development of subacromial impingement (Wong, Gallo, Kuhn, Carpenter, & Hughes, 2003). Eight cadavers were used in the study, which concluded that the more inclined the Glenoid was the less the force required to superiorly migrate the Humerus. The force required to migrate the Humerus superiorly was reduced with inclinations from 5° -15° of the

Glenoid by between 14.2 and 37.5% and so it was proposed that Glenoid inclination could play a role in the development of subacromial impingement (Wong et al., 2003).

Posture and the AHD

"The shoulder girdle functions in a kinetic chain with the trunk and the remainder of the upper extremity" (Brody & Hall, 2010)(p.575), consequently dysfunction of related regions will affect the shoulder. Spinal asymmetry in theory can have an influence on shoulder function (Brody & Hall, 2010). It is postulated that an increase in Thoracic kyphosis causes an abducted and downwardly rotated Scapula thus tilting the Glenoid Fossa inferiorly (Brody & Hall, 2010). There is evidence that an increase in Thoracic kyphosis correlates to an increase in anterior tilt of the Scapula (Kebaetse, McClure, & Pratt, 1999; Ludewig, Cook, & Nawoczenski, 1996a; H. K. Wang, 2012) and this in turn will influence the AHD. Changes in Thoracic posture have been linked to SAIS (Gumina, Giorgio, Postacchini, & Postacchini, 2008). There is contrary evidence (J. S. Lewis, Green, & Wright, 2005), from a study comparing 60 asymptomatic subjects with 60 subjects with SAIS. The findings of this study suggested that there was not a link between resting Thoracic posture and subacromial impingement symptoms. The knock on effects, or ripple effects, of alterations in the body kinetic chain on shoulder biomechanics are clinically considered factors in SAIS (Kibler et al., 2013); however, tools and rigorous methodologies to quantify the impact of the kinetic chain on shoulder performance for the purposes of research are limited, therefore limiting amount of evidence to support these theoretical assertions. Evaluating the correlation between spinal curve and the AHD is one way of trying to empirically connect theory with evidence.

Alterations in Glenohumeral kinematics and AHD

Another proposed mechanism of Impingement Syndrome, particularly Internal Impingement Syndrome, is loss of flexibility in the posterior capsule of the Glenohumeral joint (Burkhart, Morgan, & Kibler, 2003). The acronym for this is GIRD, (in full: Glenohumeral internal rotation deficit). It is suggested that a loss of more than 20° in the total arc of rotation or 10° of internal rotation in the shoulder compared to the contra lateral side is indicative of GIRD (Burkhart et al., 2003). When investigating the Acromio-Humeral distance with ultrasound a direct correlation between this measure and GIRD was found (Maenhout, Eessel, et al., 2012). Optimal Glenohumeral kinematics are dependent on an accurate location of the centre of rotation in the Glenohumeral joint which is important to balance external loads and to balance internal muscle forces (Berthonnaud, Herzberg, Morrow, An, & Dimnet, 2006). Obligatory translations and joint centre migration does occur during physiological movement of the upper limb but needs to be controlled. When there is a loss in rotatory range of motion in the GHJ in one direction an interruption in this optimal Glenohumeral kinematics can lead to increased translations of the Humeral Head in another direction and therefore compromise of the AHD (Bigliani et al., 1997). To date, an investigation into the association between Glenohumeral internal rotation and Acromio-Humeral distance has been done (Maenhout, Eessel, et al., 2012), and a positive correlation between Glenohumeral internal rotation and Acromio-Humeral distance reported. Glenohumeral internal rotation and horizontal adduction in 90° are considered reliable measures and are considered as indicators of restriction in the posterior Glenohumeral capsule (Laudner, Stanek, & Meister, 2006; Myers, Laudner, Pasquale, Bradley, & Lephart, 2006; Tyler, Nicholas, Lee, Mullaney, & McHugh, 2009).

In contrast to the above mentioned loss of rotatory GHJ range, altered Glenohumeral kinematics due to instability or laxity of the Glenohumeral capsule resulting in excessive Humeral Head translation could contribute to Internal Impingement Syndrome. This alteration of the path of instant centre of rotation of the Glenohumeral joint (Brody & Hall, 2010) can compromise the Subacromial Space. This topic is further explored under the heading in this chapter *AHD and Internal Impingement Syndrome*. It can be concluded that research quantifying the effect of GHJ range of motion on the AHD would be of value.

Alterations in Scapular kinematics and the AHD

It has been proposed that Scapular resting position can be variable depending on sport, hand dominance, age, postural habits, and muscle tone (Wilk et al., 2009). Of importance is that Acromion and Glenoid orientation is directly related to Scapular orientation. Abnormalities in Scapular kinematics have been blamed as a contributing factor in SAIS. Studies comparing healthy patients to those with SAIS (Endo, Ikata, Katoh, & Takeda, 2001; Graichen et al., 1999; Hebert, Moffet, McFadyen, & Dionne, 2002; Ludewig & Cook, 2000; McClure, Bialker, Neff, Williams, & Karduna, 2004; Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1992) report decreased posterior Scapula tilt (Endo, Yukata, & Yasui, 2004; Ludewig et al., 1996a; McClure et al., 2004),decreased upward rotation (Endo et al., 2001; McClure et al., 2004; Su, Johnson, Gracely, & Karduna, 2004), and increased internal rotation (Endo et al., 2001; Hebert et al., 2002; Warner et al., 1992) in symptomatic groups. Furthermore, it has been proposed that these changed Scapular kinematics influence the Subacromial Space. Challenging the commonly held view that downward Scapular rotation results in a decreased Subacromial Space, is a study which (Karduna, Kerner, & Lazarus, 2005), reported a decrease in Subacromial Space in eight cadavers with upward Scapular rotation (Karduna et al., 2005). No significant difference in posterior tilt is reported in subjects with SAIS (Graichen et al., 1999; Hebert et al., 2002; Warner et al., 1992). It is theorised that these changes in Scapular position could be biomechanical adaptations made in response to symptoms in order to relieve compression on the Rotator Cuff Tendon (McClure et al., 2004). There is conflicting evidence as to whether altered motion patterns seen in pathology are actually detrimental (i.e. cause the pathology) or beneficial (i.e. compensate for the pathology) (Karduna et al., 2005; Ratcliffe et al., 2014). A systematic review of the literature linking SAIS and Scapular orientation found insufficient evidence to uphold the theory that the Scapula assumes a regular position in SAIS (Ratcliffe et al., 2014). Literature linking a correlation between AHD and Scapula position in vivo is exiguous and would be beneficial because conservative interventions often aim at changing Scapular position are often used in patients with SAIS.

To date, the association between Scapular position and Acromio-Humeral distance has only been reported in three previous articles (Seitz, McClure, Lynch, Ketchum, & Michener, 2012; Silva, Hartmann, Laurino, & Biló, 2010; Solem-Bertoft, Ka, & Ce, 1993). Scapular dyskinesis was graded via observation in adolescent tennis players and ultrasound measures of Acromio-Humeral distance collected, it was reporting that there was a decrease in Acromio-Humeral distance in subjects with Scapular dyskinesis (Silva et al., 2010). Using MRI on 4 subjects, and in the supine position a negative association between Acromio-Humeral distances and Scapular protraction is reported (Solem-Bertoft et al., 1993). No link between observed Scapular dyskinesis and Acromio-Humeral distance measured with ultrasound is reported (Seitz, McClure, Lynch, et al., 2012). However, when the Scapula was assisted into upward rotation, in the same study, an increase in Acromio-Humeral distance was recorded. In these studies (Seitz, McClure, Lynch, et al., 2012; Silva et al., 2010), subjective methods were used to quantify Scapular position. An objective method is necessary to confirm findings of these studies. A clinically applicable and objective method is needed to quantify Scapular position so that the position can be measured in varying populations and the association between Scapular position and Acromio-Humeral distance can be examined.

Muscle extensibility and AHD

Subjects in a study were divided into two groups with shorter and longer Pectoralis Minor lengths. A decrease in Pectoralis Minor length (Borstad, 2006; Hebert et al., 2002) was found to decrease Scapula external rotation and posterior tilt during arm elevation between 90° to 120°. Alterations in Scapular kinematics associated with short Pectoralis Minor length have been noted in patients with SAIS (Endo et al., 2004; Hebert et al., 2002; Ludewig & Cook, 2000; Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1990); however, the extent of Pectoralis Minor shortening needed to decrease the Subacromial Space and contribute to extrinsic mechanism has yet to be determined (Seitz et al., 2011).

Dynamic structure contributions to AHD

Twenty six muscles coordinate action to control the joints of the sternoclavicular, Acromioclavicular, Scapular Thoracic, and Glenohumeral joints (Neagle & Bennett, 1994). It can therefore be appreciated just how complex it is to quantify the contribution of a single joint or a single muscle to the overall motion of the arm. To complicate matters further, a single muscle may perform multiple actions depending on how it combines with the action of other muscles. There is shared musculature between the Spine and Scapular and shoulder girdle. Muscle dysfunction can manifest in numerous ways: reflex lengthening or shortening of muscle, concentric or eccentric strength dysfunction, and poor endurance and stamina. Abnormal muscular force couples of the Scapula Thoracic muscles and Glenohumeral joint musculature can lead to faults in the path of instant centre of rotation of the Scapular and Glenohumeral joint (Brody & Hall, 2010), and thus affect Scapular and Glenohumeral joint kinematics. Defining the actions of each of these muscles is beyond the scope of this chapter. What is important is that many reports have linked deficits in muscular performance to Rotator Cuff tendinopathy (Cools et al., 2007; Cools, Witvrouw, Declercq, Danneels, & Cambier, 2003; Cools, Witvrouw, Mahieu, & Danneels, 2005; Ludewig, 2005; Moraes, Faria, & Teixeira-Salmela, 2008; Wadsworth, 2007), and to abnormal Scapular kinematics during arm elevation (Kebaetse et al., 1999; Kibler, Chandler, Shapiro, & Conuel, 2007; J. Smith, Kotajarvi, Padgett, & Eischen, 2002; Tate, McClure, Kareha, Irwin, & Barbe, 2009). The muscle action between serratus anterior and the trapezius muscles, which controls Scapular upward rotation, Scapular posterior tilt, and Scapular external rotation, as well as Scapular stability (G. R. Johnson, Stuart, & Mitchell, 1993; McQuade, Dawson, & Smidt, 1998) is an example of an essential muscle force couple vital to normal Scapular motion. Research with EMG has noted late activation onset (Moraes et al., 2008), decreases in force output (Cools et al., 2005), changes in muscle balance ratios (Cools et al., 2005), and alterations in the length/tension relationship between muscle groups, which all of which have an effect on Rotator Cuff function. Moreover, it is commonly held theory that small changes in muscle function can affect the Subacromial Space.

It has been proposed that deficits in Rotator Cuff performance, particularly in the Supraspinatus muscle, lead to superior migration of the Humeral Head which leads to compressive forces on the Rotator Cuff Tendon. The force couple between the deltoid and the Rotator Cuff controls humeral centring in the Glenoid. It is thought that fatigue of the Rotator Cuff, as often seen in swimmers and labourers who work with their arms over head, leads to deltoid dominance and hence superior migration of the Humerus (Bigliani et al., 1997). This concept has been challenged in studies by Werner et al. 2006, who paralysed the Supraspinatus and infraspinatus muscle in 10 subjects and found that this did not lead to any immediate subsequent superior migration of the Humeral Head (Werner, Blumenthal, Curt, & Gerber, 2006). It is noted that the immediate effect of this paralysis was tested in this study, and it is possible that adaptation and Humeral Head migration will take place over a longer period of time. To further confound the notion that muscle performance has an adverse effect, research by Maenhout et al. 2012 (Maenhout, Mahieu, De Muynck, De Wilde, & Cools, 2012) found that, contrary to commonly held clinical views, the Acromio-Humeral distance, evaluated with ultrasound, increased after fatigue.

Muscle peak isometric concentric and eccentric torque has be shown to be impaired in patients with Rotator Cuff tendinopathy compared with asymptomatic patients (MacDermid et al., 2007; Tyler, Cuoco, Schachter, Thomas, & McHugh, 2009; Warner et al., 1992). The question remains whether the alterations in muscle function arise as a result of the Impingement Syndrome or as a cause of Impingement Syndrome. Studies found that changes were bilateral they postulated that these were a contributing factor to the pathological process. Changes in muscle function could also be attributed to pain, which is known to influence muscle co activation levels (Hodges, P. W., 2011) and hence to lead to altered Scapular and humeral position and kinematics (Michener, Boardman, Pidcoe, & Frith, 2005)

Ergonomic and sport specific adaptations

Many activities of daily living and sporting actions require arm elevation, during which the tissues in the Subacromial Space are repeatedly compressed and exposed to shear forces. A high incidence of shoulder pain is reported in athletes who perform overhead activity (Tate et al., 2009). Neer and Welsh, 1977, identified five stages of pathology in shoulder Impingement Syndrome, and suggested that these could be progressed through more rapidly in the overhead athlete. It is unclear if compressive and shear forces alone are responsible for rotator pathology, since it is more often than not the dominant arm that presents clinically, implying that the compressive forces combined with overuse could be responsible (Seitz et al., 2011). In the athlete, the following factors could be extraneous contributors to shoulder injury: overuse; an acute traumatic episode; incorrect technique; training loads, frequency, duration, and intensity; as well as the use of training devices. In the athlete, micro trauma of the Subacromial Bursa, the Rotator Cuff Tendons, and Long Head of Biceps occurs (Edwards, Bell, & Bigliani, 2009). Such micro trauma is attributed to repetitive compressive and shear forces in the Subacromial Space. A survey with 372 respondents explored the epidemiology of shoulder Impingement Syndrome in upper arm sportsmen (Lo, Hsu, & Chan, 1990), 43.8% of the sportsmen reported shoulder problems. The incidence of such problems directly correlated to their choice of sport, hand dominance, and frequency of play. Injuries were most common in elite and full time sportspersons performing overhead sports (Lo et al., 1990). Reports have tried to quantify the effect of load and training on the shoulder in various athletes by quantifying ball speeds, number of arm repetitions in a given period, and forces generated by the upper limb (Huijbregts, 1998), and multiple studies provide converging evidence that load does play a role in the pathogenesis of shoulder Impingement Syndrome. Research by Svendsen at al. 2004, highlights the fact that arm position is a factor in the development of shoulder Impingement Syndrome, not only in sportsmen, but also in the work environment. In 136 subjects who had worked for a minimum of ten years in jobs requiring overhead arm positioning, morphological changes were detected with MRI in the Supraspinatus Tendon (Svendsen, Bonde, Mathiassen, Stengaard-Pedersen, & Frich, 2004), thus further supporting the conclusion that load plays a role in the development of SAIS. Research using ultrasound determined that a reduction in Acromio-Humeral distance occurs during arm abduction (Maenhout, Eessel, et al., 2012), quantifying the effect of load on AHD in athletes whose shoulders undergo extremes of load would further contribute to the understanding of the pathogenesis of SAIS in this population.

2.2.3 *AHD and Internal Impingement Syndrome*

There appear to be three explanations for the mechanical process occurring in internal impingement. Firstly, increased contact between the posterior superior Glenoid and the posterior cuff is thought to be due to increased Glenohumeral range of motion, laxity of the Glenohumeral joint, and humeral retroversion, all of which have been detected on the throwing side of athletes (Reinold, Wilk, Dugas, & Andrews, 2009). A perpetuating cycle in which subtle laxity of the Glenohumeral capsule leads to internal impingement (Davidson, Elattrache, Jobe, & Jobe, 1995), further stretching of the inferior Glenohumeral ligament, and subsequently increased Humeral Head translation is considered part of the process in Internal Impingement Syndrome . Results from an in vitro study support the view that excessive external rotation of the shoulder may stretch the inferior Glenohumeral ligament, and result in Internal Impingement Syndrome (Mihata, McGarry, Kinoshita, & Lee, 2010). Dysfunction of the Rotator Cuff muscles (which serve to centre the Humeral Head in the Glenoid) further contributes to the process as it results in excessive Humeral Head translations posteriorly and superiorly into the Subacromial Space, causing abutment of the Rotator Cuff .

A related second explanation, is that during the throwing action, the anterior fibres of the Glenohumeral capsule become stretched due to repetitive strain (Jobe & Lannotti, 1995; Wilk et al., 2009). This leads to anterior translation of the humeral head, and laxity, but not necessarily gross instability (Borsa, Jacobson, Scibek, & Dover, 2005; Chen, Simonian, Wickiewicz, Otis, & Warren, 1999; Harryman et al., 1990; Krarup, Court-Payen, Skjoldbye, & Lausten, 1999; Sauers, Borsa, Herling, & Stanley, 2001; Sethi, Tibone, & Lee, 2004). This allows a shift of the Humeral Head in an anterior inferior direction, pulling the posterior under surface of the cuff with it which it jams against the posterior superior Glenoid during the late cocking phase of throwing.

In contrast, a third explanation questions whether instability and laxity are actually the precursors to internal impingement. It is suggested that the mechanism of Internal Impingement Syndrome is not pathological but rather a protective mechanism against further hyper external rotation of the shoulder (Burkhart et al., 2003). Advocates for this view propose that GIRD is the precursor to Internal Impingement Syndrome, and that tightness in the posterior inferior capsule forces the Humeral Head into a more posterior superior direction impacting on the AHD and causing the pinching of the Rotator Cuff Tendon, and could be a protective mechanism.

The exact pathogenesis of internal impingement has not yet been conclusively established; currently these are the best theories. Investigating if compromise in the AHD does indeed correlate to a gain in GHJ external range may contribute to this debate.

2.3 Summary

The aim of this review was to survey the state of knowledge with regard to SAIS, pulling together what is known about the topic. Based on the current evidence, the hypothesis that a reduction in Subacromial Space is an extrinsic cause of SAIS is not conclusively established and the evidence permits no conclusion. The postulated aetiology factors of shoulder pain and Impingement Syndrome are supported by evidence of varying strength (Tate et al., 2009). Much ambiguity and conflicting evidence exists. In addition, methodological diversity and inconsistent results in the research make it difficult to provide empirical evidence for many of the theoretical assertions proposed. The exact cause of SAIS remains controversial, and possibly the causes are multifactorial (Wilk et al., 2009). Pathological factors that are considered to contribute to shoulder Impingement Syndrome can be divided into extrinsic and intrinsic categories. Whether structural reduction of AHD contributes to the pathomechanics leading to compression and shear stress of the structures within the Subacromial Space (and hence to SAIS) is debated in the literature. The biomechanical factors contributing to a structural reduction in Subacromial Space (AHD) are also debated. Separating out the various biomechanical factors thought to contribute to a reduction in AHD for the purposes of research can be limiting because the various biomechanical factors are all interrelated. Numerous factors could, therefore, influence Acromio-Humeral distance. Apart from one study (Borstad, 2006) (exploring the association between Pectoralis Minor length, degree of Thoracic curve and Scapular position) research exploring associations between multi-factorial factors contributing to subacromial impingement is limited in the literature.

Further research exploring the association between the various biomechanical factors and most especially the AHD would be beneficial, because this could influence approaches to treatment of this common shoulder syndrome. But due to the multifactorial etiological factors of SAIS research into this area will be fraught with confounding variables. In order to control the many intrinsic and extrinsic factors/variables in the research process which are postulated to affect shoulder Impingement Syndrome, a stringent screening of participants is necessary. A flow chart to summarise the factors considered to contribute to SAIS is drawn up for use when defining the selection criteria of subjects for the present research (Figure 3). A second flow chart is then drawn up to summarise the variables that will be investigate in the present research as to ascertain their effect on the AHD (Figure 4.)

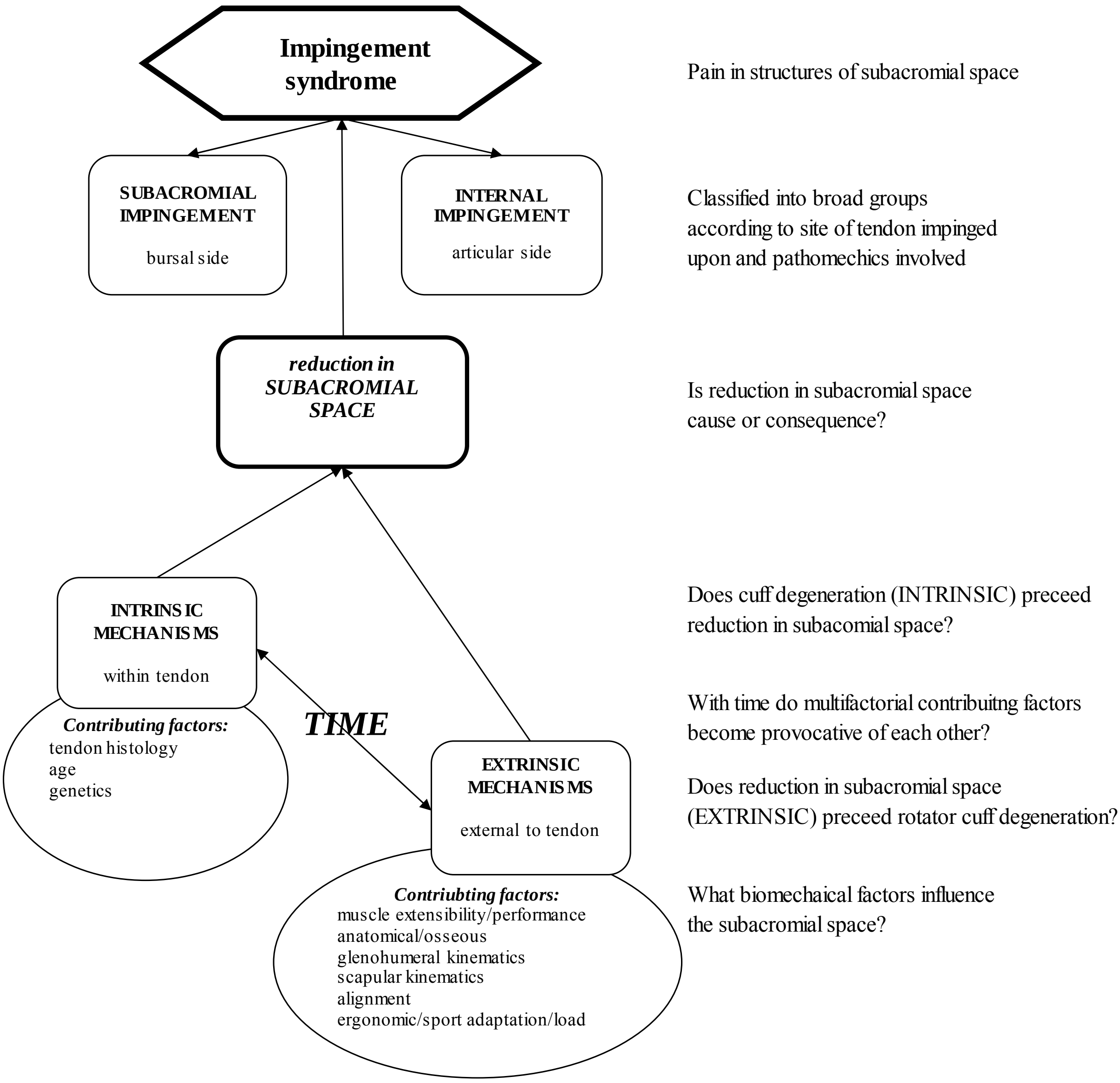

Figure 3. Flow chart summarising the state of knowledge with regard to Impingement Syndrome with specific focus on the role of the Subacromial Space.

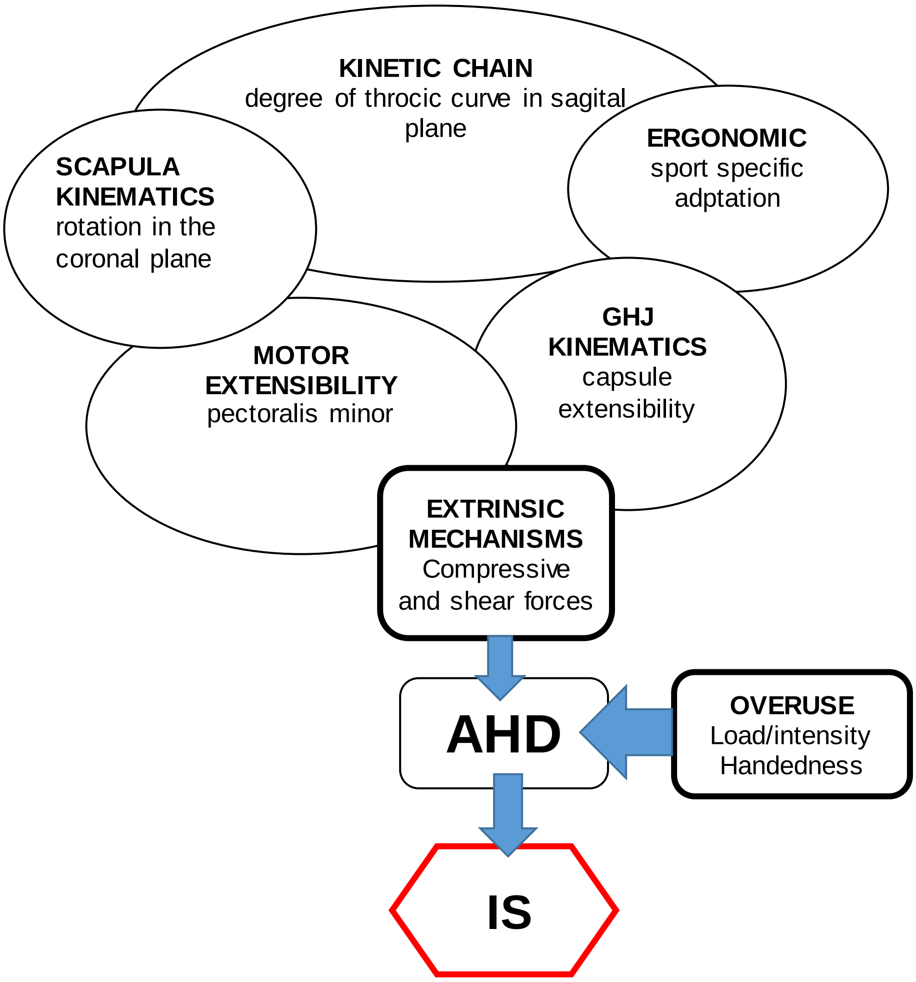

Figure 4. Variables quantified in this thesis and their association to AHD
Abbreviations: GHJ=Glenohumeral joint; AHD=Acromio-Humeral distance; IS=Impingement Syndrome.

Chapter 3 Methods: reliability of procedures and tools

List of abbreviations

AHD	Acromio-Humeral distance
AGT	Acromion-Greater Tuberosity distance
C7	Cervical Vertebra seven
CI	confidence interval
GERG	Glenohumeral external rotation gain
GHJ	Glenohumeral joint
GIRD	Glenohumeral internal rotation deficit
HOH	head of Humerus
IAS	Inferior Angle of Scapula
IAS-Sp	distance of Inferior Angle of Scapula to Spinous Process
ICC	intraclass correlation coefficient
IS	Impingement Syndrome
$MDC_{95\%}$	minimal detectable change
PALM	palpation meter
RSS	Root of Spine of Scapula
RSS-IAS	distance of Root Spine of Scapula to Inferior Angle of Scapula
RSS-Sp	distance of Root Spine of Scapula to Spinous Process
RTUS	real time ultrasound
SAIS	Subacromial Impingement Syndrome
SEM	standard error of the measure
Sp	Spinous Process
STD	standard deviation
SR	Scapular rotation
TROM	total rotational range of motion
US	ultrasound

Article in press: Mackenzie, T. A., Bdaiwi, A. H., Herrington, L., & Cools, A. (n.d.). Inter-rater Reliability of Real-Time Ultrasound to Measure Acromiohumeral Distance. PM&R, 0(0). http://doi.org/10.1016/j.pmrj.2015.11.004

Published: Mackenzie, T. A., Herrington, L., Bdaiwi, A. H., & Cools, A. (2015). The palpation meter (PALM) is reliable and valid for measuring Scapular upward rotation. International Journal of Physical Education, Sports and Health, 2(2), 54–59.

Chapter overview

- This Chapter details the methods used to quantify AHD and the variables considered to influence AHD. A literature review was conducted to search for appropriate tools to quantify the variables of AHD, Scapular rotation, Glenohumeral joint rotation, Pectoralis Minor length, and thoracic rotation. The following data bases were searched: Cochrane, CINAHL (Cumulative Index to Nursing and Allied Health Literature-EBSCO Host), Medline, Sport Discus, PubMed, ProQuest, Science Direct, Web of Knowledge, Web of Science, Google Scholar. Tools had to be field based in order to screen the desired population, therefore, the use of radiological methods other than RTUS were not appropriate to quantify AHD. Under the introduction in section 3.1, of this chapter, headed 'Inter-rater reliability of real time ultra sound to measure Acromio-Humeral distance' is a review and appraisal of the literature with respect to the use of RTUS to quantify AHD. Considering the need for a field based portable and reliable method to quantify Scapular upward rotation the use of EMT was not an option. As a result clinical measurements had to be used to determine Scapular rotation in the coronal plane. Either an inclinometer or lateral measures of the distance of the Scapular from the spine (used in the sin rule) were deemed appropriate. Since the later was a novel method to explore it was chosen and the two methods compared. Under the introduction in section 3.2, of this chapter, headed 'The palpation meter (PALM) is reliable and valid for measuring Scapular upward rotation' is a review and appraisal of the literature with respect to the use of various instrumentation reported in the literature to quantify lateral distance of the Scapular from the Spine the inclinometer to quantify Scapular upward rotation. A comparison of the two tools and methods is reported in the method and results section of 3.2 in this chapter. Further tools were required to quantify Glenohumeral joint rotation, Pectoralis Minor length, and thoracic rotation. The review and appraisal of these tools considered appropriate for this are summarized under the heading 3.3, in this chapter, headed ‘Intra-rater 24 hours apart inter-session reliability of further instrumentation’. Reliability of methods and tools is reported.

3.1 Inter-rater reliability of real time ultra sound to measure Acromio-Humeral distance.

INTRODUCTION

In 1972, Neer coined the term subacromial impingement and proposed a pathomechanical process in which mechanical compression of the soft tissues in the Subacromial Space occurred due to a narrowing of the Subacromial Space (Neer, 1983). Since contact occurs between the upper surface of the Supraspinatus Tendon and the Coracoacromial Ligament during arm elevation, Neer proposed that any reduction of the Subacromial Space would lead to Impingement Syndrome. From cadaveric studies it has been concluded that contact between the Supraspinatus Tendon and the Biceps Tendon with the Coracoacromial Ligament occurs between 45° and 60° of shoulder abduction (Burns & Whipple, 2013) and may cause compression of the subacromial structures against the Coracoacromial Arch. Advancing on this theory, with radiographs and MRI, it was determined that the distal Supraspinatus Tendon was engaged between the Greater Tuberosity and the Acromion as early as 30° of shoulder flexion and abduction (Brossmann et al., 1996).

It has been shown via x-ray determination that at rest the distance between the Acromion and Humerus is on average 11mm , and at 90° abduction this distance is reduced to 5.7mm on average (Flatow et al., 1994), thus Subacromial Space is reduced with arm elevation. RTUS has also been used to quantify a reduction in Acromio-Humeral interval during arm abduction (Desmeules, Minville, Riederer, Côté, & Frémont, 2004; Maenhout, Eessel, et al., 2012). Burkart et al., 1995, who also described the pathogenesis of SAIS due to a reduction in the height of the Subacromial Space. Their study showed a reduction in the Acromio-Humeral distance correlated to the incidence of Impingement Syndrome in subjects (Burkhart, 1995). Further evidence to support the notion that decrease in the acromial-humeral distance (Acromio-Humeral interval) is responsible for SAIS were reported in a study on 206 shoulders with Rotator Cuff tears (Werner et al., 2008). In the study, anterior-posterior radiograph and computed tomogram were used to measure the Acromio-Humeral interval, a decrease in Acromio-Humeral interval directly correlated to multiple Rotator Cuff Tendon tears and fatty degeneration in the infraspinatus and Supraspinatus muscles (Werner et al., 2008). An AHD of less than 6mm was found to correlate with a large Rotator Cuff tear (Goutallier et al., 2011). Reduced AHD has been associated with SAIS subjects compared to healthy subjects in studies using RTUS, MRI and x-ray (Girometti et al., 2006; Graichen et al., 1999; Hebert et al., 2002; Pijls, Kok, Penning, Guldemond, & Arens, 2010; Saupe et al., 2012), and proposed as a predictive marked (Cholewinski et al., 2008b). It is proposed that a measure of the Subacromial Space may be a useful method of quantifying objectively inferior GHJ instability (Kumar, Bradley, & Swinkels, 2010). In a systematic literature review (Seitz et al., 2011), it is reported that the literature consistently reports that patients with full thickness tears have smaller AHD when compared to those with healthy shoulders, and that AHD may be of prognostic value in patient with SAIS.

Intervention to increase the AHD both surgically and with rehabilitation is common clinical practice. It is therefore important to evaluate this proposed pathogenic component of Rotator Cuff disease, and a portable inexpensive and clinically applicable method is warranted. RTUS has been proposed as an appropriate tool for this purpose. In a systematic review of literature reporting on reliable and clinically applicable methods to asses AHD, (McCreesh, Crotty, & Lewis, 2013), it was concluded that there was strong evidence for the reliability of RTUS for measuring the AHD when compared to other radiological methods . Although RTUS has already been used in research to this end, previous protocols testing its reliability, lack rigour and thorough reporting of statistical results (Desmeules et al., 2004; Kumar, et al., 2010; Pijls et al., 2010). There is, therefore, little in the literature to support the inter-rater reliability of RTUS in varying shoulder positions both active and passive.

A search was done in the literature for studies reporting the reliability of using RTUS to measure the AHD, whether this was the primary aim or not. The following data bases were searched: Cochrane, CINAHL (Cumulative Index to Nursing and Allied Health Literature-EBSCO Host), Medline, Sport Discus, PubMed, ProQuest, Science Direct, Web of Knowledge, Web of Science, Google Scholar. The combination of search words used was: ultrasound, Subacromial Space, Acromio-Humeral distance, Acromio-Humeral interval, shoulder impingement, and Rotator Cuff. Reference lists of articles were also checked for additional articles not found in the first literature search process. As a result of this search, 18 of articles were found which used RTUS to quantify the AHD. Of these, nine articles (Azzoni et al., 2004; Duerr, 2010; Kalra, 2010; Kumar, et al., 2010; Leong, 2012; Maenhout, Eessel, et al., 2012; Seitz, McClure, Finucane, et al., 2012; White, Dedrick, Apte, Sizer, & Brismée, 2012) had examined intra-rater reliability and only three of the articles (Desmeules et al., 2004; Kumar, et al., 2010; Pijls et al., 2010), shown in Table 1 evaluated inter-tester reliability.

In the literature, three studies were found to have evaluated inter-rater reliability of RTUS as a tool to quantify the Subacromial Space (Desmeules et al., 2004; Kumar, et al., 2010; Pijls et al., 2010). These studies are summarised in Table 1. Of these three articles, two measured the AHD (Desmeules et al., 2004; Pijls et al., 2010) the remaining author (Kumar, et al., 2010) measured Acromion to Greater Tuberosity distance (AGT). In this study, the AGT measure was reported as reliable with inter-tester reliability of 0.79(CI=0.68-0.89), however, this inter-tester relibaility was established for the neutral arm postion only. When comparing the intra-rater reliability of measuring the two distances AGT and AHD, it was reported that the Greater Tuberosity could not be visualised on US images in abduction. This limits the clinical usefulness of the AGT as a measure (Duerr, 2010).

Of the two remaining articles (Desmeules et al., 2004; Pijls et al., 2010), both have methodological limitations. Although one (Pijls et al., 2010), reports excellent inter-rater reliability of 0.70 (neutral shoulder position) and 0.64 (60° abducted arm position) of measuring AHD, it is not reported whether the abducted arm position was executed passively or actively. The other (Desmeules et al., 2004), reports inter-tester reliability of between 0.86 (neutral shoulder position) and 0.92 (active 60° abduction). However, only used 13 shoulders for the inter-tester reliability. This resulted in an underpowered study which provided inadequate statistical validity. The low number of subjects recruited means that the study lacks the ability to detect a clinically important effect, and prevents reporting of the ICC values with confidence (Batterham & Atkinson, 2005, 2005; Donner & Eliasziw, 1987; Eliasziw & Walter, 1998; Lui & Cumberland, 1992).

The statistical results reported in these studies are not robust. Both articles fail to report standard error of measure (SEM) values, so one cannot work out how preciseness of the estimate. A large SEM would indicate an imprecise estimate, and a small SEM would indicate a precise estimate (Salkind, 2007). The absence of SEM values prevents any estimation of how much samples would vary within a population. MDC is not reported by either author. This is an important measure, because this is the smallest difference that is clinically important for the measure to be considered credible (Salkind, 2007). Furthermore, there is lack of reporting of the 95% CI range (Desmeules et al., 2004), thus reporting no interval estimate for the population parameter. This is important as it gives the range of values used to estimate the true value of a population parameter (Triola, 2009). A lack of thorough statistical reporting prevents important conclusions from being drawn confidently.

Since RTUS is used in research to quantify AHD, and is proposed as a reliable method to evaluate AHD for the impact of surgical and rehabilitation interventions on the AHD, it is important that its inter-tester reliability be ascertained. The main aim of the present study was to establish the inter-rater reliability of using RTUS to measure AHD in shoulder neutral, and in 60° of both active and passive abduction. The second aim was to compare the measure of the AHD in both active and passive 60° of arm abduction.

Table 1 Inter-tester reliability studies in the literature

Author	Population (ave age)	Transducer placement	Shoulder positions	Distance	Method	ICC inter-rater (95%CI) mm	AHD (STD) mm
Desmeules et al., 2004 (Desmeules et al., 2004)	AS N=13 (34 years) Gender NR	12.5MhZ linear 1cm lateral to Acromion Longitudinal to axis of Humerus	0°/45°/60° Active	AHD	Intra-session	ICC model NR 0°=0.86 (NR) 60°=0.92(NR) SEM=NR MDC=NR	0° = 9.9(1.5) 60°= 7.6(1.7)
Kumar et al., 2011 (Kumar, et al., 2010)	AS N=20 (21 years) 9M:11F	10-5MHz linear	0° passive	AGT	Intra-session	$ICC_{2.1}$ 0°=0.79(0.68-0.89) SEM=1.5 MDC=NR	AGT
Pijls et al., 2010 (Pijls et al., 2010)	S 0° N=21(51 years) 9M:12:F 60° N=22(52 years) 10M:12F	5-15MHz linear Longitudinal to Supraspinatus Tendon	0°/ 60° NR	AHD	Intra-session	ICC model NR 0° =0,70(0.43-0.86) 60°=0.64(0.33-0.82) SEM=NR MDC=NR	0° = 9.3(1.7) 60°= 6.7(1.7)

Abbreviations: Ave= average; AS=asymptomatic; S=symptomatic; ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; mm=millimetres; NR=not reported. M=male; F=female; AHD=Acromio-Humeral distance; AGT=Acromion-greater tuberosity; MHz =Megahertz: º = degrees.

PARTICIPANTS

Estimated sample size was based on reported guidance (Walter & Eliasziw, 1998), who suggest that with two raters, a significance level of 0.05, and a power of 80%, to determine an ICC score of 0.7 (to interpret reliability indicative of a true p0, versus an alternative ICC score of 0.9 indicating a p1), that 19 samples are required. In the present study, ten asymptomatic subjects were recruited (six male, four female) with an average age of 29.86(STD 7.8) years. Side difference in measurements taken of AHD with RTUS within this group were analysed with paired t-tests. There were no significant side to side differences with all p values exceeding 0.05. This enabled data collected on a total of 20 shoulders to be used in reliability analysis.

Subjects included in the study were of full musculoskeletal development, and had healthy shoulders. Subjects were excluded from the study if they had: cervical, shoulder, or elbow pain within six months before testing; previous fracture, surgery, or dislocation of the upper limb; scoliosis, a rheumatologic condition, or were pregnant.

The Salford Research Ethics Panel approved the study protocol. All participants were provided with a detailed information sheet, comprising details of the study and any associated risks. After a verbal briefing, participants gave written informed consent to testing and anonymised use of the data collected.

INSTRUMENTATION

A diagnostic ultrasound imaging system Mylab 60 Esaote, Xvision model, with a 523 linear transducer and frequency of image set at 13MHz was used for the scanning. Pre-set parameters were used for musculoskeletal shoulder settings.

METHOD

All participants were measured by two examiners. Both examiners had 2 years of experience with ultrasound in research collecting data on the shoulder to quantify the AHD.

Subjects' position was standardised with subjects seated, with their shoulders exposed, on a customised armless chair with a short back support. The subjects' hips and knees were flexed at 90°, and feet rested flat on the floor. The subject was asked to adopt a relaxed posture that felt comfortable to him or her. In order to evaluate AHD in a normal habitual posture, no attempt was made to make the subject conform to a single standardised posture. The seated posture eliminated the effect of possible leg length discrepancies. Three US images were captured in the arm positions, 0°, and 60° of arm abduction both active and passive. For US image capture in the neutral position, the hand on the side of the examined shoulder was rested in pronation on the subject's same side thigh with the Humerus hanging vertically alongside the subject's body. The participant's elbow was left unsupported to ensure that the shoulder girdle was not elevated. For US image capture in the 60° of passive arm abduction position, the arm was abducted in the coronal plane, and rested on a pre-cut 60° foam wedge, which rested on a table with adjustable height (Figure 5). The height of the table could be adjusted according to the subject's body length so that the arm was abducted to 60° of arm abduction without shoulder girdle elevation. The amount of shoulder abduction was verified with goniometry. Neutral humeral rotation was maintained as the foam wedge supported the Humerus and forearm, with 90° of elbow flexion and the subject's palm resting on the wedge. For the third position of 60°of shoulder active abduction, the subject was asked to lift the forearm and elbow slightly off the foam wedge to lift the elbow 1cm off the wedge.   This active movement was too small to have an effect on angle of humeral abduction. Three bilateral US images of the AHD were collected in each of the three shoulder positions.

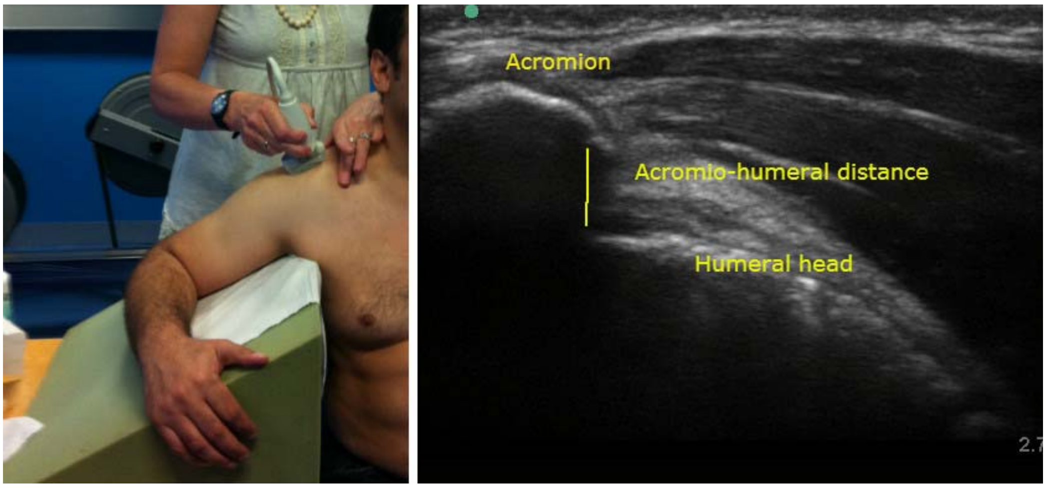

Figure 5. Subject position for ultrasound image capture in 60°of passive shoulder abduction
The shortest tangential measure between of the hyper echoic landmarks of the most superior aspect of the Humerus and Acromion are shown on the US image.

The US transducer was placed in the coronal plane, parallel with the longitudinal axis of the Humerus and positioned to visualize the shortest tangential distance between of the hyper echoic landmarks of the most superior aspect of the Humerus and Acromion on the US screen (Figure 6). The transducer was not kept in contact with the participants' skin throughout image capture. It was removed from the participants' skin between the three consecutive measures, thereby testing the true repeatability of the procedure.

US Images were collected on the subject's right shoulder first. The first examiner collected US images in all three arm positions in the following order: shoulder neutral, 60° of passive shoulder abduction, followed by 60° of active abduction. Three consecutive measurements were taken by the examiner in each of the shoulder positions. Once examiner one had completed US image capture bilaterally in all the three shoulder positions, the second examiner entered the cubicle and collected US images in the same order. Examiners were blinded to each other's captured images during the process.

Images were saved to the US scanner hard drive and retrieved for analysis. Analysis of images was done a week after capture. Images were converted and saved as jpeg files, and were randomised by a third party. As a result, the investigators were blinded to subject identity, order of collection of images, side and shoulder position the image was captured in. The stored images were reviewed using Image J 1.32 software. Hyper echoic landmarks were consistently marked to identify the external inferior of the Acromion and the most superior aspect of the Humerus, thus yielding the shortest distance between the two hyper echoic landmarks on ultrasound images. Electronic line callipers were used to make the measurements. Each investigator made AHD measures on their own captured images, as well as those of the other examiner. Hence the inter-rater testing was done for both image capture and image analysis.

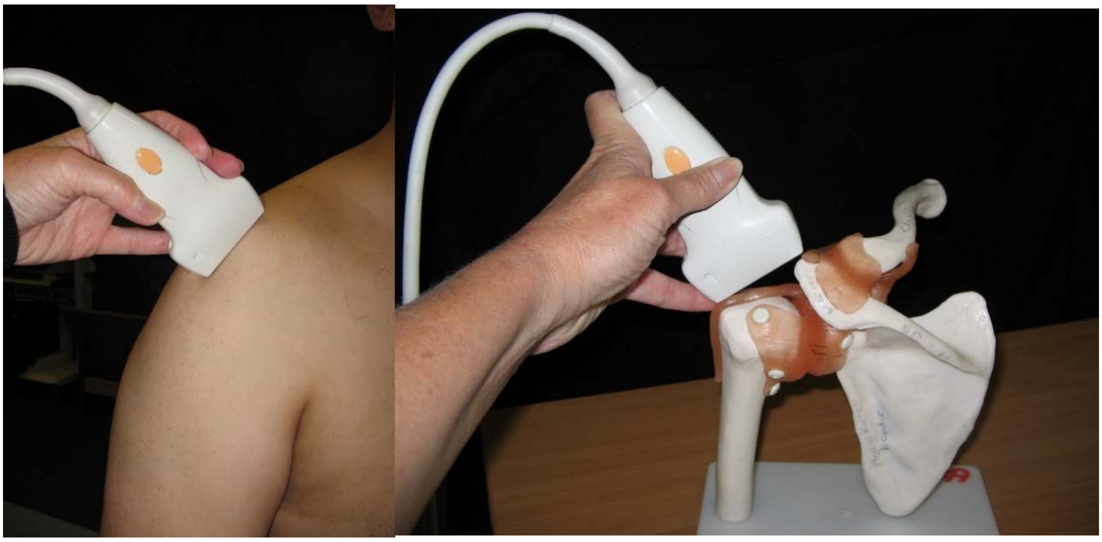

Figure 6. The US transducer was placed in the coronal plane parallel with the longitudinal axis of the Humerus

DATA ANALYSIS

Statistical Package for Social Sciences for Windows version 20.0 (SPSSinc., Chicago,IL), was used for statistical analysis.

