A DESCRIPTIVE STUDY OF FORCE PRODUCTION AND MUSCLE RECRUITMENT RATIOS IN HEALTHY SHOULDERS:
A QUANTITATIVE CROSS SECTIONAL STUDY

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A dissertation submitted to the Faculty of Health Sciences, University of the Witwatersrand, for the degree of Master of Science in Physiotherapy.

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DECLARATION

I, Sonia Briel, declare that the work contained in this dissertation is my own work, except to the extent indicated in the acknowledgement sections.

This dissertation is being submitted for a degree of Masters in Physiotherapy (by dissertation), at the University of the Witwatersrand, Johannesburg, South Africa.

This work has not been submitted for any other degree or examination in this or any other university.

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Sonia Briel Date

ABSTRACT

Background

The scapula's stabilising muscles position the glenoid dynamically as well as statically so that efficient glenohumeral articulation can occur. Due to a lack of bony support both the static and the dynamic stability of the scapulothoracic joint is dependent on the scapula's stabilising musculature. The strength of the individual muscles is important, but the ideal force ratios within the different force-couples are more important. Scapular stability ensures optimal placement of the glenoid of the scapula, which in turn ensures joint congruency at the glenohumeral joint. Normal subacromial and subcoracoid spacing is dependent on the ideal functioning of the scapulothoracic musculature. This leads to full and pain free kinematics at the scapulothoracic and the glenohumeral joints. No baseline values, to the researcher's knowledge, exist in literature of the scapula's stabiliser force couple ratios.

Objectives

The first objective was the determination of normative values for the ratios within the force couples of the scapular stabilising muscles in healthy shoulders. The force couple ratios between the upper trapezius versus the lower trapezius, the middle trapezius versus the serratus anterior upper fibres, the serratus anterior lower fibres versus the rhomboids, the serratus anterior lower fibres versus the lower trapezius and the lower trapezius versus the rhomboids, were investigated. The force couple ratios between the sexes was determined, as well as between the non-dominant versus the dominant sides, comparing the sexes. The second objective was the investigation of the electromyographical (EMG) muscle activity of the lower force couple (the serratus anterior lower fibres and the lower trapezius) in the two movement planes, namely flexion in the sagittal plane and abduction in the frontal plane. The third objective was the determination of the correlation between the EMG muscle activity ratio of serratus anterior lower fibres and of lower trapezius in the sagittal and frontal planes, using kinematic analysis.

Method

This was a cross sectional quantitative study design. There were 58 participants (29 females and 29 males) with healthy shoulders recruited for this study. A convenience sample of 42 participants, who fulfilled the required criteria, was recruited from the general public. The remaining 16 participants were recruited from the student body of the Physiotherapy Department of the University of the Witwatersrand. Measurements were collected of the force couples of the scapulae of both the shoulders of the participants. Force measurements were collected of the serratus anterior upper fibres, the upper trapezius, the middle trapezius, the serratus anterior lower fibres, the rhomboids and the lower trapezius. EMG activity was recorded of the serratus anterior lower fibres and the lower trapezius. This study utilised largely descriptive analysis. A paired-t test analysis was used for the comparison between the non-dominant and the dominant side and for the comparison between female and male participants. The means, standard deviations and ranges were calculated for all force measurements. Kinematic data collected was of the serratus anterior lower fibres and the lower trapezius in flexion in the sagittal plane and in abduction in the frontal plane. A repeated analysis of variance (ANOVA) with a Bonferroni post- hoc test was run for the variance of the serratus anterior lower fibres and lower trapezius. A Spearman test was run to determine the consistency of serratus anterior lower fibres versus lower trapezius in flexion and in abduction. In the familiarisation session all participants completed the informed consent form, were weighed, measured and kinematic inertial measurements were collected. A priori sample size calculation was calculated using G*Power (version 3.1.9.2). Statistical significance was set at $p < 0.05$, with the confidence level at 95% (alpha <0.05). It was determined that the sample size required with an alpha of 0.05, a power level of 0.95 and using a two-tailed design would be n=58.