Shapiro-Wilk tests were used to check for normality of distribution of variables. Paired T-tests (2tailed and significant if $p < 0.05$) were used for significance testing for differences between the AHD measures to examine side to side differences in AHD measures, and to test for differences in AHD measures taken in the 60° of both active and passive arm abduction.

The interclass correlation coefficients ($ICC_{3.1}$) model was used for within-day intra-rater reliability, a two-way fixed effects model (examiner is fixed effect and participants are randomised effects), with absolute agreement for each single measure. $ICC_{2.1}$ model was used for within-day inter-rater reliability, a two-way random effects model, (examiners and participants are both treated as random effects), with absolute agreement for each single measure. SEM based on the calculation SEM = SD x √(1-ICC) (Bruton, Conway, & Holgate, 2000), and $MDC_{95\%}$ based on the calculation $MDC_{95\%}$ = 1.96 x √2 x SEM (Eliasziw, Young, Woodbury, & Fryday-Field, 1994) were calculated to establish random error. The following criterion was used to interpret ICC: poor = less than 0.4, fair = 0.4-0.7, good = 0.7-0.90, and excellent = >0.90 (Coppieters, Stappaerts, Janssens, & Jull, 2002).

Intra-rater reliability was calculated for each examiner's own image capture and analysis on the same images. Inter-rater reliability was calculated for the technique as whole, with examiners analysing their own captured images as well as the images collected and captured by the other examiner.

RESULTS

Side to side difference in AHD measures, captured by both examiners, with RTUS within this group were analysed with paired t-tests, and it was determined that there were no significant side to side differences with all p values exceeding 0.05. This enabled data collected on a total of 20 shoulders to be used in reliability analysis.

Means, standard deviations, standard error of measure, minimal detectible change, ICC, and 95% confidence intervals for AHD measurements are summarised in Table 2 and Table 3. The mean AHD in neutral was 15.00mm (STD=2.63mm), decreasing to 10.6mm (STD= 3.04mm) in the 60° passive abducted arm position, and 10.65mm (3.32mm) in the 60° of active abducted arm position. For all measurements the SEM values (0.81 in neutral, 1.2 in active arm abduction , 1.2 in passive arm abduction), and the $MDC_{95\%}$ values (2.2 in neutral, 3.2 in active arm abduction , 3.3 in passive arm abduction) were less than the calculated means. $ICC_{3.1}$ values were good for AHD measures in all three of the shoulder positions tested (0.85-0.89 in neutral, 0.71-0.72 in active arm abduction, 0.77-0.99 in passive arm abduction) for intra-rater reliability (Table 2). $ICC_{2.1}$ scores were fair to good for AHD measures in all three of the shoulder positions tested (0.88 in neutral, 0.68 in active arm abduction, 0.65 in passive arm abduction) for inter-rater reliability (Table 3). Inter-rater reliability of image analysis was good for measures of AHD in all three of the shoulder positions tested (0.88 in neutral, 0.81 in active arm abduction, 0.88 in passive arm abduction). Comparison between the measures of AHD in 60° of both passive and active arm abduction (paired t-tests) showed no significant difference when p =0.91.

Table 2. Intra-rater intraclass correlation coefficients, confidence intervals, mean, standard error of measure, minimal detectible change for AHD measured with RTUS.

Arm position	Intra-rater $ICC_{3.1}$ for rater one	Intra-rater 95% CI	SEM mm	$MDC_{95\%}$ mm	Intra-rater $ICC_{3.1}$ for rater two	Intra-rater 95% CI	SEM mm	$MDC_{95\%}$ mm
neutral	0.85	0.68-0.94	1.00	2.70	0.89	0.77-0.95	0.92	2.6
60˚ passive abduction	0.72	0.41-0.88	1.2	3.3	0.71	0.39-0.88	1.4	3.8
60˚ active abduction	0.77	0.52-0.90	0.99	2.5	0.82	0.61-0.92	1.3	3.6

Abbreviations: ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; cm=centimetres; º = degrees.

Table 3. Inter-rater intraclass correlation coefficients, confidence intervals, mean, standard error of measure, minimal detectible change for AHD measured with RTUS.

Arm position	Mean(STD) mm	SEM mm	$MDC_{95\%}$ mm	Inter-rater 95% CI	Inter-rater $ICC_{2.1}$	Inter-rater image interpretation $ICC_{2.1}$ (CI)SEM/MDC
neutral	15.00(2.63)	0.81	2.20	0.78-0.95	0.88	0.88(0.78-0.93)0.96/2.70
60˚ passive abduction	10.60(3.02)	1.20	3.30	0.80-0.93	0.65	0.88(0.38-0.84)1.10/3.00
60˚ active abduction	10.60(3.28)	1.20	3.20	0.39-0.85	0.68	0.81(0.68-0.92)1.30/3.10

Abbreviations: ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; cm=centimetres; º = degrees.

DISCUSSION

Two aspects of reliability with image-based assessments exist (McCreesh, Adusumilli, et al., 2014), namely the reliability of reading the image itself and secondly that of capturing of the image. The inter-rater reliability of both of these elements was assessed in this study. The principal aim of this study was to assess inter-rater within-session reliability of using RTUS to measure AHD in different shoulder positions. Consistency of performing the technique was confirmed with $ICC_{2.1}$ scores that were fair to good for AHD measures in all three of the shoulder positions tested (0.88 in neutral, 0.68 in active arm abduction, 0.65 in passive arm abduction) for inter-rater reliability. In addition, inter-rater reliability of image analysis was good for measures of AHD in all three of the shoulder positions tested (0.88 in neutral, 0.81 in active arm abduction, 0.88 in passive arm abduction). These values confirm that the measure of AHD could be reproduced in the same participants by two examiners during one day using RTUS. These results are comparable with previsous results (Desmeules et al., 2004; Pijls et al., 2010), who reported ICC values of between 0.70 and 0.86 for the neutral shoulder position, and 0.64-0.92 for the 60° arm abduction position.

The random error associated with a measure can be reduced if the experimenter's measures are consistent. The Standard Error of Measurement [SEM] was calculated to provide a range from the experimental score within which the true score of a measure is likely to lie (Eliasziw et al., 1994). Some investigators have stated that the SEM is able to distinguish whether changes seen between tests are real or due to measurement error (Bruton et al., 2000). It is reported that only 68% of all test scores fall within one SEM of the true score, rather than the 95% criterion commonly used (Eliasziw et al., 1994). The minimal detectable change ($MDC_{95\%}$) has been obtained to allow determination of the change needed to indicate statistical significance (Triola, 2009). SEM and MDC_{95} statistics are useful for the following reasons: to distinguish real change as opposed to meaningless fluctuation; to reflect the degree one may expect a measure to vary due to measurement error; because they are expressed in the same units as measured scores; and because they are not affected by variability among individuals. As an indication of absolute reliability, the SEM values in the present study were less than the mean. The low SEM and $MDC_{95\%}$ values suggest that that there is minimal contribution of experimenter error to the overall error of the measure and error is due to systematic bias or other within-subject variation. Therefore, one can be confident that the measure is stable between different examiners.

In the present study, the overall AHD mean values recorded were greater than those recorded in previous studies involving the recording of AHD in asymptomatic populations using similar methodology (Table 4). A mean reduction in AHD of 4.38mm was noted when the arm was abducted from neutral to 60° of arm abduction. This is similar to previosu reports (Azzoni et al., 2004; Bey et al., 2007; Graichen et al., 1999; Maenhout, Eessel, et al., 2012). It is suggested (Girometti et al., 2006) that an AHD of less than 0.7cm would pose a risk for SAIS. More research is needed to determine the lower limit of normal AHD in determining SAIS risk categories.

Table 4. AHD measures reported in asymptomatic shoulders in previous reliability studies of RTUS measuring AHD

Author	AHD distance mm	60° arm abduction
Desmeules et al., 2004 (Desmeules et al., 2004)	0º=9.9 (0.15) 60º=7.6(1.7)	Active
Duerr., 2010 (Duerr, 2010)	0º=10.7(1.8) 60º=8.1(2.1) passive 60º=7.8(1.9) active	Active and passive
Seitz et al., 2012 (Seitz, McClure, Lynch, et al., 2012)	0º=10.9	NT
White et al., 2012 (White et al., 2012)	0º=9.89	NT
Maenhout et al., 2012 (Maenhout, Eessel, et al., 2012)	0º= 11.7(1.6) 60º=9.3(1.8)	Active
Present study	0º=15.00(2.63) 60º=10.60(3.28)active 60º=10.60(3.02)passive	Active and passive

Abbreviations: º = degrees; AHD=Acromio-Humeral distance; mm=millimetres; NT=not tested

Narrowing of the AHD resulting in shear forces on the structures within this space could be due to anatomical and osseous factors, or due to changes in neuromuscular mechanics (White et al., 2012). Rotator cuff action is considered necessary to counteract deltoid action, and hence excessive Humeral Head superior migration, and a subsequent decrease in the AHD. Muscle fatigue and contraction have previously been reported to influence the AHD (Chopp, Fischer, & Dickerson, 2011; Graichen et al., 1999). This is the first study to compare AHD measures in 60° of both active and passive arm abduction. Comparison between the measures of AHD in 60° of both passive and active arm abduction (paired t-tests) showed no significant difference when p =0.91. This is interesting because in rehabilitation, emphasis is placed upon the muscle force couples around the Scapula and Glenohumeral joint which centre the HOH in the Glenoid and control Glenoid orientation. The finding that there is no significant difference between the AHD measured during active and passive abduction calls into question the importance of neuromuscular control mechanisms influencing the Subacromial Space during active arm motion. Contrary results to the current study are reported in a study (White et al., 2012), which measured AHD in neutral and evaluated the effect of isometric rotation on this space. Resisted internal rotation had no effect on AHD, but resisted ER decreased the space. This would be an area worthy of more research.

Although the results of this study are useful, the current study has limitations that should be borne in mind when interpreting the results. AHD is a two dimensional measure of a three dimensional space. Compromise of this volume cannot be totally quantified by measure of AHD alone; it can only be used as guide. A second limitation is that the range of arm elevation in which the RTUS measure of AHD is possible is limited to a maximum of 60° of elevation because of acoustic shadows in higher ranges of arm elevation. To what extent the measure of AHD in 60° of abduction can be extrapolated to influence the Subacromial Space in higher ranges of arm elevation is unclear. Furthermore, the subjects in this study were young and healthy, and as previously pointed out, interpretation of US images is less reliable in symptomatic patients (Pijls et al., 2010), due to lack of clarity in the hyper echoic landmarks in the presence of fibrous or calcific changes. Therefore, if this method were to be used, further investigations would have to be undertaken: to establish the inter-rater reliability of this method in symptomatic subjects; to determine the sensitivity of this measure in Rotator Cuff pathologies; and to investigate the predictability of this measure as a risk factor in SAIS.

Apart from future research to address the methodological limitations, future investigations could be undertaken to establish normative data for different sporting and pathogenic populations with long term monitoring. These investigations may be clinically relevant and may contribute to the understanding of the pathomechanics of SAIS. Quantifying AHD may have implications in sports medicine in the identification of at-risk players. The procedure used in this study is quick, simple to perform, safe, non-invasive and easily transferable to the clinical setting.

CONCLUSION

Measurement tools and new clinical techniques need to be rigorously assessed for reliability prior to their application in the clinical setting. The technique in this study has a potential valuable application in clinical practice for assessing the AHD. In this study, inter-rater within-session reliability of using portable RTUS in the measurement of the AHD was found to be fair to good between repeated measurements for the measure of AHD in the neutral, and 60° abducted arm position both active and passive. Further investigation is required to determine the sensitivity in Rotator Cuff pathologies of this measure, or predictability of this measure as a risk factor in SAIS, and to collect normative values in differing populations over time.

3.2 The palpation meter (PALM) is reliable and valid for measuring Scapular upward rotation

INTRODUCTION

Shoulder disorders are the third most common musculoskeletal cause for medical consultation (Kibler, 1998). Optimal Scapular position and movement are considered essential to normal shoulder function (Kibler, 1998). Abnormalities in Scapular kinematics, particularly decreased upward Scapular rotation, have been associated with various shoulder pathologies in studies comparing healthy shoulders with those of patients with SAIS (Endo et al., 2001; Graichen et al., 1999; Hebert et al., 2002; Ludewig & Cook, 2000; McClure et al., 2004; Warner et al., 1992). There is conflicting evidence, however, as to whether altered Scapular resting position and motion patterns seen in painful shoulders are actually detrimental and hence a factor contributing to shoulder pathomechanics, or compensatory strategies (Karduna et al., 2005). Furthermore, it is proposed that Scapular resting position can be variable depending on sport, hand dominance, age, postural habits, and muscle tone (Wilk et al., 2009).

Underlying some of the fundamental principles in shoulder girdle rehabilitation are the following concepts: that upward rotation of the Scapula is clinically important to prevent the Humeral Head from compressing and shearing against the under-surface of the Acromion process during humeral elevation (Borsa, Timmons, & Sauers, 2003; Ludewig & Cook, 2000); that congruity of the Glenoid and head of Humerus, and centring of the axis of rotation and stability of the Glenohumeral joint, are dependent on Scapular position (Brody & Hall, 2010); that control of length/tension relationships between the Scapular and Glenohumeral muscles is affected by Scapular position (Borsa et al., 2003; J. Smith et al., 2004; Su et al., 2004); that abnormal Scapular movement is associated with Glenohumeral instability and SAIS (Borsa et al., 2003). Consequently, observation and measurement of the static Scapular position is considered essential in the clinical examination when investigating shoulder pathology**.**

Many studies (J. S. Lewis, Green, Reichard, & Wright, 2002; Nijs, Roussel, Vermeulen, & Souvereyns, 2005; Odom, Taylor, Hurd, & Denegar, 2001; Sobush et al., 1996) have used different techniques and tools to quantify Scapular rotation. Three dimensional motion analysis (Borstad & Ludewig, 2002; Hebert et al., 2002; Kawasaki, Yamakawa, Kaketa, Kobayashi, & Kaneko, 2012; Ludewig, Cook, & Nawoczenski, 1996b; McClure et al., 2004; Roy, Moffet, Hébert, St-Vincent, & McFadyen, 2007) has been used, however, this is expensive, time consuming, and requires specialised software programs, hence it is not easily transferable to the clinical setting (J. S. Lewis & Valentine, 2008). Other tools used include: inclinometer (Borsa et al., 2003; Laudner, Stanek, & Meister, 2007; Thomas, Swanik, Swanik, & Huxel, 2009; Tucker & Ingrim, 2012; Watson, Balster, Finch, & Dalziel, 2005), scoliometer (Curtis & Roush, 2006; Sobush et al., 1996), callipers (Sobush et al., 1996; Thomas et al., 2009), radiography (Sobush et al., 1996), photography, tape measurement (J. S. Lewis et al., 2002), and the PALM (da Costa et al., 2010; Rondeau, 2007). Previous reliability studies using these tools are summarised in Table 5 through to Table 7, these studies report that their methods are reliable and can be easily applied in the clinical setting, are cost, and practically effective. Despite reports of good reliability, the clinical value of Scapular lateral displacement measurements or lateral Scapular slide test has been questioned. Previous articles (Nijs et al., 2005; Odom et al., 2001), report low sensitivity (28%-50%), and report low specificity (35,2%-58%) of these measures. No association is reported between lateral Scapular slide test and pain severity or the shoulder disability index (Nijs et al., 2005). It is proposed that these measures would be more useful if used to calculate the rotation angle of the Scapula.

Table 5. Studies reporting reliability of measuring horizontal distance of the of Scapula from the Spine with the PALM

Author	Population	Method	GHJ position	Position	Measurement	Intra ICC (SEM cm) in GHJ neutral	Inter ICC (SEM cm) in GHJ neutral
Costa et al., 2010 (da Costa et al., 2010)	N=30 AS	3 raters 2 sessions a week apart	Neutral 90º scaption Full scaption	Standing	IAS-Sp RSS-Sp	0.89(0.56) 0.81(0.63)	0.89(0.59) 0.77(0.69)
Rondeau 2007 (Rondeau, 2007)	N=18 AS	1 rater 1 session	neutral 90ºabduction	Standing	IAS-T8 RSS-T3	0.96(0.30) 0.98(0.20)	NT

Abbreviations: AS=asymptomatic; GHJ=Glenohumeral joint; IAS-Sp=Inferior Angle of the Scapula to Spinous Process; RSS-Sp=Root of Spine of Scapula to Spinous Process; ICC=intraclass correlation coefficient; SEM=standard error of measure; NT=not tested; cm=centimetres; N= number of participants.

Table 6. Studies reporting reliability of measuring Scapular rotation with an inclinometer

Author	Population	Model of Inclinometer	Method	GHJ position degrees	Position	Intra ICC (SEM degrees)
Borsa et al., 2003 (Borsa et al., 2003)	N=10 AS	Modified Saunders digital	1 rater 2 sessions 1 week apart	0/30/60/90/120 abd in scaption	ST	0=0.94(1.88) 60=0.73(3.28)
Johnson et al., 1993 (G. R. Johnson et al., 1993)	N=39 AS &S	Isotrak	2 raters 1 session	0/60/90/120 abd in scaption	Seated	0=0.89(2.00)AS 0=0.96(2.80)S
Laudner et al., 2007 (Laudner et al., 2007)	N=20 AS	Pro 3600 Digital	1 rater 2 sessions 24 hours apart	0/60/90/120 abd in scaption	ST	0=0.95(0.50) 60=0.93(0.80)
Thomas et al., 2010 (Thomas et al., 2009)	N=36 AS	Modified Saunders digital	1 rater 2 sessions 3-5 days apart	0/60/90/120 abd in scaption	ST	0=0.97(0.70) 60=0.95(1.55)
Tucker and Ingram 2012 (Tucker & Ingrim, 2012)	N=30 AS	Modified Pro 390 digital protractor	1 rater 1 session	0/60/90/120 abd in scaption	ST	0=0.89(1.80)
Watson et al., 2005 (Watson et al., 2005)	N=26 S	Plurimeter-V gravity	1 rater 1 session	45/90/135 abd in coronal plane	ST	0=0.94(1.70)

Abbreviations: AS=asymptomatic; A=symptomatic; Abd=abduction; GHJ=Glenohumeral joint; ST = participant standing; ICC=intraclass correlation coefficient; SEM=standard error of measure; NT=not tested; abd= abduction; N=number of participants.

Table 7. Studies reporting reliability of measuring horizontal distance of Scapula from Spine with tape, string, and callipers.

Author	Tool	N	Methodology	GHJ position	Position	Measurement	Intra ICC(SEM cm) in neutral	Inter ICC(SEM cm) in neutral
Gibson et al., 1995 (Gibson, Goebel, Jordan, Kegerreis, & Worrell, 1995)	string	N=32 AS	2 raters 1 session	Kibler 1 to 3	ST	IAS-Sp RSS-Sp	0.81-0.94(0.49-0.59) NT	0.91-0.92(0.60-0.65) NT
T'Jonk et al., 1996 (T'Jonck, Lysens, & Grasse, 2006)	tape	N=17 AS	2 raters 1 session	Kibler 1 to 3	SIT	IAS-Sp RSS-Sp	0.80-0.96(0.18-0.62) 0.57-0.99(0.12-0.60)	0.72-0.90(0.47-0.72) 0.52-0.87(0.45-0.77)
Mckenna et al,. 2004 (McKenna, Cunningham, & Straker, 2004)	tape	N=15 AS	3 raters	Kibler 1 to 2	ST	IAS-Sp RSS-Sp	NR NR	0.87(0.53) 0.74(0.59)
Odom et al., 2001 (Odom et al., 2001)	string	N=46 AS&S	5 raters	Neutral 45 abd 90 abd	ST	IAS-Sp RSS-Sp	0.75(0.61) NT	0.67(0.79) NT
Struf et al., 2009 (Struyf et al., 2009)	tape	N=30 AS	2 raters 1session	Kibler 1 to 3	ST	IAS-Sp RSS-Sp	NR NT	0.63(1.85) NT
Lewis and Valnetine, 2008 (J. S. Lewis & Valentine, 2008)	tape	N=90 AS&S	1 rater 2 sessions ½ hour apart	neutral	ST	IAS-Sp RSS-Sp	0.90-0.98(0.83-0.99) 0.79-0.93(0.66-0.97)	NT NT
Nijs et al., 2005 (Nijs et al., 2005)	tape	N=29 AS&S	2 raters 1 session	Kibler 1 to 3	ST	IAS-Sp RSS-Sp	NR NT	0.70(0.31) NT
Sobush et al., 1996 (Sobush et al., 1996)	calliper	N=15 AS	3 raters 1 session	Kibler 1	ST	IAS-Sp RSS-Sp	NR NR	0.77(NR) 0.80(NR)
Thomas et al., 2010 (Thomas, Swanik, Swanik, & Kelly, 2010)	calliper	N=36 AS	1 rater 2 sessions 3-5 days apart	Kibler 1-3	ST	IAS-Sp RSS-Sp	0.94(0.33) NT	Not tested NT

Abbreviations: AS=asymptomatic; A=symptomatic; Kibler 1-3 = neutral shoulder thumb forward, hand on hip thumb posterior, and arm at 90 ° abduction thumb down; Abd=abduction; GHJ=Glenohumeral joint; ST = participant standing; SIT=participant sitting; IAS-Sp=Inferior Angle of the Scapula to Spinous Process ; RSS-Sp=Root of Spine of Scapula to Spinous Process ; ICC=intraclass correlation coefficient; SEM=standard error of measure; NT=not tested; NR=not reported; cm=centimetres; N=number of participants.

A previous study (Shin, Ro, Lee, Oh, & Kim, 2012) has investigated the novel idea of using an inclinometer application on a smart phone to measure shoulder ranges of motion, reporting satisfactory inter-observer reliability and good construct validity between the smart phone inclinometer application and a goniometer (Pearson's correlation coefficients = 0.79-0.97). Inclinometers, which are expensive, require further adaption with special devices to enable positioning on the Spine of Scapula while measuring Scapular rotation. Inclinometer applications for smart phones are inexpensive (£0.99) or free on the Android market, and may provide an alternative for the measurement of Scapular position.

The PALM (performance Attainment Associate, St. Paul, MN, USA), which has callipers and an analogue inclinometer, can be used to calculate the horizontal distance between the Scapula position and the Spine. The advantages of the PALM are that it is portable, quick to use, and inexpensive. Previous studies (da Costa et al., 2010; Rondeau, Padua, Thigpen, & Harrington, 2012), established that the PALM, illustrated in Figure 7, is a reliable tool to measure Scapular position in the scaption and coronal planes. Reporting established inter-rater and inter session reliability with ICC = 0.89 (SEM=0.59cm) in the neutral shoulder position, and ICC= 0.77 (0.69cm) in the 90° abducted arm position (da Costa et al., 2010) (Table 5).

The main aim of the present study was to establish the intra- and inter-rater reliability of using the PALM to capture the horizontal distance of the Scapula from the Thoracic Spine, and to propose a new method using these measures to calculate rotation of the Scapula in the coronal plane. The second aim of the study was to establish whether construct validity existed between this method of calculating Scapular rotation and measurement of Scapular rotation with a smart phone inclinometer application (namely, Winkelmesser HD- High precision clinometers published by JRSoftWorx), which guarantees up to 0.1° of precision.

Figure 7. Palpation Meter (PALM) (Performance Attainment Associate, St. Paul, MN, USA)

PARTICIPANTS

The estimated sample size was based on guidance from by Eliasziw and Walter, 1998 (Eliasziw & Walter, 1998), who suggest that with 2 raters, a significance level of 0.05, and a power of 80%, to determine an ICC score of 0.7 (to interpret reliability indicative of a true p0, versus an alternative ICC score of 0.9 indicating a p1), that 19 samples are required. In the present study ten asymptomatic participants were recruited (four females, six males) with a mean age of 29.86 (STD 7.8) years. Side to side difference in measurements taken with the PALM within this group were analysed with paired t-tests. There were no significant side to side differences with all p values exceeding 0.05. This enabled data collected on a total of 20 shoulders to be used in reliability analysis.

Participants included in the study were of full musculoskeletal development, and had healthy shoulders. Participants were excluded from the study if they had: cervical, shoulder, or elbow pain within six months before testing; previous fracture, surgery, or dislocation of the upper limb; scoliosis, or a rheumatologic condition.

Each participant was asked to read and sign a consent form approved of by the University of Salford Research Ethics Committee.

INSTRUMENTATION

The horizontal distance of the Scapular from the Thoracic Spine was measured using the PALM) Performance Attainment Associate, St. Paul, MN, USA). A smart phone inclinometer application (Winkelmesser HD- High precision clinometers published by JRSoftWorx), which can measure angles up to 360° and is guaranteed by the manufacturer to be accurate to up to 0.1°, was used to measure the angle of Scapula rotation.

PROCEDURE

Participants were seated with their shoulders exposed, on a customised chair with a short back support. Hips and knees were positioned at 90° of flexion. The participant was asked to adopt a relaxed posture that felt comfortable to them. In order to evaluate normal habitual Scapular posture no attempt was made to make the participant conform to a single standardised posture. The seated posture eliminated the effect of possible leg length discrepancies and reduced the chance of syncopal episode in the participants who although they were only with each examiner for 15 minutes this amounted to 30 minutes of full examination time. Measurements of Scapular position were taken in two arm positions, one, shoulder neutral, and two, 60° of active abduction in the coronal plane. For the neutral position, participants placed their hands pronated on their same side thigh with the elbow left unsupported to ensure that the shoulder girdle was not elevated. For the 60° of arm abduction position, the arm was abducted to 60° of abduction by the examiner as determined by a goniometer (Baseline plastic 360 ISOM Goniometer 12") and the participant was then asked to maintain this position actively. Once 60° of abduction was determined for each participant, in order to assist the participant in maintaining the correct angle of arm abduction, a marker tape was placed on an adjacent wall at the level of the participant's finger tips. The examiner could then ensure that the correct angle was being maintained by the participant while measuring. Between each measurement the participant rested the arm by the side to avoid the effects of fatigue.

The following anatomical landmarks were repeatedly palpated by the examiner: the Inferior Angle of the Scapula (IAS), the Root of the Spine of the Scapula (RSS), and the Spinous Process of the Thoracic Spine (Sp), as illustrated in Figure 8 before taking of each measurement. The participant's skin was not marked by the examiners ensuring that markings could not introduce bias between examiners, on repeated palpation and locating of the anatomical landmarks. The PALM callipers were used to measure the distances and horizontal distance was ensured by the analogue inclinometer on the PALM. The following distances were measured: the distance between the Inferior Angle of the Scapula to the closest horizontal Spinous Process of the Thoracic Spine (IAS-Sp) Figure 9; the Root of Spine of the Scapula to the closest horizontal Spinous Process of the Thoracic Spine (RSS-Sp) Figure 10; and the distance from the Inferior Angle of the Scapula to the Root of the Spine of the Scapula (RSS-IAS) Figure 11.

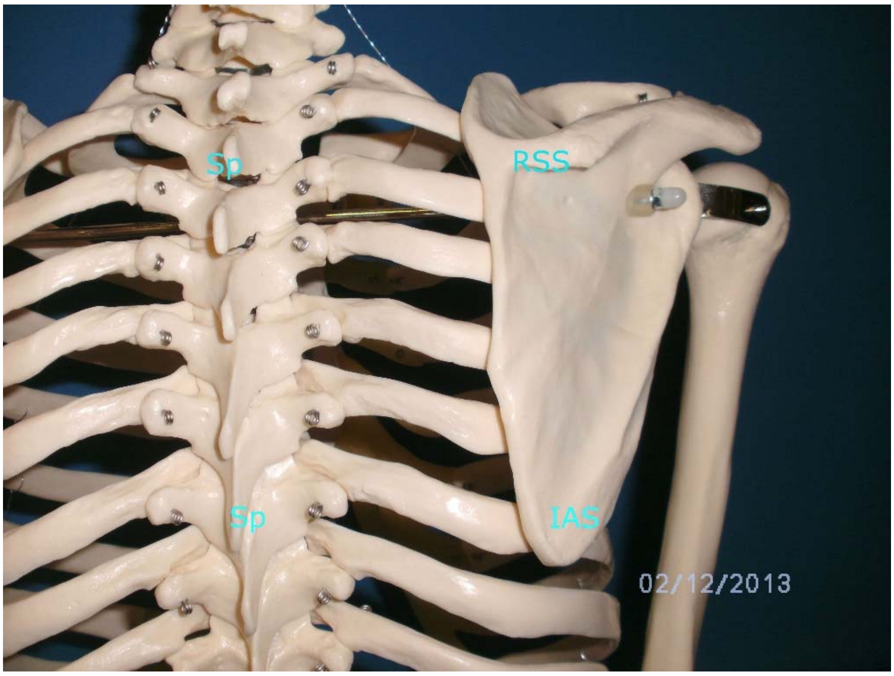

Figure 8. Anatomical landmarks
Abbreviations: Sp=Spinous Process of the Thoracic Spine. RSS=Root of Spine of Scapula. IAS=Inferior Angle of Scapula.

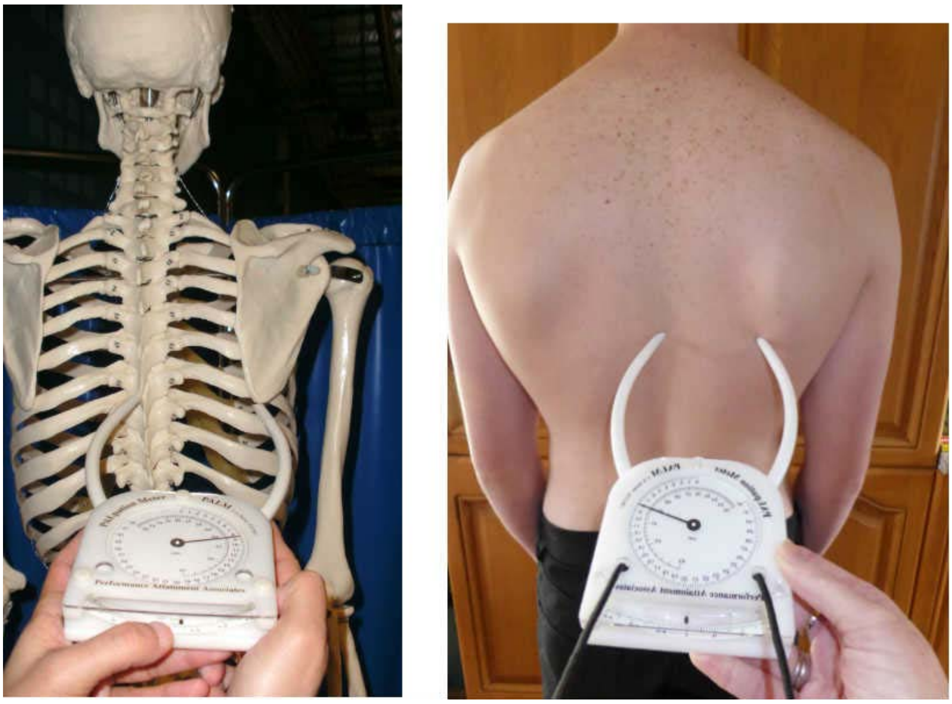

Figure 9. Measurement of the distance between the Inferior Angle of the Scapula and the closest horizontal Spinous Process of the Thoracic Spine (IAS-Sp).

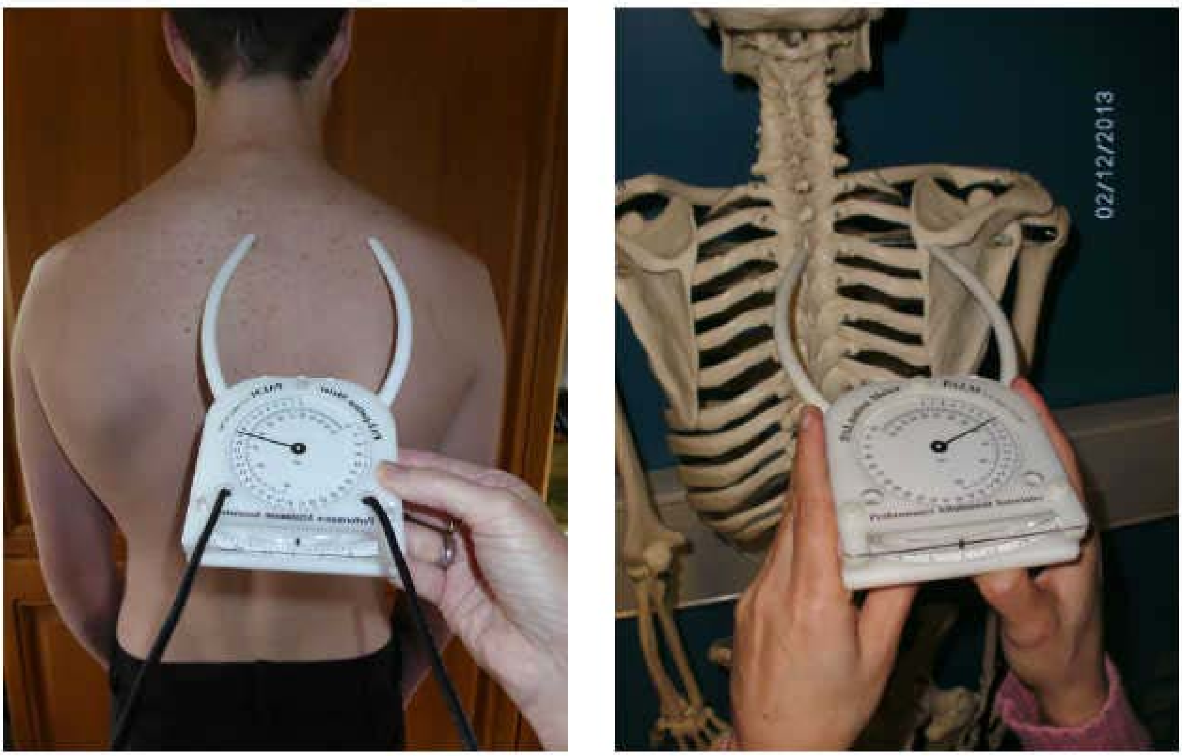

Figure 10. Measurement of the distance between the Root of the Spine of the Scapula and the closest horizontal Spinous Process of the Thoracic Spine (RSS-Sp).

Figure 11. Measurement of the distance from the Inferior Angle of the Scapula to the Root of the Spine of the Scapula (RSS-IAS)

Before commencing data collection, the PALM inclinometer was checked to be centred at 0 in the vertically aligned position. All participants were measured by two examiners. Three consecutive measurements were taken by each examiner. The examiners were separated by a room divide from each other and blinded to each other's results during collection of measurements. Once data collection was completed by one examiner the participant was asked to move to the next examiner's station.

Once the measurements were collected with the PALM, one examiner used the smart phone inclinometer application to measure Scapular rotation. The Spine of the Scapula was palpated and the longer of the smart phone borders placed along this anatomical edge. Using the same method of participant positioning and arm positioning as with the PALM, three repeated measures were taken of the angle shown on the smart phone inclinometer. The smart phone was removed from the Spine of the Scapula, the Spine of the Scapula re-palpated, and the smart phone repositioned on the Spine of the Scapula between each repeated measure.

Calculation of Scapular Rotation

The distances IAS-Sp, RSS-Sp, and IAS-RSS were used to calculate the Scapula rotation angle. As shown in Figure 12, if a perpendicular line is dropped down from the Root of the Spine of the Scapula (RSS) to intersect the horizontal line between the Inferior Angle of the Scapula and the closest Spinous Process of the Thoracic Spine (IAS-Sp), a right angle triangle is created. The hypotenuse is the distance IAS to RSS. The side opposite the angle θ (θ was defined as the angle between the hypotenuse and the vertical) and the vertical is the distance IAS-Sp minus the distance RSS-Sp. To calculate the angle one can apply

$$sin\,\theta = \frac{opposite}{hypotenuse}$$

A positive result indicates the degree of upward Scapular rotation and a negative result indicates the degree of downward Scapular rotation.

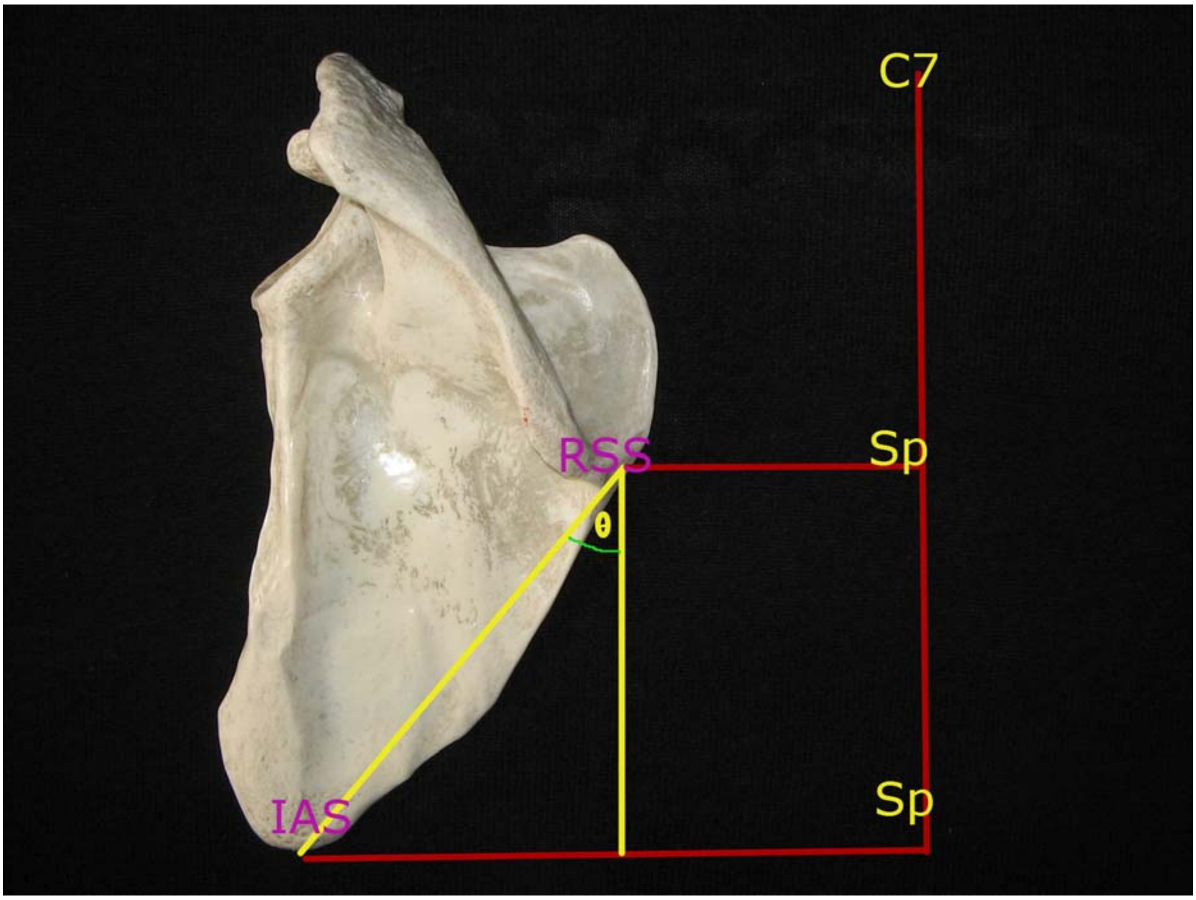

Figure 12. Calculation of the Scapular rotation angle.
Abbreviations: Sp=Spinous Process of the Thoracic Spine. RSS=Root of Spine of Scapula. IAS=Inferior Angle of Scapula; C7= Cervical Vertebra 7; ϴ= angle theta.

DATA ANALYSIS

Statistical Package for Social Sciences for Windows version 20.0 (SPSSinc., Chicago,IL), was used for statistical analysis. The interclass correlation coefficients ($ICC_{3.1}$) model was used for within-day intra-rater reliability, a two-way fixed effects model (examiner is fixed effect and participants are randomised effects), with absolute agreement for each single measure. $ICC_{2.1}$ model was used for within-day inter-rater reliability, a two-way random effects model, (examiners and participants are both treated as random effects), with absolute agreement for each single measure. SEM based on the calculation SEM = SD x √(1-ICC) (Bruton et al., 2000) and $MDC_{95\%}$ based on the calculation $MDC_{95\%}$ = 1.96 x √2 x SEM (Eliasziw et al., 1994) were calculated to establish random error. The following criterion was used to interpret ICC: poor = less than 0.4, fair = 0.4-0.7, good = 0.7-0.90, and excellent = >0.90 (Coppieters et al., 2002). Pearson's correlation coefficient was calculated to determine the association between the PALM and the smart phone inclinometer application. Pearson's correlations values (r) were interpreted as follows: weak or no association =0.0-0.2, weak association =0.2-0.4, moderate association =0.4-0.6, strong association =0.6-0.8 and very strong association =0.8-1.0 (Salkind, 2007). To assess the agreement and determine if there were systematic differences between the two measurements of Scapular upward rotation taken with the inclinometer and via calculation of Scapular upward rotation from the PALM measurements a Bland-Altman Plot analysis was done. The mean and the difference between the two measures from the two methods was calculated. A Wilcoxon signed rank test (for 1 sample) was done to determine if difference existed between the differences of the two measures. To ascertain if there was proportional bias in the distribution of data values on the Bland-Altman plot a linear regression analysis was performed.

RESULTS

Side to side difference in measurements taken with the PALM within this group were analysed with paired t-tests, and it was determined that there were no significant side to side differences with all p values exceeding 0.05. This enabled data collected on a total of 20 shoulders to be used in reliability analysis.

Means, standard deviations, standard error of measure, minimal detectible change, ICC, and 95% confidence intervals for the lateral Scapular displacement measurements are summarised in Table 8. $ICC_{3.1}$ varied from 0.90 to 0.99 for intra-rater reliability, and $ICC_{2.1}$ scores ranged between 0.74 to

0.88 for inter-rater reliability. The SEM ranged from 0.18cm to 0.20cm, and $MDC_{95\%}$ ranged between 0.50cm to 0.55cm. The SEM and $MDC_{95\%}$ for all measurements were less than the calculated means.

Means, standard deviations, standard error of measure, minimal detectible change, ICC, and 95% confidence intervals for Scapular rotation measurements taken with the smart phone inclinometer are summarised in Table 9. $ICC_{3.1}$ values were 0.94 and 0.95, in the neutral and the 60° abducted positions respectively, for intra-rater reliability. The SEM ranged from 1.25° and 1.84°, in the neutral and the 60° abducted positions respectively. $MDC_{95\%}$ was between 3.46° and 5.09° for the neutral and the 60° abducted positions respectively. The SEM and $MDC_{95\%}$ for both positions were less than the calculated means.

To assess the agreement and determine if there were systematic differences between the two measurements of Scapular upward rotation taken with the inclinometer and via calculation of Scapular upward rotation from the PALM measurements a Bland-Altman Plot analysis was done. The mean and the difference between the two measures from the two methods was calculated. A Wilcoxon signed rank test (for 1 sample) was done to determine if difference existed between the differences of the two measures. No significant difference was found between these measures with the arm in the neutral position (p=0.60), therefore it was appropriate to conduct a Bland-Altman Plot analysis of the difference between the measures taken with the arm in the neutral position. However, a Wilcoxon signed rank test (for 1 sample) was done on the differences between the measures of Scapular upward rotation taken with the inclinometer and via the calculation of Scapular upward rotation from the PALM measurements established that there was a significant difference between these values (p=0.01) when the arm was positioned in 60° abduction.Thus rendering this data inappropriate for a Bland-Altman Plot analysis, and meaning that there was no agreement in Scapular upward rotation taken with the inclinometer and via the calculation of Scapular upward rotation from the PALM measurements in the 60° arm abduction position.

The mean (2.50°) and the standard deviation (4.4°) was calculated for the differences of the two measurements of Scapular upward rotation taken with the inclinometer and via the calculation of Scapular upward rotation from the PALM measurements in the neutral arm position. These values were used to calculate the upper and lower limits of agreement (95%) in the following equations: upper limits = mean + (STD x 1.96); and lower limits = mean - (STD x 1.96). A Bland-Altman graph was constructed of the differences and means of the measurements of Scapular upward rotation taken with the inclinometer and via the calculation of Scapular upward rotation from the PALM measurements in the neutral arm position. References lines to indicate the mean of the two measures, and the upper and lower levels of agreement were inserted (Figure 13).

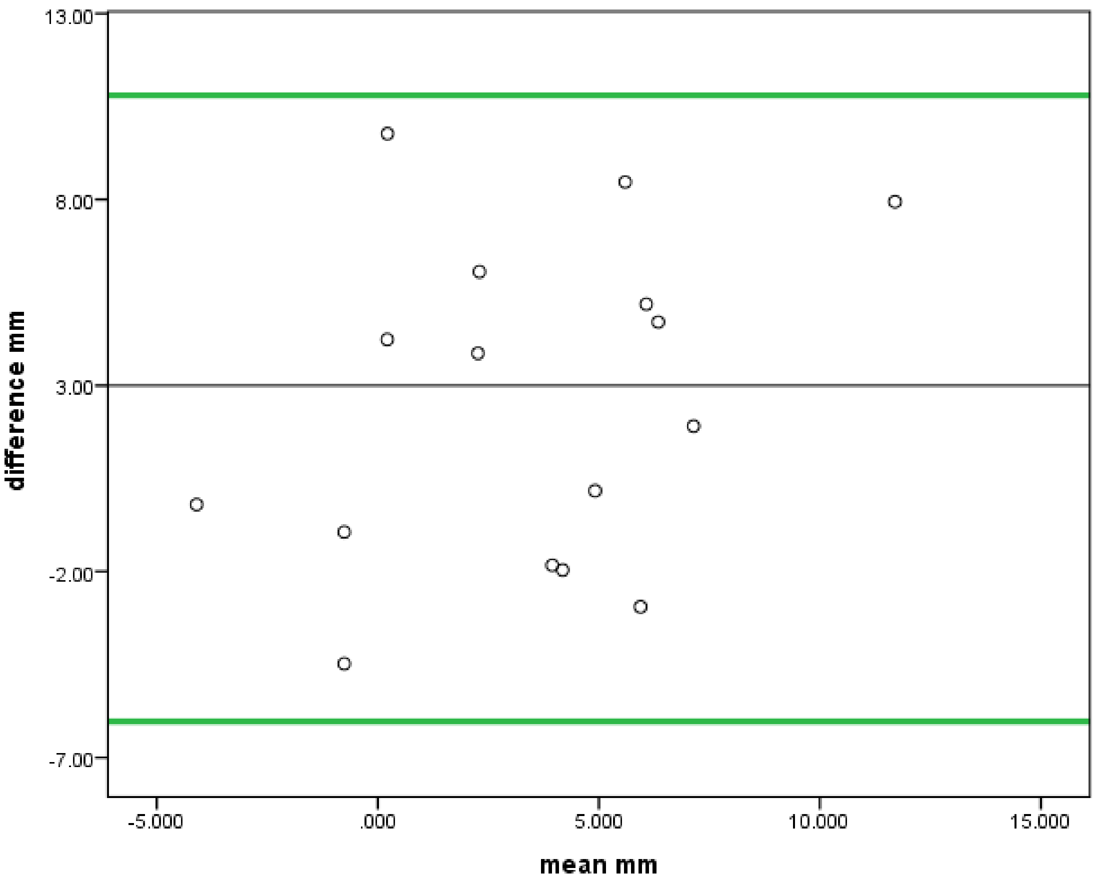

Figure 13. A Bland-Altman plot illustrated that there was a close agreement between measurements of Scapular upward rotation taken with the inclinometer and via the calculation of Scapular upward rotation from the PALM measurements in the neutral arm position.

On observation there appeared to be no proportional bias on the Bland-Altman plot of data values. However, further evidence of this was determined via a linear regression analysis. A significance value of $p = 0.27$ proved that there was no proportional bias in the distribution of data values on the Bland-Altman plot.

Table 8. Mean, 95% confidence intervals, standard error of measure, minimal detectible change, and intraclass correlation coefficient values for horizontal distance of the Scapula from the Spine measured with the PALM

Measurement	Mean cm	SEM cm	STD cm	$MDC_{95\%}$ cm	Inter-rater 95% CI	Inter-rater $ICC_{2.1}$	Intra-rater $ICC_{3.1}$ rater one	Intra-rater $ICC_{3.1}$ rater two
0 ° RSS-Sp	7.52	0.20	0.91	0.55	0.69-0.92	0.83	0.98	0.95
0° IAS-Sp	8.36	0.18	0.82	0.50	0.71-0.93	0.85	0.97	0.96
RSS-IAS	11.69	0.18	0.80	0.50	0.78-0.95	0.88	0.90	0.94
60° RSS-Sp	7.16	0.20	0.88	0.55	0.52-0.89	0.74	0.98	0.99
60° IAS-Sp	8.55	0.18	0.80	0.50	0.63-0.91	0.80	0.98	0.97

Abbreviations: IAS-Sp=Inferior Angle of the Scapula to Spinous Process; RSS-Sp=Root of Spine of Scapula to Spinous Process; RSS-IAS= Root of Spine of Scapula to Inferior Angle of Scapula; ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; cm=centimetres; º=degrees.

Table 9. Mean, standard deviation, 95% confidence intervals, standard error of measure, minimal detectible change, and intraclass correlation coefficient values for smart phone inclinometer application measurements of Scapular rotation, and Scapular rotation

Arm position	SR Inclinometer degrees	Intra-rater 95% CI	Intra-rater $ICC_{3.1}$	SEM degrees	STD degrees	$MDC_{95\%}$ degrees	SR PALM degrees
0°	**4.70**	**0.86-0.97**	**0.95**	**1.25**	**5.00**	**3.46**	**2.20**
60°	**8.65**	**0.87-0.97**	**0.94**	**1.84**	**7.37**	**5.09**	**4.07**

Abbreviations: ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; cm=centimetres; PALM=palpation meter. SR = Scapular rotation

Table 10. Descriptive statistics from previous studies measuring horizontal distance of the Scapula from the Spine with tape, string, and callipers.

Author	Tool	Arm position	Distance	Mean cm	SEM cm	STD cm
Costa et al., 2010 (da Costa et al., 2010)	PALM	neutral	IAS-Sp RSS-Sp	8.53 8.00	0.59 0.69	1.70 1.40
Gibson et al., 1995 (Gibson et al., 1995)	string	neutral	IAS-Sp RSS-Sp	8.97-10.00 NT	0.44 NT	1.80-1.91 NT
T'Jonck et al., 1996 (T'Jonck et al., 2006)	tape	neutral	IAS-Sp RSS-Sp	8.93-9.53 7.36-8.07	0.18 0.57	1.08-1.19 1.23-1.24
McKenna et al., 2004 (McKenna et al., 2004)	tape	neutral	IAS-Sp RSS-Sp	8.73-9.43 7.76-8.22	0.53 0.59	1.67-1.63 1.59-1.46
Sobush et al., 1996 (Sobush et al., 1996)	calliper	neutral	IAS-Sp RSS-Sp	8.70-8.70 8.40-8.80	NR NR	0.86-1.00 0.98-1.11
Lewis and Valentine, 2008 (J. S. Lewis & Valentine, 2008)	tape	neutral	IAS-Sp RSS-Sp	9.00-9.50AS 7.60-8.50AS	0.20 0.40-0.50	1.3-1.400 1.00-1.20
Nijs et al., 2005 (Nijs et al., 2005)	tape	neutral	IAS-Sp RSS-Sp	8.66-9.13 NT	0.31 NT	1.65-2.05 NT

Abbreviations: IAS-Sp=Inferior Angle of the Scapula to Spinous Process ; RSS-Sp=Root of Spine of Scapula to Spinous Process ; SEM=standard error of measure; STD=standard deviation; cm=centimetres; PALM=palpation meter; NT=not tested.

Table 11. Descriptive statistics from previous studies using an inclinometer to determine Scapular rotation

Author	Tool	Shoulder position	Mean degrees	STD degrees	SEM degrees	Population
Sobush et al., 1996 (Sobush et al., 1996)	sin theta	Neutral 60°	-0.70- +0.50 NT	5.30-4.60 NT	NR NT	AS
Thomas et al., 2010 (Thomas et al., 2010)	inclinometer	Neutral 60°	4.81-7.17 13.05-16.07	3.00-4.36 5.72-6.46	NR NR	AS baseball players
Laudner et al., 2007 (Laudner et al., 2007)	inclinometer	Neutral 60°	4.00-6.00 6.40-10.30	3.20-3.50 4.90-3.90	NR NR	pitchers and - non pitchers
Downar and Sauers, 2003 (Downar & Sauers, 2005)	inclinometer	Neutral 60°	4.70-6.40 6.00-8.40	4.10-4.70 4.30-6.10	NR NR	AS baseball players
Borsa et al., 2003 (Borsa et al., 2003)	inclinometer	Neutral 60°	-2.86- -3.97 2.35-0.06	6.89-7.92 5.38-7.18	1.88 3.28	AS
Lewis and Valentine, 2008 (J. S. Lewis & Valentine, 2008)	inclinometer	Neutral	-2.90-3.60AS -3.60-3.90S	4.10.00-3.90AS 4.10.00-4.60S	1.20 0.70	AS S

Abbreviations: SEM=standard error of measure; STD=standard deviation; cm=centimetres; PALM=palpation meter; NT=not tested; NR=not reported; AS=asymptomatic; S=symptomatic; abd=abduction; º=degrees.

DISCUSSION

The principal aim of this study was to assess intra- and inter-rater reliability of using the PALM to measure lateral distance of the Scapula from the Spine and from these measures to use the sin rule to calculate Scapula rotation. As seen in Table 8 the current study found an excellent degree ($ICC_{3.1}$ = 0.90 to 0.99) of intra-rater reliability and a good degree ($ICC_{2.1}$ = 0.74 to 0.88) of inter-rater reliability for within-day measurements of lateral Scapular displacement from the Spine using the PALM device with two examiners in arm neutral and 60° of abduction. Additionally, the ICC values for three trials measuring the distances RSS-IAS indicated substantial reliability (Table 8), confirming that this measure could be reproduced in the same participants by two examiners during one day using the PALM device in arm neutral. Results indicate that the PALM is a reliable device when used between two examiners, for measuring the Scapular position, within the same day.

The current study's findings of an excellent degree of intra-rater reliability and a good degree of inter-tester reliability for within day measurements of lateral Scapular displacement from the Spine using the PALM (RSS-Sp and IAS-Sp) are in an agreement with the results obtained by previous researchers using the PALM (da Costa et al., 2010), who reported ICC values of 0.89-0.81 for intra tester reliability and 0.98-0.77 for inter tester reliability between three raters over two sessions a week apart (Table 5); and (Rondeau, 2007), (although Rondeau did not test inter-rater reliability, they did report ICC values of 0.89 to 0.98 for 1 rater in one session) (Table 5). There are two main differences in methodology between previsou reports and this study: firstly, the participant was positioned in standing in Costa et al., 2010 and Rondeau, 2007, studies and seated in the present study; and secondly, the arm of the participant was positioned in neutral, 90° of scaption, and full scaption for the measuring of the IAS-Sp and RSS-Sp in this previsou study. Due to this second methodological difference in the positioning of the participants arm, comparison of ICC scores for the measurement RSS-Sp and IAS-Sp between previous reports and the results of this study when using the PALM have been made only in the neutral arm position. In the present study an additional measure was taken, namely the RSS to the IAS, to date no other researcher has reported taking this measure. A study (Sobush et al., 1996) used geometry to calculate the degree of Scapula rotation, used a vertical distance between Spinous Process , measured off x-ray, giving the adjacent triangle side to the calculated angle, in contrast to this study which used the RSS-IAS measure as the hypotenuse of the created triangle (Figure 12). The advantages of using the PALM rather than x-ray are numerous, and in the present study inter-rater reliability was established for the simple method of measuring the distance RSS-IAS using the PALM (Table 8. ICC3.1=0.94). The intra-class correlation coefficient of measuring Scapular position has been reported in previosu studies (see Table 10) using simple clinical approaches with other tools such as tape measures, string and callipers (Gibson et al., 1995; J. S. Lewis et al., 2002; McKenna et al., 2004; Nijs et al., 2005; Odom et al., 2001; Struyf et al., 2009; Thomas et al., 2011; T'Jonck et al., 2006). As can be seen in Table 10 previous studies report intra- rater reliability ICC values between 0.57-0.99 (Gibson et al., 1995; J. S. Lewis & Valentine, 2008; Odom et al., 2001; Thomas et al., 2011; T'Jonck et al., 2006) and inter-rater reliability of between 0.52 -0.92 (Gibson et al., 1995; McKenna et al., 2004; Nijs et al., 2005; Odom et al., 2001; Sobush et al., 1996; Struyf, Nijs, Baeyens, Mottram, & Meeusen, 2011; Thomas et al., 2011; T'Jonck et al., 2006) for the measurements of RSS-Sp and IAS-Sp. There are major differences beyond the choice of instrumentation used between these studies and the present study, which should be borne in mind when making comparison of descriptive statistics between the studies, namely: arm position, static versus dynamic testing, and body positioning. Despite these methodological differences, the mean measure of RSS-Sp in the present of 7.53cm (STD 0.91cm) (Table 8) in the neutral arm position is in keeping with previous studies who report a range of 7.36cm-8.50cm (STD0.98cm-1.59cm) as seen in Table 10.

The random error associated with a measure can be reduced if the experimenter's measures are consistent. The Standard Error of Measurement (SEM) was calculated to provide a range from the experimental score within which the true score of a measure is likely to lie. Some investigators have mentioned the SEM as being able to distinguish whether changes seen between tests are real or due to measurement error. It has been reported that only 68% of all test scores fall within one SEM of the true score, rather than the 95% criterion commonly used. The minimal detectable change ($MDC_{95\%}$) has been calculated to allow determination of the change needed to indicate statistical significance. In addition to the excellent intra-and inter-tester reliability scores demonstrated associated SEM and $MDC_{95\%}$ values were low, suggesting that that there is minimal contribution of experimenter error to the overall error of the measure and that error is due to systematic bias or other within-participant variation. Therefore, we can be confident that the measure is stable between different examiners.

The second aim of the study was to establish if construct validity existed between the Scapular rotation angle calculated with the PALM measurements and sin rule, and Scapular rotation measured with the smart phone inclinometer application. Intra-rater reliability of using the smart phone to measure Scapular position was first established; the study found excellent ($ICC_{3.1}$ = 0.95 in neutral and $ICC_{3.1}$=0.94 in 60° of arm abduction) intra-rater reliability of using a smart phone inclinometer application to measure Scapular rotation. In addition to the excellent intra-tester reliability scores demonstrated associated SEM (1.25° in neutral and 0.94° in 60° arm abduction see Table 9), and $MDC_{95\%}$ (3.46° in neutral and 5.09° in 60° arm abduction see Table 9) scores were less than the mean. Apart from Lewis et al., 2008, and Borsa el al., 2003., previous studies have not reported on the SEM or MDC values or 95% CI (Table 11). In agreement with Lewis et al., 2008., and Borsa el al., 2003, the present study found that when Scapular rotation was measured with an inclinometer, SEM and MDC values were low, suggesting that that there is minimal contribution of experimenter error to the overall error of the measure, and that error is due to systematic bias or other within-participant variation. Previous studies (Borsa et al., 2003; G. R. Johnson et al., 1993; Laudner et al., 2007; Thomas et al., 2011; Tucker & Ingrim, 2012; Watson et al., 2005) using a modified inclinometer and the Spine of the Scapula as a guide, as used in this study, report good intra-rater reliability with ICC ranges between 0.89 to 0.94 in the neutral shoulder position (see Table 11), and ICC values between 0.73 and 0.95 (see Table 11) in the 60° arm abducted position. No author to date has reported the inter-rater reliability of using an inclinometer to assess rotation of the Scapula and herein lies an opportunity for further research. In this present study, the mean angle of upward Scapular rotation in the neutral shoulder position was 4.70° (STD=5.00° shown in Table 9). Although the populations between studies were not homogenous, this angle of rotation is within the mean range (-2.90° to 7.17° in Table 11) reported by most previous studies (Borsa, Laudner, & Sauers, 2008; Downar & Sauers, 2005; Laudner et al., 2007; J. S. Lewis & Valentine, 2008; Sobush et al., 1996; Thomas et al., 2011) taking this measure with an inclinometer. The present study recorded a mean upward rotation of the Scapula in the 60° abducted arm position of 8.65° (STD=7.35°) Table 9. This is in accordance with some studies and not others. Two studies (Downar & Sauers, 2005; Laudner et al., 2007) concur with those in this study Table 11. In contrast, one study (Thomas et al., 2011), reports figures double that of the present study (13.05°-16.07° Table 11) in the same arm position, whereas as another (Borsa et al., 2008), reports far less Scapular rotation than the present study (2.35°-0.06° Table 11). On one hand, there is agreement on the degree of Scapular rotation in the neutral arm position between studies, on the other hand there is a discrepancy in the degree of Scapular rotation in the active 60° abducted arm position between studies. This may be due to variations in the populations studied.

To assess the agreement and determine if there were systematic differences between the two measurements of Scapular upward rotation taken with the inclinometer and via calculation of Scapular upward rotation from the sin rule a Bland-Altman Plot analysis was done. A Bland-Altman plot illustrated that there was a close agreement between measurements of Scapular upward rotation taken with the inclinometer and via the calculation of Scapular upward rotation from the sin rule in the neutral arm position. But there was no agreement found in Scapular upward rotation taken with the inclinometer and via the calculation of Scapular upward rotation from the sin rule in the 60° arm abduction position. Previous literature has not reported construct validity between measures of Scapular rotation with an inclinometer and the method used in this study calculating the rotation of the Scapula with the PALM measures and geometry. However, in a previous study (Sobush et al., 1996), criterion reliability between the measurements RSS-Sp, IAS-Sp taken with a scoliometer (adapted callipers) and on X-ray was established. In Table 9 the mean values for Scapular rotation taken with the smart phone inclinometer application and the Scapular rotation determined with the sin rule using PALM measures are shown. In neutral the inclinometer measured 4.70° and the sin θ value was 2.20°. In the 60° abducted arm position the inclinometer value was 8.65° and via the sin θ approach the value was 4.07°. It is noted that in both instances the value measured with the inclinometer is double that of the angle calculated via the PALM measures and sin rule.

Validity of surface palpation of bony landmarks of RSS, IAS and Sp as used in this study has been confirmed by previous studies (J. S. Lewis et al., 2002; Sobush et al., 1996). One study (J. S. Lewis et al., 2002), verified surface palpation on cadaveric specimens, and the other (Sobush et al., 1996), verified it on x-rays. Both studies report moderate to high association between skin palpation their respective verifying methods reporting Pearson's correlation of between 0.69 and 0.82.

The rationale of using the 60° abducted arm position while evaluating Scapular position is worthy of debate. Previous studies have used various degrees of arm elevation in the scaption and coronal plane (ref); others have used the three Kibler positions, namely arm in neutral with the thumb pointing forward, hand on hip with the thumb pointing posteriorly, and 90° arm abduction with the thumb pointing forwards (ref). Reliability of surface palpation of the IAS and the RSS has been proven to be poor when the arm is elevated above 90° (ICC=0.56-0.7)(Borsa et al., 2008), (0.26--0.64) (McKenna et al., 2004). For the measure of RSS-Sp in 90° of arm abduction, (T'Jonck et al., 2006), inter-rate reliability ICC scores 0.57-0.52 are reported. As a result, these studies suggest caution when interpreting measures taken at 90°. Clinically, patients with SAIS present with an arc of pain commencing at 60° arm abduction, so if this method is to be used to evaluate the Scapular position in symptomatic patients it is likely that patients will not be able to hold the arm in more than 60° of abduction during measurement collection. For these reasons, the 60° arm abducted position was chosen.

The clinical value of Scapular lateral displacement measurements is questionable; this has been illustrated in research by previous studies (Nijs et al., 2005; Odom et al., 2001). Reporting low sensitivity (28%-50%), and low specificity (35,2%-58%) of these measures. Furthermore, no association was found between lateral Scapular displacement measures and pain severity and the shoulder disability index (Nijs et al., 2005). In a further article a specificity of 4% is reported (Shadmehr, Bagheri, Ansari, & Sarafraz, 2010). It is proposed that these measures would be more useful if used to calculate the rotation angle of the Scapula, which would have more clinical relevance. One study (Sobush et al., 1996), used the method of calculating Scapular rotation from lateral displacement measurements similar to those used in the present study. However, construct validity was not established with this method and any other tool, and since 1996 this approach to calculation of Scapular rotation has not been used again by researchers. To add to the debate, opinion is divided about whether the medial Scapular border should be parallel to the Spine as originally proposed by Sahrmann, 2002. (Sahrmann, 2002) and supported in previsou studies who propose an ideal mean distance for lateral displacement of the Scapula from the Spine (Sobush et al., 1996). Recent research has shown that asymmetry exists between sides in athletes (Downar & Sauers, 2005; Oyama, Myers, Wassinger, Daniel Ricci, & Lephart, 2008). The commonly used LSST as proposed by Kibler is based on bilateral assessment of sides, but previous reports have proposed that this comparison is not appropriate (Ozunlu, Tekeli, & Baltaci, 2011). Koslow et al., 2003, report that 73% of asymptomatic sportsmen were found to have asymmetry. A further study reports that in subacromial impingement patients, Scapular position did not change after six weeks of exercise intervention, although their symptoms improved (McClure et al., 2004).

There is an absence of objective data on what constitutes normal Scapular position in varying populations, but despite this physiotherapy evaluation emphasises the importance of postural evaluation, specifically head and shoulder posture in patients with spinal and upper extremity dysfunction (Sahrmann, 2002). This is often subjectively assessed. Sahrmann, 2002 (Sahrmann, 2002), proposed that two positions of the Scapula were abnormal: the downwardly rotated Scapula and a lack of posterior Scapular tilt. This makes quantification of Scapular position important. A clinical test to quantify Scapular position and to document normal positional data for systematic investigation is imperative (Sobush et al., 1996). Only then can the influence of exercise, and therapeutic intervention, and postural effects on Scapular position be evaluated objectively.

Although the results of this study are useful, the current study has limitations that should be borne in mind when interpreting the results and addressed in future studies. Firstly, measurement sequence on the participants was not randomised when using the PALM and the inclinometer. Secondly, the study was conducted on asymptomatic participants and reliability of both the PALM and the inclinometer for measuring Scapular rotation needs to be established on symptomatic participants. Thirdly, Scapular rotation includes movement over three axes in three planes, and this method at present only evaluates the movement of the Scapula in the frontal plane.

CONCLUSION

The Palmmeter was found to have excellent intra-reliability and good inter-rater reliability as a tool to measure horizontal distance of the Scapula from the Spine. These measures can be used to calculate Scapular rotation. This method that has been developed to quantify Scapular rotation provides an objective measure of Scapular rotation at rest and in the abducted arm position, which is inexpensive, practical and easy to perform in healthy individuals.

3.3 Intra-rater 24 hours apart inter-session reliability of further instrumentation.

INTRODUCTION

Appraisal of tools and methods to assess GHJ range of motion.

Clinical methods used commonly to evaluate shoulder range of motion are goniometry and inclinometry and in a systematic review of the methods to determine passive shoulder ranges the following was recommended: that measurements of physiological range of motion using instruments were more reliable than using vision; measurements of physiological range of motion were also more reliable than measurements of end-feel (van de Pol, van Trijffel, & Lucas, 2010). Techniques which control for accessory Scapulothoracic motion are recommended because these techniques may represent more valid measures of GHJ motion (Awan, Smith, & Boon, 2002). In addition, participant positioning to standardize the trunk are recommended (Cools et al., 2014). A comprehensive intra- and inter-rater reliability study has been conducted assessing several testing protocols to measure shoulder external and internal rotation ranges of motion and reported in previous research (Cools et al., 2014). Of the differing procedures, body and shoulder positions, and testing equipment used to measure passive shoulder range Cools et al., 2014 found good to excellent reliability for passive measure of internal and external shoulder ranges regardless of patient position. In the same study the inclinometer had slightly higher ICC scores than goniometry. This finding is backed up in further studies with a trend for better reliability with an inclinometer (Kolber, Vega, Widmayer, & Cheng, 2011). Inclinometry was decided on for the present study and intra-rater inter-session reliability investigated because it has the advantage of being easier to operate with only one examiner. In the study by Cools et al., 2014, two examiners collected the measures of internal and external shoulder ranges and this may account for the lack of discrepancy in reliability results in varying participant positions. In the current study only one researcher was available to collect the data thus necessitating a participant position to stabilise the trunk and Scapula. Thus the supine position was chosen. The technique used in the current study is elaborated on in the methods section in 3.3, headed ‘Intra-rater 24 hours apart inter-session reliability of further instrumentation’.

Appraisal of tools and methods to assess Thoracic curve.

In order to qualify the thoracic curve in the sagittal plane a cost effective, non-invasive, and field based portable method was necessary. Previously reported field based tools to qualifying the thoracic curve are photography (Burdett, Brown, & Fall, 1986), kyphometers (Lundon, Li, & Bibershtein, 1998), specialised goniometers (Burdett et al., 1986), inclinometers (J. S. Lewis & Valentine, 2010), and flexible rulers (Burdett et al., 1986; de Oliveira et al., 2012; Hinman, 2004; Lovell, Rothstein, & Personius, 1989; Lundon et al., 1998; Teixeira & Carvalho, 2007). Bearing in mind the limited time per participant allocated to collect data photography would have been too time-consuming to set up. Furthermore, low degree of validity has been reported for the use of photography to quantify thoracic curve (Burdett et al., 1986; Flint, 1963). Specialised equipment was not readily available for the study and hence the choice of the flexicurve to contour measure the thoracic curve. The choice of the flexicurve to quantify the thoracic curve was fortified by the fact that it has been validated with radiography (de Oliveira et al., 2012). Inter- and intra-rater reliability for the use of the flexicurve has been well established by numerous previous studies (de Oliveira et al., 2012; Hinman, 2004; Lovell et al., 1989; Lundon et al., 1998). De Olivera et al., 2012, point out the advantage of the flexicurve over the above mentioned instrumentation as the the flexicurve to provides a representation of spinal curvature in a continuous line and not only specific points. The technique used in the current study is elaborated on in the methods section in 3.3, headed 'Intra-rater 24 hours apart inter-session reliability of further instrumentation'.

Appraisal of tools and methods to assess Pectoralis Minor length.

A method was sort to directly measure the resting length of Pectoralis Minor muscle. At present there is no gold standard reference test for the measurement of pectoralis minor length (J. S. Lewis & Valentine, 2007a). A review of data bases (Cochrane, CINAHL {Cumulative Index to Nursing and Allied Health Literature-EBSCO Host}, Medline, Sport Discus, PubMed, ProQuest, Science Direct, Web of Knowledge, Web of Science, Google Scholar) and a manual literature search; using the search terms; pectoralis minor, muscle length, length test, posture, forward head posture, scapular position, shoulder, and reliability identified only three previous which studies had examined in vivo direct measure of pectoralis minor length (Borstad, 2008; Borstad & Ludewig, 2006; Rondeau et al., 2012). One further study used an indirect method to examine Pectoralis Minor length, namely measuring the posterior acromion to the supporting surface with the participant in supine. Although the findings of this study suggest that the test demonstrates acceptable clinical reliability (J. S. Lewis & Valentine, 2007a), it is not a direct measure of the muscles length. Furthermore, measurements obtained with this method have been shown to be poorly correlated with a normalized measure of pectoralis minor length (Borstad, 2008) and to have poor diagnostic accuracy (J. S. Lewis & Valentine, 2007a). Of the authors directly measuring Pectoralis Minor length, Borstad & Ludewig, 2006, validated measuring of pectoralis minor length in cadavers using an electromagnetic motion capture system, Borstad, 2008, also validated measurement of pectoralis minor using surface palpation in cadavers and validated the use of a calliper or tape measure in determine the lengthening this muscle. Rondeau, Padua, Thigpen, & Harrington, 2012, used the novel instrumentation; the PALM. Significant correlations were found between pectoralis minor length measures with the electromagnetic motion analysis system and the PALM (Rondeau et al., 2012). The advantage of the PALM over the tape measure and calliper is that the PALM measures are not influenced by the chest contours. For this reason the PALM was the selected tool of preference to quantify Pectoralis Minor length. The technique used in the current study is elaborated on in the methods section in 3.3, headed 'Intra-rater 24 hours apart inter-session reliability of further instrumentation'.

The intra-rater inter-session 24 hours apart for these tools is reported in this section. An additional measure with the aim of determining the height of the Scapula was also taken with the PALM, however despite determining its reliability, the validity of the measure to indeed quantify Scapular height and its relevance to the study was questioned and it was decided to not use this measure further in the study. The reliability of RTUS to measure AHD and the PALM to determine Scapula rotation in the coronal plane in sitting is reported in sections 3.1. and 3.2 respectively, again, the intra-rater inter-session 24 hours apart reliability for these two instruments on subjects in the standing position (versus the seated position reported in these previous sections), is reported in this section.

PARTICIPANTS

Students at the University of Salford and from the general public were invited to partake in the study by letters of approach.   Participants included in the study were of full musculoskeletal development (over 18 years of age). Participants with non-symptomatic shoulders were included. Participants were excluded if they had previous fracture or dislocation of the shoulder girdle, shoulder surgery, pain of cervical origin, scoliosis, a leg length discrepancy of more than 1cm, a rheumatologic condition, a chronic respiratory condition, or were pregnant. Male and female participants were both included in the study.

Thirty four subjects were recruited to the study. Eight subjects did not meet the recruitment criteria. (2 x scoliosis, 1 x spinae bifida, 3 previous collar bone fractures, 1 previous fractured Thoracic Spine, and 1 previous GHJ dislocation) A total of 26 subjects were available for test re-testing 24 hours apart. This enabled a total of 52 shoulders to be used in the reliability analysis. Thirty two subjects re-completed and returned the Roa-Marx activity score two weeks later.

The Salford Research Ethics Panel approved the study protocol (HSCR14/76). All participants were provided with a detailed information sheet, comprising details of the study and any associated risks. After a verbal briefing, participants gave written informed consent to testing and allowing their data collected to be disclosed anonymously. Participants completed 2 further forms, a questionnaire on demographics and shoulder injury history (Appendix 3. and 4.) and the Roa-marx shoulder activity scale (Appendix 5.).

INSTRUMENTATION

Roa-marx activity scale

To measure the impact of activity as a variable, the Roa-marx activity scale was used to collect data on the load, frequency, and level of activity to which the participant's shoulder was exposed. The Roa-marx activity scale for the shoulder was developed (Brophy, Beauvais, R L, Jones, E C, Cordasco, S A, & Marx, R G, 2005) using established principles. Reliability and validity have accordingly been established. Five activities are rated: carrying an object 8lb or heavier by hand, handling objects overhead, weight-training with arms, swinging motion (i.e. hitting a tennis ball or golf ball), and lifting objects 25lb or heavier. Numerical sums of scores for the five activities are rated on a five-point frequency scale from never performed (0) to daily (4). Two multiple choice questions score participation in contact and overhead sports with possible responses being: (A) No; (B) Yes, without organised officiating; (C) Yes, with organised officiating; or (D) Yes, at a professional level (i.e. paid to play).

Flexicurve to quantify Thoracic curve

A 40cm Helix flexicurve ruler was used to profile the participants' Thoracic Spine in order to quantify Thoracic ratio (Figure 17). Tracings of the convex surface of the flexicurve were transcribed on to mm graph paper (Figure 18).

Inclinometer

A 360° inclinometer with digital protractor and angle finder gauge (Universal Supplies Limited), was used to determine the degree of arm abduction during data collection and to measure internal and external rotation range of Glenohumeral joint motion (Figure 14). The instrument was used to provide a real-time digital reading of angles in relation to the vertical plane. The manufacturer reports accuracy to 0.1°. The inclinometer was adapted with a 30cm plastic ruler (Figure 15) attached along the length of the inclinometer, and the ruler was used to align the inclinometer between the Olecranon Process and the Ulnar Styloid.

Figure 14. A 360° inclinometer, with digital protractor and angle finder gauge (Universal Supplies Limited)

Figure 15. The inclinometer was adapted with a 30cm plastic ruler attached along the length of the inclinometer, and the ruler was used to align the inclinometer between the Olecranon Process to the Ulnar Styloid.

Palpation meter (PALM)

The horizontal distance of the Scapular from the Thoracic Spine was measured using the PALM (Performance Attainment Associate, St. Paul, MN, USA) which has callipers and an analogue inclinometer (Figure 7).

Real Time ultrasound

A portable dynamic RTUS scanner M Turbo with HFL38/13-6 MHz linear transducer (Sonosite Limited. Hitchen, UK), was used for ultrasound image capture. Pre-set parameters were used for musculoskeletal shoulder settings.

METHODS

Participants completed the Roa-marx shoulder activity scale (Appendix 5.) at the first screening session. Thirty-two participants cooperated in a test re-test of the form which was re-sent to participants after a 2 week interval.

Participant position

For data collection, participants removed their shoes and had their shoulders exposed. Participants assumed a normal standing posture looking ahead. The participants were asked to adopt a relaxed posture that felt comfortable to them, and no attempt was made to modify the participants' posture during testing or to make any participant conform to a single standardised posture. Once participants had adopted their normal standing posture they were required not to alter their foot position and distribute their weight evenly between the two feet.

Two arm positions were used during testing, one, shoulder neutral, and two, 60° of active arm abduction in the coronal plane. For the neutral position, participants allowed the arm to hang naturally at the side of the body this resulted in the thumbs naturally pointing forwards. For the 60° of arm abduction position, the participant's arm was abducted to 60° of abduction as determined by an inclinometer, the thumb pointing forwards. The participant was then asked to maintain this position actively (Figure 16). In order to ensure that the participant maintained the correct angle of arm abduction, a marker tape was placed on an adjacent wall at the level of the participant's finger tips. The examiner could then visually ensure that the correct angle was being maintained by the participant while measuring. Between each measurement the participant rested the arm by the side to avoid the effects of fatigue.

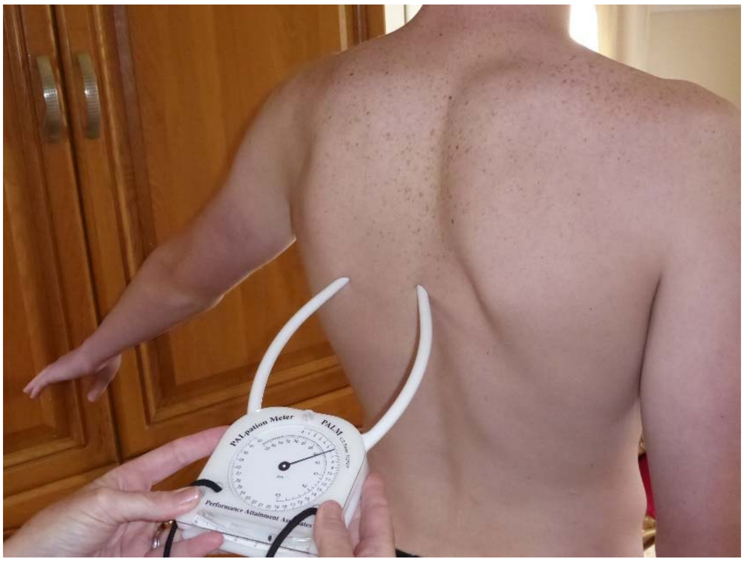

Figure 16. For the 60° of arm abduction position the participant's arm was abducted to 60° of abduction as determined by an inclinometer, the thumb pointing forwards.

Flexicurve to quantify Thoracic curve

The bony landmarks of the Spinous Processes of C7 and T12 were palpated and marked on the skin with a felt pen. C7 was located by asking the participant to flex and extend the neck, and C7 was identified as the Spinous Process that remained prominent during this motion. T12 was located by location of the L4-5 inter-space, considered to be mid-line on an imaginary line running from the superior aspect of the participant's iliac crests. Once this space was located, the examiners palpated up five Spinous Processes to locate the T12 Spinous Process. The flexi curve was moulded to the contour of the participant's Thoracic Spine and the previously marked bony landmarks of C7 and T12 were transferred over to the flexicurve with a water soluble pen (Figure 17). The flexicurve was then carefully moved from the participants' Spine as not to alter the shape, and placed on mm graph paper. The concave side of the flexicurve was traced onto the graph paper. The corresponding levels of C7 and T12 were also transcribed on the graph paper (Figure 18). The marks on the flexicurve were removed with alcohols swabs, and the procedure repeated a total of three times. On each transcribed curve on the graph paper, a line was drawn intersecting the points demarking C7 to the point demarking T12. This was considered to represent the height of the curve. It was measured to the nearest mm and labelled H (Figure 19). A set square was used to determine the point perpendicular to the mid line of H to measure the depth of the curve. This distance was measured to the nearest mm and labelled D. A Thoracic curve ratio was calculated using the equation below. This value could then be used in statistical analyses to represent the Thoracic curve ratio variable. To avoid examiner bias, the measurements were taken by an independent rater.

The angle of the curve was calculated by using the equation $\theta = 4 \times [\arctan(2D/H)]$.

Figure 17. The flexi curve was moulded to the contour of the participants' Thoracic Spine and the previously marked bony landmarks of C7 and T12 were transferred over to the flexicurve with a water soluble pen.

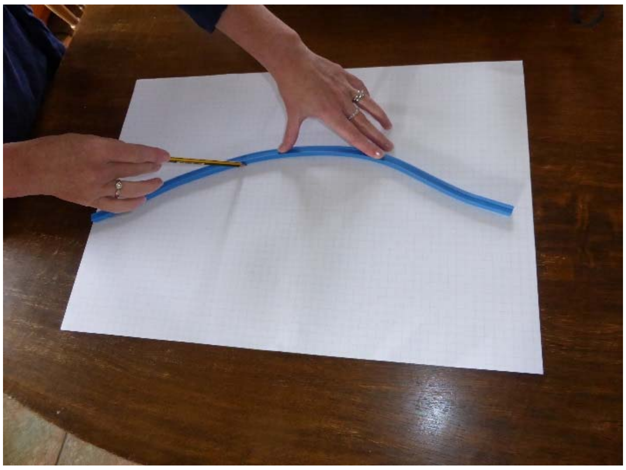

Figure 18. The concave side of the flexicurve was traced onto the graph paper. The corresponding levels of C7 and T12 were also transcribed on the graph paper.

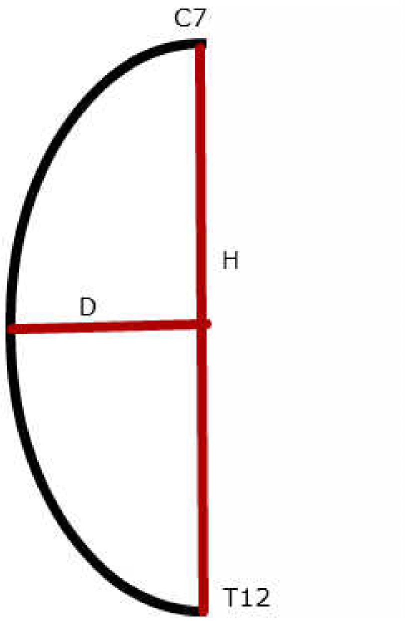

Figure 19. Calculation of Thoracic ratio.

PALM to quantify Pectoralis Minor length

Measurement of Pectoralis Minor length with the PALM was done with the participant in the supine position on an examination plinth. A small pillow was placed under the participant's head for comfort, taking care to ensure that the pillow was not under the shoulder girdle. The participant's arm was passively placed along the side of the body in the neutral position resting on the plinth, ensuring that the participant was relaxed. The elbow was straight with the palm of the hand resting on the side of the participants' thigh, thus placing the thumb in the forwards pointing position. The PALM was used to measure the distance between the two palpated landmarks of the anterior aspect of the Coracoid and the ipsilateral Fourth Rib Sternal Notch (Figure 20). Three bilateral measures were taken of this distance.

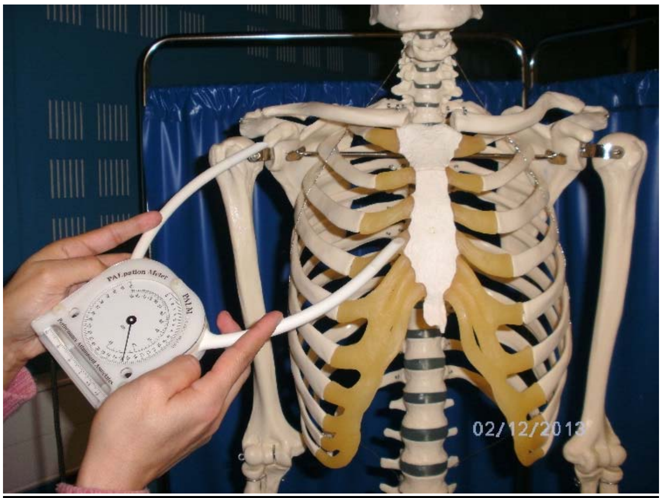

Figure 20. The PALM was used to measure the distance between the two palpated landmarks of the anterior aspect of the Coracoid and the ipsilateral Fourth Rib Sternal Notch

Inclinometer to quantify Glenohumeral rotation range

Measurement of GHJ rotations was undertaken with the participant in the supine position on an examination plinth. A small pillow was place under the participant's head for comfort, taking care to ensure that the pillow was not under the shoulder girdle. The arm on the side being tested was abducted to 90° of abduction and positioned with the Humerus in the neutral horizontal position (Humerus in line with the Acromion). The upper arm was supported on the plinth with a small towel to ensure maintenance of the neutral horizontal position of the Humerus. The elbow was flexed to 90°. To determine this position, an inclinometry were used. Participants were instructed to relax while the examiner passively moved and measured the joint range of rotation. For measures of external GHJ range, the examiner moved the GHJ passively to end of range, while noting that no compensatory movement occurred at the shoulder girdle. If resistance was felt or the shoulder girdle moved this was considered the end point of range. For internal range of GHJ motion, the examiner palpated the anterior aspect of the Acromion with one hand and moved the shoulder into passive internal rotation. End of range was considered to be the last point in range before the Acromion started to move. The inclinometer was adapted with a 30cm plastic ruler attached along the length of the inclinometer, and the ruler was used to align the inclinometer between the Olecranon Process and the Ulnar Styloid. The angle was measured in the vertical plane (Figure 21). Between three repeated measures of both internal and external rotation angles the arm was repositioned in the neutral position.

Figure 21. The inclinometer was adapted with a 30cm plastic ruler attached along the length of the inclinometer, and the ruler was used to align the inclinometer between the Olecranon Process and the Ulnar Styloid. The angle was measured in the vertical plane.

Measurement of AHD with RTUS

The identical procedure as detailed in 3.1 was used with the exception of the participant position. For the intra-tester inter-session reliability the standing position was used as detailed in this section.

Measurement of Scapular position with PALM

The identical procedure as detailed in 3.1 was used with the exception of the participant position. For the intra-tester inter-session reliability the standing position was used as detailed in this section.

DATA ANALYSIS

Statistical Package for Social Sciences for Windows version 20.0 (SPSSinc., Chicago,IL), was used for statistical analysis. The interclass correlation coefficients ($ICC_{3.1}$) model was used for inter-session intra-rater reliability, a two-way fixed effects model (examiner is fixed effect and participants are randomised effects), with absolute agreement for each single measure. SEM based on the calculation SEM = SD x √(1-ICC) (Bruton et al., 2000) and $MDC_{95\%}$ based on the calculation $MDC_{95\%}$ = 1.96 x √2 x SEM (Eliasziw et al., 1994) were calculated to establish random error. The following criterion was used to interpret ICC: poor = less than 0.4, fair = 0.4-0.7, good = 0.7-0.90, and excellent = >0.90 (Coppieters et al., 2002).

RESULTS

Intra-rater inter-session reliability 24 hours apart was established for all instruments. Estimated sample size was based on advice from Eliasziw and Walter, 1998(Eliasziw & Walter, 1998), that 19 samples are required to determine an ICC score of 0.7 (to interpret reliability indicative of a true p0, versus an alternative ICC score of 0.9 indicating a p1) with a significance level of 0.05 and a power of 80%.. Data from 26 control participants - 18 females and 8 males with a mean age of 44.19 (STD 13.65) years and range of 20-66 years - was used in intra-rater inter-session reliability analysis. Data for the dominant and non-dominant sides was analysed separately for the reliability analysis. The Roa-marx shoulder activity questionnaire was assessed for reliability in 32 participants, who were asked to re-complete the scale 2 weeks after initially completing the form. An average of 20 (STD =9.14) days elapsed between initial and second completion of the form.

Means, standard deviations, standard error of measure, minimal detectible change, $ICC_{3.1}$, and 95% confidence intervals for each of the protocols and instrumentation used are summarised in Table 12 Roa-Marx shoulder activity scale, Table 13 technique to measure of Thoracic kyphosis, Table 13 technique to measure of GHJ rotations, Table 15 technique to measure of Pectoralis Minor length, Table 16 RTUS to measure AHD, Table 17 technique to measure Scapula position with PALM.

Table 12. Mean, standard deviation, 95% confidence intervals, standard error of measure, minimal detectible change, and intraclass correlation coefficient values for the Roa-Marx shoulder activity scale.

$ICC_{3.1}$(95%CI)	Mean/26	STD/26	Range	SEM/26
0.88 (0.74-0.94)	7.03	3.5	0-13	0.62

Abbreviations: ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation.

Table 13. Mean, standard deviation, 95% confidence intervals, standard error of measure, minimal detectible change, and intraclass correlation coefficient values for the technique as a whole and measurements of the height and depth of the Thoracic curve

Measure of Thoracic curve	$ICC_{3.1}$(95%CI)	Mean cm	STD cm	SEM cm	$MDC_{95\%}$ cm
Height	0.98(0.97-0.99)	33.47	3.15	0.62	1.71
Depth	0.96(0.93-0.98)	3.50	0.84	0.17	0.46

Abbreviations: ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; cm=centimetres

Table 14. Mean, standard deviation, 95% confidence intervals, standard error of measure, minimal detectible change, and intraclass correlation coefficient values for measurement of GHJ rotations taken with an inclinometer

Side/ GHJ rotation	$ICC_{3.1}$(95%CI)	Mean cm	STD cm	SEM cm	$MDC_{95\%}$ cm
Dominant IR	0.94(0.88-0.97)	55.59	9.19	1.80	4.99
Dominant ER	0.98(0.96-0.99)	84.14	10.80	2.12	5.88
Non-dominant IR	0.91(0.85-0.96)	58.51	10.80	2.12	5.88
Non-dominant ER	0.94(0.89-0.97)	81.90	10.56	2.07	5.73

Abbreviations: ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; cm=centimetres; IR=internal rotation; ER=external rotation; GHJ=Glenohumeral joint.

Table 15. Mean, standard deviation, 95% confidence intervals, standard error of measure, minimal detectible change, and intraclass correlation coefficient values for measurement of Pectoralis Minor length taken with the PALM

PALM Measure	$ICC_{3.1}$(95%CI)	Mean cm	STD cm	SEM cm	$MDC_{95\%}$ cm
Dom pec length	0.98(0.96-0.99)	15.12	1.75	0.34	0.95
Non-dom pec length	0.99(0.98-0.99)	15.57	1.70	0.33	0.92

Abbreviations: ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; cm=centimetres; Dom=dominant; non-dom=non-dominant;

Table 16. Mean, standard deviation, 95% confidence intervals, standard error of measure, minimal detectible change, and intraclass correlation coefficient values for RTUS measures of AHD.

Side/Arm position	$ICC_{3.1}$(95%CI)	Mean cm	STD cm	SEM cm	$MDC_{95\%}$ cm
0° dominant	0.95(0.91-0.98)	1.51	0.23	0.05	0.13
60°dominant	0.94(0.88-0.97)	1.02	0.25	0.05	0.13
0°non-dominant	0.94(0.88-0.97)	1.56	0.20	0.04	0.12
60° Non-dominant	0.92(0.84-0.96)	1.12	0.25	0.05	0.15

Abbreviations: ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; cm=centimetres; abd=abduction

Table 17. Mean, standard deviation, 95% confidence intervals, standard error of measure, minimal detectible change, and intraclass correlation coefficient values for measurement for Scapula position taken with the PALM.

PALM Measure	$ICC_{3.1}$(95%CI)	Mean cm	STD cm	SEM cm	$MDC_{95\%}$ cm
Dom RSS-Sp 0°	0.97(0.96-0.99)	7.85	1.45	0.29	0.79
Dom IAS-Sp 0°	0.99(0.97-0.99)	8.25	1.71	0.34	0.94
Dom RSS-Sp 60°	0.95(0.91-0.97)	6.12	1.29	0.25	0.70
Dom IAS-Sp 60°	0.99(0.97-0.99)	7.80	1.83	0.36	0.99
Dom RSS-IAS	0.98(0.97-0.99)	14.68	1.89	0.37	1.02
Non-dom RSS-IAS	0.92(0.87-0.96)	14.15	1.84	0.36	1.00
Non-dom RSS-Sp 0°	0.95(0.89-0.97)	7.19	0.91	0.18	0.50
Non-dom IAS-Sp 0°	0.98(0.97-0.99)	7.57	1.43	0.28	0.77
Non-dom RSS-Sp 60°	0.94(0.90-0.97)	5.50	1.14	0.22	0.62
Non-dom IAS-Sp 60°	0.98(0.97-0.99)	7.05	1.70	0.28	0.77

Abbreviations: ICC=intraclass correlation coefficient; SEM=standard error of measure; 95% CI=95% confidence interval; STD=standard deviation; $MDC_{95\%}$=minimal detectable differences with 95% confidence; cm=centimetres; Dom=dominant; non-dom=non-dominat;0=neutral shoulder position; 60°= 60 degree abducted arm position; pec=Pectoralis Minor muscle; IAS-Sp=the distance between the Inferior Angle of the Scapula to the closest horizontal Spinous Process of the Thoracic Spine; RSS-Sp =the Root of Spine of the Scapula to the closest horizontal Spinous Process of the Thoracic Spine; RSS-IAS= the distance between the Inferior Angle of the Scapula to the Root of the Spine of the Scapula; º=degrees.