Results

Statistically significant differences were found to exist within the combined (females and males) groups in some of the mean force couple ratios. The mean force couple ratio for upper trapezius versus lower trapezius was found to be higher in the non-dominant and the dominant sides in the females, compared to that of the males. The ratio between the middle trapezius versus serratus anterior upper fibres in the non-dominant and the dominant sides of the females was lower compared to that of the males. The other major finding was the increased EMG activity of serratus anterior lower fibres versus lower trapezius in abduction in the frontal plane, at 70%, 80% and 90%. Correlating the EMG muscle activity ratios of the lower fibres of serratus anterior and the lower fibres of trapezius in sagittal flexion and in frontal abduction: a

significant negative relationship concluded from the start to 10% of abduction, and no relationship existed for the rest of the movement cycle of both flexion and abduction.

Conclusion

The most significant finding was that different force couple ratios exist within some of the force couples of the scapula between sexes. The main results obtained with the EMG and kinematic analysis were that the lower fibres of serratus anterior were consistently more active in abduction in the frontal plane, compared to flexion in the sagittal plane. The EMG ratio correlation between the lower fibres of serratus anterior and the lower fibres of trapezius was consistent at the start and at 10% of abduction.

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‘Chance favours the prepared mind. The more I study nature the more I stand amazed at the work of the Creator.’ Louis Pasteur, more than a century ago.

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LIST OF ABBREVIATIONS

Anova – analysis of variance

3-D – three dimensional

CCL – confidence level

CV – coefficients of variance

EMG – electromyographic

F- female

GL – gimbal lock

HHD – handheld dynamometer

ICC – intraclass correlation coefficient

iEMG – integrated EMG

IMUs – inertial measurement units

ISB – International Society of Biomechanics

L – left

M – male

MVC – maximum voluntary contraction

MVIC – maximum voluntary isometric contraction

R- right

ROM – range of motion

RMS – root mean square

SAU-SO – slow twitch oxidative

VR – variance ratio

CHAPTER 1: INTRODUCTION AND SCOPE OF THE DISSERTATION

1.1 Introduction

The poor anchoring of the scapula by bony attachments results in the dynamic and static stability of the scapula being largely dependent on the balanced actions of the scapular musculature (Kibler and Sciascia, 2010; Kibler *et al.,* 2013; Sahrmann, 2001). It is generally accepted that proper dynamic scapular stability is provided through the combined actions of the force couples of the serratus anterior and all the parts (upper, middle and lower) of the trapezius (Bagg and Forrest, 1988; Inman *et al*., 1944; Kibler, 1988, a). In the clinical setting, visual observation as well as testing of the periscapular muscles are warranted in the evaluation of scapular dysfunction (Kibler *et al.,* 2013). Although muscle activity of the serratus anterior, upper, middle and lower trapezius has been investigated with electromyographic (EMG) studies, the actual relationship between EMG studies, performance, symptoms and function or outcomes is not well understood (Cools *et al.,* 2004; Kibler *et al.,* 2007; Ludewig and Cook, 2000). The scapular stabilisers (upper, middle and lower trapezius and serratus anterior), have thus been studied extensively by many researchers in an attempt to identify movement patterns that exist in abnormal, pathological shoulders and in normal pain free individuals. Total clarity on the functioning of the scapula and on the scapular stabilisers are even then still lacking in literature. It is well recognised that postural evaluation of the scapula is important during the objective examination (Kibler and McMullen, 2003). The ultimate goal of shoulder examination is the identification of scapular asymmetry in symptomatic patients. The presence of pain will cause scapular dyskinesis and dyskinesia, to develop, symptomatic individuals with present with both. There is however still uncertainty as to the meaning of scapular asymmetry found to be present during the physical examination. More research is needed in this area to clarify the presence of scapular asymmetry (Kibler and McMullen, 2003). This in turn will help develop treatment plans for symptomatic individuals (Ludewig and Reynolds, 2009). Scapular asymmetry can thus not be seen conclusively of underlying pathology, unless proven by more tests than just visual observation. The conclusion of shoulder pathology can thus not be based solely on the visual presence of scapular asymmetry (Cools *et al.,* 2003). The enhancement of neuromuscular control around the scapula is dependent on ideal force production, as well as optimal recruitment, timing and activity of the scapular stabilising musculature (Cools *et al.,* 2003).

The scapula plays a key role in the function of the shoulder and is an important link in the kinetic energy transfer chain of the body (Kibler *et al.,* 2002). Optimal functioning of the glenohumeral joint is dependent on proper alignment of the scapula (Kibler and Sciascia, 2010). The scapular stabilisers' balanced actions function as force couples for the scapula (Cools *et al.,* 2004; Inman *et al.,* 1944; Ludewig and Reynolds, 2009; Voight and Thomson, 2000; Wadsworth and Bullock– Saxton, 1997). The upper force couple consists of the upper fibres of the serratus anterior and the upper trapezius muscles (Bagg and Forrest, 1986). The lower force couple, which consists of the lower fibres of the serratus anterior and the lower trapezius, also plays a vital role in the efficient functioning and control of scapulohumeral movement (Inman *et al.,* 1944). Force couples can be defined as: 'Two equal forces acting in opposite directions to rotate a part about its own axis of movement' (Kent, 1971:870).

Force couples around the scapula relevant to arm elevation are best described by Bagg and Forrest (1986) in the following phases:

- In the first 60^0 of upward rotation of the scapula, the main muscles involved are the serratus anterior upper fibres and the upper trapezius. This conclusion was supported by Schenkman (1987).
- In the next 60^0 of rotation of the scapula, the main contributors to rotation change to the lower trapezius, the serratus anterior lower fibres, and the upper trapezius. This is in support of the findings by Basmajian and De Luca (1985) and Inman *et al*. (1944).
- In the final stages of elevation of the scapula, 120^0 and above, the main muscle contributors towards upward rotation are the lower trapezius and the serratus anterior lower fibres.

Normal scapular position and biomechanics are altered when weakness and dysfunction are present in the scapular stabilisers. This can lead to scapular dyskinesis (Kibler, 1998, b; Voight and Thomson, 2000). If the length/tension curve is altered the muscles of both the scapula and the rotator cuff are less efficient in their eccentric and concentric actions (Sahrmann and Caldwell, 1998). Conflicting evidence of EMG recruitment patterns of the scapular stabilisers was found in the literature. Wadsworth and Bullock–Saxton (1997) found that the upper trapezius was recruited first, followed by the middle trapezius and then the lower trapezius. Other authors agreed that all parts of the trapezius were more active in abduction than in flexion (Bagg and Forrest, 1986; Inman *et al.,* 1944). The serratus anterior is thought to be more active in forward flexion (Inman *et al.*, 1944). To control joint movement, ideal activation timing as well as optimal force production should be present in the scapular stabilisers. Coordinated synergistic and antagonistic scapular stabilising muscle functioning will contribute to stable scapulothoracic joint arthokinematics (Cools *et al.*, 2003). Taking these considerations into account, the EMG muscle activity patterns with EMG analysis are included in this study.

1.2 Problem statement

A muscle tested in isolation, without taking synergistic or antagonistic muscle actions into consideration, may test strongly in a normal manual muscle testing position, but may perform poorly in a functional movement activity (Magarey and Jones, 2003). To my knowledge there is no data in the literature on isometric force production ratio measurement figures of the scapular force couple muscles. Scapular stability depends on the optimal force couple ratios within the scapular musculature. To effectively treat the scapular complex, a normal baseline figure needs to be established for the scapular stabilising ratios in a healthy population. In the clinical setting access to measuring tools is not always available. With no baseline figures available on which to base rehabilitation, imbalances in the ratio of the scapular stabilisers can easily be created during the rehabilitation process. This can lead to subacromial and subcoracoid impingement. No link between the isometric force production ratios of the scapular stabilisers, and the EMG recruitment patterns of the scapular stabilisers, the serratus anterior lower fibres and the lower trapezius could be found in the literature. The two muscles of the scapular complex found most frequently to be weakened or inhibited were the serratus anterior and the lower trapezius (Solem–Bertoffe *et al*., 1993) These muscles were therefore chosen to be investigated in the present study.

1.3 Aim of the study

The aim of this study was to establish:

- the force production ratios of the scapular stabilisers, and
- the EMG activity of the lower force couple (serratus anterior lower fibres and lower trapezius)

in healthy shoulders and in both sexes.

1.4 Objectives of the study

The objectives of this study were:

- to determine the isometric force production ratios within the different force couples of the scapula's stabilising musculature: in healthy shoulders, in both the non-dominant versus the dominant arm and in both sexes, using a handheld dynamometer. The force couples are: upper trapezius versus lower trapezius, middle trapezius versus serratus anterior upper fibres, serratus anterior lower fibres versus lower trapezius, serratus anterior lower fibres versus rhomboids and lower trapezius versus rhomboids.
- to determine muscle activity using a surface EMG combined with kinematic analysis, of the lower trapezius versus the serratus anterior lower fibres, in the movements of forward flexion in the sagittal plane and of abduction in the frontal plane.
- to determine the correlation between the EMG activity ratio of the lower force couple, serratus anterior lower fibres versus lower trapezius.