CONCLUSION

Values for the Roa-marx activity scale were 0.88, indicating good reliability for the scale. ICC3.1 values for all remaining protocols and instrumentation used were more than 0.9, indicating excellent inter-session intra-rater reliability. The low SEM and $MDC_{95\%}$ values suggest that that there is minimal contribution of experimenter error to the overall error of the measures and that error is due to systematic bias or other within-subject variation. Therefore, one can be confident that the measures are stable for one examiner between sessions 24 hours apart.

3.4 Method issues encountered

Construct validity between portable ultrasound units

The company Fuji Sonosite lent the researcher the portable US unit to measure the AHD. During the course of the research period the company changed models from the MicroMaxx® ultrasound system to the M-Turbo® ultrasound system. In order to establish construct validity between the machines the shoulders of 10 subjects were ultra-sounded and three repeated measures of the AHD in both shoulder neutral and in 60 ° of arm abduction were captured on both machines. ICC scores between 0.92 and 0.97 indicated good reliability between the portable US units. (Raw data in Appendix 10.)

Stability of the measure

In order to establish stability of the measures. The shoulders of ten subjects (eight female, two male) with and average age = 45 STD 19.91 years were re-screened for all the variables in this research. The periods between data collection ranged from 17 to 19 months (mean=18.6 months). Paired t-tests showed no significant differences in measures in any single variable over this period. See Appendix 11, for results.

Chapter 4 Sport specific adaptation in the elite athlete's shoulder

List of abbreviations

AHD	Acromio-Humeral distance
CI	confidence interval
GERG	Glenohumeral external rotation gain
GHJ	Glenohumeral joint
GIRD	Glenohumeral internal rotation deficit
$MDC_{95\%}$	minimal detectable change
RTUS	real time ultrasound
SAIS	Subacromial Impingement Syndrome
SEM	standard error of the measure
STD	standard deviation
SR	Scapular rotation
TROM	total rotational range of motion
US	ultrasound

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Chapter overview

An elite sport population was chosen to investigate what factors influence AHD, because (with the exception of baseball and tennis) there is limited data in the literature on this variable in elite athletes and it is known that athletes may suffer from SAIS which has an impact on their sporting careers. In addition, they represent a population whose shoulders are exposed to the extremes of load. To confirm the hypothesis that the athlete adapts in order to enhance sporting performance and that this adaptation will influence the AHD, descriptive profiling of athletes' shoulders in varying disciplines was undertaken and the results are reported in this Chapter section 4.1. Profiling the variables of GHJ rotation, Scapular position, and Pectoralis Minor length in the athlete's shoulder; within and between sport comparisons. Detailed inferential and comparative statistical results between controls and male golfers are reported in this Chapter section 4.2. Sport-specific adaptation in the elite golfer's shoulder. Conflicting results exist in the literature with regards to whether the AHD is indeed greater in athletes compared to non-sports populations. How the AHD is influenced in athletes is discussed in this Chapter section 4.3. AHD in the athletes shoulder.

4.1 Profiling the variables of GHJ rotation, Scapular position, and Pectoralis Minor length in athlete's shoulder; within and between sport comparisons

INTRODUCTION

Problems in the sporting shoulder

The shoulder may adapt biomechanically to different sports. What influences the AHD in athletes may be determined by the sport under review. Before investigating what variables correlate to the AHD, it was first necessary to collect measures of the variables considered to influence the AHD in order to test the hypothesis that the athlete's shoulder does indeed adapt to enhance sporting performance. Shoulder injury in sport can result in ending sport careers. The incidence of injuries in upper extremity sports is reported to be 7% in golfers, 29% in javelin throwers, 44% in college volley ball players, 57% in professional pitchers and 66% in elite swimmers (J. E. Johnson, Sim, & Scott, 1987; Perry, 1983). In an epidemiological survey collecting data on prevalence and frequency of shoulder pain among different athletic groups that demanded vigorous upper arm activities of 372 respondents, 43.8 percent indicated that they had shoulder problems (Lo et al., 1990). In sport, mobility is required to reach extreme positions but at same time the Glenohumeral joint needs stability within the Glenoid (Wilk et al., 2011). The soft tissue around the shoulder is loaded repetitively in sport and can 'approach ultimate failure load,' making the shoulder vulnerable to injury (Bedi, 2011).To date, the populations of athletes reported in the literature are principally the high velocity overhead, throwing athletes including baseball, tennis and swimming. There is a lack of normative data defining normal shoulder physical characteristics in a healthy sporting shoulder which do not necessarily perform in the high velocity overhead position. These clinical measures are important, as they are used by clinicians in the sports arena and in the clinical setting to screen and assess shoulders and the outcomes of interventions.

In the literature, the sports that require high velocity performance have been assumed to represent all sporting shoulders. In reality, the demands on the shoulder vary in differing sports disciplines. Although some of the sports included in this study involve high velocity shoulder movements, most of the sports considered either generate shoulder forces in the mid-range, such as boxing, archery and gymnastics or require a combination of high and mid ranges generating force rather than velocity as in canoeing. Golf places further complex and varied demands on the shoulder, as the dominant shoulder replicates the high range velocity required in many other sports in the abducted externally-rotated position, but the lead shoulder has to assist with generation of speed and power in high range cross-body adduction with internal rotation.

A brief overview of what is reported in the literature on the variables examined in this thesis in adult athletes is first presented. Results for studies on athletes under the age of 18 are not summarised here because of the lack of skeletal maturing in the participants included in these studies. There are no reported norms for Pectoralis Minor length in athletes in the literature, so only the variables GHJ rotations and Scapular position are covered. The AHD in athletes will be discussed in a separate section 4.3 of this chapter. The population and descriptive analysis will be individually reported for each sport included in this study.

GHJ rotation in the adult athlete's shoulder

The shoulder in overhead athletes adapts in sport-specific ways (Borsa et al., 2008). Increased or decreased mobility is often noted in this population. A resultant decrease in GHJ IR of 20° or more on the non-dominant side compared with the opposite side is often noted in these sports and in the throwing shoulder compared with the non-throwing shoulder (Brown, Niehues, Harrah, Yavorsky, & Hirshman, 1988; Burkhart et al., 2003; Crockett et al., 2002; Downar & Sauers, 2005; Ellenbecker, Roetert, Piorkowski, & Schulz, 1996; Osbahr, Cannon, & Speer, 2002; Reagan et al., 2002). These findings are reported in Table 18 and Table 19. Not all studies report a corresponding loss in the total arc of GHJ rotation. The omission of reported TROM in the literature limits interpretation of the data in these articles because it is important that the label GIRD be applied in the context of the total motion of rotation in the GHJ (Reinold, Escamilla, & Wilk, 2009). A 'total arc shift phenomenon' can be present without GIRD. True GIRD coincides with a loss in the total rotation arc (Wilk et al., 2011). Despite reported incidence of shoulder injury and performance-related kinematic data, there is a lack of reported norms on clinical measurements of GHJ ROM in elite athletes. Without this knowledge, it is not possible to know confidently what degree of loss or gain in GHJ rotation is related to sport-specific adaptation and what contributes to a pathomechanical process. Witwer and Sauers (Witwer & Sauers, 2006) assessed GHJ rotation in water polo players and found a significant difference in external rotation and total arc of motion on the dominant side. Apart from this one article reporting the GHJ rotational ranges in water polo, GHJ rotational ranges in the sports examined in this thesis have not previously been reported

Table 18. Literature reporting gain or loss in rotational ranges in adult athletes

Author	population	GERG °	GIRD °
Borsa et al., 2005. (Borsa, Wilk, et al., 2005)	baseball	9 ±7.7	9.7 ±.6
Brown et al., 1988. (Brown et al., 1988)	baseball	9	15
Crocket et al., 2002. (Crockett et al., 2002)	baseball	9	9
Oshabr et al., 2002 (Osbahr et al., 2002)	baseball	12.3	12.1
Reagan et al., 2002 (Reagan et al., 2002)	baseball	9.7	8
Thomas et al., 2010 (Thomas et al., 2010)	baseball	2.33 ±4.46	17.04 ±8.6
Torres and Gomes, 2009 (Torres & Gomes, 2009)	Tennis Swimming	NR	23.9 ± 8.4 12 ± 6.8

Abbreviations: GERG=Glenohumeral external rotation gain; GIRD=Glenohumeral internal rotation deficit; ± = standard deviation.

Table 19. Literature reporting rotational ranges in adult athletes.

Authors	Population	Throw arm ER degrees	Throw arm IR degrees	TROM degrees
Borsa et al., 2005 (Borsa, Wilk, et al., 2005)	baseball	134.8 ±10.2	68.±9.2	203.4 ±9.7
Downer & Sauers 2005 (Downar & Sauers, 2005)	baseball	108.9 ±9	56.6 ±12.5	165 ±14.4
Reagan et al., 2002 (Reagan et al., 2002)	baseball	116.3 -11.4	43.0 -7.4	157.8-159.5
Laudner et al., 2010 (Laudner, Moline, & Meister, 2010)	baseball	115.5 ±7.8	44.7 ±6.3	NR
Witwer & Sauers, 2006 (Witwer & Sauers, 2006)	water polo	83.8 ± 10.9	48.3 ± 12.2	132.1 ± 17.4

Abbreviation: TROM=total range of motion, ± = standard deviation; ER=external rotation; IR = internal rotation

Scapular position in adult sportsmen

Appropriate Scapular position is necessary to optimise maximum force generation in athletes (Kibler et al., 2013; J. Smith, Dietrich, Kotajarvi, & Kaufman, 2006). If Scapular function is compromised, so too is the GHJ, and the risk of injury is correspondingly higher (Burkhart et al., 2003; Hebert et al., 2002; Laudner, Jb, Mr, Jp, & Sm, 2006; Ludewig & Cook, 2000; Ludewig et al., 1996b; Lukasiewicz, McClure, Michener, Pratt, & Sennett, 1999; van der Helm, 1994). Loss of Scapular upward rotation, if detected early in athletes, could limit soft tissue damage (Laudner, et al., 2006). It was advocated by Sahrmann (Sahrmann, 2002) that deviation from symmetry between the Scapulae was pathological. However, in athletes, asymmetry may be normal (Ozunlu et al., 2011; Schwartz et al., 2014) and using the contralateral side as a reference may not be appropriate., Furthermore, asymmetry in one plane may not be a risk factor on its own (Schwartz et al., 2014). A study (Uhl, Kibler, Gecewich, & Tripp, 2009) reports that asymmetric findings in the non-athletic population due to dominance effect, finding that 51% of population has asymmetric Scapular motion in one single plane and 14.3% in several planes. Despite agreement that Scapula asymmetry may be normal, actual measures of Scapular position vary between studies. One study (Matsuki, 2011), reported the dominant side Scapula to be more downwardly rotated by ten degrees in a healthy male population. The opposite is reported by Morais and Pascoal, 2013, who report 15° more upward rotation on the dominant side (Morais & Pascoal, 2013). It is reported that upward rotation of the Scapula should be between 5.4° and 3.6°(Ludewig et al., 1996b; Watson et al., 2005). Variations in reporting of norms for scapular position in both symptomatic and asymptomatic participants in studies is highlighted in the systematic review by Ratcliffe, Pickering, McLean, & Lewis, 2014, who propose that unorthodoxy scapular position may be part of normal variation.

Asymmetry of Scapulae should be considered as normal; in fact, it may be an adaptive alteration. What has been reported thus far in the literature regarding “normal” in sporting populations is summarised in Table 19. It is noted that the populations are predominantly representative of the sports requiring high velocity generation in high ranges: baseball, tennis, and volleyball. The only studies not to find symmetry are Witwer and Sauers, 2006 (Witwer & Sauers, 2006), who assessed Scapular upward rotation in water polo players and found no significant difference between sides. It is noted that Scapular position may be influenced by participation in a specific sport (Crotty, 2000; Forthomme, Crielaard, & Croisier, 2008; McKenna et al., 2004; Ozunlu et al., 2011; H. K. Wang, Lin, Pan, & Wang, 2005), although differing tools and methodology does not allow exact comparison of results from each study. Level of participation in sport (Thomas et al., 2010) and fatigue (Ebaugh, McClure, & Karduna, 2006; McQuade et al., 1998; Su et al., 2004) have also been shown to influence Scapular position leading to adaptive changes in elite sportsmen who do repetitive arm movements.

Table 20. Literature reporting Scapular position in adult athletes

Author	Population	Shoulder position degrees	Tools	Reported	SR coronal plane degrees(STD)
Oyama et al., 2008. (Oyama et al., 2008)	15 Baseball 15 Volley ball 13 Tennis	neutral	EMT	Asymmetry	Dom=3.46(6.17) Nondom=2.00(7.42)
Downar and Sauers, 2005. (Downar & Sauers, 2005)	27 baseball	0/60/90/120 scaption	EMT	↑SUR in throwing shoulder at 9º0 abd.	Throwing sh 0º=6.4(4.7) 60º=8.4(6.1) non throw sh 0º=4.7(4.1) 60º=5.6(4.3)
Laudner et al., 2007. (Laudner et al., 2007)	30 baseball	0/60/90/120	inclinometer	Pitchers had ↓SUR at 60º & 90º.	pitcher 0º=4.0(3.2 60º=6.4(4.9) Non-pitcher 6(3.5) 10.3(3.9)
Thomas et al., 2010. (Thomas et al., 2010)	31 collegiate baseball 21 school baseball	0/60/90/120 scaption	inclinometer	↓ SUR Collegiate players at 90º and 120º.	Collegiate 0º=7.17(4.36) dom 60º=16.07(6.46) dom 0º=4.81(3) non-dom 60º=13.05(5.72)nondom
Seitz et al., 2012. (Seitz, Reinold, Schneider, Gill, & Thigpen, 2012)	45 baseball	0/30/60/90/120/ weighted arm 2.3kg	EMT	↑SUR Throwing side	throwing 25.0 nonthrowing 21.4
Witwer et al., 2006. (Witwer & Sauers, 2006)	31 water polo	0/60/90/120/135	inclinometer	No side to side differences in SUR	NR
Struyf et al., 2011. (Struyf, Nijs, De Graeve, Mottram, & Meeusen, 2011)	36 (19 F 17 M) tennis 9 volleyball 12 baseball 1 badminton 10 handball 4	Coronal plane 0/45/90/135	inclinometer	no differences between groups or genders.	0º= 7.72 (6.68)

Abbreviations: SR= Scapula rotation. Dom = dominant; nondom = non- dominant; SUR = Scapular upward rotation; NR=not reported; sh = shoulder; F=female; M=male; sh=shoulder; EMT= electromagnetic tracking; º=degrees.

METHOD

Intra-rater reliability of tools and procedures used in this section are reported in Chapter 3.

PARTICIPANTS

Athletes from the sports included were all elite professional or national level athletes. This included professional golfers on the (European) Challenge tour, and the following athletes who represent the Great Britain team Olympians (podium and podium potentials): gymnastics, water polo, archery, boxing and canoeing. Table 21 and Table 22 summarise the participants included. Criteria for inclusion are listed in Chapter 3 under the heading "Participants". All athletes were evaluated during training camps and golfers were evaluated on tour 48 hours prior to the tournament.

Table 21. Summary of male participants screening in the study

Group	N screened	N screened out	N included in analysis
controls	46	2 x clavicle fracture 1 fractured Thoracic Spine 10 did not fit age matching	36
gymnasts	17	1 x SC dislocation 1 x fractured clavicle	15
golf	53	2 SAD 2 ACJ dislocations 1 post op SLAP 1 post op stabilisation 1 GHJ dislocation 1 fractured clavicle	45
canoeists	9	1 dislocation	8
boxing	18	0	18
archery	7	0	7

Abbreviations: SC=sternoclavicular; SA subacomial decompression; ACJ=Acromioclavicular joint; GHJ= Glenohumeral joint; op= operations; SLAP=superior labrum anterior posterior; N=number of participants.

Table 22. Summary of female participants screening in the study

Group	N screened	N screened out	N included in analysis
controls	55	2 x scoliosis 1 x spina bifida I x GHJ dislocation I x fractured clavicle 20 did not meet age matched criteria	30
water polo	16	1 x RA 3 x surgery SLAP	12
canoeist	9	1 x dislocation	8
archery	8	3 post operation labral repairs	5
boxing	6	1 post operation bankart repair	5

Abbreviations: SC=sternoclavicular; SA subacomial decompression; ACJ=Acromioclavicular joint; GHJ= Glenohumeral joint; RA= rheumatoid arthritis; SLAP=superior labrum anterior posterior; N=number of participants.

DATA ANALYSIS

Healthy shoulders were included in analysis and sorted according to dominant and non-dominant sides. The mean of three measures was calculated. Outliers were removed. Normality of distributions was ensured with Shapiro Wilk and Kolmogorov-Smirnow tests. Data from genders were analysed separately. Descriptive tests were run for each sporting group. Paired t-tests were used for within-group analysis and independent t-tests were used for between-group analysis where the number of participants was sufficient according to calculated power analysis. Where the number of participants would have resulted in an underpowered study, bar graphs were used to represent the data.

Power analysis

Using the information in Table 23 the following sentence can be completed: to perform an independent t-test, a sample size of at least N per group is required to be able to detect a difference of X °/cm mean score, with an 80% power and a 5% (0.05) significance level. This is assuming a STD of Y for the measure of V variable. (See Table 23 for N and X and Y and V values)

Table 23. Power analysis for Independent T Tests

Variable = V	Mean =X	STD =Y	N required
TROM	144.72°	14.31°	32
GHJ ER	81.54°	6.96°	53
Scapula 0°	2.4°	4.04°	25
Scapula in 60°	13.68°	9.68°	21
Pectoralis minor length	15.62cm	1.24cm	21

Abbreviations: TROM = total rotational motion; GHJ ER Glenohumeral joint external rotation; cm = centimetres; º=degrees.

Using the information in Table 24 the following sentence can be completed: for a paired t-test, a sample size of N per group is required to be able to detect an absolute difference of D (Delta score) in the variable V between groups with a 80% power at a 5% (0.05) significance level. (See Table 24 for N and X and Y and V values)

Table 24. Power analysis for Paired T Tests

Variable =V	Delta = D	STD =Y	N required
TROM	6.9°	12.33°	22
GHJER	6.9°	12.3°	22
Scapula rotation	5.14°	9.78°	24
Pectoralis minor length	0.81cm	1.3cm	18

Abbreviations: TROM = total rotational motion; GHJ ER Glenohumeral joint external rotation; cm = centimetres; º=degrees.

RESULTS

Within-group analysis

Male controls

Data from 36 male controls (mean age 24.28years STD 6.81 years) were included in the study.

Table 25. Descriptive statistics for male controls

	Min°	Max°	Mean°	STD°	Paired t-test p value
Dom TROM	99.46	158.50	133.73	13.76	
Non- dom TROM	85.67	154.53	132.13	13.49	
Dom IR	38.33	76.89	52.25	23.81	
Non- dom IR	35.67	87.67	55.25	12.04	
Dom ER	59.13	104.87	81.18	11.13	
Non- dom ER	59.33	103.83	79.25	10.91	
Dom SR 0°	-4.82	12.23	3.72	4.18	0.04
Non-dom ER 0°	-2.41	10.48	2.38	3.41	
Dom SR 60°	-1.48	24.36	10.17	6.36	
Non-dom SR 60°	2.43	16.63	8.53	3.61	
Dom PM	14.53cm	19.90cm	16.30cm	1.30cm	0.01
Non-dom PM	14.53cm	19.10cm	16.84cm	1.31cm	

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

Descriptive statistics for male controls are reported in Table 25. There is no significant difference in side to side comparison between controls in the GHJ total arc of rotation(TROM) (dominant side133.73° STD 13.76° and non-dominant side 132.13° STD 13.49°), nor in IR (dominant side 52.25° STD 23.81° non dominant side 55.25° STD 12.04°), nor in ER (dominant side 81.18° STD 11.13° and non-dominant side 79.25° STD 10.91°). The dominant Scapula of controls is more upwardly-rotated in both neutral (dominant side 3.72° STD 4.18° and non-dominant side 2.38° STD 3.41°) and in 60° of shoulder abduction (dominant side 10.17° STD 6.36° and non-dominant side 8.53° STD 3.61°). However, only the Scapular rotation angle in neutral achieved significance between sides (Paired t-test p=0.04). Controls exhibited a significantly longer Pectoralis Minor muscle on the non-dominant side (dominant side 16.30cm STD 1.30cm and non-dominant side 16.84cm STD 1.31cm. Paired T-test p=0.01). However, the difference of 0.54cm is less than $MDC_{95\%}$ reported for this measure in Chapter 3. ($MDC_{95\%}$=0.92cm-0.95cm).

Male gymnasts

Data from 15 male gymnasts (mean age 20.07years STD 2.34 years) were included in the study.

Table 26. Descriptive statistics for male gymnasts

	Min°	Max°	Mean°	STD°
Dom TROM	104.67	157.97	134.78	14.91
Non- dom TROM	106.90	143.47	127.98	9.22
Dom IR	35.67	71.33	55.54	11.56
Non- dom IR	28.67	67.33	49.13	10.66
Dom ER	66.67	98.00	79.24	10.69
Non- dom ER	65.00	91.80	78.84	8.19
Dom SR 0°	-1.24	7.59	4.21	2.85
Non-dom ER 0°	-1.29	9.22	3.23	2.98
Dom SR 60°	-.31	11.23	6.16	3.61
Non-dom SR 60°	1.89	15.54	7.22	3.62
Dom PM	12.87cm	16.80cm	14.58cm	1.14cm
Non-dom PM	11.53cm	17.00cm	14.72cm	1.79cm

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

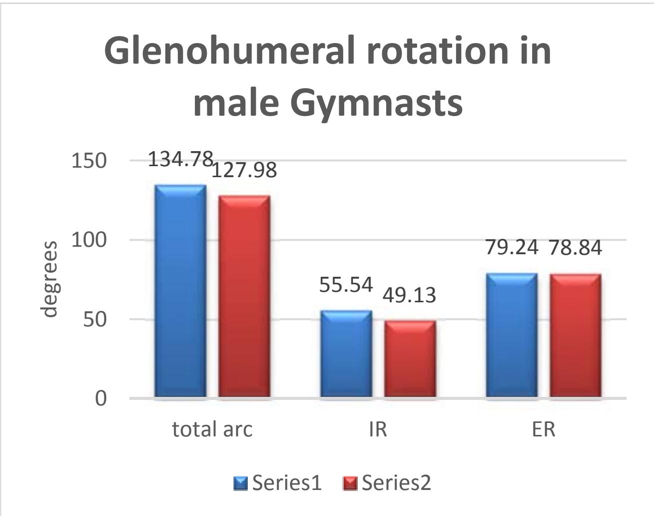

Figure 22. Glenohumeral rotation in male gymnasts
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; total arc=total arc of rotation; IR=internal rotation; ER=external rotation

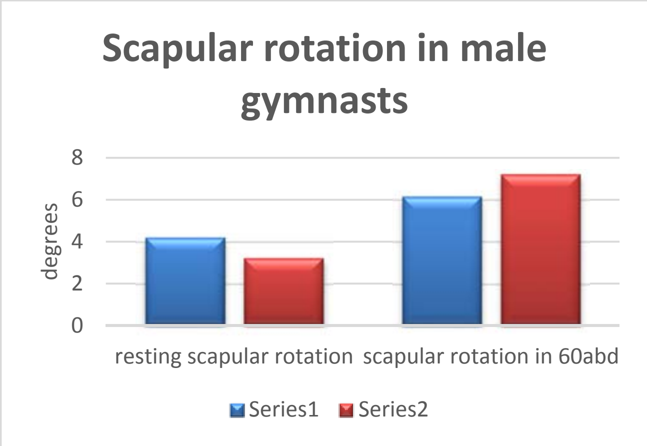

Figure 23. Scapular rotation in male gymnasts
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; abd=abduction.

Descriptive statistics for male gymnasts are reported in Table 26. The number of gymnastic participants does not allow for comparative statistical analysis. It can be observed from the graph in Figure 22. that there is no observable difference in side to side comparison between gymnasts in the GHJ total arc of rotation (dominant side134.78° STD 14.91° and non-dominant side 127.98° STD 9.22°), nor in IR (dominant side 55.54° STD 11.56° non dominant side 49.13° STD 10.66°), nor in ER (dominant side 79.24° STD 10.69° and non-dominant side 78.84° STD 8.18°). As observed the graph in Figure 23, the dominant Scapula of gymnasts is more upwardly-rotated in neutral (dominant side 4.21° STD 2.85° and non-dominant side 3.23° STD 2.98°). The opposite is observed in 60° of shoulder abduction where the non-dominant shoulder is more upwardly-rotated (dominant side 6.16° STD 3.61° and non-dominant side 7.22° STD 3.62°). Gymnasts had no discernible difference in Pectoralis Minor muscle length between sides (Dominant side 14.58cm STD 1.14cm and non-dominant side 14.72cm STD 1.79cm).

Male canoeists

Data from eight male canoeists (mean age 27.13 years STD 4.73 years) were included in the study.

Table 27. Descriptive statistics for male canoeists

	Min°	Max°	Mean°	STD°
Dom TROM	101.33	137.03	121.36	11.89
Non- dom TROM	103.33	125.13	113.36	9.85
Dom IR	24.00	45.67	36.86	6.86
Non- dom IR	28.33	48.67	38.11	6.88
Dom ER	55.67	97.00	82.28	13.37
Non- dom ER	64.33	90.00	75.24	9.30
Dom SR 0°	2.45	9.69	5.81	2.24
Non-dom ER 0°	-.27	12.64	4.84	4.42
Dom SR 60°	3.68	13.45	7.48	3.29
Non-dom SR 60°	6.25	13.34	9.00	2.69
Dom PM	13.60cm	18.47cm	15.89cm	1.57cm
Non-dom PM	13.87cm	18.27cm	16.26cm	1.55cm

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

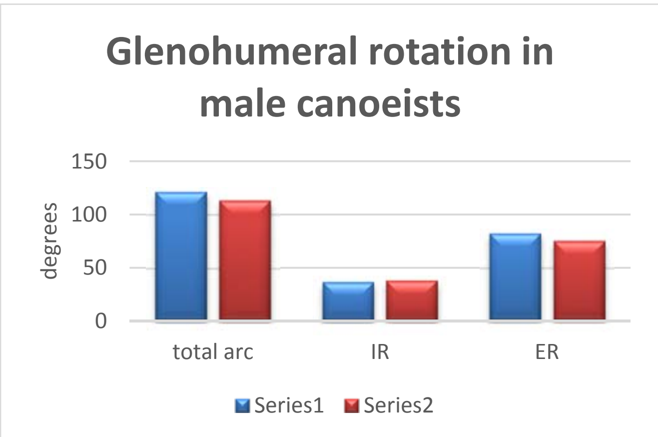

Figure 24. Glenohumeral rotation in male canoeists
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; total arc=total arc of rotation; IR=internal rotation; ER=external rotation

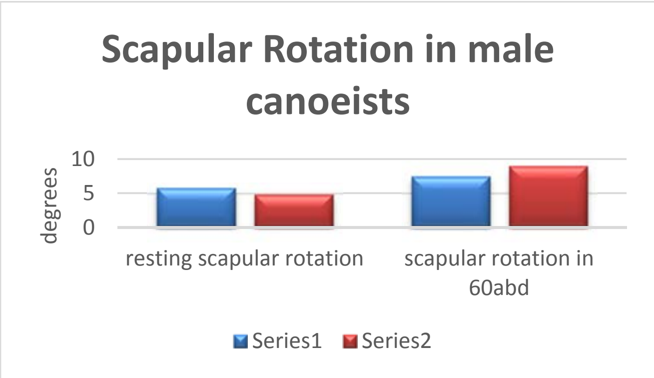

Figure 25. Scapular Rotation in male canoeists
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; abd=abduction.

Descriptive statistics for male canoeists are reported in Table 27. The number of male canoeist participants does not allow for comparative statistical analysis. It can be observed from the graph in Figure 24 that there is 8.00 ° difference in side to side comparison between canoeists in the GHJ total arc of rotation (dominant side121.36° STD 11.89° and non-dominant side 113.36° STD 9.85°). This does not exceed the $MDC_{95\%}$ of 10.89°-11.61 °. There is no side difference in in IR (dominant side 36.86° STD 6.86° non dominant side 38.11° STD 6.88°). However, a difference of 7.04° is noted in ER between sides. This exceeds the $MDC_{95\%}$ 5.73-5.88. (Dominant side 82.28° STD 13.37° and non-dominant side 75.24° STD 9.30°). As observed from the graph in Figure 25 the dominant Scapula of canoeists is more upwardly-rotated in neutral (dominant side 4.21° STD 2.85° and non-dominant side 3.23° STD 2.98°). The opposite is observed in 60° of shoulder abduction where the non-dominant shoulder is more upwardly-rotated (dominant side 6.16° STD 3.61° and non-dominant side 7.22° STD 3.62°). Canoeists exhibited a longer Pectoralis Minor muscle on the non-dominant side (dominant side 15.89cm STD 1.57cm and non-dominant side 16.26cm STD 1.55cm). However, the difference of 0.37cm is less than $MDC_{95\%}$ reported for this measure in Chapter 3. ($MDC_{95\%}$=0.92cm-0.95cm).

Male boxing

Data from 18 male boxers (mean age 21.78 years STD 2.39 years) were included in the study.

Table 28. Descriptive statistics for male boxers

	Min°	Max°	Mean°	STD°	Paired t-test p value
Dom TROM	100.17	144.70	120.67	11.28	
Non- dom TROM	105.83	145.00	125.34	10.70	
Dom IR	34.50	50.33	43.56	4.22	
Non- dom IR	30.00	66.00	45.31	8.66	
Dom ER	63.67	87.70	76.39	8.16	0.02
Non- dom ER	70.67	92.50	80.99	5.64	
Dom SR 0°	-1.14	11.79	4.53	3.44	
Non-dom ER 0°	-3.31	9.44	3.28	3.11	
Dom SR 60°	6.91	17.06	12.86	2.72	0.04
Non-dom SR 60°	7.74	15.90	11.31	2.24	
Dom PM	15.33	19.10	16.60	1.16	
Non-dom PM	14.20	18.90	16.60	1.25	

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

Descriptive statistics for male boxers are reported in Table 28.There is no significant difference in side to side comparison between boxers in the GHJ total arc of rotation (dominant side 120.67° STD 11.28° and non-dominant side 125.34° STD 10.70°), nor in IR (dominant side 43.53° STD 4.22° non dominant side 45.31° STD 8.66°). A significant difference was noted between sides in ER with greater ER on the non-dominant side (dominant side 76.39° STD 8.16° and non-dominant side 80.99° STD 5.64°. Paired t-test p=0.02). The difference in ER of 4.60 does not exceed the $MDC_{95\%}$ of 5.73-5.88). The dominant Scapula of boxers is more upwardly-rotated in both neutral (dominant side 4.53° STD 3.44° and non-dominant side 3.28° STD 3.11°) and in 60 ° of shoulder abduction (dominant side 12.60° STD 2.72° and non-dominant side 11.44° STD 2.24°). However, only the Scapular rotation angle in 60° of arm abduction achieved significant differences between sides (Paired t-test p=0.04. Table 28). Pectoralis minor length was noted to be equal between sides in boxers. (Dominant side 16.60cm STD 1.16cm and non-dominant side 16.60cm STD 1.25cm).

Male archers

Data from eight male archers (mean age 21.00 years STD 2.89 years) were included in the study

Table 29. Descriptive statistics for male archers

	Min°	Max°	Mean°	STD°
Dom TROM	98.00	150.50	125.71	18.35
Non- dom TROM	97.00	145.40	123.48	16.30
Dom IR	27.50	59.00	44.69	11.15
Non- dom IR	30.00	56.50	44.45	10.08
Dom ER	70.50	97.00	81.02	8.98
Non- dom ER	67.00	93.00	79.03	9.76
Dom SR 0°	1.43	6.52	3.96	1.97
Non-dom ER 0°	-.22	3.89	1.74	1.47
Dom SR 60°	2.97	14.84	9.17	4.67
Non-dom SR 60°	5.74	7.23	6.50	0.60
Dom PM	16.00cm	19.00cm	17.19cm	1.27cm
Non-dom PM	16.60cm	18.70cm	17.62cm	0.75cm

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

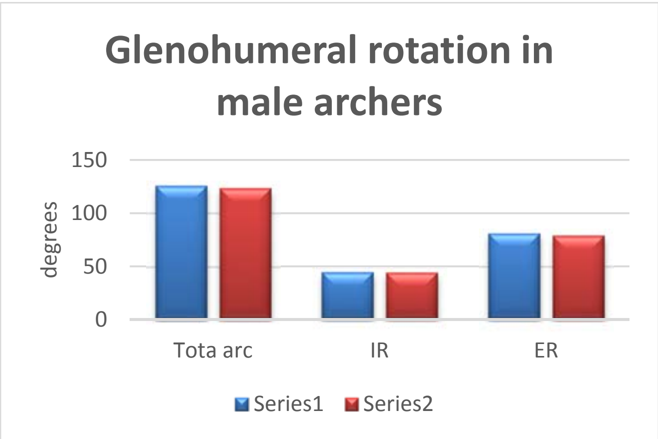

Figure 26. Glenohumeral rotation in male archers
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; total arc=total arc of rotation; IR=internal rotation; ER=external rotation

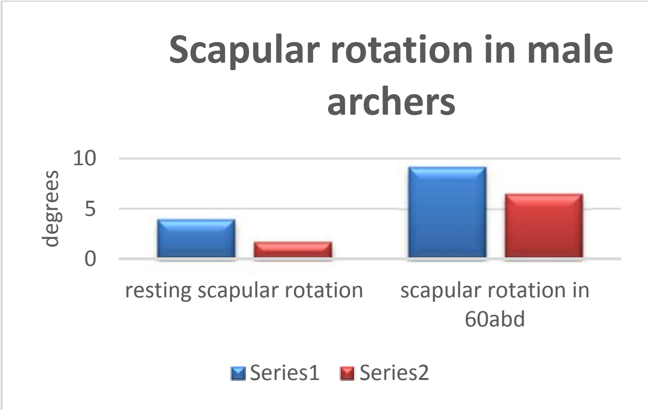

Figure 27. Scapular rotation in male archers
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; abd=abduction.

Descriptive statistics for male archers are reported in Table 29. The number of male archer participants does not allow for comparative statistical analysis. It can be observed from the graph In Figure 26 that there is no observable difference in side to side comparison in archers in the GHJ total arc of rotation (dominant side125.71° STD 18.35° and non-dominant side 123.48° STD 16.30°), nor in IR (dominant side 44.69° STD 11.15° non dominant side 44.35° STD 10.08°), nor in ER (dominant side 81.02° STD 8.98° and non-dominant side 79.03° STD 9.76°). As observed from the graph In Figure 27, the dominant Scapula of archers is more upwardly-rotated in neutral and in 60° of arm abduction (neutral = dominant side 3.96° STD 1.94° and non-dominant side 1.74° STD 1.97°/ in 60° abduction = dominant side 9.17° STD 4.67° and non-dominant side 6.50° STD 0.60°). Archers exhibited a longer Pectoralis Minor muscle on the non-dominant side (dominant side 17.19cm STD 1.27cm and non-dominant side 17.62cm STD 0.75cm). However, the difference of 0.43cm is less than $MDC_{95\%}$ reported for this measure in Chapter 3 ($MDC_{95\%}$=0.92cm-0.95cm).

Male Golfers

Data from 45 male golfers (mean age 27.91 years STD 4.74 years) were included in the study.

Table 30. Descriptive statistics for male golfers

	Min °	Max°	Mean °	STD °	Paired t-test p value
Dom TROM	116.16	170.03	149.03	11.55	
Non- dom TROM	114.37	183.60	154.11	15.87	
Dom IR	34.33	82.53	58.46	11.72	
Non- dom IR	34.67	93.43	63.19	12.12	
Dom ER	57.00	106.67	89.68	11.65	
Non- dom ER	72.87	108.33	90.29	9.05	
Dom SR 0°	-1.26	13.42	5.43	3.18	0.01
Non-dom ER 0°	-5.29	10.97	3.03	3.72	
Dom SR 60°	-1.59	15.27	6.93	3.78	0.01
Non-dom SR 60°	.00	15.68	8.67	3.52	
Dom PM	14.47cm	18.73cm	16.67cm	1.13cm	0.01
Non-dom PM	12.67cm	18.93cm	15.80cm	1.25cm	

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

Descriptive statistics for male golfers are reported in Table 30. Results from paired t-tests showed that there is no difference in side to side comparison between in golfers in the GHJ total arc of rotation (dominant side149.03° STD 11.55° and non-dominant side 154.11° STD 15.87°), nor in IR (dominant side 58.47° STD 11.72° non dominant side 63.19° STD 12.12°), nor in ER (dominant side 89.68° STD 11.65° and non-dominant side 90.29° STD 9.05°). The dominant Scapula of golfers is significantly more upwardly-rotated in neutral (dominant side 5.41° STD 3.22° and non-dominant side 3.17° STD 3.80°) (p=0.01) and in the non-dominant side is significantly more upwardly-rotated in 60° of shoulder abduction (dominant side 6.89° STD 3.77° and non-dominant side 8.89° STD 3.36°)(p=0.01). Golfers had a significantly longer Pectoralis Minor muscle on the dominant side (dominant side 16.89cm STD 1.14cm and non-dominant side 15.82cm STD 1.20cm. Paired T-test p=0.01). The difference of 0.87cm is less than $MDC_{95\%}$ reported for this measure in Chapter 3 ($MDC_{95\%}$=0.92cm-0.95cm).

Female controls

Data from 30 female controls (mean age 26.56 years STD 6.44 years) were included in the study.

Table 31. Descriptive statistics for female controls

	Min	Max°	Mean°	STD°	Paired t test p value
Dom TROM	105.40	173.90	143.28	16.68	
Non- dom TROM	109.06	175.10	145.36	15.27	
Dom IR	40.00	73.10	54.75	9.63	
Non- dom IR	36.33	82.77	57.05	12.03	
Dom ER	62.00	111.00	88.29	11.78	
Non- dom ER	67.83	113.00	86.51	12.32	
Dom SR 0°	-7.42	8.90	1.17	3.33	
Non-dom ER 0°	-7.87	8.06	0.55	3.35	
Dom SR 60°	-.43	16.49	7.34	4.80	
Non-dom SR 60°	2.83	14.56	8.28	3.27	
Dom PM	11.07cm	15.87cm	14.13cm	1.17cm	0.01
Non-dom PM	13.47cm	17.07cm	14.82cm	0.95cm	

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

Descriptive statistics for female controls are reported in Table 31. Results from paired t-tests showed that there is no difference in side to side comparison between in female controls in the GHJ total arc of rotation (dominant side143.28° STD 16.68° and non-dominant side 145.36° STD 15.27°), nor in IR (dominant side 54.75° STD 9.63° non dominant side 57.05° STD 12.02°), nor in ER (dominant side 88.29° STD 11.78° and non-dominant side 86.51° STD 12.32°). There is no significant difference in upward rotation of the Scapula in either neutral or in 60° of abduction in female controls. (neutral =Dominant side 1.17° STD 3.33° and non-dominant side 0.55° STD 3.35°) (60 abduction =dominant side 7.34° STD 4.80° and non-dominant side 8.28° STD 3.27°). Female controls had a significantly longer Pectoralis Minor muscle on the non-dominant side (dominant side 14.26cm STD 1.12cm and non-dominant side 14.83cm STD 0.97cm. Paired T-test p=0.01). The difference of 0.69cm is less than $MDC_{95\%}$ reported for this measure in Chapter 3 ($MDC_{95\%}$=0.92cm-0.95cm).

Water polo females

Data from 12 female water polo players (mean age 23.67 years STD 4.94 years) were included in the study.

Table 32. Descriptive statistics for female water polo players

	Min°	Max°	Mean°	STD°
Dom TROM	131.57	174.67	150.35	12.65
Non- dom TROM	130.97	176.67	150.13	13.03
Dom IR	54.67	65.33	60.06	3.86
Non- dom IR	48.67	75.33	59.31	7.28
Dom ER	74.20	101.83	89.88	7.86
Non- dom ER	68.83	93.60	82.56	8.19
Dom SR 0°	-1.29	4.35	0.60	2.15
Non-dom ER 0°	-4.53	9.84	2.05	4.08
Dom SR 60°	1.45	11.15	5.57	3.51
Non-dom SR 60°	.00	11.60	7.46	3.22
Dom PM	13.47cm	15.93cm	14.84cm	0.75cm
Non-dom PM	14.13cm	15.60cm	14.92cm	0.56cm

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

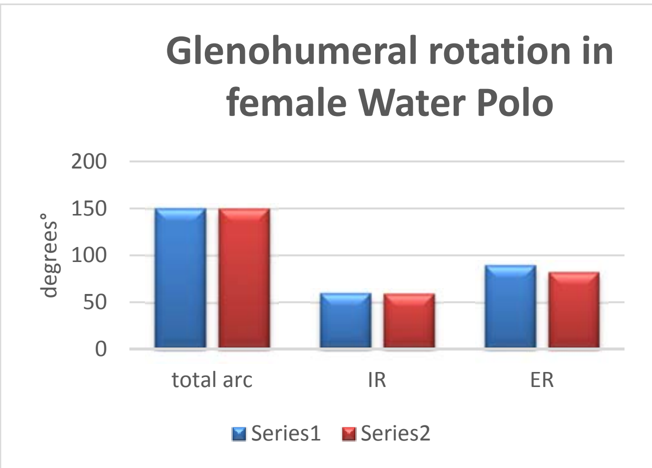

Figure 28. Glenohumeral rotation in female water polo players
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; total arc=total arc of rotation; IR=internal rotation; ER=external rotation

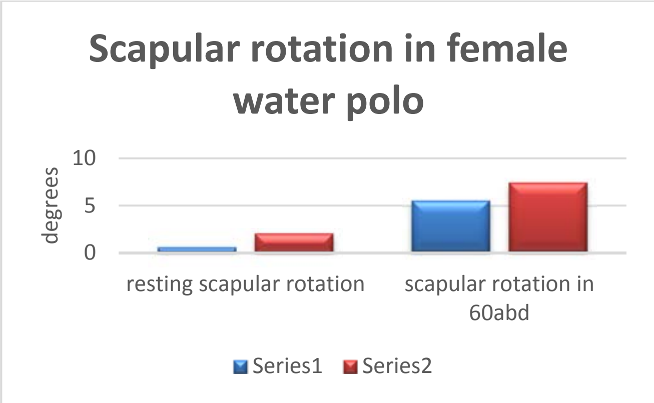

Figure 29. Scapular rotation in female water polo players
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; abd=abduction.

Descriptive statistics for female water polo players are reported in Table 32. On graph in Figure 28, no difference in side to side comparison between water polo players is observed in the GHJ total arc of rotation (dominant side150.35° STD 12.65° and non-dominant side 150.13° STD 13.03°) nor in IR (dominant side 60.06° STD 3.86° non dominant side 59.31° STD 7.28°). ER is observed to be greater on the dominant side by 7.32° which is more than the $MDC_{95\%}$ reported in Chapter 3. of 5.73°-5.88° (dominant side 89.88° STD 7.86° and non-dominant side 82.56° STD 8.19°). The non-dominant Scapula of female water polo players is observed to be more upwardly-rotated in both neutral and in 60° of abduction (neutral=dominant side 0.60° STD 2.15° and non-dominant side 2.05° STD 4.08°) (60° abduction =dominant side 5.57° STD 3.51° and non-dominant side 7.46° STD 3.22°)(Figure 29). Water polo players were observed to have a no discernible difference in Pectoralis Minor muscle between sides (Dominant side 14.84cm STD 0.75cm and non-dominant side 14.92cm STD 0.56cm).

Canoeists female

Data from eight female canoeists (mean age 25.88 years STD 2.42 years) were included in the study.

Table 33. Descriptive statistics for female canoeists

	Min°	Max°	Mean°	STD°
Dom TROM	113.00	135.00	122.94	9.02
Non- dom TROM	108.00	136.33	124.64	9.71
Dom IR	39.67	60.00	49.86	7.37
Non- dom IR	41.33	68.00	53.00	8.97
Dom ER	53.00	93.27	73.09	13.98
Non- dom ER	40.00	91.83	71.64	16.34
Dom SR 0°	-2.12	7.90	3.20	3.67
Non-dom ER 0°	-2.52	3.06	0.98	1.87
Dom SR 60°	5.53	14.48	8.76	3.13
Non-dom SR 60°	5.22	12.50	8.84	2.54
Dom PM	14.13cm	16.07cm	14.60cm	0.74cm
Non-dom PM	13.93cm	16.20cm	14.92cm	0.79cm

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

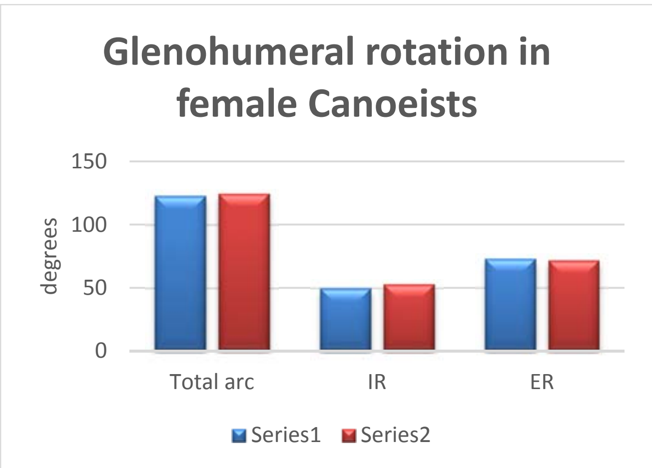

Figure 30. Glenohumeral rotation in female Canoeists

Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; total arc=total arc of rotation; IR=internal rotation; ER=external rotation

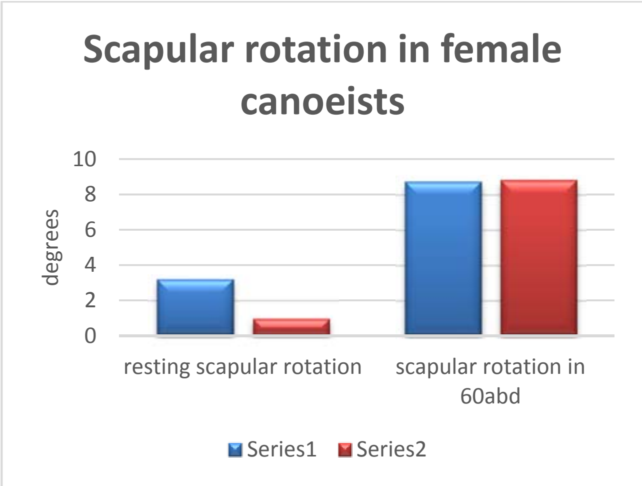

Figure 31. Scapular rotation in female canoeists
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; abd=abduction.