1.5 Significance of the study

When rehabilitating the shoulder complex in the clinical setting, with or without access to the use of a sophisticated measuring tool, the clinician is often faced with a number of dilemmas:

- What is a working baseline value for the isometric ratios of scapula's force couples?
- What are the optimal isometric force production ratios within the different force couples?
- What are the target isometric force production ratios to which the force couples must be rehabilitated?

- How can progression be monitored without available data with which to compare rehabilitation?

In a time where the call for evidence is practise-based, there is a need for better scientific protocols. Therefore, establishing a baseline figure for the force production ratios of the scapular stabilisers can aid in an improved understanding of the shoulder complex, resulting in the implementation of measurable, scientific-based, evaluation and rehabilitation strategies. Using the dynamometer as the tool for the evaluation process, an evidenced-based, scientific, measurable and reproducible protocol can easily be implemented in the clinical setting. 'Improved understanding of the contributions of muscle forces, not only towards joint stability but also towards instability, will improve rehabilitation protocols in the treatment of joint stability throughout the body' (Labriola *et al*., 2004:802). The strength of muscles tested in isolation is often considered less important than the muscle balance within the muscle force couples (Kibler, 1998, b; Kibler and Chandler, 1994). Functionally, the muscle balance within force couples, as well as the strength of individual muscles and muscle groups, should be considered. It is in our interest as clinicians to establish norms of muscle strength and function.

1.6 Organisation of the dissertation

Table 1. 1 Organisation of the dissertation.

Chapter 1	• An introduction to the research is presented. The lack of present baseline figures of the scapular stabilisers in literature is hightlighted. • The research aims, objectives and significance of the dissertation are presented.
Chapter 2	• A review of the literature is introduced. The biomechanical aspects of the scapulothoracic joint are discussed. The scapular stabilisers, anatomy and function are included. The scapula's movements are covered. The scapulohumeral rhythm is covered. • Attention is given to scapula dyskinesis and it's implications.
Chapter 3	• Methodology is covered in this chapter. The sample size of the population and the inclusion and exclusion criteria are discussed. • The data collection process is described e.g. the physical examination and the outcome measures used. Ethical considerations are covered and the final analysis included.
Chapter 4	• Presentation of the results, with the accompanying graphs and tables are presented. • The force couple ratios of the scapular stabilisers, the EMG activity and EMG correlation results are presented.
Chapter 5	• Discussion, highligting of the main findings and the relevancy to current existing literaure is presented.
Chapter 6	• Conclusion of the dissertation is presented. • The impact of the outcomes reached on the clinical field is discussed. • Suggestions as to further research are presented.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The role of the scapula has been studied by many researchers and it is considered to be a key component of the normal functioning of the scapulothoracic and the glenohumeral joints. The stability of the scapula, dynamically and statically, is dependent on the scapulothoracic stabilising muscles. A stable scapula is required to functionally and efficiently centre the humeral head. This leads to improved kinematics of the glenohumeral joint in functional, daily and sporting activities (Kibler and McMullen, 2003; Ludewig and Reynolds, 2009; Van der Helm, 1994; Von Eisenhart–Rothe *et al.*, 2005). Very little ligamentous support is provided to the scapula. This emphasises the significant role of the scapulothoracic stabilising muscles in the scapulothoracic joint. Struyf *et al*. (2014), concluded that knowledge of the scapulothoracic motion is important for several reasons: (1) for the development of clinical assessment tests that can flow from it, (2) for preventative strategies that can be developed for asymptomatic individuals, (3) and for effective treatment strategies that can be developed for symptomatic patients. In the literature review the known aspects of the scapulothoracic stabilisers are highlighted.

The scapular stabilising muscles need correct recruiting and contractile properties (Mottram, 1997). This is important for full and pain free kinematics of the scapulohumeral complex. Several authors agree that research on a consistent recruitment and firing muscle activation pattern needs to be established (Brindle *et al*., 1999). Antagonistic and synergistic action of the scapulothoracic muscles is required to a varying degree for efficient stability and movement of the scapula during glenohumeral elevation (Lucado, 2011). The alignment of the scapula on the thorax is dependent on the ideal length, tension and recruitment of the scapular stabilising muscles. This allows the correct positioning of the glenoid for articulation at the glenohumeral joint during elevation of the humerus (Neuman, 2010).