Descriptive statistics for female canoeists are reported in Table 33. On the graph in Figure 30 no difference in side to side comparison between in female canoeists is observed in the GHJ total arc of rotation (dominant side122.94° STD 9.02° and non-dominant side 124.64° STD 9.71°), nor in IR (dominant side 49.86° STD 7.37° non dominant side 53.00° STD 8.97°) nor in ER (dominant side 73.09° STD 13.98° and non-dominant side 71.64° STD 16.34°). The dominant Scapula of female canoeists is observed to be more upwardly-rotated in neutral but equal between sides in 60° of abduction (neutral=dominant side 3.20° STD 3.67° and non-dominant side 0.98° STD 1.87°) (60° abduction =dominant side 8.76° STD 3.13° and non-dominant side 8.84° STD 2.54°)(Figure 31). Female canoeists were noted to have a longer Pectoralis Minor muscle on the non-dominant side by only 0.32 which is less than the MDC 0.92-0.95 reported in Chapter 3 and therefore not clinically discernible. (Dominant side 14.60cm STD 0.74cm and non-dominant side 14.90cm STD 0.79cm).

Boxing females

Data from five female boxers (mean age 22.80 years STD 4.03 years) were included in the study.

Table 34. Descriptive statistics for female boxers

	Min°	Max°	Mean°	STD°
Dom TROM	121.53	143.83	131.73	8.44
Non- dom TROM	122.00	147.30	131.81	10.12
Dom IR	34.50	45.67	40.27	4.69
Non- dom IR	42.00	53.00	48.00	4.97
Dom ER	83.53	100.60	91.47	7.95
Non- dom ER	73.43	99.50	88.91	10.38
Dom SR 0°	-1.41	8.58	2.34	4.15
Non-dom ER 0°	.00	11.34	4.45	4.84
Dom SR 60°	6.55	13.75	9.64	3.46
Non-dom SR 60°	5.07	14.48	9.31	4.14
Dom PM	14.07cm	15.20cm	14.67cm	0.47cm
Non-dom PM	12.60cm	14.93cm	13.83cm	1.24cm

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

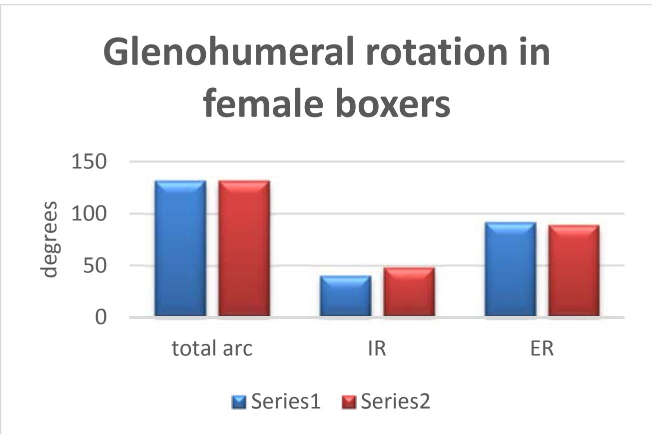

Figure 32. Glenohumeral rotation in female boxers

Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; total arc=total arc of rotation; IR=internal rotation; ER=external rotation

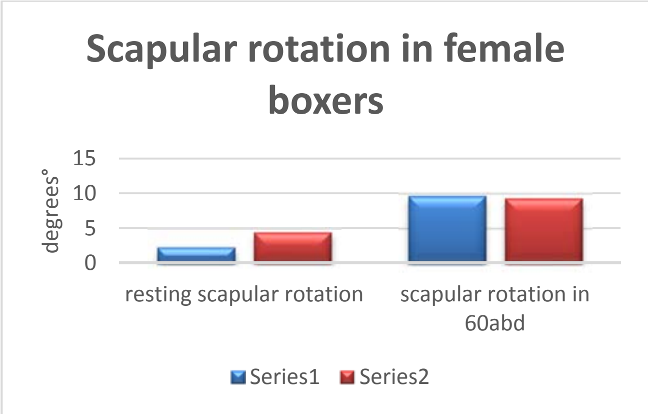

Figure 33. Scapular rotation in female boxers
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; abd=abduction.

Descriptive statistics for female boxers are reported in Table 34. On graph in Figure 32 no difference in side to side comparison between in female boxers is observed in the GHJ total arc of rotation (dominant side131.73° STD 8.44° and non-dominant side 131.81° STD 10.12°). A differences is noted in in IR with 7.73° more IR on the non-dominant side (dominant side 40.27° STD 4.69° non dominant side 48.00° STD 4.97°). This exceeds the $MDC_{95\%}$ of 4.99°-5.88°. ER is observed to be similar between the sides (dominant side 91.47° STD 7.95° and non-dominant side 88.91° STD 10.38°). The non-dominant Scapula of female boxers is observed to be more upwardly-rotated in neutral but there was no observable difference in 60° of abduction (neutral=dominant side 2,34° STD 4.15° and non-dominant side 4.45° STD 4.84°) (60° abduction =dominant side 9.64° STD 3.46° and non-dominant side 9.31° STD 4.14°)(Figure 33). Female boxers were observed to have a longer Pectoralis Minor muscle on the dominant side by only 0.84cm which is less than the MDC 0.92cm-0.95cm reported in Chapter 3 and therefore not clinically discernible. (Dominant side 14.67cm STD 0.47cm and non-dominant side 13.83cm STD 1.24cm).

Female Archers

Data from five male archers (mean age 24.88 years STD 5.89 years) were included in the study.

Table 35. Descriptive statistics for female archers

	Min°	**Max°**	**Mean°**	**STD°**
Dom TROM	136.67	172.67	149.07	16.11
Non- dom TROM	135.00	163.00	146.35	10.60
Dom IR	44.00	62.67	53.67	8.69
Non- dom IR	48.50	66.67	58.10	6.60
Dom ER	78.33	114.00	95.41	12.70
Non- dom ER	77.00	105.00	88.25	11.44
Dom SR 0°	-8.10	5.53	-0.80	5.09
Non-dom ER 0°	-2.65	3.68	0.98	2.54
Dom SR 60°	.00	14.03	5.02	5.73
Non-dom SR 60°	1.86	10.94	6.96	3.34
Dom PM	13.23cm	15.27cm	14.47cm	0.84cm
Non-dom PM	14.27cm	16.67cm	15.37cm	0.88cm

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation; min=minimum value; max=maximum value.

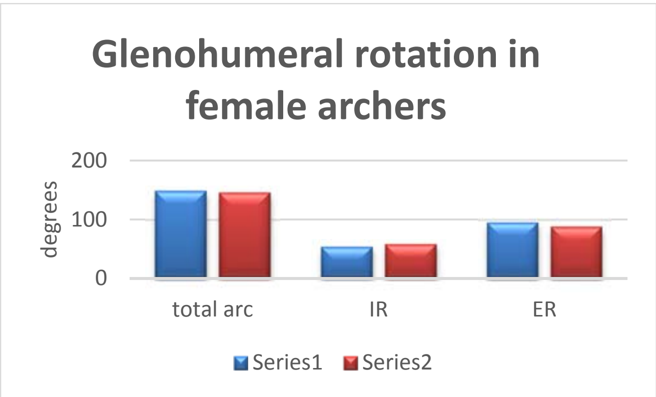

Figure 34. Glenohumeral rotation in female archers
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side; total arc=total arc of rotation; IR=internal rotation; ER=external rotation.

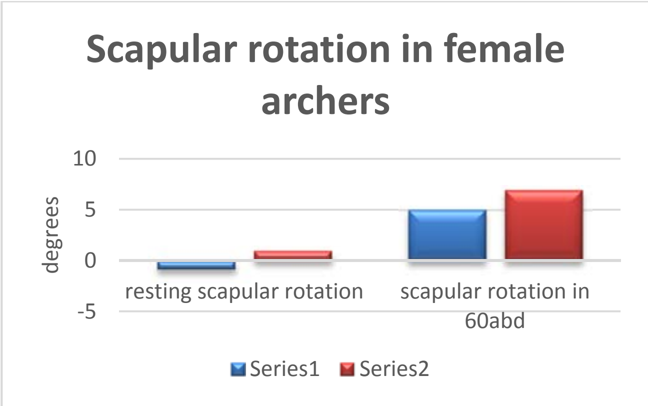

Figure 35. Scapular rotation in female archers
Abbreviations: Series 1 = dominant side; Series 2 = non-dominant side.

Descriptive statistics for female archers are reported in Table 35. On graph in Figure 34 no difference in side to side comparison between in female archers is observed in the GHJ total arc of rotation (dominant side 149.07° STD 16.11° and non-dominant side 146.35° STD 10.60°), nor in IR (dominant side 43.67° STD 8.69° non dominant side 58.10° td 6.60°). ER is noted to be greater on the dominant side by 7.16 ° which is more than the $MDC_{95\%}$ reported in Chapter 3. of 5.73-5.88° (dominant side 95.41° STD 12.70° and non-dominant side 88.25° STD 11.44°). The non-dominant Scapula of female archers is observed to be more upwardly-rotated in both neutral and in 60° of abduction (neutral=dominant side -0.08° STD 5.09° and non-dominant side 0.98° STD 2.54°) (60 abduction =dominant side 5.02° STD 5.73° and non-dominant side 6.96° STD 3.34°)(Figure 35). Female archers were observed to have a longer Pectoralis Minor muscle on the non-dominant side by 0.90cm which is less than the MDC 0.92cm-0.95cm reported in Chapter 3 and therefore not clinically discernible (Dominant side 14.47cm STD 0.84cm and non-dominant side 15.36cm STD 0.88cm).

DISCUSSION

GHJ IR Male groups

In all male athletes and controls, there is no observable or statistical difference in side to side comparison in the GHJ total arc of rotation nor in IR. The athletes in this study are all healthy and performing at the highest level, and so the findings of this study support the previously-reported theory that loss of IR in the context of loss of total arc of rotation would be a pathological finding in sportsmen. Compared with previous findings in the literature (Table 18 and Table 19) relating to the high velocity throwing shoulder of male sportsmen (which range from loss of 8°-23° in tennis, swimming and baseball shoulders), the athletes in this study were not found to have a deficit of GHJ IR (GIRD) in the context of a loss in TROM.

GHIR Female groups

Results from observed bar graphs or paired t-tests showed that there is no difference in side to side comparison in GHJ total arc of rotation in female controls and sportswomen. A non-significant (not exceeding the $MDC_{95\%}$ loss in IR is noted, however, since this is not significant and does not correspond to a loss in the total arc of rotation the theory of 'total arc of rotation shift', rather than GIRD, is upheld in these female athletes.

Further example of this is seen in female boxers, a loss of IR of 7.73°on the dominant side is noted (dominant side 40.27° STD 4.69° non dominant side 48.00° STD 4.97°).In this group this does exceeds the $MDC_{95\%}$ of 4.99-5.88 but it does not correspond to a loss of range in the total rotational arc. It can be concluded then that this is not presence of GIRD but rather an adaptive change to boxing performance.

GHJ ER Male groups

In male controls, gymnasts, and archers there is no side to side difference noted in ER. However, in canoeists and boxers, a side to side difference in GHJ ER with a GERG on the dominant side is noted. This corresponds to a non-significant but never the less increase in the total arc of rotation. Canoeists have a GERG of 7.04° on the dominant side (exceeds the $MDC_{95\%}$ of 5.88°). Boxers have a significant (p=0.02) GERG of 4.60, although this does not exceed the $MDC^{95\%}$ of 5.73-5.88). In the literature, baseball players are reported to have a GERG of between 2.33° and 12.30° and the GERG found in this sample of canoeists and boxers is within this range.

GHJ ER Female groups

In female controls, canoeists and boxers there is no observed or statistical difference in ER between sides. In female archers, however, ER is noted to be greater on the dominant side by 7.16°, which is more than the $MDC_{95\%}$ reported in Chapter 3 of 5.73°-5.88° (dominant side 95.41° STD 12.70° and non-dominant side 88.25° STD 11.44°). The same is true in water polo players: ER is observed to be greater on the dominant side by 7.32°, which is more than the $MDC_{95\%}$ reported in Chapter 3. of 5.73°-5.88° (dominant side 89.88° STD 7.86° and non-dominant side 82.56° STD 8.19°). These results are in keeping with those of Witwer and Sauers (Witwer & Sauers, 2006) who also reported an increase in ER and total arc of rotation in water polo players. Direct comparison of actual measures of rotation, are difficult due to varying methodology in the studies. It would appear that in the female archers and boxers there is presence of GERG.

Scapular rotation in the coronal plane in male groups

In all male sportsmen and controls, the dominant Scapula is more upwardly-rotated in the neutral resting position. In controls and golfers this is significant with Paired t-testing. The difference between sides is 2.24° in golfers and 1.34° in controls.

In 60° abduction controls, boxing and archery have greater upward rotation on the dominant side, this being significant in boxers. The opposite is found in golfers, gymnast and canoeists, who have more upward rotation on the non-dominant side in 60° abduction with this being significant in golfers.

Scapular rotation in the coronal plane in female groups

In female controls, Scapular symmetry is noted in neutral and in 60° abduction. Asymmetry is noted in all sportswomen in the neutral positon with the dominant Scapula being more upwardly-rotated in water polo, canoeing and boxing. Female archers, on the other hand, exhibit the opposite, with the non-dominant shoulder more upwardly-rotated in the neutral arm position. In 60 abduction female canoeists and female boxers display symmetry of Scapular position, but female archers (on the non-dominant side) and female water polo players (on the dominant side) exhibit more upward rotation. Unlike the findings in water polo players in this study, Witwer and Sauers (Witwer & Sauers, 2006), using an inclinometer, reported symmetry in a mixed gender of water polo players in neutral and 60° abduction. Though actual measures and MDC are not reported in the published article.

Asymmetry of Scapular position is noted in both male controls and sportsmen and sportswomen in neutral and in the early ranges of shoulder abduction. Actual measures of Scapular upward rotation are within the ranges previously reported in the literature (Downar & Sauers, 2005; Laudner et al., 2007; Oyama et al., 2008; Seitz, McClure, Finucane, et al., 2012; Struyf, Nijs, De Graeve, et al., 2011; Thomas et al., 2009). Asymmetry in the Scapular position in the coronal plane in sportsmen is also in keeping with previous study's findings (Downar & Sauers, 2005; Laudner et al., 2007; Oyama et al., 2008; Seitz, McClure, Finucane, et al., 2012; Thomas et al., 2009). Previous literature, mostly in baseball, found that the dominant Scapula of athletes was more upwardly rotated (Downar & Sauers, 2005; Seitz, McClure, Finucane, et al., 2012).In the sportsmen and sportswoman tested in this study, this was not invariably the case and which side was most upwardly rotated depended on the sport discipline under examination.

Assessment of Scapular position is often used by clinicians and the asymptomatic side is used as a baseline reference, with asymmetry assumed as pathological (Morais & Pascoal, 2013). But studies (Morais & Pascoal, 2013) have demonstrated with EMT that at rest and during arm elevation, Scapular movement on each side was not symmetrical in healthy individuals. Six kinematic studies (Lukasiewicz et al., 1999; Matsuki, 2011; Morais & Pascoal, 2013; Oyama et al., 2008; Uhl et al., 2009) report asymmetry and yet (Yano et al., 2010) report symmetry. It is interesting that those that report symmetry offset the starting position of the Scapula at zero degrees, thus not taking into consideration the resting position of the Scapula. It is advocated that (Morais & Pascoal, 2013), that the magnitude of movement between sides was similar, although asymmetry existed in static positions. From this, it could be concluded that the pattern and magnitude of motion is more important to evaluate in the Scapula and not the resting or isometrically held position.

Pectoralis length sportsmen

In gymnasts and boxers, symmetry was noted in the length of the Pectoralis Minor muscles. Canoeists, archers, and male controls all exhibited a longer Pectoralis Minor muscle on the non-dominant side; this was significant in controls. The opposite was seen in golfers, who had a significantly longer Pectoralis Minor muscle on the dominant side.

Pectoralis length sportswomen

Female water polo players had symmetry in the length of the pectorals minor muscles. Pectoralis minor was longer in female canoeists, archers, and controls on the non-dominant sides, and this difference was significant in controls. The opposite was the case in female boxers, in which the dominant side pectoralis muscle was longer.

It is noted that the in groups that exhibited a difference between sides, the delta score did not exceed the $MDC_{95\%}$. It is likely that the difference between sides is not meaningful because it did not exceed the potential measurement error.

FURTHER DISCUSSION

Trainers and sports therapists need to prevent shoulder injuries in athletes by implementation of exercise intervention to modify suboptimal physical characteristics (Oyama et al., 2008). Research has contributed to understanding the kinematics of sport and the load on the athlete's shoulder. Few studies have, however, looked at the physical makeup of the athlete using clinically measurable methods. If screening and exercise intervention is going to be used to prevent athletes from injury, then it is important to determine whether altered motion patterns observed in athletes are detrimental or beneficial. The challenge for the physiotherapist and trainers who treat the shoulder of athletes who place high demands on their shoulders is to enhance athletic performance, extend longevity, and prevent injury (Silliman & Hawkins, 1991). But the demands on the shoulder during athletics often times exceed the physiological limits of the shoulder and results in injury (Silliman & Hawkins, 1991). Understanding the sporting activity, the anatomy of the shoulder girdle and the biomechanics of the shoulder girdle are all essential to restore normal anatomy and physiology, and clinical research is essential to this understanding (Silliman & Hawkins, 1991). Clinical measures as used in this study are important for sports therapists and trainers. The demands that sport places on the shoulder are great, and require interaction between the GHJ and Scapula kinematics (Kibler, 1998). A high incidence of shoulder problems is reported in the literature in athletes, but other than identifying the repeated throwing action as a contributing factor, there is little evidence regarding causation (Webster, Morris, & Galna, 2009). Repeating clinical evaluation throughout rehabilitation informs the choice of treatment. Screening and prehab of physical characteristics in the shoulder needs to be sport-specific and the link between physical characterises and sport proficiency needs to be established (Sell, Tsai, Smoliga, Myers, & Lephart, 2007). Scientific evidence is necessary to produce normative data regarding what physical characteristics improve performance in sports, as this will give clinicians parameters for training programs.

4.2 Sport specific adaptations in the elite golfer's shoulder

INTRODUCTION

Shoulder problems in golf

In professional golf, the shoulder is the third most commonly injured area (Gosheger, Liem, Ludwig, Greshake, & Winkelmann, 2003). The lead shoulder is three times more likely to be injured than the dominant shoulder (D. H. Kim, Millett, Warner, & Jobe, 2004). A study (Jobe & Pink, 1996), reported that 93% of shoulder injuries in the golfer were due to Rotator Cuff disease or sub-acromial impingement. The professional golfers swing, which is complex and repetitive, can be repeated as much as 2000 times per week (Jobe & Pink, 1996).

GHJ rotation in golf

Kinetics and kinematics using 3D analysis techniques of the swing are bountiful (Hume, Keogh, & Reid, 2005). Using 3D swing analysis, the dominant shoulder external rotation at top of back swing ranged from 78°-102° and in follow-through, external rotation in the lead shoulder ranged between 59°-80°. This depended on age and level of proficiency the player (Burden, Grimshaw, & Wallace, 1998; Hume et al., 2005). Range of motion in all directions in the lead shoulder is considered to determine the length of the back swing (Hume et al., 2005). From these data an asymmetry could be expected in passive range of the golfers' GHJ rotations. Kinematic assessment of flexibility during the golf swing is prolific (Hume et al., 2005; Mitchell, Banks, Morgan, & Sugaya, 2003) but there are few studies which investigate physiological GHJ rotational ROM which is important because the passive GHJ ROM will determine the range the golfer can achieve during the swing (Keogh et al., 2009; Sell et al., 2007).

Rotation of shoulder affects club-head speed and hence ball distance (D. M. F. Smith, 2010). In older golfers, greater shoulder ER correlated to lower handicaps (Keogh et al., 2009), More proficient players are noted to have more dominant shoulder ER than less able players (Sell et al., 2007). Physical screening of golfers to assess shoulder flexibility is important as this flexibility is required to ensure power during the dynamic movement of the golf swing (D. M. F. Smith, 2010) but it needs to be based on results from scientifically rigorous and reliable screening (D. M. F. Smith, 2010). To date, no literature has investigated this variable in the professional elite open golfers.

In previous literature reporting GHJ ROM in golf, the sample population, though referred to as "elite golfers" only had handicaps less than five (Brumitt, Meria, Nee, & Davidson, 2008). A study compared sides in 24 male golfers, finding no statistical difference between sides for IR and ER. This study concluded that in golf no unique passive GHJ ROM pattern existed. In this same study (Brumitt et al., 2008) the mean age of the included golfer was 39.67 range with a range from 24 to 57 and this may have skewed results as older golfers are reported to have as much as 38° less GHJ ER than younger players (Mitchell et al., 2003). GHJ rotation ranges are reported to be greater in more proficient golfers (Sell et al., 2007).

The anatomical makeup of the body of a golfer will determine the dynamics of the golf swing (D. M. F. Smith, 2010).Data relating to the physical characteristics of proficient professional elite players would therefore be useful. It would help to understand what the optimal physical attributes in the shoulder of golfers are. Golfers have to be able to achieve and sustain movement positions between and during the swing to execute an effective swing and shot, and so limited ROM in the shoulder could result in a poor swing technique

Pectoralis minor length in golfers

High levels of pectoralis muscle activity are observed with EMG during the acceleration phase of the golf down swing (Jobe & Pink, 1996). High muscle torque at each joint in the kinetic link aggregates to produce a resultant torque which dictates club head velocity which in turn is linked to driving distances (Keogh et al., 2009). The overall resultant torque or angular velocity and the length of the lever determine linear velocity and, in the case of golf, the club head speed. The golfer's arm length and the length of the club are finite (Hume et al., 2005). To generate a longer lever on the back swing, however, the golfer may use the extremes of external (in the dominant shoulder) and internal (in the lead shoulder) rotation in the shoulder. This challenges the pectoralis muscles in the golfer to generate power but also to allow extremes of shoulder ROM during the golf backswing. This muscle is required to have strength and flexibility in golfers. The stretch-shorten cycle and the X factor stretch in golf have been proposed as underlying mechanisms for improving power and generating greater club head speeds (Hume et al., 2005). The short stretch cycle theory is that a short stretch followed by a contraction (shortening) of the muscle increased elastic energy, enhancing the power of the concentric contraction (Hume et al., 2005). In the backswing the golfer maximises the short stretch cycle by stretching the hip, trunk and shoulder musculature (Hume et al., 2005). The pectoralis muscle would be a strategic part of this kinetic link.

Scapular position in golf

No previous literature quantifying Scapular position in golfers was found. The turn of the hip relative to the shoulder is the X-factor in golf and a longer X-factor is associated with a longer driving distance. Computer simulation suggests that a greater distance is shot off the tee if the length of the back sing is increased. As mentioned previously, the resting pectoralis muscle length, and the dominant shoulder GHJ ER ROM, and the lead shoulder GHJ IR may affect the X-factor stretch in golfers. Because Pectoralis Minor extensibility is a factor which can influence Scapular upward rotation. In the same vein, it is proposed that the degree of upward Scapular rotation in the golfer may also enhance the X-factor length.

HYPOTHESES OF STUDY

Based on the above, it is hypothesised that golfers would have more ER on the dominant shoulder and more IR on the lead shoulder while controls would have no difference in GHJ rotations patterns between sides. It is hypothesised that golfers would have a more upward rotated Scapula on the dominant shoulder compared to the lead side while this pattern would not be significant in controls. In addition, it is hypothesised that golfers would have a longer pectoralis muscle on the dominant side compared with the lead shoulder while the opposite would be found in controls.

METHOD

Intra-rater reliability of tools and procedures used in this section are reported in Chapter 3.

ANALYSIS

Healthy shoulders were included in analysis and sorted according to dominant and non-dominant sides. The mean of three measures was calculated. Outliers were removed. Normality of distributions was ensured with Shapiro Wilk and Kolmogorov-Smirnow tests. Descriptive analysis was run and Paired t-tests used for within-group analysis and independent t-tests used for between-group analysis (significance level is set at 0.05).

RESULTS

Data from 36 male controls (mean age 24.28years STD 6.81 years) were included in the study. Data from 45 professional male golfers on the Challenge Tour (mean age 27.91 years STD 4.74 years) were included in the study.

Within group analysis

Descriptive statistics for male controls are reported in

Table 36. There is no significant differences in side to side comparison between controls in the GHJ total arc of rotation (dominant side133.73° STD 13.76° and non-dominant side 132.13° STD 13.49°), nor in IR (dominant side 52.25° STD 23.81° non dominant side 55.25° STD 12.04°), nor in ER (dominant side 81.18° STD 11.13° and non-dominant side 79.25° STD 10.91°). The dominant Scapula of controls is more upwardly-rotated in both neutral (dominant side 3.72° STD 4.18° and non-dominant side 2.38° STD 3.41°) and in 60° of shoulder abduction(dominant side 10.17° STD 6.36° and non-dominant side 8.53° STD 3.61°). Only the Scapular rotation angle in neutral achieved significance between sides (paired t-test p=0.04). Controls exhibited a significantly longer Pectoralis Minor muscle on the non-dominant side (dominant side 16.30cm STD 1.30cm and non-dominant side 16.84cm STD 1.31cm. Paired T-test p=0.01), however the difference of 0.54cm is less than $MDC_{95\%}$ reported for this measure in Chapter 3. ($MDC_{95\%}$=0.92cm-0.95cm).

Results from paired t-tests showed that there is no difference in side to side comparison between in golfers in the GHJ total arc of rotation (dominant side149.03° STD 11.55° and non-dominant side 154.11° STD 15.87°), nor in IR (dominant side 58.47° STD 11.72° non dominant side 63.19° STD 12.12°), nor in ER (dominant side 89.68° STD 11.65° and non-dominant side 90.29° STD 9.05°). The dominant Scapula of golfers is significantly more upwardly-rotated in neutral (dominant side 5.41° STD 3.22° and non-dominant side 3.17° STD 3.80°) (p=0.01) and in the non-dominant side is significantly more upwardly-rotated in 60° of shoulder abduction(dominant side 6.89° STD 3.77° and non-dominant side 8.89° STD 3.36°)(p=0.01). Golfers had a significantly longer Pectoralis Minor muscle on the dominant side (dominant side 16.89cm STD 1.14cm and non-dominant side 15.82cm STD 1.20cm. Paired T-test p=0.01). The difference of 0.87cm is less than $MDC_{95\%}$ reported for this measure in Chapter 3. ($MDC_{95\%}$=0.92cm-0.95cm).

Table 36. Descriptive for variables and results of t-tests in both golfers and controls.

	Golfers Mean (STD) degrees	Paired t-test golfers p value	Controls mean (STD) degrees	Paired t-test controls p value	Mean difference degrees	Independent t- test p value
Dom TROM	149.03(11.55)		133.73(13.76)		-15.30	0.01
Non- dom TROM	154.11(15.87)		132.13(13.49)		-21.98	0.01
Dom IR	58.46(11.72)		52.25(23.81)		-2.52	0.55
Non- dom IR	63.19(12.12)		55.25(12.04)		-8.50	0.01
Dom ER	89.68(11.65)		81.18(11.13)		-7.94	0.01
Non- dom ER	90.29(9.05)		79.25(10.91)		-11.04	0.01
Dom SR 0°	5.43(3.18)	0.01	3.72(4.18)	0.04	-1.71	0.05
Non-dom SR 0°	3.03(3.72)		2.38(3.41)		0.65	0.40
Dom SR 60°	6.93(3.78)	0.01	10.17(6.36)		3.24	0.01
Non-dom SR 60°	8.67(3.52)		8.53(3.61)		-0.14	0.86
Dom PM	16.67(1.13)cm	0.01	16.30(1.30)cm	0.01	-0.36cm	0.20
Non-dom PM	15.80(1.25)cm		16.84(1.31)cm		1.04cm	0.00

Abbreviations: Dom=dominant; Non-dom = non-dominant; TROM=total range of motion; IR=internal rotation; ER = external rotation; SR= Scapular rotation in coronal plane; PM=Pectoralis Minor length; °=degrees; cm =centimetres; STD = standard deviation.

Between-group analysis

Significant difference was found bilaterally in GHJ total arc of rotation (15.30° -21.98° greater total arc of rotation in golfers p=0.01) and bilaterally in GHJ ER (7.94° -11.04° greater GHJ IR rotation in golfers p=0.01) and in non-dominant GHG IR (8.50° greater GHJ IR rotation in golfers p=0.01) between golfers and controls. It is noted that for all these variables other than dominant shoulder IR golfers have significantly more measures of motion. There was no significant difference in Scapular rotation between golfers and controls in neutral but controls had significantly more upward rotation on the dominant side compared with the dominant side of golfers in 60° of abduction (difference = 3.24° p=0.01). No significant length difference was noted between golfers and controls in Pectoralis Minor length on the dominant side. Significance was achieved in Pectoralis Minor length on the non-dominant side with controls exhibiting a longer Pectoralis Minor length by 1.04 (p=0.01).

DISCUSSION

GHJ rotation

It was hypothesised that golfers would have more ER on the dominant shoulder and more IR on the lead shoulder while controls would have no difference in GHJ rotations patterns between sides. The results do not support his hypothesis as professional golfers were not found to have a unique pattern of increased GHJ rotations on either side. However, golfers' shoulders did have significantly more degrees of rotation than controls in total arc of rotation and external rotation. Golfers have more internal rotation than controls, this was significant in the lead/non-dominant shoulder but not on the dominant side. Results are in keeping with those of previous studies (Brumitt et al., 2008; Sell et al., 2007) in players with a lower handicap than golfers included in this study (Table 1.). Methods used to determine the end of rotation range differs between studies so care needs to be taken when comparing the definite measurements. The present study used the movement of the Coracoid as an indication of end of range whereas previous studies used over pressure and capsular end feel to determine limits range as a result definite measurements would be expected to be less in the current study. Based on this probability it can be conclude that the professional elite golfers than the present study exhibited greater range of shoulder rotations than those reported in the previous studies, but this comparison is conjecture. The aim of the current study is to provide a reference for ranges of shoulder rotation in healthy elite professional golfers for screening purposes it does not examine the influence of stretching in these ranges, therefore, cautiousness needs to be taken when interpreting the clinical implications of the results. Previous research advocating the benefits of aggressive stretching of the shoulder for golfers was done on golfers with a mean age of 58 years who are known to loose range due to increased age. In addition, rotation and increase of range of the X-factor during the back swing does not only occur at the shoulder and although awareness of the golfer’s anatomical shoulder make up is useful it is only one component of the kinetic link in the summation of forces between the hip, and trunk, and upper limbs.

Scientific evidence of what physical characteristics improve performance in sports will give clinicians parameters for training programs and prevention of injury. Golfers’ shoulders have significantly more degrees of rotation than controls in total arch of rotation and external rotation. The professional golfers in this study were not found to have a unique pattern of shoulder rotations between sides. Thus supporting that side to side comparison of shoulder rotational range is appropriate in the golfer when screening. If unique loss of range is noted between sides in the context of a loss of total rotational range it may have consequences for the efficacy of the swing technique as well imply risk to injury

Table 37. Passive GHJ ROM in golfers reported in the literature.

Author	GHJ ER degrees	GHJ IR degrees	TROM degrees	Golf handicap	Method
Brumitt et al., 2008 (Brumitt et al., 2008)	Dom 91.04 (7.85) Lead 90.32(6.54)	Dom 50.11(9.34) Lead 51.76(10.40)	Dom 141.15(10.87) Lead 142.08(13.67)	handicap less than 5	End of capsular range used to determine range of motion
Sell et al., 2007 (Sell et al., 2007)	Right 106.30(11.5) Left 99.30(12.2)	Right 59.7(13.7) Left 65.4(12.8)	NR	scratch	
Current study	Dom 89.68(11.65) Lead 90.29(9.05)	Dom 58.46(11.72) Lead 63.19(12.12)	Dom149.03(11.55) Lead 154.11(15.87)	Challenge tour <scratch	motion of Coracoid determined ROM

Abbreviations: Dom=dominant shoulder; lead= lead shoulder; ROM = range of motion; TROM=total range of motion; GHJER= Glenohumeral external rotation; GHJIR = Glenohumeral internal rotation; NR= not reported.

Scapular rotation in the coronal plane

It was hypothesised that golfers would have significantly more upwardly-rotated Scapula on the dominant side compared with the lead side while this pattern would not be significant in controls. This hypothesis was upheld in golfers when in the neutral shoulder position, the dominant Scapula of golfers is significantly more upwardly-rotated (dominant side 5.41° STD 3.22° and non-dominant side 3.17° STD 3.80°) (p=0.01). In 60° of abduction in golfers it was the non-dominant side which was significantly more upwardly-rotated (dominant side 6.89° STD 3.77° and non-dominant side 8.89° STD 3.36°)(p=0.01). In neutral both golfers and controls had significantly greater upwardly rotated dominant Scapulae when compared to the contralateral side. However on abduction to 60°, the golfers' lead Scapula was significantly more upwardly rotated in comparison to the dominant Scapula being more upwardly rotated in controls. There was no significant difference in Scapula rotation between golfers and controls in neutral but controls did have significantly more upward rotation on the dominant side compared to the dominant side of golfers in 60° of abduction (Δ=3.24°, p=0.01). Asymmetry of Scapula upward rotation is noted in both male controls and sportsmen in neutral and in the early ranges of shoulder abduction. Actual measures of Scapula upward rotation are within the ranges previously reported in the literature (Downar & Sauers, 2005; Laudner et al., 2007; Oyama et al., 2008; Seitz, McClure, Finucane, et al., 2012; Struyf, Nijs, De Graeve, et al., 2011; Thomas et al., 2009). Asymmetry of Scapula position in the coronal plane in sportsmen is also in keeping with previous studies findings (Downar & Sauers, 2005; Laudner et al., 2007; Oyama et al., 2008; Seitz, McClure, Finucane, et al., 2012; Thomas et al., 2009) Although the results of this study are useful, in this study only one component of the five possible degrees of freedom of Scapular motion is examined. Upward rotation occurs not in isolation but in combination with these other Scapular motions, but upward Scapular rotation is the only measurement that can reliably be measured without the use of three dimensional electromagnetic tracking systems, which for obvious reasons are not easily transferable into the clinical setting.

Assessment of Scapular position is often used by clinicians and the asymptomatic side used as a baseline reference, with asymmetry assumed as pathological (Morais & Pascoal, 2013) , however, this study confirms in elite golfers what previous studies have demonstrated (Lukasiewicz et al., 1999; Matsuki, 2011; Morais & Pascoal, 2013; Oyama et al., 2008; Uhl et al., 2009) that asymmetry of Scapula position in the coronal plane is not an indication of risk to injury. Previosu studies (Morais & Pascoal, 2013), found that the magnitude of movement between sides was similar although asymmetry existed in static arm positions. From this it could be concluded that the magnitude of Scapular upward rotation during motion may be more important to evaluate than resting Scapula position. Side to side differences in Scapula positon may be due to optimal adaptation for function. Asymmetry of Scapula position in the coronal plane in golfers as an indicator of risk in the golfers shoulder is not appropriate during screening. Asymmetry of Scapula rotation in the coronal plane in golfers as an indicator of risk in the golfers shoulder is not appropriate during screening. Magnitude of Scapula upward rotation may be a better indicator of risk to injury.

Pectoralis minor length

It was hypothesised that golfers would have a longer pectoralis muscles on the dominant side compared with the lead shoulder while the opposite would be found in controls. This hypothesis was supported by the results of this study. Male controls exhibited a significantly longer Pectoralis Minor muscle on the non-dominant side compared to their dominant side. The opposite was seen in golfers who had a significantly longer Pectoralis Minor muscle on the dominant side. The dominant shoulder pectorals minor length did not differ significantly between controls and golfers but did differ significantly between the controls' non-dominant side and golfers lead side. Because the side with the shortest resting Pectoralis Minor length is the dominant side in controls and this is not significantly different to the same side measure in golfers, and golfers exhibit a shorter Pectoralis Minor length than controls on the non-dominant (lead) side it can be concluded that golfers bilaterally have shorter resting lengths of their Pectoralis Minor muscles. Thus justifying the need for regular maintenance of pectorals muscles length in golfers and attention to correct sequencing of muscle recruitment between the trapezius, serratus anterior, and Pectoralis Minor muscles (Lucado, 2011). Ensuring equal strength length relationships between these agonist and antagonist muscles is suggested in golfers to prevent shoulder pathology.

The range in which a muscle works can range from that of a position of full stretch to maximal shortening with contraction (Clarkson, 2000). The full range of a muscles contractions can be divided into inner range, mid-range and outer range. The position in range where the active length tension curve is optimal is known to be the muscles resting length, which is normally in mid-range (Comerford & Mottram, 2012). The muscle is most effective in generating optimal force in a mid-range nearest the resting length (Comerford & Mottram, 2012; Porter, 2008). Golfers exhibited a unique pattern of lengthened Pectoralis Minor muscle resting length on the dominant side which may help them to optimise range during the back swing, permitting a longer X factor stretch. In addition, the Pectoralis Minor muscle on this side has to generate force in a more lengthened position and hence has a resultant longer resting length. In the back swing the Pectoralis Minor in the golfers' lead shoulder must generate optimal force in a position of cross body adduction and therefore has a shorter resting length. It must be borne in mind that in this study it is assumed that if the sample of golfers are playing at this level of proficiency the physical characteristics observed are beneficial. But what deviation in alignment will to lead to impairment is not known, nor is the length of time an individual must sustain a deviation in alignment before dysfunction begins (Borstad, 2006): time is not normally considered as a variable. A long-term prospective follow up design study is necessary to determine this. Screening and prehab of physical characteristics in the shoulder needs to be sport specific. This study has gone part way in highlighting a unique pattern of resting pectorals minor muscle length in profession elite golfers. Male golfers exhibit a longer resting length of this muscle in the dominant shoulder when compared to age matched controls.

CONCLUSION

Scientific evidence of what physical characteristics improve performance in sports will give clinicians parameters for training programs. Screening and prehab of physical characteristics in the shoulder needs to be sport specific although the link between these physical characterises and sport proficiency needs more research to be established (Sell et al., 2007). This study has gone part-way in establishing these parameters in professional elite golfers with a scratch handicap and may aid in the design of golf training and rehab programs (Sell et al., 2007). The golf swing is a complex motion. Understanding the range of GHJ ROM and asymmetry of Pectoralis Minor length within the sport may be important in risk identification and injury prevention. The results of this study suggest that Scapula position should not be considered a risk factor when screening golfers.

4.3 AHD in the athlete's shoulder

INTRODUCTION

From cadaveric studies it has been concluded that contact between the Supraspinatus Tendon and the Biceps Tendon with the Coracoacromial Ligament occurs between 45° and 60° of shoulder abduction (Burns & Whipple, 1993) and may cause compression of the subacromial structures against the Coracoacromial Arch. Preservation of the AHD is important in athletes to prevent impingement of the Rotator Cuff Tendons in the Subacromial Space. Reduced AHD has been associated with SAIS participants compared to healthy participants in studies using ultrasound, MRI and x-ray (Girometti et al., 2006; Graichen et al., 1999; Hebert et al., 2002; Pijls et al., 2010; Saupe et al., 2012), and proposed as a predictive marker (Cholewinski et al., 2008b). The sporting shoulder adapts to enhance sporting performance and cope with extremes of load (Borsa et al., 2008; Sell et al., 2007). 'It is important to elucidate the correlation between sport adaptation and AHD (Maenhout, Eessel, et al., 2012). Few previous studies have quantified AHD in athletes (Girometti et al., 2006; Maenhout, Eessel, et al., 2012; Silva et al., 2010; Thomas et al., 2013; H. K. Wang et al., 2005). Of these one paper included non-skeletally mature athletes (Silva et al., 2010) and another included symptomatic and asymptomatic shoulders (Girometti et al., 2006) making it difficult to discern whether differences in AHD were actually due to adaptation to demand in the athletes shoulder. Table 38. summarises the previous three studies investigating AHD in asymptomatic musculoskeletally mature athletes. When compared to controls two studies report that the Acromio-Humeral distance in athletes is greater (Maenhout, Eessel, et al., 2012; H. K. Wang et al., 2005), with one study finding this to be the case in female athletes in the coronal plane (Maenhout, Eessel, et al., 2012) and the other in male athletes in the scaption plane (H. K. Wang et al., 2005). One study investigated the percentage reduction in AHD with arm abduction, reporting that this reduction was greater in the elite female athletes' shoulder (Maenhout, Eessel, et al., 2012). Populations and methods between studies make conclusions difficult to collate. Physical characteristics between sporting and non-sporting populations too may confound measures of AHD. From this limited literature it can be conclude that further study is warranted to ascertain if the AHD in athletes adapts due to the demands of sport. It is also proposed that measuring the AHD in the standing position would be more sport specific that in the seated position used by previous studies. It is hypothesised that the AHD is maintained in the athletic population manifesting in less percentage reduction of the AHD during arm abduction. The aim of the study is to establish if differences exist in percentage reduction of this space during arm abduction between athletes and non-athlete control groups.

Table 38. AHD reported in the literature in skeletally mature asymptomatic sports populations

Author	Population	N	Authors concluded	Position of participant	Active vs passive	Plane	Position of GHJ degrees	Transducer position
Thomas et al., 2013 (Thomas et al., 2013)	baseball male	24	AHD throwing = non-throwing	seated	active	coronal	0/90 abd & 90 ER.	Mid-lateral Acromion
Maenhout et al., 2012 (Maenhout, Eessel, et al., 2012)	mixed overhead athletes female	62	↑AHD athletes. ↑ AHD dominant side. < % reduction to 45° abd in athletes	seated	active	coronal	0/60	smallest AHD longitudinal to axis Humerus
Wang et al., 2005 (H. K. Wang et al., 2005)	baseball male	42 baseball 16 controls	↑AHD athletes in Scapular plane but no difference in AHD between groups in the coronal plane.	seated	passive	coronal and frontal	0/90	Mid-lateral Acromion

Abbreviations: AHD = Acromio-Humeral distance; ↑= greater ;< =less; abd =abduction; N= number of participants

METHODS

Intra-rater reliability of tools and procedures used in this section are reported in Chapter 3.

PARTICIPANTS

Data from 30 male asymptomatic controls and 93 male asymptomatic sportsmen were used in analysis (controls: 24 STD 7 years, sportsmen: 25 STD 5 years). Asymptomatic sportsmen consisted of 45 professional golfers paying on the European Challenge Tour, 15 national gymnasts, 18 national boxers, 8 national canoeists, 6 national archers. Data from 30 female asymptomatic controls and 30 female asymptomatic athletes were used in analysis (controls 24 STD four years: sportswomen: 27 STD six years). Asymptomatic sportswomen consisted of: 12 national water polo players, 5 national boxers, 8 national canoeists, 5 national archers. National athletes were representatives of Team GB (Great Britain) Olympic and podium potential squads. Data from 2 symptomatic female water polo players and 1 symptomatic female canoeist were included. Data from 2 symptomatic male golfers and 4 symptomatic male gymnasts were included

DATA ANALYSIS

Healthy and symptomatic shoulders were included in analysis and sorted according to dominant and non-dominant sides. The mean of three measures was calculated. Outliers were removed. Normality of distributions was ensured with Shapiro Wilk and Kolmogorov-Smirnow tests. Data from genders was analysed separately. Graphic presentation was used to observe differences between symptomatic and asymptomatic shoulders in the male and female groups within each sports' discipline. Independent t-tests were used for between-group analysis (significance levels were set at $p < 0.05$).

RESULTS

Intra-and inter-rater reliability was established for the measure of AHD with RTUS and is reported in Chapter 3. In the reliability study the minimal detectable change ($MDC_{95\%}$) was found to be 0.27mm in neutral and 0.25mm in 60 abduction.

Data from 30 male asymptomatic controls and 93 male asymptomatic sportsmen were used in analysis (controls: 24 STD 7 years, sportsmen: 25 STD 5 years). Data from 30 female controls and 30 female athletes were used in analysis (controls 24 STD 4 years: sportswomen: 27 STD 6 years). Data from 2 symptomatic female water polo players and 1 symptomatic female canoeist were included. Data from 2 symptomatic male golfers and 4 symptomatic male gymnasts were included.

Graphic presentation and observed differences between symptomatic and asymptomatic athletes' shoulders in the male and female groups and within each sports' discipline show that in symptomatic athletes' shoulders the AHD is lesser (Figure 36 and Figure 37).

Descriptive statistics for percentage reduction in AHD in male controls and sportsmen are reported in Table 39. A repeated measures ANOVA used to detect between-group differences found no significant differences in AHD between varying disciplines of sport in sportsmen ($p>0.05$). Results show a greater percentage reduction in AHD in male controls compared to sportsmen when the arm is abducted to 60°, this does not achieve significance in the dominant shoulder ($\Delta=0.80\%$ STD 2.60%, $p=0.77$) but is significant in the non-dominant shoulder ($\Delta=5.90\%$ STD 2.50%, $p = 0.02$).

Descriptive statistics for percentage reduction in AHD in female controls and sportswoman are reported in Table 40. A repeated measures ANOVA used to detect between-group differences found no significant differences in AHD between varying disciplines of sport in sportswoman (p>0.05). A greater percentage reduction in AHD is bilaterally present in female controls (Δ=10.76% STD 0.06%, p=0.01 dominant, Δ=15.54% STD 0.07%, p=0.02 non-dominant)

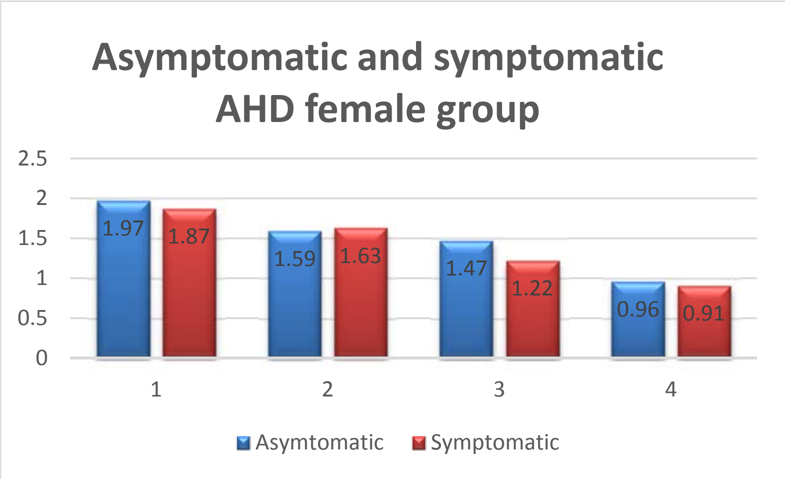

Figure 36. Bar graph illustrating the difference between asymptomatic and symptomatic AHD in female groups
(N= 2 water polo players and 1 canoeist).

Abbreviations: 1 = water polo 0 AHD; 2 = canoe 0AHD; 3 = water polo 60 AHD; 4 = canoe 0AHD.

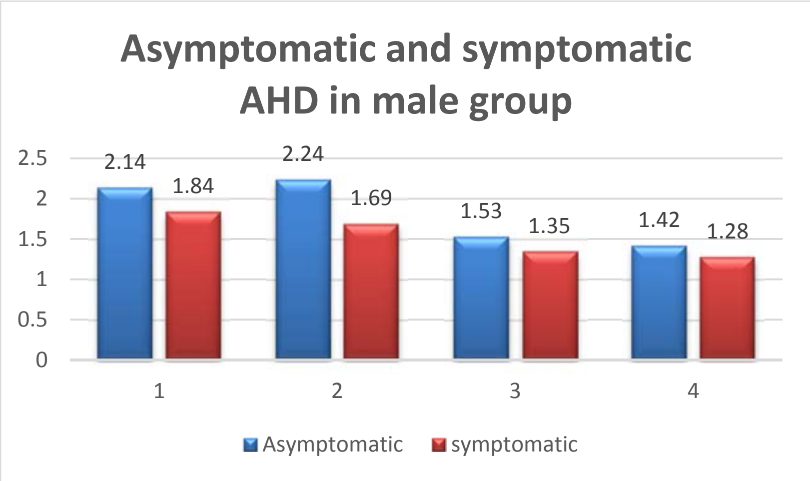

Figure 37. Bar graph illustrating the differences between asymptomatic and symptomatic AHD in male groups
(N= 2 golfers and 4 gymnasts).

Abbreviations: 1 = golf 0 AHD; 2 = gymnast 0AHD; 3 = golf 60 AHD; 4 = gymnast 0AHD.

Table 39. Percentage reduction in AHD in male controls and sportsmen

	Sportsmen mean(STD)	Male controls mean(STD)	Mean difference (STD)	Independent t test p value
% reduction dominant	31.14(13.24)%	30.62(12.13)%	0.80(2.60)%	0.77
% reduction non-dominant	30.06(15.82)%	35.24(10.23)%	5.90(2.50)%	0.02

Abbreviations: %=percentage; cm = centimetres; STD=standard deviation; °=degrees arm abduction

Table 40. Percentage reduction in AHD in female controls and sportswomen

	Sportswomen mean(STD)	Female controls mean(STD)	Mean difference (STD)	Independent t test P value
% reduction dominant	28.78(0.19)%	39.54(0.24)%	10.76(0.06)%	0.01
% reduction non-dominant	27.78(0.28)%	43.32(0.22)%	15.54(0.07)%	0.02

Abbreviations: %=percentage; cm = centimetres; STD=standard deviation; °=degrees arm abduction

DISCUSSION

Although numbers of symptomatic athletes' shoulders were small, graphic presentation and observed differences between symptomatic and asymptomatic athletes' shoulders in the male and female groups and within each discipline of sports show that in symptomatic athletes' shoulders the AHD is lesser. Reduced AHD has been associated with SAIS subjects compared to healthy subjects in studies using RTUS, MRI and x-ray (Girometti et al., 2006; Graichen et al., 1999; Hebert et al., 2002; Pijls et al., 2010; Saupe et al., 2012). These results encourage further investigation into the factors which may influence the AHD in the athletes' shoulder.

There is a larger percentage reduction in AHD in male controls when the arm is abducted to 60°. This does not achieve significance in the dominant shoulder but is significant in the non-dominant shoulder. The lack of significant difference in reduction in AHD in the dominant shoulder of male controls when compared with sportsmen may be attributable to the fact that, although male controls were non-sportsmen, the dominant shoulder is nevertheless subject to higher loads and activity than the non-dominant shoulder and hence may likewise adapt to preserve the AHD. Female controls have a significantly greater percentage reduction in AHD bilaterally when compared with sportswomen. It is conjectured that female controls' shoulders are exposed to less load than their male counterparts. This would explain why bilateral significance was achieved when comparing the percent reduction in AHD in the female population in both shoulders but only in the non-dominant shoulder in the male population. Results concur with a similar study (Maenhout, Eessel, et al., 2012) which reports that percentage reduction in AHD was less in the elite female athlete compared with recreational athletes.

The two previous studies measure AHD in 90 abduction (Thomas et al., 2013; H. K. Wang et al., 2005). The current study used the 60 degree arm abducted position because the 90° arm position for measuring AHD with RTUS has been reported to have poor reliability in a previous study (Duerr, 2010). Accordingly, the results of the current study cannot be compared directly with the two previous studies.

Previous studies have reported that short term loading decreased the AHD (McCreesh, Donnelly, & Lewis, 2014) in non-sportsmen by as much as 11% (Thompson, Landin, & Page, 2011), a process that, if not counteracted, could be pathogenic in Impingement Syndrome. Preservation of the AHD in athletes is important to prevent impingement of the Rotator Cuff Tendons in the Subacromial Space (Burns & Whipple, 1993). The finding that elite athletes of both genders have a smaller percentage reduction in AHD during arm abduction when compared with non-sporting controls may indicate an adaptive response to maintain AHD in the shoulder of athletes. Factors which influence the Subacromial Space are considered to be multifactorial (Mackenzie, Herrington, Horsley, & Cools, 2015; Seitz et al., 2011) and it may be that adjustment of these factors occurs in the athlete's shoulder. For example, hyper-kyphosis (Gumina et al., 2008) has been associated with AHD and athletes may sustain a more upright posture during arm abduction. A study (Seitz, McClure, Lynch, et al., 2012) noted a non-significant increase in the AHD with manual upward rotation and posterior tilting of the Scapula, so another explanation could be that athletes develop Scapular kinematics which preserve the AHD. A third explanation could be that athletes evolve neuro-muscular dynamic shoulder control to preserve this space. The operation of these extrinsic mechanical factors is conjecture and requires further research. An intrinsic cause for a smaller percentage reduction in AHD may be that the Biceps Tendon and the Supraspinatus Tendon are thicker as has been noted in a study comparing college baseball athletes with controls (H. K. Wang et al., 2005). The thickness of the Tendon may restrict the extent to which the Subacromial Space can be reduced.

Limitations

The results of this study must be interpreted in the light of its limitations. AHD is a 2 dimensional measurement of a 3 dimensional space. Compromise of this volume cannot be totally quantified by measurement of AHD; it can only be used as a guide. A second limitation is that the range of arm elevation in which the ultrasound measurement of AHD is possible is limited to a maximum of 60° of elevation because of acoustic shadows in higher ranges of arm elevation. To what extent the measurement of AHD in 60° of abduction can be extrapolated to influence the Subacromial Space in higher ranges of arm elevation is unclear. Limiting the extrapolation of these results is the fact that asymptomatic subjects were used in this study; thus, a direct relationship between impairment cannot be assumed. Furthermore, muscle contractions around the Humeral Head produce larger translations during arm movement and can therefore impact on the AHD. In this study, Acromio-Humeral distance was evaluated during an isotonic hold of the arm; this may not represent true influence of load on the AHD. Variety in athletic population is paradoxically a strength and weakness in this thesis. It is a strength, in as much as it allowed for the investigation of the AHD in a range of sporting disciplines but although it was determined via ANOVA analysis that no differences in AHD existed between sporting disciplines, it can be argued that the numbers per sporting discipline were not sufficient to ensure adequate power for such analysis. The population in this study was representative of sports which place high demands on the shoulder and the results of this study may not necessarily apply to all sportspersons, since forces in the shoulder are sport-specific (Usman, McIntosh, & Fréchède, 2011).

CONCLUSION

Although numbers of symptomatic athletes' shoulders were small, graphic presentation and observed differences between symptomatic and asymptomatic athletes' shoulders in the male and female groups within each sports' discipline show that in symptomatic athletes' shoulders the AHD is lesser. Preservation of the AHD in athletes is important to prevent impingement of the Rotator Cuff Tendons in the Subacromial Space. The finding that elite athletes of both genders have a smaller percentage reduction in AHD during arm abduction (although not significant in the non-dominant shoulder of male athletes) when compared with non-sporting controls may indicate an adaptive response to maintain AHD in the shoulder of athletes.

Chapter 5 Association between factors influencing the AHD

List of abbreviations

AHD	Acromio-Humeral distance
GERG	Glenohumeral external rotation gain
GHJ	Glenohumeral joint
GIRD	Glenohumeral internal rotation deficit
IS	Impingement Syndrome
$MDC_{95\%}$	minimal detectable change
RTUS	real time ultrasound
SAIS	Subacromial Impingement Syndrome
SEM	standard error of the measure
STD	standard deviation
SR	Scapular rotation
TROM	total rotational range of motion
US	ultrasound

Under review: Association between extrinsic factors and the Acromio-Humeral distance. **Authors**: Tanya Anne Mackenzie, Lee Herrington, Ian Horsley, Lennard Funk, and Ann Cools. Re**submitted**: (30 December 2015) Manual Therapy.

Chapter overview

To establish if there is an association between the independent variables of Scapular rotation, GHJ internal rotation, GHJ external rotation, Pectoralis Minor length, Thoracic curve, shoulder activity level and the dependant variables: AHD in 0° abduction, AHD in 60° abduction, and percentage reduction in AHD during abduction a correlation analysis was run. To estimate the associations among variables a regression analysis is run. As the participants, methods, power analysis, and data analysis are conjoint to all variables, these are first reported, followed by a section on each independent variable. Each independent variable is covered under its own pertinent headings: introduction, results, discussion and conclusion.

METHODS

Intra-rater reliability of tools and procedures used in this section are reported in Chapter 3.

PARTICIPANTS

Data from 72 male control shoulders (24.28years STD 6.81 years), 54 female control shoulders (26.56 STD 6.37 years), 172 elite sportsmen's shoulders (25.19 STD 5.17 years) and 50 elite sportswomen's shoulders (24.20 STD 4.09) were included in the analysis. Sportsmen included golfers (professional playing on the European Challenge Tours) and sportsmen representing Great Britain at national level in gymnastics, canoeing, boxing, water polo, and archery. Table 21 and Table 22 in Chapter 4 summarise the participants included. Criteria for inclusion are listed in Chapter 3 under the heading "Participants". All athletes were evaluated during training camps and golfers were evaluated on tour 48 hours prior to the tournament. Each participant was asked to read and sign a consent form approved of by the University of Salford Research Ethics Committee**.**

Power analysis for Pearson's Correlation

It was calculated that 37 subjects were required to achieve a 70% power to show that the correlation is greater that 0.4 (which indicates that the correlation is at least substantial) and a 0.05 significance level, assuming the true correlation is 0.8. An estimate of 0.8 was observed in a pilot study of 20 similar subjects.

DATA ANALYSIS

Statistical Package for Social Sciences for Windows version 20.0 (SPSSinc. Chicago, IL), was used for statistical analysis. Outliers for each variable were computed and removed before correlation analysis. The Correlation Coefficient [r], which is known as the Pearson product-moment, was calculated to determine the association between variables and AHD for all subjects. The value of (r) indicates that the correlation coefficient can range from -1 (perfect negative association) to 0 (no correlation), to +1 for a perfect positive correlation (Triola, 2009). Statistical significance of the correlation coefficient is equally important, with the p-value indicating the probability that the observed association could have occurred by chance. A small p-value is evidence that the null hypothesis is false and the attributes are, in fact, correlated (Triola, 2009). Pearson's correlations values (r) were interpreted as follows: weak or no association =0.0-0.2, weak association =0.2-0.4, moderate association =0.4-0.6, strong association =0.6-0.8 and very strong association =0.8-1.0 (Salkind, 2007). Where more than one independent variable had a determined association with the dependant variable a multiple regression analysis was run. To confirm that linear regression model was appropriate for the data, suitability of the model was assessed by defining residuals and examining residual plots. The correctness of the linear regression was confirmed with the mean of all the residuals equalling zero, being homoscedastic (the assumption that that the dependent variable exhibits similar amounts of variance across the range of values for an independent variable), and that no outliers were present.

5.1 Correlation between Scapular rotation in the coronal plane and AHD

The Scapula is considered to be imperative to shoulder function as it maintains the centre of rotation of the Glenoid (Kibler, 1998), is a kinetic chain link between upper and lower extremities (Kibler, 1998; Paine & Voight, 1993) and provides an anchor to muscles (Burkhart et al., 2003) which control shoulder motion.

The association between Scapular position and AHD has been explored by two previous studies (Silva et al., 2010; Thomas et al., 2013). These two studies are summarised in Table 41. In the study by Silva et al. 2010, the population studied was not skeletally mature with a wide range of ages studied i.e. 11-18 years. A great variation in AHD measures due to varying stages of skeletal growth between these ages would therefore be expected. In the study by Thomas et al., 2013, the 90° shoulder abduction and 90° elbow flexion position with combined GHJ external rotation was used. RTUS of the AHD in this position has been reported in previous studies as unreliable. These studies report no correlation between Scapular position assessed with a digital inclinometer and AHD.

As the arm elevates, the Scapula has been shown to rotate progressively upwardly and to post tilt in healthy individuals (de Groot, H, van Woensel, & Helm, 1999; Ludewig et al., 1996b). In contrast, in impingement subjects it has been noted that the Scapula has decreased upward rotation, decreased post tilt and increased internal rotation (Endo et al., 2001; Flatow et al., 1994; Hebert et al., 2002; Kibler, 1998; Ludewig & Cook, 2000; Struyf, Nijs, De Graeve, et al., 2011; Thigpen, Padua, Morgan, Kreps, & Karas, 2006). Other studies (Graichen et al., 2001; Hebert et al., 2002; Warner et al., 1992) all report no significant difference in Scapular upward rotation in subjects with impingement. In sportsmen, during active elevation the Scapula was found to be more upwardly-rotated (Cools, Cambier, & Witvrouw, 2008; Meyer et al., 2008) – these studies suggest that this mechanism lifts the Acromion for increased AHD.

One study (Seitz, McClure, Lynch, et al., 2012) evaluated the effect of the Scapular assistance test, which manually places the Scapula in upward rotation, on AHD in subjects both with and without Scapular dyskinesia. This study found firstly no difference in AHD between groups, and secondly, that the Scapular assistance test increased AHD but that changes in the measure of AHD failed to achieve statistical significance.

The aim of this study was to investigate the association between Scapular rotation in the coronal plane and Acromio-Humeral distance

Table 41. Studies correlating AHD with physical characteristics in the shoulder.

Author	Population	N=	Authors concluded	Position of participant	plane	Position of GHJ degrees	Transducer position	limitations
Thomas et al., 2013. (Thomas et al., 2013)	AS baseball	24	No correlation in SUR and AHD	seated	coronal	0 90 abd & 90 ER.	mid-lateral Acromion	Other studies report 90 abd not a reliable position to measure AHD
Silva et al., 2010. (Silva et al., 2010)	AS tennis (11-18yrs)	53 tennis 20 controls	↓ AHD in presence of Scapular dyskinesia.	NR	coronal	0/60	Smallest AHD.	Subjective evaluation of Scapular dyskinesia Skeletally immature population

Abbreviations: AS=asymptomatic; SUR=Scapular upward rotation, AHD= Acomio-Humeral distance; NR = not reported; abd = abduction; ↓= decrease.

.

RESULTS

Descriptive statistics for Scapular rotation and AHD are summaries in Table 43 for the male population and in Table 45 for the female population. Using Pearson's correlations there was not a significant correlation between Scapular rotation in the coronal plane and Acromio-Humeral distance in either the resting or the 60° abducted arm positions for all groups (Male controls: neutral arm position r=0.16 p=0.18, 60° abducted arm position r=0.05 p=0.70 see Table 42. Female control group: neutral arm position r=0.05 p=0.73, 60° abducted arm position r=-0.02 p=0.92 see Table 44. Sportsmen: neutral arm position r=0.03 p=0.74, 60° abducted arm position r=-0.14 p=0.08 see Table 42. Sportswomen neutral arm position r=0.14 p=0.36, 60° abducted arm position r=-0.28 p=0.70 see Table 44). Scatter plots to illustrate the best fit linear association between Scapular rotation and AHD in neutral for male controls (Figure 38) and male athletes (Figure 40) were prepared. Scatter plots to illustrate the best fit linear association between Scapular rotation and AHD in 60° abduction for male controls (Figure 39) and male athletes (Figure 41) were prepared.

Table 42. Results of Pearson's correlation between Scapular rotation and AHD in male population.

Variable	Group	Mean degrees	STD degrees	Pearson's correlation to AHD	
				r value	p value
0° SR	Male controls	3.04	3,84	0.16	0.18
	sportsmen	4.15	3.42	0.03	0.74
60° SR	Male controls	9.34	5.18	0.05	0.70
	sportsmen	8.55	3.90	-0.14	0.08

Abbreviations: SR = Scapular rotation; STD=standard deviation; AHD = Acromio-Humeral distance; °=degrees abduction.

Table 43. Descriptive statistics for AHD in male population.

Variable	Group	Mean cm	STD cm
0° AHD	Male controls	1.69	0.22
	sportsmen	1.64	0.24
60° AHD	Male controls	1.13	0.22
	sportsmen	1.13	0.23

Abbreviations: AHD = Acromio-Humeral distance; STD = standard deviation; cm = centimetres; °=degrees abduction.

Table 44. Results of Pearson's correlation between Scapular rotation and AHD in female population.

Variable	Group	Mean degrees	STD degrees	Pearson's correlation to AHD	
				r value	p value
(0°) SR	female controls	0.86	3.32	0.05	0.73
	sportswomen	2.02	3.48	0.14	0.36
(60°) SR	female controls	7.80	4.12	0.02	0.92
	sportswomen	7.86	3.41	-0.28	0.07

Abbreviations: SR = Scapular rotation; STD=standard deviation; AHD = Acromio-Humeral distance; °=degrees abduction)

Table 45. Descriptive statistics for AHD in female population

Variable	Group	Mean cm	STD cm
0° AHD	female controls	1.42	0.22
	sportswomen	1.59	0.22
60° AHD	female controls	1.00	0.18
	sportswomen	0.98	0.23

Abbreviations: AHD = Acromio-Humeral distance; STD = standard deviation; cm = centimetres; °=degrees abduction.

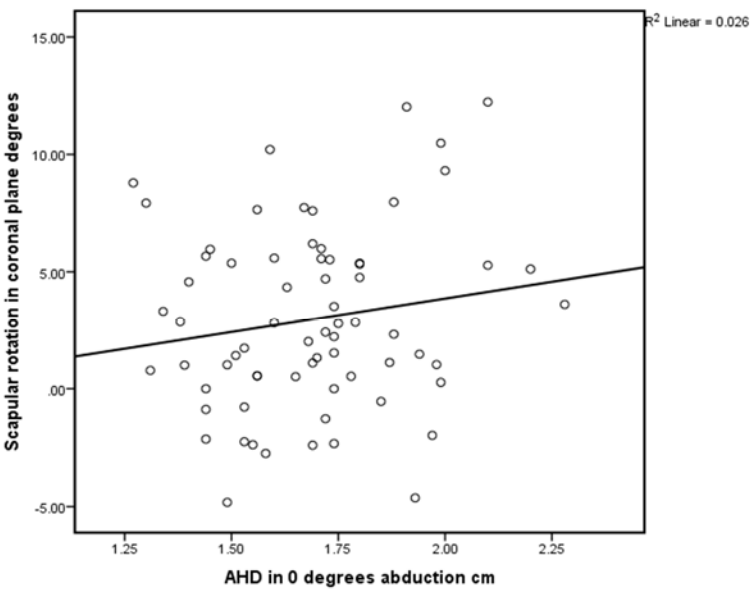

Figure 38. Scatter plot illustrating the best fit linear association between Scapular rotation angles in the coronal plane and AHD in neutral shoulder position in male controls.
Abbreviations: AHD = Acromio-Humeral distance; abd = abduction, cm=centimetres, SR = Scapular rotation.

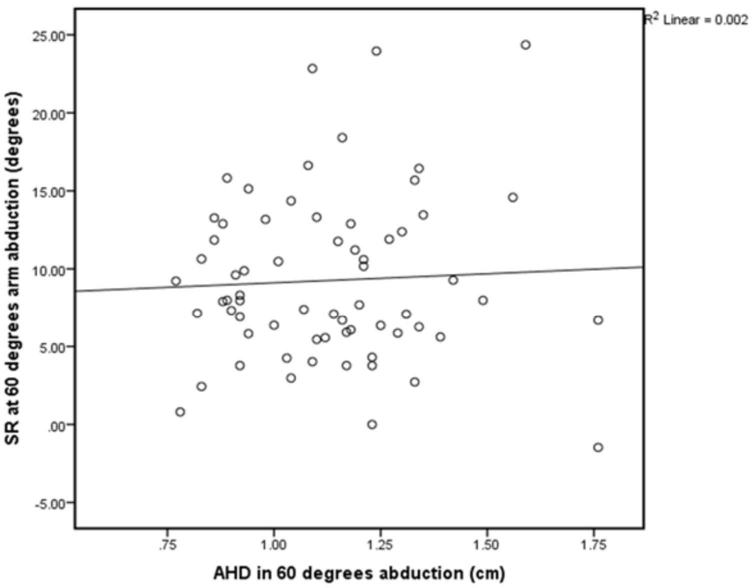

Figure 39. Scatter plots illustrating the best fit linear association between Scapular rotation angles in the coronal plane and AHD in 60° abduction of the shoulder in male controls.

Abbreviations: AHD = Acromio-Humeral distance; abd = abduction, cm=centimetres, SR = Scapular rotation.

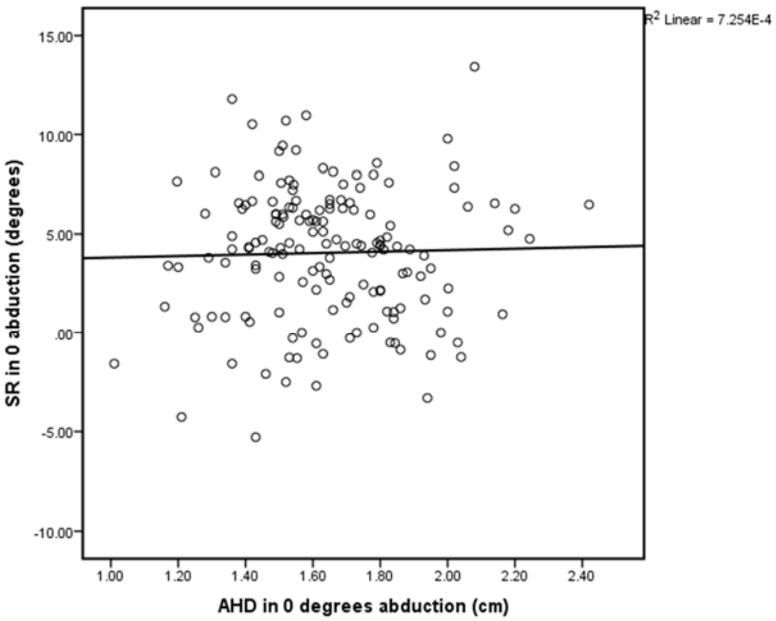

Figure 40. Scatter plot illustrating the best fit linear association between Scapular rotation angles in the coronal plane and AHD in neutral shoulder position in sportsmen.

Abbreviations: AHD = Acromio-Humeral distance; abd = abduction, cm=centimetres, SR = Scapular rotation.

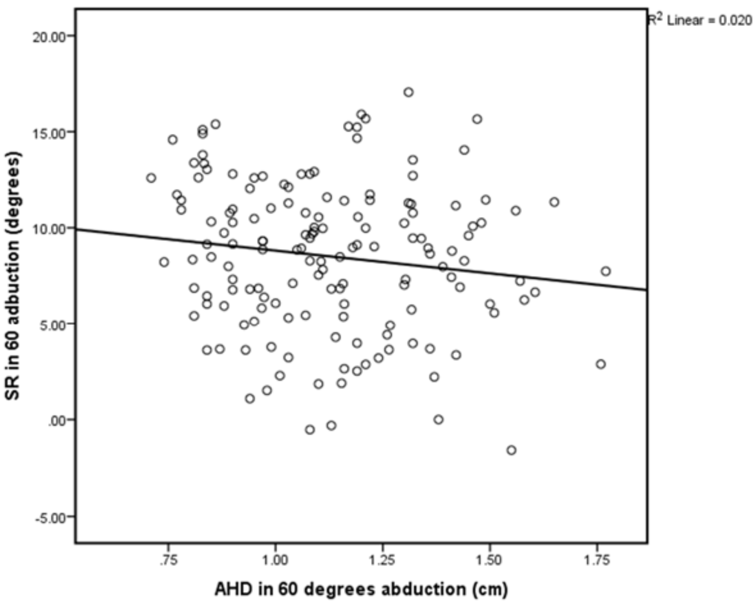

Figure 41. Scatter plot illustrating the best fit linear association between Scapular rotation angles in the coronal plane and AHD in 60° abduction of the shoulder in sportsmen
Abbreviations: AHD = Acromio-Humeral distance; abd = abduction, cm=centimetres, SR = Scapular rotation. cm=centimetres.

DISCUSSION

The results of the present study concur with those of Thomas et al. (Thomas et al., 2013) with the arm at rest and isometrically held in abduction of 60° in the coronal plane. No correlation was found between Scapular rotation in the coronal plane and AHD. Although both studies report the same results it must be borne in mind that Thomas et al., 2013, not only assessed AHD and Scapular position during arm abduction to 90° but also added an additional variable as the Glenohumeral joint was also externally rotated.

Factors influencing Scapular upward rotation may include fatigue of the lower mid and upper trapezius and the serratus anterior (Ebaugh, McClure, & Karduna, 2005) studies have reported an association between muscle fatigue and changes in Scapular upward rotation (McQuade et al., 1998; Su et al., 2004; Tripp & Uhl, 2003; Tsai, McClure, & Karduna, 2003). Also contributing to a decrease in Scapular upward rotation could be peri-capsular restraint in the GHJ and activity of the peri-Scapular musculature (Laudner et al., 2007). Interesting debate is offered by Ratcliffe, Pickering, McLean, & Lewis, 2014, who propose that Scapular upward rotation could be a consequence of intrinsic mechanisms within the tissues of the subacromial space due to oedema, thickening and fibrosis and that these increase in the volume of this space and consequently tilt the scapular upwards and posteriorly.

Based on reported research the link between Scapular orientation and SAIS is tenuous (Ratcliffe et al., 2014) with contradictory findings reported in the literature. In their systemic literature review exploring this link, Ratcliffe, Pickering, McLean, & Lewis, 2014, site population dissimilarity, lack of vigour in reliability testing, and methodological inconsistencies as a possible reason for this. Or alternately these results may be a manifestation of the complexity and multifactorial nature of SAIS and due to lack of precision in the diagnosis of SAIS (Ratcliffe et al., 2014). Moreover it may be a reflection that ideal scapular position does not exist.

Limitations

Limitations common to all of the correlation studies are listed at the end of this chapter. Pertinent to this section is the limitation that Scapular rotation includes movement over three axes in three planes, and this method at present only evaluates the movement of the Scapula in the coronal plane and is limited to the early ranges of arm abduction.

CONCLUSION

Scapular rotation in the coronal plane was not found to correlate to Acromio-Humeral distance in neutral or in early range abduction in controls or in national level elite athletes of varying disciplines.

5.2 Correlation between GHJ internal rotation and AHD.

Decrease in GHJ IR has been associated with shoulder impingement in overhead athletes (Borich et al., 2006; Harryman et al., 1990; Tyler, Nicholas, Roy, & Gleim, 2000) and with internal impingement (Myers et al., 2006). The throwing arm of baseball players has been reported to have posterior shoulder tightness manifesting in a reduction of GHJ IR (Laudner, et al., 2010; Laudner et al., 2006; Tyler, et al., 2009). This may be attributed to adaptation of the posterior capsule or changes in posterior shoulder contractile tissues (Burkhart et al., 2003; Laudner et al., 2006). One previous author has assessed the effect of GHJ IR on AHD (Maenhout, Eessel, et al., 2012) reporting that increase of GHJ IR after stretching increased the AHD in a group of athletes from varying disciplines. This is the first study to assess the association between AHD and GHJ IR. The purpose of this study is to investigate the association between range of Glenohumeral internal rotation and Acromio-Humeral distance in national level elite male and female athletes.

RESULTS

Male group data

Using Pearson's correlations there was not a significant correlation between Glenohumeral internal rotation and AHD in either the resting or the 60° abducted arm positions for male controls (resting arm position r=05. p=0.72.; 60° arm abduction r=-0.4 p=0.77.). Pearson's correlation analysis computed a weak positive significant association between Glenohumeral internal rotation and resting Acromio-Humeral distance in sportsmen (r= 0.26, p=0.03), with linear regression the overall model fit was R^2 = 0.08. There was not a significant correlation between variables in the 60° abducted arm positions for male athletes (r=0.13 p=0.29).

For the female groups, both controls and sportswoman, no significant correlation was found between GHJ IR and AHD (resting arm position: controls r=03 p=0.83 and sportswomen r=0.16 p = 0.30; 60° arm abduction controls r=-0.05 p=0.70 and sportswomen r= 0.30 p = 0.06) as presented in Table 46. Scatter plots illustrating the best fit linear association between Glenohumeral internal rotation and AHD in sportsmen is shown in Figure 42 and in sportswomen in Figure 43.

Table 46. Descriptive statistics and Pearson's correlation for Glenohumeral internal rotation and AHD

Variable	Scapular rotation	Mean degrees	STD degrees	Pearson's correlation to ahd 0° r = (p=)	Pearson's correlation to ahd 60° r = (p=)
GHJ IR	male controls	55.59	18.74	0.05(0.72)	-0.04(0.77)
	sportsmen	54.18	13.45	0.26(0.03)	0.14(0.29)
	female controls	55.88	10.82	0.03(0.83)	-0.05(0.70)
	sportswomen	53.63	9.09	0.16(0.30)	0.30(0.06)

Abbreviations: ahd=Acromio-Humeral distance; GHJIR=Glenohumeral internal rotation; STD=standard deviation; °=degrees abduction.

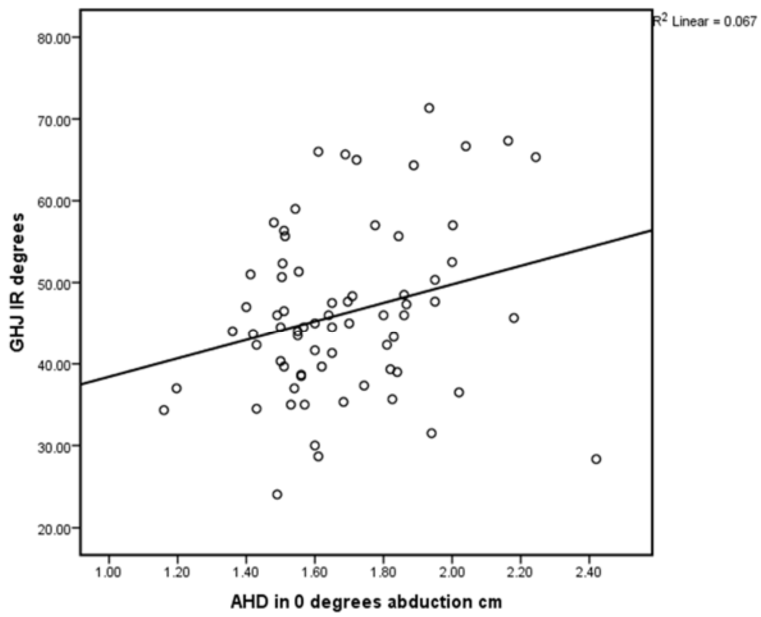

Figure 42. Scatter plot illustrating the best fit linear association between Glenohumeral internal rotation and AHD in neutral shoulder position in sportsmen.

Abbreviations: GHJ IR= Glenohumeral joint internal rotation; AHD = Acromio-Humeral distance; cm = centimetres.

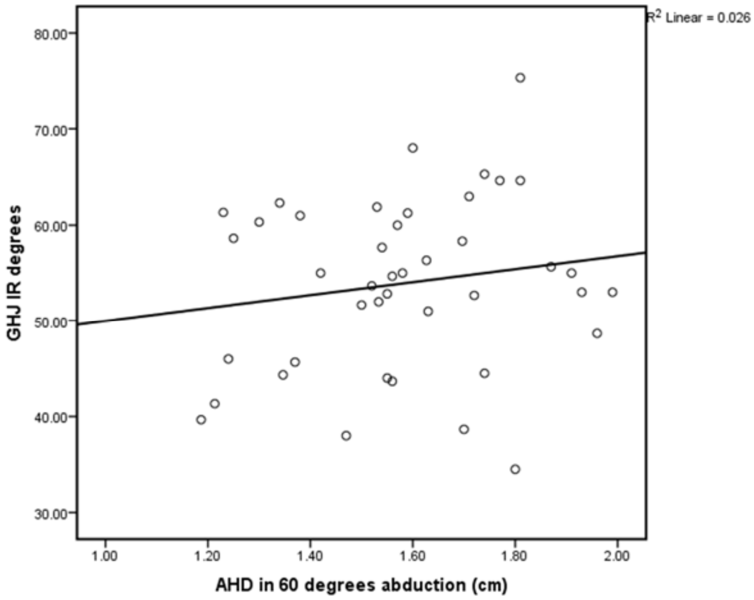

Figure 43. Scatter plot illustrating the best fit linear association between Glenohumeral internal rotation and AHD in 60° abduction of the shoulder in sportswomen.
Abbreviations: GHJ IR= Glenohumeral joint internal rotation; AHD = Acromio-Humeral distance; cm =centimetres.

DISCUSSION

In the present study range of shoulder internal rotation was found to have a weak influence on resting AHD in sportsmen, however no correlations between shoulder internal range was noted in 60° of arm abduction. Results support the pathogenic explanation that loss of internal rotation could be influential in SAIS in the sporting population in lower ranges of arm elevation. However, when the arm is abducted other factors may play a part in determining AHD. An *in vitro* study (Muraki et al., 2010) report that a simulated tight posterior capsule leads to an increased contact pressure under the subacromial arch (Huffman et al., 2006; Muraki et al., 2010). A loss of 20° or more of internal rotation (Wilk et al., 2011) has been correlated to injury. Athletes with a total motion deficit of five degrees had a higher rate of shoulder injury. A change in GHJ IR has been noted over the course of a season and warrants monitoring in sportsmen (Dwelly, Tripp, Tripp, Eberman, & Gorin, 2009; Thomas et al., 2009).

CONCLUSION

Range of Glenohumeral internal rotation was found to have a weak influence on resting Acromio-Humeral distance in sportsmen only. No correlation between Glenohumeral internal range and AHD was noted in the early ranges of arm abduction.

5.3 Correlation between GHJ external rotation and AHD.

A gain in ER is often seen in sports that require throwing (Herrington, 1998). When performing overhead action it is suggested (Karduna, McClure, Michener, & Sennett, 2001), that in order to keep the joint centre of rotation in the Glenoid, the cuff muscles had to apply additional forces. This in turn offsets tension in the capsular ligaments. With sports requiring repetitive motion of the shoulder, these cuff muscles fatigue and are less able to control the humeral head, thus leading to pathological change in the joint (Chen et al., 1999; Herrington, 1998). GHJ motion is more reflective of capsular mobility than other motions involving complex ROM (Downar & Sauers, 2005; Sauers et al., 2001). Surgeons have noted arthroscopically that the Rotator Cuff Tendons and the posterior superior labrum fray on the articular side in throwing athlete's shoulders (Davidson et al., 1995). Increased Glenohumeral rotation, angulation, and anterior translation can lead to injury of the Rotator Cuff between the posterior superior Glenoid rim (Davidson et al., 1995) when the arm is abducted and externally rotated as occurs in the late cocking phase of throwing. Jobe and Llanotti, 1995 (Jobe & Lannotti, 1995) have described the instability theorem in which athletes requiring greater Glenohumeral range of motion in order to perform develop occult or subtle GHJ instability: this gives rise to Rotator Cuff injury during the late cocking phase of throwing. A study (Grossman et al., 2005) in cadavers simulated anterior laxity and post-capsule tightness and noted that the HOH moved more posteriorly superiorly (Crockett et al., 2002). In theory, this would compromise the AHD. The aim of this study is to evaluate if an association exists between the AHD and GHJ ER range and total arc of GHJ rotation.

RESULTS

Descriptive statistics for percentage reduction in AHD are reported in Table 49. Using Pearson's correlations, there was a significant correlation between Glenohumeral external rotation and total arc of rotation to percentage reduction in Acromio-Humeral distance in male controls (Glenohumeral external rotation r=040 p=0.01. Total arc of rotation r=0.32 p=0.01.), with linear regression the overall model fit was R^2 = 0.15 for GHJ external rotation and R^2 = 0.09 for total arc of rotation. No significant correlation between these variables existed in sportsmen (r= 0.02, p=0.77) (Table 47). No significant correlation between these variables existed in female controls nor in sportswomen see Table 48. Scatter plots illustrating the best fit linear association between Glenohumeral external rotation and percentage reduction in AHD in male controls is shown in Figure 44. Scatter plots illustrating the best fit linear association between TROM and percentage reduction in AHD in male controls is shown in Figure 45.

Table 47. Pearson's correlation analysis result for male groups between Glenohumeral external rotation and percentage reduction in AHD

Variable	group	Mean degrees	STD degrees	Pearson's correlation to % reduction ahd r = (p=)
GHJ ER	Male controls	80.21	10.99	0.40(0.01)
	sportsmen	84.74	11.16	0.02(0.77)
TROM	Male controls	132.93	13.55	0.32(0.01)
	sportsmen	138.99	18.88	-0.10(0.20)

Abbreviations: AHD=Acromio-Humeral distance; GHJ ER=Glenohumeral external rotation; TROM=total range of rotational motion; STD standard deviation; %=percentage.

Table 48. Pearson's correlation analysis result for female groups between Glenohumeral external rotation and percentage reduction in AHD.

Variable	Scapula rotation	Mean degrees	STD degrees	Pearson's correlation to % reduction ahd r = (p=)
GHJ ER	female controls	87.38	11.97	0.18(0.22)
	sportswomen	82.55	12.82	0.22(0.16)
TROM	female controls	144.30	15.88	0.19(0.19)
	sportswomen	138.17	16.03	-0.11(0.48)

Abbreviations: AHD = Acromio-Humeral distance; GHJ ER=Glenohumeral external rotation; TROM=total range of rotational motion; STD standard deviation; %=percentage.

Table 49. Descriptive results for percentage reduction in AHD.

Variable	Group	Mean %	STD %
% reduction AHD	male controls	33	11.34
	sportsmen	30.38	14.62
	female controls	28.84	12.78
	sportswomen	38.16	12.56

Abbreviations: STD standard deviation; %=percentage; AHD = Acromio-Humeral distance.

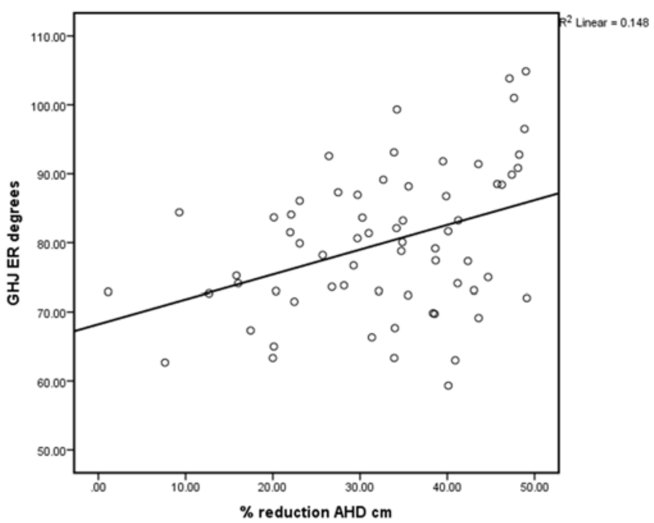

Figure 44. Scatter plot illustrating the best fit linear association between Glenohumeral external rotation and AHD in neutral shoulder and 60° abduction of the shoulder in male controls.

Abbreviations: GHJ ER= Glenohumeral joint internal rotation, AHD= Acromio-Humeral distance; %=percentage.

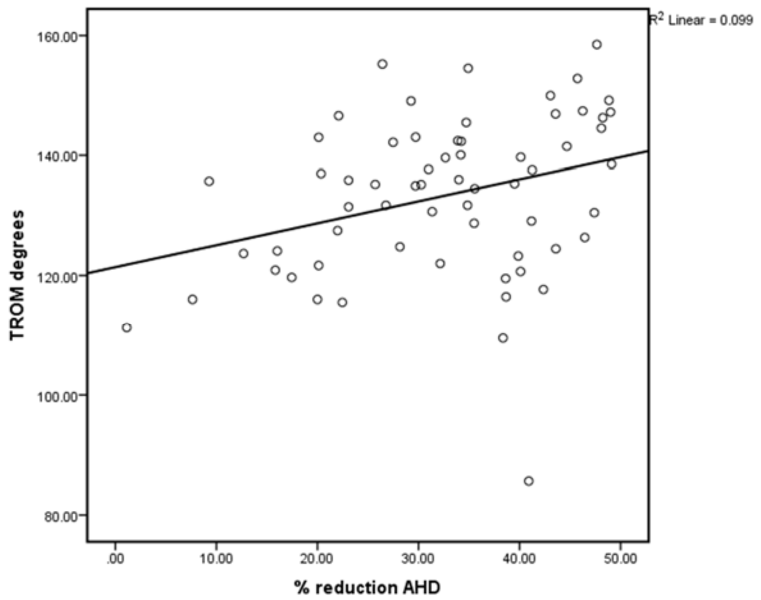

Figure 45. Scatter plot illustrating the best fit linear association between total rotational arc and AHD in neutral shoulder and 60° abduction of the shoulder, in male controls.
Abbreviations: TROM= total range of motion, AHD= Acromio-Humeral distance; %=percentage.

DISCUSSION

Increased contact between the posterior superior Glenoid and the posterior cuff is thought to be due to increased Glenohumeral range of motion, laxity of the Glenohumeral joint, and humeral retroversion, all of which have been detected on the throwing side of athletes (Reinold, Wilk, et al., 2009). A perpetuating cycle in which subtle laxity of the Glenohumeral capsule leads to internal impingement (Davidson et al., 1995), further stretching of the inferior Glenohumeral ligament, and subsequently increased Humeral Head translation is considered part of the process in Internal Impingement Syndrome . Results from an *in vitro* study support the view that excessive external rotation of the shoulder may stretch the inferior Glenohumeral ligament, and result in Internal Impingement Syndrome (Mihata et al., 2010).

Using Pearson's correlations, there was a significant correlation between Glenohumeral external rotation and total arc of rotation to percentage reduction in Acromio-Humeral distance in male controls: with linear regression the overall model fit was $R^2 = 0.15$ for GHJ external rotation and $R^2 = 0.10$ for total arc of rotation. No significant correlation between these variables existed in sportsmen. Strengthening programs planned to control excessive joint rotational range may be beneficial in avoiding injury (Burkhart et al., 2003; Chen et al., 1999; Herrington, 1998; Reinold, Escamilla, et al., 2009).

CONCLUSION

Greater Glenohumeral external rotation gain correlates with greater percentage reduction in Acromio-Humeral distance in resting and the early ranges of arm abduction in male controls but not in elite male athletes. GERG is reported to contribute to the pathogenesis of Internal Impingement Syndrome, this finding implies that GERG could also impact on the AHD. This finding is not seen in national level elite sportsmen in whom additional factors such as dynamic stabilisers may influence AHD during arm abduction.

5.4 Correlation between Pectoralis Minor and AHD.

To ensure that the Scapula is optimally positioned in relation to the Humerus, and thus preserve the AHD, the correct length, strength, and sequence of recruitment of Scapula Thoracic muscles is important to control Scapular motion (Lucado, 2011). Pectoralis minor is likely to play a significant role in Scapular orientation. It originates on the Coracoid and inserts on the 3rd to 5th ribs. Pectoralis minor is the only anterior Scapular Thoracic muscle (Borstad & Ludewig, 2002). Previously short Pectoralis Minor in healthy subjects has been linked to a decrease in Scapular post tilt, a decrease in Scapular external rotation, and impairment of normal Scapular upward rotation (Borstad & Ludewig, 2002; Flatow et al., 1994; Kibler & Sciascia, 2009; Lucado, 2011). During Scapular upward rotation the Pectoralis Minor must lengthen during arm elevation in healthy individuals (Borstad & Ludewig, 2002; Ludewig & Cook, 2000; McClure et al., 2004), but if this muscle has an increase in passive tension, this will restrict Scapular upward rotation (Ludewig & Cook, 2000).

Abnormal muscular force couples of the Scapular Thoracic muscles and Glenohumeral joint musculature can lead to faults in the path of instant centre of rotation of the Scapular and Glenohumeral joint , and thus affect Scapular and Glenohumeral joint kinematics (Ludewig & Borstad, 2005). SAIS is associated with dysfunctional movement of the Scapula but it is unclear whether this is cause or compensation (Lucado, 2011). It is a commonly held belief that small changes in muscle function can affect the Subacromial Space (Borstad, 2008). From this it can be hypothesised that not only would a short Pectoralis Minor lead to decrease in Scapular upward rotation but will also decrease AHD (Borstad & Ludewig, 2002).

A reduction in AHD has been noted in patients with shoulder Impingement Syndrome (Borstad et al., 2009). It has been hypothesised in previous reports (Borstad, 2006; Flatow et al., 1994; Kibler & Sciascia, 2009; Lucado, 2011) that there is an association between Scapular upward rotation and Impingement Syndrome. Studies found that Scapular upward rotation is in part influenced by Pectoralis Minor muscles but as yet, a direct association between the resting position variables of Pectoralis Minor length and AHD has not been established. Research exploring the association between the Pectoralis Minor muscle length and AHD would be beneficial because this could influence approaches to treatment and rehabilitation. The aim of the study is to determine the strength of the association between resting Pectoralis Minor length and AHD. No previous study has evaluated the association between these variables.

RESULTS

Mean standard deviations for Pectoralis Minor length are presented in Table 50. Using Pearson's correlations there was a significant correlation between Pectoralis Minor length and Acromio-Humeral distance in all male participants in the neutral arm position (male controls r=0.20 p=0.01. sportsmen r=0.22 p=0.01.), with linear regression the overall model fit was R^2 = 0.04 in controls and R^2 = 0.06 in sportsmen. An association was noted in 60° arm abduction between AHD and Pectoralis Minor length in sportsmen (r=0.20, p= 0.02), with linear regression the overall model fit was R^2 =0.04(Table 50). In female groups, although Pearson's r was indicative of a correlation, this failed to achieve significance. Scatter plots illustrate the best fit linear association between Pectoralis Minor length and AHD in neutral shoulder position, in all male population (Figure 46), and male athletes (Figure 47), and female controls (Figure 48).

Table 50. Means and standard deviations for Pectoralis Minor length and results of Pearson's correlation between Pectoralis Minor length and AHD.

Variable	Group	Mean cm	STD cm	Pearson's correlation ahd in neutral r = (p=)	Pearson's correlation ahd in 60° abd r = (p=)
Pectoralis minor length	male controls	16.21	1.43	0.20(0.01)	0.06(0.44)
	sportsmen	16.04	1.45	0.22(0.01)	0.20(0.02)
	female controls	14.46	1.12	0.28(0.05)	-0.03(0.83)
	sportswomen	14.73	0.76	0.27(0.09)	0.04(0.79)

Abbreviations: AHD = Acromio-Humeral distance; abd = abduction; cm = centimetres; °=degrees.

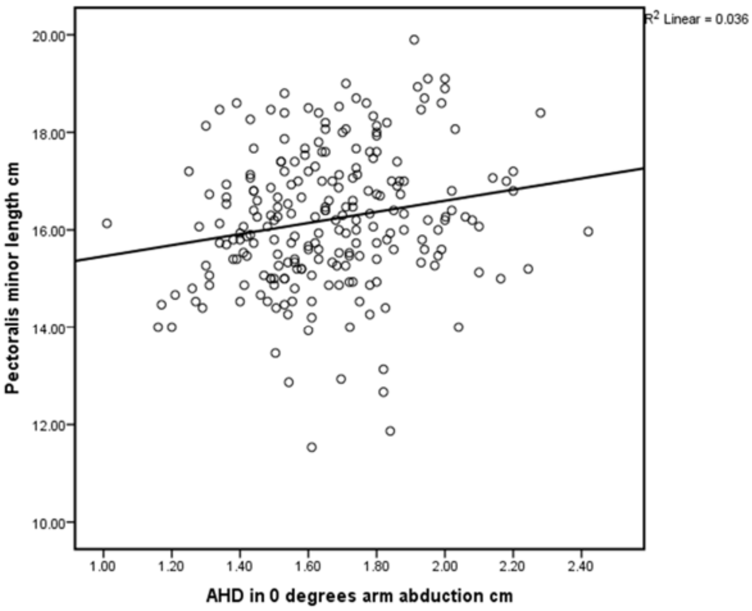

Figure 46. Scatter plot illustrating the best fit linear association between Pectoralis Minor length and AHD in neutral shoulder position, in combined male groups.
Abbreviations: AHD = Acromio-Humeral distance, cm=centimetres.

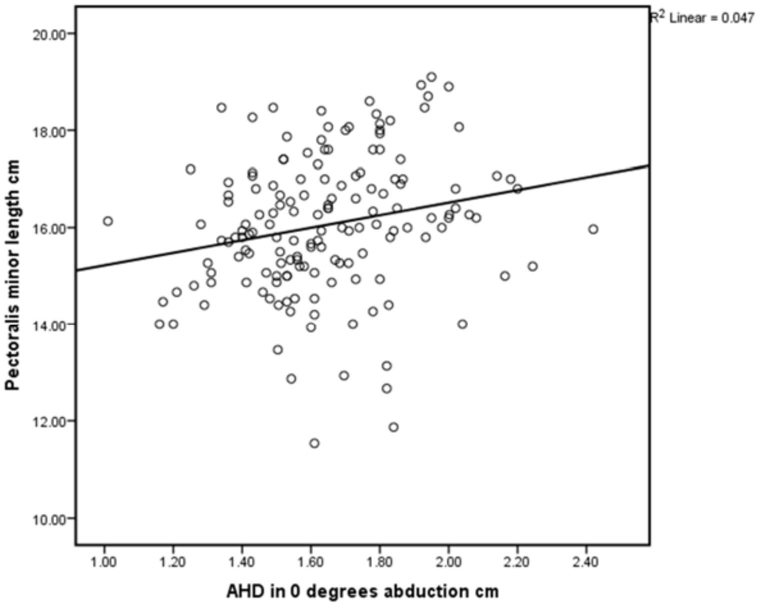

Figure 47. Scatter plot illustrating the best fit linear association between Pectoralis Minor length and AHD in neutral shoulder position, in male athletes.
Abbreviations: AHD = Acromio-Humeral distance, cm=centimetres.

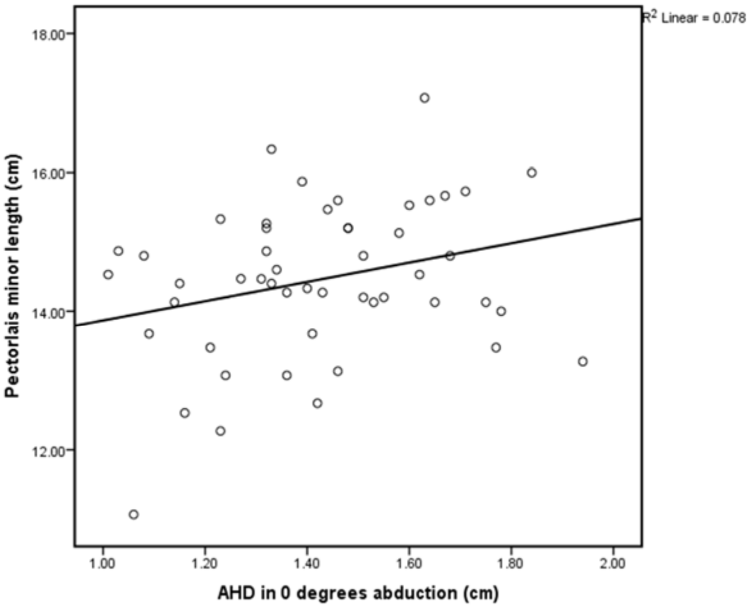

Figure 48. Scatter plot illustrating the best fit linear association between Pectoralis Minor length and AHD in neutral shoulder position, in female controls.
Abbreviations: AHD = Acromio-Humeral distance, cm=centimetres.

DISCUSSION

Twenty six muscles coordinate action to control the joints of the sternoclavicular, Acromioclavicular, Scapular Thoracic, and Glenohumeral joints (Neagle & Bennett, 1994). It can therefore be appreciated just how complex it is to quantify the contribution of a single joint or a single muscle to the overall motion of the arm. To complicate matters further, a single muscle may perform multiple actions depending on how it combines with the action of other muscles. Measurement of the Pectoralis Minor length was, therefore, done in supine in order to evaluate passive restraints of this muscle thus eliminating the confounding variable effects of contraction in other Scapular Thoracic muscles. It is, therefore, *resting* Pectoralis Minor length that is quantified in this study.

What amount of shortening in the Pectoralis Minor muscle is classified as short enough to lead to pathology is unclear. Sahrmann, 2002 (Sahrmann, 2002) proposed that more than 2.5cm off the plinth in the supine test form plinth to Acromion was indicative, it was proved (J. S. Lewis & Valentine, 2007b) to have a specificity of 0%, and lacked diagnostic value (J. S. Lewis & Valentine, 2008). The amount of deviation in alignment that will to lead to impairment is not known. The length of time an individual must sustain a deviation in alignment before dysfunction begins is unclear (Borstad, 2006), since time it is not normally considered as a variable in research. This statement suggests that in future research it would be useful to track the effect of biomechanical alterations over time in individuals and link these to any development of shoulder symptoms.

Although it is most likely that many factors influence AHD, in the uninjured asymptomatic population a correlation is reported between Pectoralis Minor length and AHD in the resting arm position. These findings support the alignment-impairment model and it is proposed that Pectoralis

Minor length has a pathogenic role in the development of SAIS. Results suggest that appropriate investigation and restoration of resting length of Pectoralis Minor is important in rehabilitation for SAIS. Because no correlation was found between pectorals minor length and the AHD in 60° abduction, it is likely that reciprocal relaxation occurs, resulting in lengthening of this muscle when the antagonist muscle group contracts during arm abduction.

CONCLUSION

Results indicate that 4-6% of variance in Acromio-Humeral distance at rest can be explained by Pectoralis Minor length.

5.5 Correlation between Thoracic curve and AHD.

As part of physical assessment of patients with shoulder symptoms, it is considered necessary to assess the Thoracic Spine (Crosbie, Kilbreath, Hollmann, & York, 2008). Previous research has established that posture influences resting position and kinematics of the Scapula (Finley & Lee, 2003; Kebaetse et al., 1999; Thigpen et al., 2010) and proposes that a forward head posture and increased Thoracic kyphosis influence shoulder biomechanics which in turn may lead to shoulder pathology. Despite this evidence, previous studies (Greenfield et al., 1995; J. S. Lewis et al., 2005) evaluating the association between Thoracic posture and the presence of pathology found no association, concluding that further research was necessary in order to determine if upper body posture did have a role in the pathogenesis of SAIS.

The nature of the vertebral curvature is that it is has plasticity properties or changeability. Since the physique of the sportsmen is related to performance in a specific sport discipline, the vertebral curvature may reflect this adaptation to performance. In an elite athlete who trains extensively over a long period in one sport, the configuration of the vertebral curve may change (Uetake, Ohtsuki, Tanaka, & Shindo, 1998). For example, throwers benefit from having a superficial Thoracic curvature. Posture may be particularly suited to an individual in a particular sport or activity (Uetake et al., 1998).

To investigate the clinical assumption that AHD was decreased in patients with Thoracic hyper kyphosis a study (Gumina et al., 2008), using CT scan to quantify the AHD and radiograph to determine the severity of Thoracic kyphosis in healthy individuals, concluded that subacromial width was directly related to Thoracic kyphosis. Subjects were divided into two groups based on more or less than 50° of kyphosis. Concurring with this results are those of a study (Kalra, 2010) in which it was found that during 45° of arm abduction, the AHD was influenced by a slouched or upright posture. The first study selected female subjects with known Thoracic hyper kyphosis and in the second study the altered body posture was not quantified. It would be beneficial to explore the association between AHD and degree of Thoracic curvature in the general population both male and female.

PARTICIPANTS

Data from 63 male control shoulders (32.25 STD 15.41 years) and 78 female control shoulders (41.09 STD 14.48 years) were included in the study.

RESULTS

Data were analysed according to gender. Using Pearson's correlations there was not a significant correlation between angle of Thoracic curve and AHD in either the resting or the 60° abducted arm positions for both groups (Male volunteers: resting arm position r=0.18 p=0.27; 60° arm abduction r=-0.06 p=0.72. Female volunteers: resting arm position r=0.10 p=0.44; 60° arm abduction r=-0.05 p=0.70 see Table 51).

Table 51. Means and standard deviations for Thoracic curve and results of Pearson's correlation between Thoracic curve and AHD

Variable	Participants	Mean degrees	STD degrees	Pearson's correlation ahd in neutral r = (p=)	Pearson's correlation ahd in 60° abd R = (p=)
Ts curve	Male	43.77	9.08	0.18(0.27)	-0.06(0.72)
	female	46.87	9.74	-0.10(0.44)	0.05(0.70)

Abbreviations: AHD = Acromio-Humeral distance; abd = abduction; Ts = Thoracic Spine; °= degrees; STD=standard deviation.

DISCUSSION

The shape of the curvature at rest may not necessarily be the same as during activity (Uetake et al., 1998), but nevertheless, resting posture is clinically assessed and is often used to explain symptoms and pain in the shoulder. It is the foundation of much physiotherapy intervention and is blamed for being part of the pathogenesis and aetiology for shoulder pain (J. S. Lewis & Valentine, 2007b), particularly in Impingement Syndrome (Sahrmann, 2002). It is therefore important to establish the association between AHD and degree of Thoracic curvature in the general population both male and female. The results of this present study show that there was not a significant correlation between angle of Thoracic curve and AHD in either the resting or the 60° abducted arm positions for either male or female participants. The population studied was reflective of a wide age range as well as presenting with a wide enough range of degree of Thoracic curve (Male population range 34.69° - 52.85° female population range 37.13°-56.61°) to make the correlation between this variable and AHD worthwhile.

Limitations

Although instructed to stand in a relaxed position it is possible that participants assumed a more upright position which would have influenced the degree of Thoracic curve. Although intra-rater reliability for the flexi cure to measure Thoracic curve was established (Chapter 3.), inter-tester reliability was not. Previous studies have reported good intra-rater reliability but poor inter-rater reliability (Lovell et al., 1989). When compared with x-ray, however, studies report good reliability and validity. In posture there are many variables in various planes. In this study only Thoracic sagittal posture was evaluated and not found to correlate to AHD in the resting arm position or in the range of 60° of abduction. The amount of deviation that will link to impairment may differ in individuals (Borstad, 2006), and how Thoracic posture influences AHD in higher ranges of arm motion still needs evaluating. For this type of research, kinematic analysis of Thoracic motion during arm movement would be more beneficial since it may be more beneficial during assessment to evaluate range of Thoracic motion.

CONCLUSION

No association was found between resting Thoracic sagittal posture and Acromio-Humeral distance in healthy volunteers as was preciously suggested. Factors other than Thoracic resting posture may be contributing to resting Acromio-Humeral distance and AHD in the early ranges of arm motion. A direct association between Thoracic posture and AHD is not found. Evaluation of Thoracic movement dysfunction may be more pertinent.

5.6 Correlation between shoulder activity score and AHD.

It is asserted that the biomechanics of the shoulder girdle are influenced by load and sport demands. In the literature this has been quantified in a limited number of sporting disciplines. Existing reports are conflicting. One previous author, (Maenhout, Eessel, et al., 2012), reported that sportsmen participating in overhead sports were found to have greater Acromio-Humeral distances than non-sportsmen. In contrast, a study (Silva et al., 2010), which evaluated Acromio-Humeral distance in adolescent tennis players, reported the opposite to be true. This discrepancy could be attributed to lack of homogeneity of the populations tested. More research to explore the influence of load on biomechanical adaptations in the shoulder girdle is necessary. SAIS has been attributed to tasks requiring overhead arm work (Borstad & Ludewig, 2002) with increased incidence in athletes (Burkhart et al., 2003; Lo et al., 1990). The AHD reduces during arm abduction (Maenhout, Eessel, et al., 2012). Two previous studies (McCreesh, Donnelly, et al., 2014; Thompson et al., 2011) found that AHD reduced further with load. The aim of this study was to determine if association existed between percentage reduction in AHD and shoulder activity level quantified by the Roa-Marx activity scale.

PARTICIPANTS

Data from 100 male control shoulders (24.28years STD 6.81 years), and 92 national level sportsmen's shoulders (25.19 STD 5.17 years) were included in analysis. Data from 96 females control shoulders (26.56 STD 6.37 years) and 80 female athletes (24.20 STD 4.09years) were included in analysis

RESULTS

Pearson's correlation analysis computed a positive significant association between Shoulder Activity Scores and percentage reduction in Acromio-Humeral distance in male controls (r= 0.40, p=0.01), with linear regression the overall model fit was R^2 = 0.16. A significant negative association between Shoulder Activity Scores and percentage reduction in Acromio-Humeral distance in male athletes (r= -0.54, p=0.01. Table 52), with linear regression the overall model fit was R^2 = 0.29. Scatter plots illustrating the best fit linear association between shoulder activity score and percentage reduction in AHD in male controls shown in Figure 49 and in male athletes in Figure 50. Similar pattern of association was noted in the female population to the male population. Shoulder Activity Scores and percentage reduction in Acromio-Humeral distance had a positive significant relationship in female controls (r= 0.05, p= 0.74). A significant negative association was noted in sportswomen (r= -0.22, p=0.05), with linear regression the overall model fit was R^2 = 0.05.

Table 52. Means and standard deviations for shoulder activity scale and results of Pearson's correlation between shoulder activity scale and AHD.

Variable	Participants	Mean Score/26	STD score/26	Pearson's correlation % reduction ahd R = (p=)
Shoulder activity scale	male	12.16	4.45	0.40(0.01)
	sportsmen	22.00	1.89	-0.54(0.01)
	female	8.42	4.14	0.05(0.74)
	sportswomen	19.00	3.71	-0.22(0.05)

Abbreviations: AHD = Acromio-Humeral distance; % = percentage. STD=standard deviation.

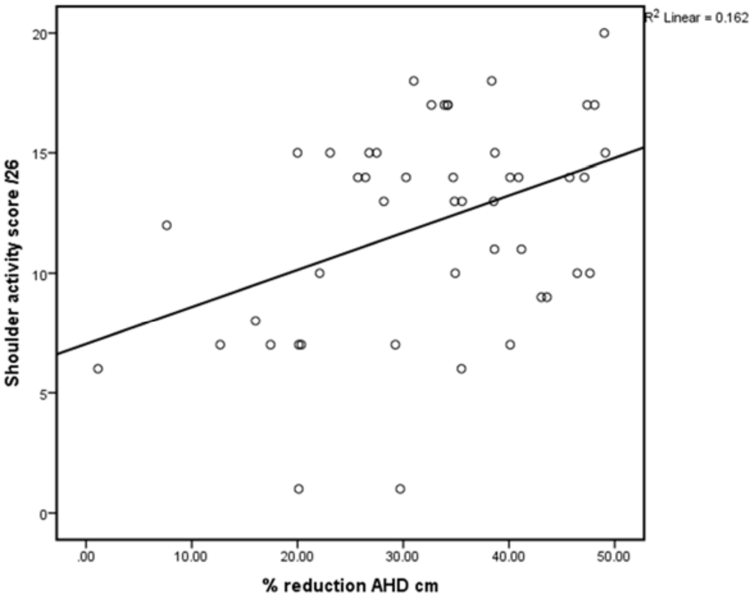

Figure 49. Scatter plots illustrating the best fit linear association between shoulder activity score and percentage reduction in AHD in male controls.
Abbreviations: AHD = Acromio-Humeral distance; %=percentage.

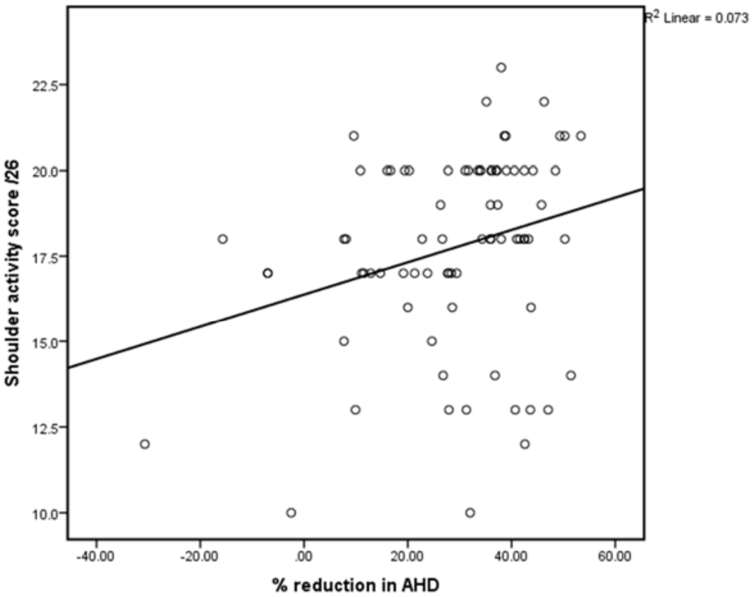

Figure 50. Scatter plot illustrating the best fit linear association between shoulder activity score and percentage reduction in AHD in male athletes.
Abbreviations: AHD = Acromio-Humeral distance; %= percentage.

DISCUSSION

The Roa-Marx activity Score was designed to quantify what level of activity a person does. It is self-administered, quick to complete, and can be used across differing sporting disciplines and daily activities (Brophy et al., 2005). Previous studies (Brophy et al., 2005) designed the questionnaire to determine the role of activity as a prognostic variable in shoulder disorders. It was therefore considered an appropriate tool to quantify level of shoulder activity in the population of this study. It is advantageous that the questionnaire does not evaluate activity at one given time but rather over the period of time. Research by (Thompson et al., 2011) showed that immediate load application to the arm in scaption reduced the AHD by 11% in heathy baseball players. The same was noted by (McCreesh, Donnelly, et al., 2014) in both symptomatic and asymptomatic subjects. In this present study there was a positive correlation between percentage reduction and AHD in non-athletes and a negative correlation in national level sportsmen. In order to maintain AHD, sportsmen may biomechanically adapt to the demands of load.

CONCLUSION

A high shoulder activity score evaluated with the Roa-Marx activity scale was associated with a greater percentage reduction in Acromio-Humeral distance in male controls but the inverse was noted in sportsmen. This may suggest that in order to maintain AHD sportsmen may biomechanically adapt to the demands of load. This is in keeping with previous studies which report that compared to controls the Acromio-Humeral distance in athletes is greater (Maenhout, Eessel, et al., 2012; H. K. Wang et al., 2005).

Multiple linear regression

Multiple linear regression analysis was appropriate to evaluate the combined influence of shoulder external rotation, total arc of rotation and shoulder activity levels on percentage reduction in male controls. Simultaneous entry multiple regression identified a significant model of the association between shoulder external rotation, total arc of rotation, and shoulder activity levels with AHD in a neutral arm position (R^2=0.25, F=4.55, p=0.01). One of the predictor variables, shoulder activity level (ß =0.40, t=2.58, p= 0.02), was significantly and positively related to percentage reduction in AHD. The two other predictor variables, shoulder external rotation (ß =0.05, t=0.25, p= 0.80) and total rotation range of motion (ß=0.25, t=0.1.31, p= 0.19) were not significant.

5.7 Chapter Discussion

In all groups independent variables which showed no correlation to AHD or percentage reduction in AHD were Scapular rotation and Thoracic curve. The results of the present study concur with those of previous studies (Silva et al., 2010; Thomas et al., 2013) who found no correlation between Scapular upward rotation in the coronal plane and AHD, though, it must be borne in mind that in the present study only one component of the five possible degrees of freedom of Scapular motion is examined. Previous studies report no association between Thoracic posture and the presence of pathology (Greenfield et al., 1995; J. S. Lewis et al., 2005) while others investigated the AHD in patients with more than 50° hyper kyphosis (Gumina et al., 2008) concluded that subacromial width was directly related to Thoracic kyphosis. These conflicting results infer that the role of Thoracic posture in Impingement Syndrome is controversial.

In the female population although weak correlations were noted and none achieved significance. In male populations linear regression estimated the variation in AHD attributed to each independent variable. Shoulder internal rotation and Pectoralis Minor length, explained 8% and 6% respectively of variance in AHD in 0° arm abduction in sportsmen while Pectoralis Minor length accounted for 4% of variance in 60° arm abduction in sportsmen (Figure 51.). Total arc of rotation and shoulder external rotation ranges explained 9% and 15% of variance in the percentage reduction in AHD during arm abduction to 60° in controls (Figure 52.). Shoulder activity scores explained 16% and 29% of variance in the percentage reduction in AHD during arm abduction to 60° in both controls and sportsmen, although direction of association was the opposite between the two groups (Figure 51 and Figure 52). The variation in these findings support the assertion that extrinsic factors and the strength of influence on AHD appear to be multifactorial, dependant on arm position, and possibly population specific.

Loss of shoulder internal rotation is reported in athletes (Borich et al., 2006; Burkhart et al., 2003; Harryman et al., 1990; Laudner et al., 2006; Tyler et al., 2000) with a loss of 20° or more correlated to injury (Wilk et al., 2011). In an *in vitro* study a simulated tight posterior capsule in 90° arm abduction led to increased contact pressure under the subacromial arch (Huffman et al., 2006; Muraki et al., 2010). In the present study range of shoulder internal rotation was found to have a weak influence on resting AHD in sportsmen, however no correlations between shoulder internal range was noted in 60° of arm abduction. Results support the pathogenic explanation that loss of internal rotation could be influential in SAIS in the sporting population in lower ranges of arm elevation. However, when the arm is abducted other factors may play a part in determining AHD. Changes in shoulder internal rotation have been noted over the course of a season and warrants monitoring in sportsmen (Dwelly et al., 2009; Thomas et al., 2009).

For optimal performance the Pectoralis Minor must lengthen during arm elevation in healthy individuals (Borstad & Ludewig, 2002; Ludewig & Cook, 2000; McClure et al., 2004), but if this muscle has an increase in passive tension, this will restrict normal Scapular kinematics (Ludewig & Cook, 2000) which have been hypothesised as a factor in SAIS (Borstad, 2006; Flatow et al., 1994; Kibler & Sciascia, 2009; Lucado, 2011). The current study illustrates that longer Pectoralis Minor length is associated with greater AHD in elite male sportsmen in both the resting arm position and in early ranges of arm abduction.

The evidence that total arc of rotation and shoulder external rotation ranges contribute to variance in the percentage reduction in AHD during arm abduction in controls has implications in practice. From this it can be deducted that greater total arc of rotation and greater ranges of external rotation are associated with greater reduction in AHD during abduction and that motor control programmes planned to control excessive shoulder joint rotational range may be beneficial in limiting AHD compromise and avoiding injury (Burkhart et al., 2003; Chen et al., 1999; Herrington, 1998; Reinold, Escamilla, et al., 2009). This trend was not seen in the elite sportsmen in this study; all of whom are regularly supervised by team physiotherapists during training. This observation may have been due to dynamic stabilisers controlling humeral rotation and hence maintenance of the AHD. This is conjecture but worthy of further investigation.

Sportsmen represent a population whose shoulders are exposed to the extremes of load which may lead to adaptive changes in the athletes shoulder (Borsa et al., 2008; Sell et al., 2007). Two previous studies (McCreesh, Donnelly, et al., 2014; Thompson et al., 2011) found that AHD reduced further with load. A high shoulder activity score evaluated with the Roa-Marx activity scale was associated with a greater percentage reduction in Acromio-Humeral distance in male controls but the inverse was noted in sportsmen. This may suggest that in order to maintain AHD sportsmen may biomechanically adapt to the demands of load. This is in keeping with previous studies who report that compared to controls the Acromio-Humeral distance in athletes is greater (Maenhout, Eessel, et al., 2012; H. K. Wang et al., 2005).

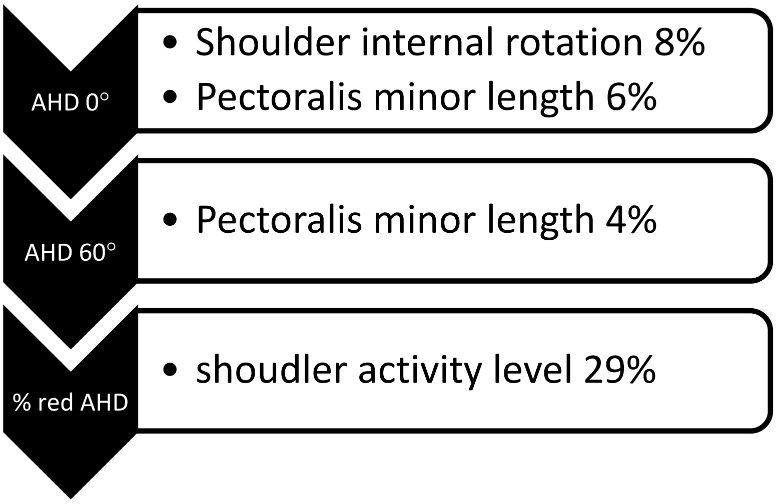

Figure 51. Flow chart to summarise the factors found in this thesis to correlate to AHD and the percentage variance attributed to the factor in sportsmen
Abbreviations: GHJ = Glenohumeral joint; IR = internal rotation; ER = external rotation; TROM total range of motion; % = percentage, AHD = Acromio-Humeral distance.

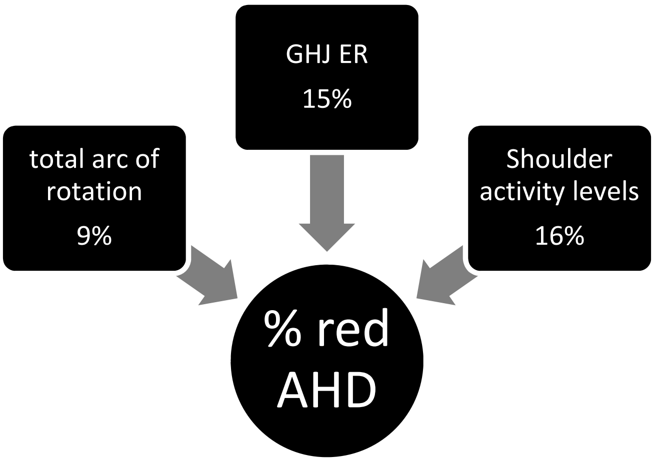

Figure 52. Flow chart to summarise the factors found in this thesis to correlate to AHD and the percentage variance attributed to the factor in male controls
Abbreviations: GHJ = Glenohumeral joint; IR = internal rotation; ER = external rotation; TROM total range of motion; % = percentage, AHD = Acromio-Humeral distance.

Limitations to Chapter 5.

The current study has limitations that should be borne in mind when interpreting the results. AHD is a two dimensional measure of a three dimensional space. Compromise of this volume cannot be totally quantified by measure of AHD alone; it can only be used as guide. A second limitation is that the range of arm elevation in which the RTUS measure of AHD is possible is limited to a maximum of 60° of elevation because of acoustic shadows in higher ranges of arm elevation. To what extent the measure of AHD in 60° of abduction can be extrapolated to influence the Subacromial Space in higher ranges of arm elevation is unclear. Peak Rotator Cuff activity is however, reported to occur between 30°-60° of abduction (Alpert, Pink, Jobe, McMahon, & Mathiyakom, 2000) because in this range the deltoid produces significant upward force on the Humerus which could narrow the AHD. In order to counter-balance the deltoid force and maintain AHD, the RC is required to centre the HOH in the Glenoid (Thompson et al., 2011) at this range. Interestingly the AHD is reported to be at its smallest at 60 degrees of abduction when the Rotator Cuff is reported to be at its peak of activity. The combination of these two factors makes it relevant that the AHD be evaluated in 60 degrees of abduction.

Limiting the extrapolation of these results is the fact that asymptomatic subjects were used in this study; thus, a direct association between impairment cannot be assumed.

Muscle contractions around the Humeral Head produce larger translations during arm movement and can therefore impact on the AHD. In this study, AHD was evaluated during an isotonic hold of the arm. This may not represent true strength of muscle contractions when the arm is under dynamic loading and therefore the true association of the AHD to the variables may not be adequate.

In this study, only one component of the five possible degrees of freedom of Scapular motion is examined. Upward rotation occurs not in isolation but in combination with these other Scapular motions, but upward Scapular rotation is the only measurement that can reliably be measured without the use of three dimensional electromagnetic tacking systems, which for obvious reasons is not easily transferable into the clinical setting.

CHAPTER CONCLUSION

Pectorals minor length and shoulder internal rotation ranges were found to have a weak positive association and contribute to variance in AHD in elite male athletes. Total arc of shoulder rotation and shoulder external rotation range were found to have a weak positive association with percentage reduction in AHD during arm abduction in male controls. Shoulder activity levels were found to have a positive moderate association with percentage reduction in AHD during arm abduction in male controls and a negative moderate association in elite male sportsmen. These findings support the assertion that extrinsic factors and the strength of influence on AHD appear to be multifactorial and possibly population specific. Although these factors should be considered in prevention and treatment programs, in this study the factors investigated only account for small variances in AHD with the most variance in AHD attributed to shoulder activity levels, these results indicate that in addition to these factors there are other factors involved in determining AHD. Extrinsic factors influencing AHD appear to be multifactorial and population specific clinicians need to be mindful of the various factors that can influence the AHD and take this into consideration during screening of athletes and planning treatment programs.

Chapter 6 General discussion

List of abbreviations

AHD	Acromio-Humeral distance
GERG	Glenohumeral external rotation gain
GHJ	Glenohumeral joint
GIRD	Glenohumeral internal rotation deficit
IS	Impingement Syndrome
PALM	palpation Meter
RTUS	real time ultrasound
SAIS	Subacromial Impingement Syndrome
TROM	total rotational range of motion
US	ultrasound

6.1 Summary and clinical implications of the results

6.1.1 *Aim one: An evidence-based review of current perceptions with regard to SAIS and the role of AHD in SAIS; why AHD is important and what influences it. (Chapter 1)*

The first aim of the thesis was to identify the current perceptions with regard to SAIS. It was identified as a broad terminology used to cover numerous types of pathogenic possibilities. Broadly, terms such SAIS and Internal Impingement Syndrome are used to categorise impingement occurring on the bursal side of the Rotator Cuff (Brossmann et al., 1996; Flatow et al., 1994; Mackenzie et al., 2015) or on the articular side of the cuff (Davidson et al., 1995; Mackenzie et al., 2015; Seitz et al., 2011) respectively. The pathogenesis of each of these types of Impingement Syndrome was reviewed. Most aetiologies are based on currently best held theories.

The SAS which is superiorly roofed by the Acromion and the Coracoacromial Ligament with the inferior floor made up of the Glenoid and the Humeral Head is a finite space in the shoulder. In this space are encased the Subacromial Bursa, the cuff Tendons and the long head of Biceps. Elevation of the Humerus results in a normal reduction of the SAS. *In vivo*, MRI studies have shown that contact occurs between the cuff and the Acromion at 30° abduction (Brossmann et al., 1996). *In vitro*, contact has been demonstrated to occur between the cuff and the Coracoaromial Ligament in the range of 45-60 abduction (Burns & Whipple, 1993). A norm average of 11 mm AHD, which is used to quantify the SAS, has been determined on X-ray. This reduces to 5.7mm at 90 abduction (Flatow et al., 1994). From these dimensions it is clear that there is little room for error during arm elevation and that it is imperative for the anterior Acromion to elevate to maintain the SAS.

Various factors are considered to influence reduction in SAS and are broadly grouped into intrinsic and extrinsic causes. The extrinsic causes are those outside of the cuff Tendons such as skeletal alignment factors, muscular factors and Glenohumeral kinematic factors. In this study: the skeletal alignment factors investigated included Scapular rotation in the coronal plane and Thoracic curvature in the sagittal plane; pectorals minor extensibility was examined as it is considered to be one of the causative muscular factors; and anatomical Glenohumeral rotation ranges of motion were used to quantify Glenohumeral kinematics. Intrinsic factors are those from within the Tendon and in this category only the influence of load was considered. Stringent inclusion and exclusion criteria were set to control the numerous other factors, and hence confounding variables, considered to influence the AHD.

The 2 dimensional measure of AHD is used to quantify the 3 dimensional SAS. Measures of AHD with RTUS have been validated (McCreesh, Adusumilli, et al., 2014) with a phantom model. A pilot study was set up to test the hypothesis that the AHD was of importance in SAIS and worthy of further investigation. Data collected on symptomatic subjects was compared with that of asymptomatic athletes within the same disciplines. As the numbers of symptomatic athletes who volunteered was small, observation only could be made or statistical analysis would have been underpowered. It was noted that the AHD was less in both the neutral and the 60° abducted arm position in the symptomatic subjects. This is supportive of previous study’s claims (Burkhart, 1995; Werner et al., 2008) that a reduction in AHD is noted in subjects with SAIS, but it does not indicate if this is a cause or consequence.

Research (Haahr et al., 2005; Haahr & Andersen, 2006), comparing outcome from subacromial decompression and physiotherapy rehabilitation found that at 12 months and at four years the outcomes were no different, concluding that non-operative treatment is very effective. This research has been used to argue that subacromial decompression is an unnecessary intervention and that a reduction in this space is therefore not relevant to Impingement Syndrome. What has not been determined is whether biomechanical factors or a change in these factors actually influence the Subacromial Space and if this is the case the conclusion may be quite different. It is possible that physiotherapy around the shoulder girdle (which assesses, and with rehabilitation attempts to influence, the biomechanics of the shoulder) actually increases the AHD.

From the literature review, it was concluded that factors influencing the AHD were multifactorial and interactional. Therefore, a study quantifying a number of the considered causes and using the data in regression analysis was appropriate. Determining which factors are influential and to what extent they influence the AHD is important because there are many aetiological theories for SAIS for which the evidence is exiguous. Both an elite sport population and controls were chosen to investigate what factors influence AHD, because there is limited data in the literature on these variables in elite athletes and it is know that athletes suffer from SAIS, which has impact on their sporting careers. In addition, they represent a population whose shoulders are exposed to the extremes of load. Assessment, prehab programs for the prevention of SAIS in athletes, and interventions to treat SAIS all need to rely on research evidence and not postulated theories if they are to be justified. Hence the main aim of the thesis was to determine the correlation between factors and AHD as this may help to plan appropriate conservative interventions.

6.1.2 *Aim two: establish reliability of procedures and tools. (Chapter 2)*

Prior to data collection, reliability of tools and procedures had to be established. Tools had to be clinically appropriate and portable to enable the proposed athletic population to be screened. Inter-rater reliability had already been established by previous studies for the use of the inclinometer to measure joint ranges of motion (Green, Forbes, Buchbinder, & Bellamy, 1998) and the flexicurve to measure Thoracic angle (Hinman, 2004; Lundon et al., 1998). The validity of the Roa-Marx Activity Scale has been determined to measure shoulder activity (Brophy et al., 2005). As a result for these mentioned tools it was only necessary to test intra-rater reliability in the current study. Although use of RTUS to measure AHD had been reported fairly extensively in the literature (Desmeules et al., 2004; Kumar, et al., 2010; Pijls et al., 2010), it was remarkable that there was no rigorous study establishing its inter-rater reliability. The previous studies that assessed inter-rater reliability of this tool lacked rigorous statistical analysis. Hence it was decided to design and undertake a study to ascertain if RTUS was indeed a reliable tool when used by two different examiners to measure AHD. The PALM has been used to measure horizontal distance between various anatomical body landmarks (da Costa et al., 2010; Rondeau, 2007; Rondeau et al., 2012)and although the notion of measurements between the Scapula and Spine (called lateral displacement measurements (Kibler et al., 2002)) is not original, the use of these measurements to calculate the degree of Scapular upward rotation is. The originality of this approach to establishing Scapular upward rotation meant that it was necessary to establish inter-rater reliability. All intra-class correlation scores indicated good intra-rater reliability for all the tools used and the same applies to the tools for which inter-class correlation was tested.

6.1.3 *Aim three: Explore sport specific adaptation in the elite athletes shoulder. (Chapter 4)*

Although numbers of symptomatic athletes were small, graphic presentation and observed differences between symptomatic and asymptomatic shoulders in the male and female groups and within each sports' discipline show that in symptomatic shoulders the AHD is lesser. Reduced AHD has been associated with SAIS subjects compared to healthy subjects (Girometti et al., 2006; Graichen et al., 1999; Hebert et al., 2002; Pijls et al., 2010; Saupe et al., 2012). These results encouraged further investigation into the factors which may influence the AHD in the athletes' shoulder.

If therapists are going to screen shoulders for risk indicators and perform prehab, what physical characteristics in the shoulder are due to sport specific adaptations and enhance performance needs to be established (Sell et al., 2007). It was hypothesised that in asymptomatic athletes, asymmetry of characteristics would be observed and, based on the theories projected by previous studies (Mackenzie et al., 2015), these factors would correlate to AHD. The variance observed in the different athletic groups in all of the variables studied was an indicator that between groups shoulder characteristics did indeed differ according to the sporting discipline. Observed differences were reported in Chapter 4, and in Chapter 5, results of statistical correlation analysis between characteristic variables and their association with AHD are reported.

The notion of a posture impairment model in SAIS has been challenged (J. S. Lewis et al., 2005), challenged, finding a poor correlation between posture and shoulder pathology. Posture, too, has been illustrated to alter Scapular kinematics and this in turn is associated with Impingement Syndrome. Based on Sahrmann's posture impairment model (Sahrmann, 2002) is the assumption that asymmetry is pathological and the asymptomatic side is the base line reference. Interventions to improve posture and establish symmetry in physiotherapy intervention is prolific. But the results of many kinematic studies point out the fallacy on the notion that symmetry is normal (Forthomme et al., 2008; Myers, Laudner, Pasquale, Bradley, & Lephart, 2005). The results of the current study support the later conclusion and the fact that comparison between groups of athletes and between sides is not appropriate in the clinical setting. Using Scapular asymmetry as an indicator of risk is not appropriate. Noteworthy was asymmetry in the golf population. In this sub-group numbers were high enough (n=42) to run a well-powered statistical analysis. Specific example of this is noted in Scapular position. The dominant side of the golfers shoulder was more upwardly-rotated in the resting Scapular positon but the opposite was the case when the arm was abducted to 60° and the non-dominant Scapula became more upwardly-rotated (p=0.01 in both positions). Based on descriptive statistics, in the 60° abducted arm position, the dominant Scapula was more upwardly-rotated in controls, boxing, and archers. The opposite was noted in gymnasts and canoeists who had more Scapular upward rotation on the non-dominant side.

'Muscular patterning' has become a fashionable phrase in physiotherapy based on the understanding of force couples in the shoulder girdle and the need for balance between agonist and antagonist muscle groups which control forces in the joint (Borstad & Ludewig, 2002). Resultant force changes will affect kinematics, alter the centre of rotation and joint reaction forces with in a joint. With respect to the Scapula and its force couples, there is only one anterior Scapular Thoracic muscle which forms part of the numerous force couple muscle groups and this is the Pectoralis Minor muscle. It is commonly assumed in practice that the side with a smaller resting length in

Pectoralis Minor is ‘short’ and requires stretching. In the cohort of athletes in this study, the longer range of Pectoralis Minor was noted in canoeists, archers and controls on the non-dominant side. The opposite was noted in golfers with their dominant side Pectoralis Minor being longer. And symmetry between sides was noted in gymnast boxers and water polo players. The question asked is: which is the lengthen range and which is the shorter range muscle? This cohort of athletes were asymptomatic subjects and normally, symptoms and short Pectoralis Minor length conjunctly are used to interpret the presence of a pathologically short pectoralis muscle. Of interest were the statistically significant differences in this variable between controls and golfers, which would indicate not that the pectorals minor in the golfer’s non-dominant side was not ‘shorter’ but that in actual fact, the dominant side had a longer resting length.

Occult laxity in the Glenohumeral joint is considered to be a component of the pathogenesis of Impingement Syndromes (Brukner & Khan, 2010). Using physiological range of rotational motion in the Glenohumeral joint is used as measure to evaluate capsular flexibility (Tyler et al., 2000). Terms such as GIRD and GERG have come to be interpreted in a negative context. GIRD classification is applied if a loss of more than 25° of GHJ IR (Wilk et al., 2009)when compared with the contralateral side is present or if there is a 15°-20° loss GHJ IR with a corresponding loss in TROM of 5% (Andrews, Wilk, & Rienold, 2008). If it is noted that the TROM bilaterally is equal despite discrepancies in IR and ER ranges, this is not termed GIRD but total rotational arc shift. This shift, as well as GIRD and GERG, have been extensively reported in the literature in sports that require high range high velocity arm motion such as baseball (Borich et al., 2006; Burkhart et al., 2003; Harryman et al., 1990; Laudner et al., 2006; Myers et al., 2006; Tyler et al., 2000). Baseball exhibits the extremes of shoulder rotation demands placed on the shoulder joint. This information has been extrapolated to all overhead and throwing sportsmen’s shoulders. In this present study, the cohort of sportsmen were predominantly involved in sports requiring mid-range high force generation such as canoeing, boxing, gymnastics. It was noted in this group of sportsmen that there was not significant side differences in GHJ IR or TROM. In the female boxers, a side difference was detected in GHJ IR but with no side differences in TROM. Bearing in mind these athletes had healthy shoulders performing at a very high level of demand, these results are supportive of current theory which is that a total arc shift is an adaptation to performance and that side to side comparison of GHJ rotation is appropriate in risk identification. The female boxing observation further supports the fact that loss of IR without the corresponding loss of TROM is not a risk in itself. In both male and female sportspersons it was interesting that GERG with a corresponding increase in GHJ ER and TROM was significantly present. Although these alterations are mentioned in the literature as part of the pathogenesis of Impingement Syndromes the correlation between GHJ rotational ranges and the AHD has not previously been established.

Conflicting results exist in the literature with regard to whether the AHD is indeed greater in athletes compared with non-sports populations (Maenhout, Eessel, et al., 2012; Thomas et al., 2013; H. K. Wang et al., 2005). Preservation of the AHD in athletes is important to prevent impingement of the Rotator Cuff Tendons in the Subacromial Space. The finding in this thesis that elite athletes of both genders have a smaller percentage reduction in AHD during arm abduction when compared with non-sporting controls may indicate an adaptive response to maintain AHD in the shoulder of athletes. Because factors which influence the Subacromial Space are considered to be multifactorial (Mackenzie et al., 2015; Seitz et al., 2011) it is debatable whether an adjustment of extrinsic factors occurs in the athlete's shoulder. Alternately an intrinsic cause for a smaller percentage reduction in AHD may be that the Biceps Tendon and the Supraspinatus Tendon are thicker as has been noted in a study comparing college baseball athletes with controls (H. K. Wang et al., 2005). The thickness of the Tendon may restrict the extent to which the Subacromial Space can be reduced

Descriptively establishing that adaptation occurs in the shoulder of the athlete was justification to undertake further research to examine how these adaptations impact on the AHD, in an attempt to understand possible biomechanical contributors to Impingement Syndrome in this population. Since asymmetry is not necessarily an indicator of risk (as it could be adaptive), a study using correlation analysis rather than comparative statistics was deemed to be more appropriate.

6.1.4 *Aim four: establish association between factors (Scapular rotation in the coronal plane, Pectoralis Minor length, Thoracic curvature, GHJ rotation and load) and the AHD. (Chapter 5)*

With AHD as the main outcome measure, data on each independent variable were correlated using Pearson's correlation to AHD. If a significant correlation was found, data were further analysed with linear regression to predict the amount of variance in AHD that could be contributed to the independent variable in question.

In all groups independent variables which showed no correlation to AHD or percentage reduction in AHD were Scapular rotation and Thoracic curve. In the female population although weak correlations were noted between the remaining independent variables and the dependant variables none achieved significance. In Male populations linear regression estimated the variation in AHD attributed to each independent variable. Shoulder internal rotation and Pectoralis Minor length, explained 8% and 6% respectively of variance in AHD in 0° arm abduction in sportsmen while Pectoralis Minor length accounted for 4% of variance in 60° arm abduction in sportsmen (Figure 51.). Total arc of rotation and shoulder external rotation ranges explained 9% and 15% of variance in the percentage reduction in AHD during arm abduction to 60° in controls (Figure 52.). Shoulder activity scores explained 16% and 29% of variance in the percentage reduction in AHD during arm abduction to 60° in both controls and sportsmen, although direction of association was the opposite between the two groups (Figure 51. and Figure 52). The variation in these findings support the assertion that extrinsic factors and the strength of influence on AHD appear to be multifactorial, dependant on arm position, and possibly population specific. Furthermore, since these factors only contribute to a low percentage of variance in AHD this leaves other factors unaccounted for.

6.2 Strengths and limitation of the thesis

This thesis has both strengths and weakness which need to be borne in mind when interpreting the results. Its primary strength is that it does not examine one isolated variable’s influence on the AHD but attempts to examine a combination of possible contributing factors. This is important because it is clear from review of current opinion that the factors considered to predispose the shoulder to Impingement Syndrome and to reduce the AHD are multifactorial and that examination of one variable with the exclusion of others may give a skewered perception of causation. The clinical appropriateness of the tools chosen can be interpreted as a strength, because they will transfer into the clinical and athletic arena setting. Intrinsic to the use of these tools are however, also weaknesses which are discussed under the respective tool headings below. Variety in athletic population is paradoxically a strength and weakness in this thesis. It is a strength, in as much as it allowed for the investigation of the variables in a range of sporting disciplines and populations, illustrating how association and causation may differ according to the population studied. It is a weakness, in that the strength of the correlations between variables differed between groups and therefore when combined for analysis, the correlation was weaker. However, it was first determined by means of scatterplots, removal of outliers, and determining that the same direction, significance, and range of correlations already existed in the individual populations before they were grouped as collectively into the categories of sportsmen, sportswomen, and controls. Correlation and regression analysis is normally used in the disciplines of social sciences with larger numbers of data. It can be argued that the number included in this study were not sufficient to ensure adequate power of correlation analysis. Power analysis previously undertaken demonstrated that a smaller population than included in this study was sufficient to ensure adequate power of analysis.

6.2.1 *Measurement tools and methods*

Flexicurve to quantify Thoracic curve in the sagittal plane

Although intra-rater reliability for the flexicurve to measure Thoracic curve was established (Chapter 2), inter-tester reliability was not established. Previous studies have reported good intra-rater reliability but poor inter-rater reliability (Lovell et al., 1989). Though when compared with x-ray, studies report good reliability and validity. Although instructed to stand in a relaxed position, it is possible that participants assumed a more upright position which would have influenced the degree of Thoracic curve. In posture, there are many variables in various planes. In this study, only Thoracic sagittal posture was evaluated and was not found to correlate to AHD in the resting arm position or in the range of 60° of abduction. How Thoracic posture influences AHD in higher ranges of arm motion still needs evaluating. For this type of research, kinematic analysis of Thoracic motion during arm movement may well be more illuminating, as results from this study imply that it may be more beneficial during assessment to evaluate ranges of Thoracic motion instead of resting Thoracic curve.

RTUS to measure AHD

AHD is a 2-dimensional measure of a three dimensional space. Compromise of this volume cannot be totally quantified by measure of AHD alone; it can only be used as guide. A second limitation is that the range of arm elevation in which the RTUS measure of AHD is possible is limited to a maximum of 60° of elevation because of acoustic shadows in higher ranges of arm elevation. To what extent the measure of AHD in 60° of abduction can be extrapolated to influence the Subacromial Space in higher ranges of arm elevation is unclear. The advantages over other forms of radiography are numerous and in this thesis the inter-rater reliability of its use was established. The added advantage of being able to evaluate the AHD in standing was an advantage since in this position the Scapula is free to move in space, in contrast to when in the supine position required for other radiological methods.

In addition, the cuff has been visualised to compress under the Acromion at 60° of abduction on MRI and from 40° of arm abduction on the Coracoacromial Ligament *in vitro*, justifying the measurement of the AHD in the ranges chosen in this study. Further to this, a study using MRI (Graichen et al., 1999) ascertained that the most reduction in AHD occurred between the ranges of 0-60 abduction. In the same study, monitoring of the Scapular motion illustrated that the reduction in AHD in this range was not due to lack of early Scapular motion but due to humeral elevation. A further reduction in AHD was noted at 90° abduction. The results of the study imply that it is in the ranges of 0°-60° that the AHD is most important and in fact in higher ranges of abduction, the AHD increased. One more limitation is that the subjects in this study were young and healthy, and, as previous studies have pointed out, interpretation of US images is less reliable in symptomatic patients (Pijls et al., 2010), owing to the lack of clarity in the hyper echoic landmarks in the presence of fibrous or calcific changes.

PALM to measure SUR

In this study only one component of the five possible degrees of freedom of Scapular motion is examined. Upward rotation occurs not in isolation but in combination with these other Scapular motions, but upward Scapular rotation is the only measurement that can reliably be measured without the use of three dimensional electromagnetic tracking systems, which for obvious reasons are not easily transferable into the clinical setting. In this study, assessment is not undertaken of the functional movement of the athlete, but in abduction only; to assess the Scapular motion in the sporting position is difficult because displacement between the Scapula and the skin makes assessing Scapular position using a skin-based marker/sensor system in a functional movement difficult. An invasive method such as bone pins would be necessary to do this type of assessment (Myers et al., 2005).

General methodological limitations

Limiting the extrapolation of these results is the fact that asymptomatic subjects were used in this study; thus, a direct relationship between impairment cannot be assumed. It was intended at the commencement of the study to collect data from enough symptomatic athletes to run a well powered comparative analysis between the AHD in symptomatic and asymptomatic shoulders. In addition, it was hoped via a prospective study that data could be collected on athletes who developed shoulder symptoms. This would then have enabled comparison between the investigated independent and dependant variables between symptomatic and asymptomatic groups allowing a direct relationship between variables and impairment to be assumed. In retrospect this was an unrealistic expectation bearing in mind the incidence of athletes presenting with shoulder problems in various reported literatures. For example, literature reports 17% of golfers (Kim, Millett, Warner, & Jobe, 2004) present with shoulder problems. In the present study the total number of golfers' shoulders was 106 of which 18 would make up the quota of 17%. Sixteen symptomatic shoulders were screened out according to the exclusion criteria (2 Subacromial Decompression surgeries, 2 Acromio Clavicular joint dislocations, 1 post-operative SLAP {Superior Labrum Anterior Posterior}, 1 post-operative stabilisation, 1 GHJ dislocation, 1 fractured Clavicle). The exclusion criteria included any factor that was previously reported in the literature to influence the AHD but not quantified in this study. Thus controlling for independent variables not qualified in this study. Over and above those screened out remained 4 symptomatic golfers legible for inclusion in the study. So few symptomatic participants meant that an observational analysis only could be done to observe differences between symptomatic and asymptomatic shoulder variables and limited assumptions of a direct relationship to impairment. A prospective study would be possible but only if a long period of time was allocated to the study and the athletes' included in the study remained dependable. Bearing in mind the later and the active length of the sporting life of the Olympic athletes, this would not be a likely prospective study, however, it may be possible in the golf population where the turnover of athletes is less regular. It would also require the researcher to have regular access to the athletes to enable regular screening of the variables. Thus ensuring stability of meaures in the asymptomatic athletes and monitoring of changes in meaures in the symptomatic athletes.

Muscle contractions around the Humeral Head produce larger translations during arm movement and can therefore impact on the AHD. In this study, AHD was evaluated during an isotonic hold of the arm; this may not represent true strength of muscle contractions when the arm is under dynamic loading and therefore the true association of the AHD to the variables may not be adequate. Although subjects were instructed to adopt a relaxed posture, it is possible that they assumed a more upright posture for testing under scrutiny.

Minimal detectable change cannot be calculated on data subject to a mathematical formula (sin rule and calculation of percentage). The MDC can only be calculated for an actual measurements taken (US measure of AHD and PALM measurements). As a result this is a potential limitation in the methods chosen to quantify AHD and Scapular upward rotation and needs to be considered when interpreting the results.

6.2.2 *Subacromial Impingement Syndrome and underlying mechanism*

In this thesis, association between Pectoralis Minor length, GHR rotation ranges, and shoulder activity levels, with AHD has been shown, but the underlying mechanism remains hypothetical. There are still other factors to consider which influence the AHD, and results of the linear regression illustrate that these variables are only in part associated with AHD leaving many influences upon AHD unexplained by this thesis. This thesis may go part way in contributing to the knowledge of what factors affect the AHD but it has not conclusively established cause or consequence of factors.

6.2.3 *Pathogenic or adaptive and cause or consequence*

Are physical characteristics observed in athletes detrimental or beneficial? What deviation in alignment will to lead to impairment is not known, nor is the length of time an individual must sustain a deviation in alignment before dysfunction begins (Borstad, 2006): time is not normally considered as a variable. A long-term prospective follow up design study is necessary to determine this. It was hoped in the time given for this thesis that this would be possible and athletes were followed up after the initial assessment for a period of 18 months. It became apparent that the number of symptomatic athletes that were initially screened and the number of athletes developing symptoms over this period would be too small to draw any conclusions other than clinical assertions. It is not possible to deduce the cause-consequence sequence of these findings only association has been proven.

6.3 Directions for future research

6.3.1 *Reliability of RTUS in the symptomatic population*

As previous reports have pointed out, interpretation of US images is less reliable in symptomatic patients (Pijls et al., 2010), owing to lack of clarity in the hyper echoic landmarks in the presence of fibrous or calcific changes. Therefore, if this method were to be used, further investigations would have to be undertaken: to establish the inter-rater reliability of this method in symptomatic subjects; to determine the sensitivity of this measure in Rotator Cuff pathologies; and to investigate the predictability of this measure as a risk factor in SAIS.

6.3.2 *Effect of muscular activity and exercise interventions on the AHD*

This study assessed the resting length of Pectoralis Minor and during measures of AHD the arm was isometrically held in 60 degree abduction. Effect of muscular activity and short term application of load was not evaluated. A study (Thompson et al., 2011), found loaded exercises in scaption at varying ranges decreased the AHD by 11%. Previous studies have included: the effect of isometric adduction and abduction on the AHD (Henseler et al., 2014; White et al., 2012); the effect of humeral rotation on the AHD, (H. Kim, Kim, Shim, Kwon, & Jung, 2014), and resisted shoulder adduction on AHD. Further research to establish exactly how various isometric contractions in various arm positions influence the AHD would help to devise rehab interventions. A study (Maenhout, Mahieu, et al., 2012) investigated the effect of fatigue on AHD, reporting an increase in AHD which was contrary to expectation. Two studies (Desmeules et al., 2004; C. H. Wang et al., 1999) assessed the influence of multi-intervention programmes in SAIS subjects on AHD. In the one study (C. H. Wang et al., 1999) a young heathy population was selected and in the other study (Desmeules et al., 2004) the population only incorporated seven SAIS subjects. The influence of single interventions in a larger number of SAIS subjects is therefore warranted. The effect of specific exercise interventions using EMG and AHD simultaneous measures together to illustrate how muscle activity affects the AHD has implications for choice of exercise and interventions in physiotherapy programs, the exact ranges between which to perform the exercise, and which muscles to target in rehab. This would assist in exercise prescription.

6.3.3 *Commonly used orthopaedic tests and AHD*

The effect of commonly-used diagnostic orthopaedic tests on the AHD, such as the empty can and full can on AHD would be interesting a study (Thigpen et al., 2010) has shown that when this test is performed in various ranges, the range influences the amount of Scapular internal and anterior tipping that occurs and proposed that this would decrease the volume of the Supraspinatus outlet during the empty can exercise. Direct measurement of the outlet was not undertaken: This would be a new direction for research.

6.3.4 *AHD throughout the athletic season*

All athletes in this study were tested mid-season. It has been shown by previous studies that Scapular position varied throughout the athletic season (Thomas et al., 2009) and so it is possible that measurement of the variables investigated in this study throughout season may yield differing results. This might help to determine when the athlete is more at risk. In addition, it is worth investigating the incidence of Impingement Syndrome-related pathology in athletes with decreased AHD, decreased resting length of Pectoralis Minor and GIRD and GERG.

6.4 Conclusion for clinical practice

6.4.1 Multifactorial factors influences on AHD need to be considered.

Many physiotherapy interventions have been drawn up around theoretical models of postural and muscle imbalances, suggesting that these lead to a decrease in AHD. The assumed cause has been that a decrease in AHD will lead to RC tissue irritation and SAIS. The idea was first challenged by Jeremy Lewis (J. S. Lewis, 2010) who proposed that the pathogenic cause of SAIS was not predominantly extrinsic but intrinsic in nature. A broad look into the literature taking into consideration different professions' points of view, (anatomists, surgeons, biomechanics, and physical therapies) proposes that factors affecting AHD are multifactorial (Mackenzie et al., 2015; Seitz et al., 2011). The results of this study support this conclusion and illustrate that the factors associated with SAIS may be population-specific and the strength of the influence of the variable affecting AHD may also be population-specific. This study demonstrates that the strength of the associations varies between genders and sport disciplines. Correlations in this study were found to be either weak or moderate: Pectoralis Minor resting length, Glenohumeral rotation ranges, and shoulder activity scores were the influential on AHD. Considering the sport-specific adaptations that occur to enhance performance in the sports person's shoulder, it is not surprising that several different factors affecting AHD will vary in the strength of their influence on the AHD. There is strong evidence that high scores on shoulder pain severity and longevity of symptoms are prognostic factors considered to influence outcomes in patients with shoulder pain (Struyf, Gerates, Noten, & Nijs, 2016). Movement is changed in pain. Motor adaptation to pain occurs as action is reordered in muscles in order to offload and protect the tissues from further pain or injury. This may result in alterations at multiple levels of the motor system including the central nervous system with potential long-term consequences (Hodges, P. W., 2011). Although the participants in these studies were pain free, a further factor not deliberated in this thesis is that shoulder symptoms and characteristics may be affected by alterations at multiple levels of the motor system. This is an additional factor that needs to be considered when assessing and rehabilitating patients with shoulder pain.

Physiotherapists need to evaluate and draw up treatment programs for athletes accordingly.

6.4.2 Assessment of resting Scapular rotation in the clinical setting

Despite literature suggesting the use of Scapular asymmetry as an indicator of pathology (Sahrmann, 2002) and its' prevalence in physiotherapy assessment, it is not an appropriate indicator of risk (Matsuki, 2011; Morais & Pascoal, 2013; Ozunlu et al., 2011; Schwartz et al., 2014; Uhl et al., 2009; Watson et al., 2005) in the athletic population. The result of this study supports the view that it is inappropriate to used Scapular asymmetry as an indicator of risk to pathology and shows that Scapular position differs between sport disciplines. Not only is between-group comparison inappropriate; neither is with in subject side to side comparison in the athletic population. Resting Scapular position as well as Scapular upward rotation in the 60° abducted position did not correlate to AHD. Scapular rotation in the coronal plane was not found to correlate to AHD in any group in either neutral or 60° of abduction. It is, however, possible that Scapular motion in other planes and in higher ranges of abduction may influence AHD. It is therefore suggested that resting Scapular upward rotation is not useful in assessment but rather that magnitude of Scapular motion be used as an assessment of risk in the athletic population.

6.4.3 *Assessment of GHJ rotational ROM and the clinical implications*

Unlike previous research, which reported unique bilateral patterns in Glenohumeral rotation ranges in the overhead high range velocity generation athletes (Brown et al., 1988; Burkhart et al., 2003; Crockett et al., 2002; Downar & Sauers, 2005; Ellenbecker et al., 1996; Osbahr et al., 2002; Reagan et al., 2002), analysis of the athletes in this study did not exhibit any significant bilateral differences. Specifically, asymptomatic professional golfers were not found to have a unique pattern of GHJ rotations, making bilateral comparison appropriate for risk indication. Differences in rotational ranges of motion between sides needs to be evaluated in the context of the total rotation arc shift (Wilk et al., 2011). In addition, screening and prehab of physical characteristics in the athletes' shoulder needs to take into consideration the unique adaption of shoulder range of motion to individual sport demands.

Greater Glenohumeral external rotation gain was found to correlate to greater percentage reduction in Acromio-Humeral distance in early ranges of arm abduction in male controls but not in elite male athletes. GERG could impact on the AHD. This finding is not seen in national level elite sportsmen, who were undergoing current prehab programs targeting shoulder stabilisation. This supports the theory that dynamic stabilisers may influence AHD during arm abduction. The clinical implication of this is that athletes with GERG would benefit from rehabilitation programs developed to address GHJ dynamic stability.

Range of Glenohumeral internal rotation was found to have a weak influence on resting Acromio-Humeral distance in sportsmen. No correlation between Glenohumeral internal rotation range was noted in the early ranges of arm abduction in the athletic population. Results support the pathogenic explanation that GIRD could be influential in SAIS in the sporting population compromising AHD in the neutral arm positon. When the arm is abducted, however, other factors may play a part in determining AHD. True GIRD and not apparent GIRD must be determined within the context of the total rotational arc shift (Wilk et al., 2011) and results from this study support the defining of GIRD in this context of total range. Stretching of posterior structures to address GIRD is advocated in previous studies who determined that a tight posterior GHJ capsule was responsible for GIRD. This theory has further evolved to suggest that it is not only the posterior GHJ capsule that influenced GIRD, but also restriction in the posterior contractile tissue around the GHJ. Since internal rotation range had an association with AHD in resting but not in 60° of abduction, this would appear to be the case in this particular cohort of athletes and when dynamic factors came into control AHD was maintained in 60° abduction.

6.4.4 *Assessment of Pectoralis Minor resting length and the clinical implications*

Shorter Pectoralis Minor length on the symptomatic side is often concluded to be ‘short’ and pathogenic (Ludewig & Borstad, 2005). In this study it was noted that the non-dominant side in canoeists, archers, and controls was greater in length; the opposite was the case in golfers with a longer Pectoralis Minor length on the dominant side. While symmetry was noted in gymnasts, boxers and water polo players. Comparison of Pectoralis Minor length in controls and golfers led to the conclusion that golfers, rather than having a shorter pectoralis muscle on the lead side, have lengthened Pectoralis Minor muscle on the dominant side. This poses various questions: to what degree is Pectoralis Minor length attributable to sport adaptation? Which side is shorter or longer? Is it appropriate to stretch Pectoralis Minor? Pectoralis minor length was found to correlate positively to AHD and so, it might be concluded, is a factor influencing AHD in the athletic population. It needs to be ascertained whether the best approach in treatment is stretching of this muscle or stimulation of its agnostic to address correct balance of function with this muscle.

6.4.5 *Shoulder activity levels and the clinical implication of this in Impingement Syndrome*

A high shoulder activity score evaluated with the Roa-Marx activity scale was associated with a greater percentage reduction in Acromio-Humeral distance in male controls in the early ranges of arm abduction. The converse was true in male athletes, suggestive of adaptation to load in this population. Lewis, 2010 (J. S. Lewis, 2010), proposed that the Tendon unit is able to adapt accordingly to load and progressively-increased stress. He defined the spectrum from the under-loaded to the degenerated Tendon. From the present research, it can be concluded that load has an impact on AHD and that with progressive graduated load in the athletic population this was accommodated with a maintenance of AHD during abduction. Clinically, this implies, consistent with the recommendation by Lewis, 2010 (J. S. Lewis, 2010), that Tendons be gradually placed under the required load to perform and avoidance of sudden load is advised in the athletic population.

6.5 Concluding ideas

Concluded from the literature review was that maintenance of AHD is important in Impingement Syndromes and in athletes, regardless of whether reduction in AHD is a cause or consequence. It is apparent that causes are multifactorial and previous literature has investigated differences in variables in participants with impingement syndrome but not examined multiple factors simultaneously and their effect on the AHD with correlations analysis. This study set out to do that. Factors quantified in this study were: Thoracic curve in the sagittal plane, Scapular rotation in the coronal plane, Glenohumeral joint capsule extensibility, Pectoralis Minor resting length, and shoulder activity levels (Figure 53). Although the results of this thesis have not conclusively determined if the factors examined are pathogenic, it has established that GHJ IR and ER, Pectoralis Minor length, and shoulder activity are associated with AHD in the athletic population (Figure 53). Therefore, evaluating these factors during clinical assessment is recommended. Further recommendations for assessment of these factors are also summarised in the flow chart in Figure 53. Namely: it is recommend that magnitude of spinal motion in the sagittal plane may be more applicable during shoulder motion; assessing Scapular asymmetry as an indicator of risk is not appropriate and it is recommended that assessment of magnitude of scapular rotation in the coronal plane may be more applicable; comparison of IR and ER bilaterally is relevant when assessed in the context of the total rotational arc shift as a risk indicator; assessment of pectoralis minor needs to be within the context of sport adaptation and it cannot be assumed which is the lengthen range and which is the shortened range of the muscle; and lastly monitoring of load and activity levels important in athletes.

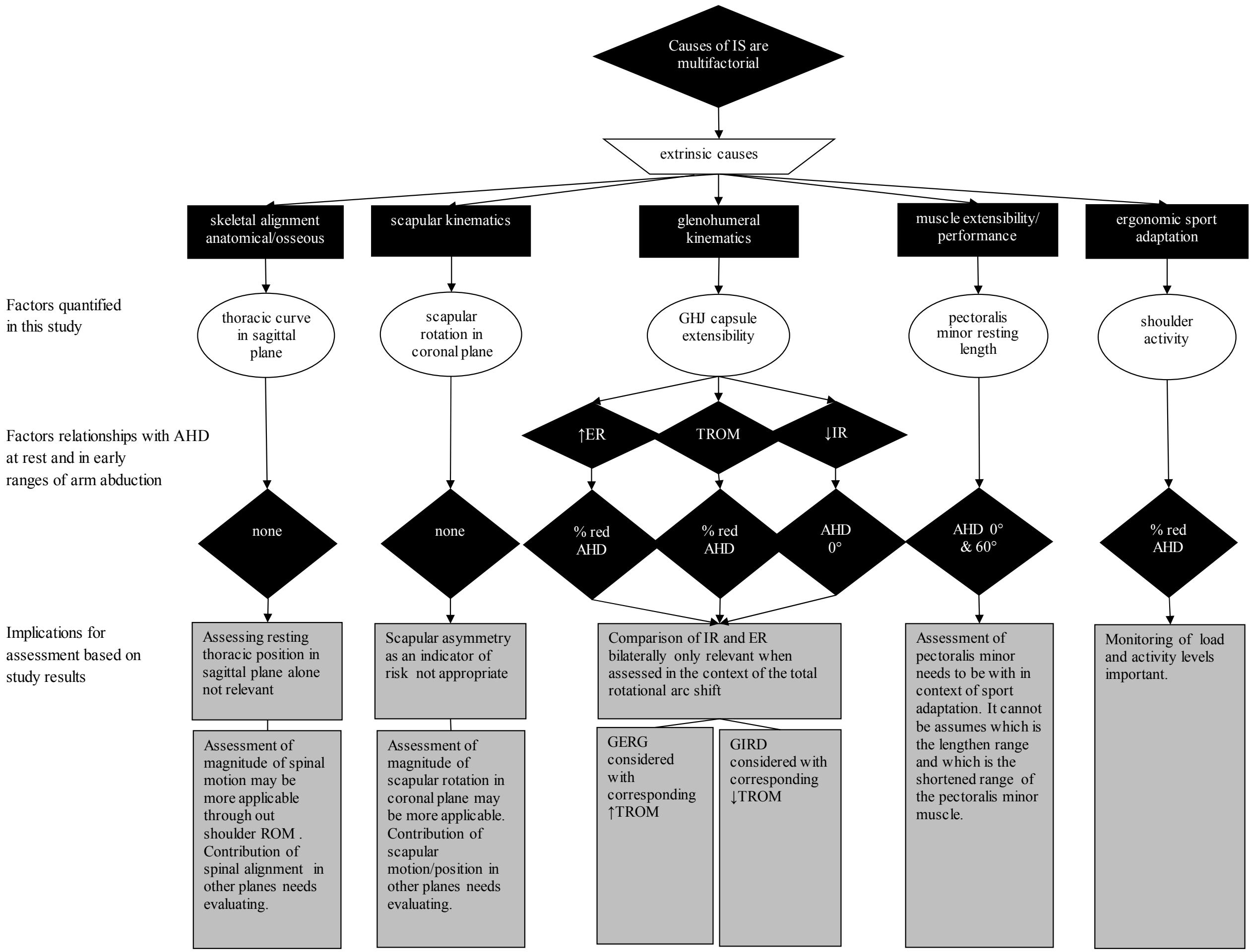

Figure 53. Flow chart to summarise the clinical assessment implications in the athletic population

Abbreviations: IS = Impingement Syndrome; GHJ = Glenohumeral joint; IR = internal rotation; ER= external rotation; red = reduction; AHD = Acromio-Humeral distance; 0° = 0 degrees arm abduction; 60° = 60° arm abduction; GERG = Glenohumeral external rotation gain; GIRD= Glenohumeral internal rotation deficit; TROM = total range of motion; ↑=increase; ↓= decrease.

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Appendices

Appendix 1. Literature search terms

ab(Scapula*) AND ab(subacromial) AND ab(impingement)

ab(Scapula*) AND ab(shoulder) AND ab(kinematics)

ab(Scapula*) AND ab((tennis OR impingement)) AND ab((golf OR impingement)) AND all((swimming OR impinge ent)) AND all((rugby OR impingement))

Your search for *ab(Scapula*) AND ab(tennis) AND ab(golf) AND all(swimming) AND all(rugby)*

Your search for *ab(Scapula*) AND ab(dyskinesia) AND ab(kinematics) AND ab(muscles)*

ab(Scapula*) AND ab(muscle)

ab(ultrasound) AND ab(Subacromial Space)

Your search for ab(Scapula*) AND all(rugby) AND all(Subacromial Space) found 0 results

ab(Scapula*) AND all(tennis) AND all(Subacromial Space)

ab(Scapula*) AND all(golf) AND all(Subacromial Space)

ab(Scapula*) AND all(swim*) AND all(Subacromial Space)

ab(Scapula*) AND ab(kinematic*) AND ab(Subacromial Space)

ab(palpation) AND ab(Scapula*)

ab(palpation-meter)AND ab(Scapula)

Lateral Scapular slide test

Scapula*AND dyskineis OR Kinematics Or muscle

Scapula* AND Tennis OR golf OR swimming OR rugby

Subacromial spce AND tennis OR golf OR swimming OR rugby

Impingement AND tennis OR golf OR swimming OR rugby

Posture and Scapula*

(posture[abstract]) AND Scapula[abstract]

Glenohumeral joint AND Scapula

(ultrasound[abstract]) AND Subacromial Space[abstract]

(Scapula) AND shoulder[abstract])AND kinematics [abstract]

Appendix 2. Consent form

Version 1

Patient Identification Number for this trial:

CONSENT FORM

Title of Project:

Clinical tests to assess Scapular kinematics and the clinical relevance of these.

Name of Researcher: Tanya Anne Mackenzie

Please tick the boxes if you agree or place a cross if you disagree.

1. I confirm that I have read and understood the Participant Information Sheet dated for the above study and have had the opportunity to ask and receive answers to any questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my rights being affected in any way.

3. I understand that the researcher will hold all information and data collected securely and in confidence and that all efforts will be made to ensure that I cannot be identified as a participant in the study (except as may be required by law) and I give permission to the researchers to hold relevant personal data.

4. I agree to take part in the above study.

5. I agree to be contacted in the future regarding any future shoulder injury

Your email address: ____

Your mobile number: ____

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Name of Participant	Date	Signature
---------------------------------	-----------	-----------------------------------
Name of Witness	Date	Signature
---------------------------------	-----------	-----------------------------------
Name of Researcher	Date	Signature

Appendix 3. Subject demographic sheet

Version 1.

Subject number ☐

Subject name……………………………………………..

Contact number (optional)…………………………………..

Please place a cross through INCORRECT answer i.e. X ☐

Which is your dominant hand i.e. the one you throw with	Right	Left
Indicate your sex	male	female
Do you currently have any shoulder pain?	Yes	no
Are you currently being treated for any shoulder problems?	Yes	no
Have you had treatment or rehabilitation for your shoulder in the past 6 months?	Yes	no

If yes please give details…………………………………………………………

……………………………………………………………………………………

Have you had a previous fracture of the Spine or arm or shoulder blade or collar bone or ribs	Yes	No
Have you had a previous surgery to the Spine or arm or shoulder blade or collar bone or ribs?	Yes	No
33Are you pregnant?	Yes	No
Do you have a respiratory condition i.e. asthma?	Yes	No
Do you have any known congenital spinal or Scapular defects i.e. Scheurmans or scoliosis?	Yes	No
Have you ever dislocated your shoulder or AC joint?	Yes	No

Appendix 4. Sportsperson demographic sheet

Version 2.

Name_____________________________ Date________________________

Sex_______________________________ Age________________________

Dominant hand ………….. R☐ L☐ Ambidextrous ☐

Is your shoulder currently injured? Yes☐ NO ☐

Have you missed participation in your sport in the last year due to your shoulder?

Yes ☐ NO ☐

Have you been diagnosed with an injury to your shoulder? Yes ☐ NO☐

If yes which side shoulder was injured? ________________ Right☐ Left ☐

If yes what was the diagnosis? ____

Have you had surgery to either of your shoulders? Yes ☐ No ☐

If yes please give details of surgery ______________________________________

And Date of surgery______________

Please tick the one category that best describes your current status:

☐ Participating in my sport without any shoulder trouble

☐ Participating in my sport but with shoulder trouble

☐ Not Participating in my sport due to shoulder trouble

Have you fractured or dislocated any of the following: your shoulder, collar bone, shoulder blade, or ribs?

Yes ☐ No ☐ details: _______________

Appendix 5. Roa-Marx Shoulder Activity Scale

Name________________ Age_______ Sex______ Date of Examination_______

Please indicate **with an "X"** how often you performed each activity in your healthiest and most active state, **in the past year**.

	Never or less than once a month	**Once a month**	**Once a week**	**More than once a week**	**Daily**
Carrying objects 8 pounds or heavier by hand (such as a bag of groceries)					
Handling objects overhead					
Weight lifting or weight training with arms					
Swinging motion (as in hitting a tennis ball, golf ball, baseball, or similar object)					
Lifting objects 25 pounds or heavier (such as 3 gallons of water) NOT INCLUDING WEIGHT LIFTING					

For each of the following questions, please **circle the letter** that best describes your participation in that particular activity.

1) Do you participate in contact sports (such as, but not limited to, American football, rugby, soccer, basketball, wrestling, boxing, lacrosse, martial arts, etc)?

A No

B Yes, **without** organized officiating

C Yes, **with** organized officiating

D Yes, at a professional level (ie, paid to play)

2) Do you participate in sports that require hard overhand throwing (such as baseball, cricket, or quarterback in American football), overhand serving (such as tennis or volleyball), or lap/distance swimming?

A No

B Yes, **without** organized officiating

C Yes, **with** organized officiating

D Yes, at a professional level (i.e., paid to play)

Appendix 6. Removal of outliers

To remove outliers in SPSS the explore option was selected and removal of outliers identified in the stem-and-leaf plots or box plots by deleting the individual data points.

In addition, to determine a value that excludes the outliers the following method was used:

Percentiles were calculated using SPSS. From the SPSS output screen the twenty five percentile (Q_1), the median, and the seventy five percentile (Q_3) values were noted. The inter quartile range was calculated (IQR) i.e. the difference between the upper and lower quartiles ($IQR=Q_3-Q_1$). Then the following equation was used to calculate the upper and lower limts for the outliers.

Lower limit = Q1 – 1.5(IQR)
Upper limit = Q3 + 1.5(IQR)

Any data lying outside these defined bounds was considered an outlier.

Reference

Hoaglin, D. C., & Iglewicz, B. (1987). Fine-Tuning Some Resistant Rules for Outlier Labeling. Journal of the American Statistical Association, 82(400), 1147–1149.

Appendix 7. Residual analysis results

To evaluate the appropriateness of linear regression for the data residuals were defined and residual plots examined. The residuals are the differences between the observed values of the dependant variable and the predicted value.

I.e. Residual = Observed value - Predicted Value (of dependant variable).

Both the sum and the mean of the residuals are equal to zero. This is illustrated in Table 53 in which the residual mean is equal to zero.

The residual plot in Figure 54 shows the residual on the vertical access of the dependant variable (percentage reduction of AHD) and the independent variable (GHJ external rotation) on the horizontal axis. Because the points on the residual plot are randomly dispersed around the horizontal zero axis a linear regression model is appropriate for the data. In addition, from the scatter plot of the residuals it can be observed that the variance of the errors is constant i.e. homeostatic and the residuals have an error of zero as seen by the line of best fit.

Table 53. Summary of residual statistics for the dependant variable (percentage reduction of AHD) and the independant variable (GHJ external rotation)

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	22.3434	34.3980	30.0454	2.46113	82
Residual	-42.08539	21.13896	.00000	14.37417	82
Std. Predicted Value	-3.129	1.769	.000	1.000	82
Std. Residual	-2.910	1.462	.000	.994	82

a. Dependent Variable: percetredahd

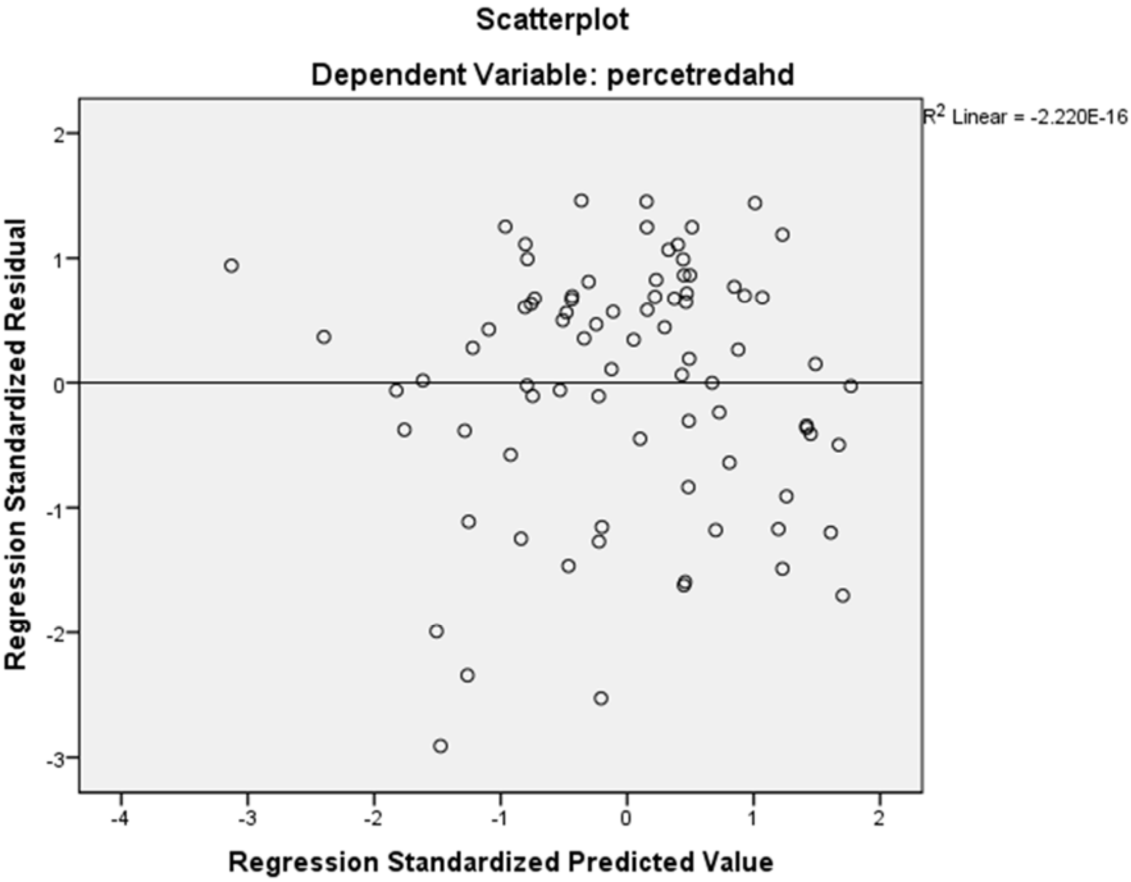

Figure 54. Residual plot of the dependant variable (percentage redution of AHD) and the independant variable (GHJ external rotation)

Appendix 8. Ethical approval

Research, Innovation and Academic Engagement Ethical Approval Panel

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10 December 2012

Dear Tanya,

RE: ETHICS APPLICATION HSCR12/71 **– Clinical tests to assess biomechanical factors contributing to subacromial impingement in elite overhead sportsmen and controls, and the clinical relevance of these**

Following your responses to the Panel's queries, based on the information you provided, I am pleased to inform you that application HSCR12/71 has now been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible.

Yours sincerely,

Rachel Shuttleworth

Rachel Shuttleworth College Support Officer (R&I)

Appendix 9. Examples of raw data

Table 54. Male Gymnast raw data

no	domtotrot	nondomtotrot	domIR	domER	nondomIR	nondomER	domscap0angle	domscap60angle	nondscap0angle	nondscap60angle	dompec	nondompec	dom0ahd	dom60ahd	nond0ahd	nond60ahd
301	147.77	138.33	65.00	82.77	55.67	82.67	6.22	10.56	5.87	11.02	14.00	15.27	1.72	1.19	1.51	0.99
302	148.30	135.50	52.33	95.97	44.00	91.50	7.58	5.37	9.22	7.09	14.40	16.33	1.51	1.16	1.55	1.16
303	141.33	126.37	64.33	77.00	57.00	69.37	4.22	11.23	2.25	8.79	17.40	16.27	1.89	1.32	2.00	1.41
304	104.67	120.23	35.67	69.00	47.67	72.57	7.59	10.66	4.39	15.54	14.40	12.93	1.83	1.71	1.70	2.23
306	145.67	135.60	71.33	74.33	55.67	79.93	1.69	8.94	-0.53	6.65	15.80	17.00	1.93	1.36	1.84	1.61
307	999.00	134.90	999.00	999.00	47.33	87.57	999.00	999.00	3.00	2.88	999.00	17.00	999.00	999.00	1.87	1.76
309	140.97	128.20	57.33	83.63	50.67	77.53	6.63	8.25	4.29	5.82	14.53	13.47	1.48	1.11	1.50	0.97
310	123.67	130.67	57.00	66.67	65.67	65.00	4.06	5.74	6.30	7.31	16.80	16.87	1.78	1.32	1.69	1.30
311	157.97	143.47	65.33	92.63	67.33	76.13	4.76	3.36	0.94	1.89	15.20	15.00	2.24	1.42	2.16	1.15
313	126.73	129.00	59.00	67.73	51.00	78.00	7.49	6.38	0.55	9.69	12.87	14.87	1.54	0.97	1.41	1.09
314	124.00	121.33	48.33	75.67	51.33	70.00	1.82	3.63	-1.29	4.91	15.27	14.53	1.71	1.26	1.55	1.27
315	116.07	120.00	39.33	76.73	39.00	81.00	1.08	1.85	0.72	2.52	13.13	11.87	1.82	1.10	1.84	1.19

no	domtotrot	nondomtotrot	domIR	domER	nondomIR	nondomER	domscap0angle	domscap60angle	nondscap0angle	nondscap60angle	dompec	nondompec	dom0ahd	dom60ahd	nond0ahd	nond60ahd
316	138.33	120.47	40.33	98.00	28.67	91.80	2.83	4.41	5.64	9.99	10.67	11.53	1.50	1.26	1.61	1.21
317	999.00	128.70	999.00	999.00	41.67	87.03	999.00	999.00	5.70	8.93	999.00	13.93	999.00	999.00	1.60	1.06
318	136.67	106.90	66.67	70.00	34.33	72.57	-1.24	-0.31	1.32	5.31	14.00	14.00	2.04	1.13	1.16	1.03
305	144.43	141.20	60.67	83.77	62.67	78.53	5.79	6.59	5.26	8.44	15.27	14.80	2.19	2.01	1.99	1.75
308	127.73	130.03	50.00	77.73	53.33	76.70	4.10	2.41	1.84	6.32	15.07	14.80	1.87	1.31	1.72	1.26
312	119.57	999.00	49.33	70.23	999.00	999.00	-0.61	0.92	999.00	999.00	15.27	999.00	1.88	1.56	999.00	999.00
317	143.53	999.00	47.67	95.87	999.00	999.00	5.80	10.11	999.00	999.00	12.53	999.00	1.63	1.27	999.00	999.00

Abbrieviations: Dom = dominant; tot= total; rot=rotation; nondom= nondominat; IR = external rotation; ER = external rotation; scap = Scapula; pec = pectoralis; ahd = Acromio-Humeral distance; nond= non-dominant.; STD = standard deviation.

Table 55. Boxing raw data.

no	gender 1=male 2=female	domtotrot	nondomtotrot	domIR	domER	nondomIR	nondomER	domscap0angle	domscap60angle	nondscap0angle	nondscap60angle	dompec	nondompec	dom0ahd	dom60ahd	nond0ahd	nond60ahd
1200	1	109.00	126.00	45.00	64.00	48.50	77.50	1.53	17.06	1.25	18.16	18.00	16.90	1.70	1.31	1.86	1.35
1201	1	121.67	124.00	43.67	78.00	45.00	79.00	6.65	13.04	5.11	10.26	15.47	15.60	1.42	0.84	1.60	1.48
1202	1	116.50	123.50	47.00	69.50	47.50	76.00	0.82	14.90	2.69	9.44	15.80	16.40	1.40	0.83	1.65	1.34
1203	1	102.00	129.60	34.50	67.50	44.50	85.10	3.42	13.79	0.00	12.59	15.90	15.20	1.43	0.83	1.57	0.95
1204	1	133.17	119.67	46.00	87.17	39.67	80.00	4.67	14.59	6.20	12.61	17.60	17.30	1.80	0.76	1.62	0.82
1205	1	124.33	108.00	50.33	74.00	31.50	76.50	-1.14	7.23	-3.31	7.74	19.10	18.70	1.95	1.57	1.94	1.77
1206	1	126.80	121.83	41.33	85.47	43.33	78.50	6.52	11.45	5.42	10.89	17.60	18.20	1.65	1.49	1.83	1.56
1207	1	125.50	124.17	46.50	79.00	47.67	76.50	5.99	11.41	3.27	12.80	15.50	16.20	1.51	1.16	1.95	1.08
1208	1	117.67	125.33	44.00	73.67	46.00	79.33	11.79	15.23	4.51	12.79	15.70	17.60	1.36	1.19	1.64	1.06
1209	1	133.05	143.33	46.00	87.05	42.33	101.00	-0.86	6.91	4.21	9.59	17.40	16.70	1.86	1.43	1.81	1.45
1210	1	127.47	140.67	43.50	83.97	39.67	101.00	6.69	12.26	3.99	12.05	15.73	16.67	1.55	1.02	1.51	0.94
1211	1	113.50	147.00	44.50	69.00	66.00	81.00	5.50	12.59	-0.55	8.21	15.80	14.20	1.50	0.71	1.61	0.74
1212	1	110.67	117.00	32.33	78.33	36.00	81.00	-1.08	5.25	0.00	9.15	15.93	14.93	1.63	1.29	1.73	0.90
1213	2	135.10	135.67	34.50	100.60	42.00	93.67	0.00	8.29	999.00	999.00	14.80	999.00	1.80	0.94	999.00	999.00
1214	2	143.83	147.30	44.50	99.33	53.00	94.30	8.58	12.93	3.21	10.60	14.07	12.93	1.74	1.08	1.93	1.06
1215	2	131.27	129.67	45.67	85.60	46.00	83.67	0.00	6.66	0.00	7.09	12.40	12.60	1.37	1.00	1.24	0.87
1216	2	126.93	122.00	38.67	88.27	22.50	99.50	4.53	6.55	11.34	5.07	15.20	14.87	1.70	0.86	2.12	0.85
1217	2	121.53	124.43	38.00	83.53	51.00	73.43	-1.41	13.75	3.24	14.48	14.60	14.93	1.47	0.84	1.63	0.87
1218	1	116.00	130.57	46.00	70.00	44.50	86.07	6.00	13.38	6.28	11.72	16.30	16.40	1.49	0.81	1.65	0.77
1219	1	122.57	119.33	38.50	84.07	30.00	89.33	5.69	14.66	3.14	15.90	15.33	15.67	1.56	1.19	1.60	1.20
1220	1	100.17	105.83	36.50	63.67	19.00	86.83	7.33	13.54	6.27	11.34	16.40	16.80	2.02	1.32	2.20	1.65
1221	1	144.70	145.00	57.00	87.70	52.50	92.50	5.99	10.96	1.07	10.08	18.60	18.90	1.77	0.90	2.00	1.46
1222	1	127.33	127.00	54.33	73.00	56.33	70.67	5.99	15.65	9.44	15.09	16.67	16.47	1.58	1.47	1.51	0.83

Abbrieviations: Dom = dominant; tot= total; rot=rotation; nondom= nondominat; IR = external rotation; ER = external rotation; scap = Scapula; pec = pectoralis; ahd = Acromio-Humeral distance; nond= non-dominant.; STD = standard deviation.

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Appendix 10. Raw data for calculation of construct validity between MicroMaxx® ultrasound system and the M-Turbo® ultrasound system.

N =10 (3 x repeated measures) of the right 0AHD and the left 0AHD.

Inter session. Two months apart.

Summary Item Statistics Right side

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	144.102	136.398	151.655	15.257	1.112	40.387	6

Intraclass Correlation Coefficient Right side

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.853[a]	.687	.954	48.975	9	45	.000
Average Measures	.972[c]	.929	.992	48.975	9	45	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Summary Item Statistics Left side

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	153.495	146.071	161.974	15.903	1.109	59.237	6

Intraclass Correlation Coefficient right side

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.653[a]	.409	.874	14.473	9	45	.000
Average Measures	.919[c]	.806	.977	14.473	9	45	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Appendix 11. Raw data stability of measure

N= 10 shoulders (8 female, 2 male)

Average age = 45 STD 19.91 years.

Data collection period 18.6months range 17-19 months.

Paired Samples Test

		Paired Differences					t	Sig. (2-tailed)
		Mean	STD. Deviation	STD. Error Mean	95% Confidence Interval of the Difference			
					Lower	Upper		
Pair 1	domtotrot - domtotrot2	-5.9540000	12.0894535	5.4065680	-20.9650391	9.0570391	-1.101	.333
Pair 2	nondomtotrot - nondomtotrot2	.3106667	12.4539582	5.5695794	-15.1529648	15.7742982	.056	.958
Pair 3	domIR - domIR2	6.5593333	10.3717403	4.6383833	-6.3188832	19.4375499	1.414	.230
Pair 4	domER - domER2	-8.9793333	11.4836056	5.1356245	-23.2381129	5.2794463	-1.748	.155
Pair 5	domscap0angle - domscap0angle2	-4.0962169	4.8671341	2.1766486	-10.1395621	1.9471283	-1.882	.133
Pair 6	domscap60angle - domscap60angle2	2.4212029	11.4503842	5.1207675	-11.7963269	16.6387327	.473	.661
Pair 7	nondscap0angle - nondscap0angle2	-.2132707	5.5847177	2.4975617	-7.1476135	6.7210722	-.085	.936
Pair 8	nondscap60angle - nondscap60angle2	.7650856	5.9250982	2.6497844	-6.5918955	8.1220666	.289	.787
Pair 9	dompec - dompec2	-.7326667	1.5790669	.7061802	-2.6933372	1.2280038	-1.038	.358
Pair 10	nondompec - nondompec 2	-.8866667	.7424097	.3320157	-1.8084901	.0351568	-2.671	.056
Pair 11	dom0ahd - dom0ahd2	.0700000	.1604681	.0717635	-.1292474	.2692474	.975	.385
Pair 12	dom60ahd - dom60ahd2	.02400	.13221	.05913	-.14016	.18816	.406	.706
Pair 13	nond0ahd - nond0ahd2	.01400	.07266	.03250	-.07622	.10422	.431	.689
Pair 14	nond60ahd - nond60ahd2	-.00800	.29786	.13321	-.37784	.36184	-.060	.955

Abbrieviations: Dom = dominant; tot= total; rot=rotation; nondom= nondominat; IR = external rotation; ER = external rotation; scap = Scapula; pec = pectoralis; ahd = Acromio-Humeral distance; nond= non-dominant.; STD = standard deviation.

Appendix 12. Declaration of originality

UNIVERSITY OF SALFORD

DECLARATION OF ORGINALITY – CONDUCT OF ASSESSED WORK

Name of candidate ………TANYA ANNE MACKENZIE………………………………………….

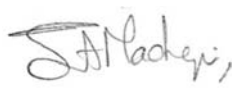
Roll number/Student number: ………@002255780……………

School: ….………… School of Health Sciences ……………………………………………………………………

Degree:……….PhD…………………

This is to certify that the copy of my thesis, which I have presented for consideration for my postgraduate degree: -

1. embodies the results of my own course of study and research
2. has been composed by myself
3. has been seen by my supervisor before presentation



Signature of candidate: Date: ………14 February 2016……