Inman in 1944, was the first to study and analyse the scapulothoracic movements. He examined shoulder elevation in the coronal plane in asymptomatic subjects (Struyf *et al*., 2014). Stability and mobility of the scapulothoracic joint is mainly provided through the scapula. A firm platform, for the attachments of the scapular stabilising muscles is provided by the scapula. The scapula positions the glenoid for articulation at the glenohumeral joint. It thus optimises the length-tension relationship at the scapulohumeral complex. Elevation of the glenoid during elevation of the glenohumeral joint, provides an ideal length-tension ratio in the deltoid during the abduction movement (Hart and Carmichael, 1985; Hogfors *et al.*, 1991; van der Helm, 1994). Both the functioning of the individual muscles of the scapular stabilising musculature and the synergistic and antagonistic actions of the force couples are important in controlling the dynamic and static position of the scapula.

Optimal positioning of the glenoid, mainly by the scapular stabilising muscles, is a key component of the ideal functioning of these stabilising muscles. Optimal positioning of the glenoid leads to ideal glenohumeral arthokinematics, thereby increasing upper limb mobility (Mottram, 1997). Proper positioning of the glenoid of the scapula is mainly provided by the scapular stabilising muscles. A stable scapula ensures proper placement of the glenoid, which in turn leads to increased joint stability and congruency at the glenohumeral joint (Saha, 1971). The scapula upwardly rotates the acromion (by means of lateral rotation of the scapula), allowing full abduction without impingement, which is critical for throwing and overhead activities (Kamkar *et al*., 1993). A fully upward rotated glenoid is important for mechanical stability at the glenohumeral joint during abduction. This achieves ideal arthokinematics of the glenoid and the humeral head (Lucas, 1973). The positioning of the glenoid is important in the prevention of subacromial impingement.

Rotator cuff function is influenced by the orientation of the glenoid (van der Helm, 1994). According to Smith *et al.* (2002), the position of the scapula influences rotator cuff functioning. They concluded that the best functional position for full functioning of the rotator cuff is midway between protraction and retraction of the scapula. Apparently, either excessive protraction or retraction of the scapula, can be detrimental to full functioning of the rotator cuff (Smith *et al*., 2002). Excessive scapular protraction causes glenoid ante-tilt, which may cause increased compensation of the rotator cuff muscles subjecting the posterior labrum to shear forces. The increased sheer forces applied to the posterior superior labrum can lead to labral pathologies (Smith *et al*., 2002).

In clinical practice joint congruency refers to the geometric similarity of the two articular joint surfaces. It is taken as an indication of the joint's capability to withstand an applied load. The assumption is that the more congruent the surfaces are, the smaller the peak pressures generated will be, as determined by Wolff's law (Cowin, 1986). Currently the literature indicates that the ideal positioning of the scapula should be sought because of the direct effect the glenoid position has on the functioning of the rotator cuff and indirectly on the intra-articular surface of the labrum.

The finely coordinated actions of the scapula's stabilising muscles play a significant role in the ideal position and maintenance of the acromiohumeral distance. The coordinated kinematics of the scapula and the humerus around the thorax during arm elevation in the sagittal, scapular and/or frontal planes is essential for full, pain free glenohumeral articulation (Parel *et al*., 2012). It was concluded by Bdaiwi *et al.* (2015), that during simultaneous or individual neuromuscular stimulation of the serratus anterior and the lower trapezius, an increase in the acromiohumeral distance was observed. Holterman *et al.* (2009), using EMG biofeedback to monitor the serratus anterior lower fibres and the lower trapezius, observed that during specific activation of serratus anterior lower fibres, spontaneous synergistic activation of the lower trapezius occurred. A definite relationship between the serratus anterior lower fibres and lower trapezius can thus be seen, it can be deducted that they act as a synergistic force couple. This result is in support of the findings by Inman *et al.* (1944) who argued that the lower force couple of the scapula might consist of the serratus anterior and the lower trapezius. Inman *et al.* (1944) conceptualised the concept of force couples, in particular the upper force couple consisting of serratus anterior upper fibres and upper trapezius, and the lower force couple consisting of the serratus anterior lower fibres and the lower trapezius.

Smith *et al.* (2003) drew attention to the fact that, anatomically, the upper trapezius is more involved in elevation of the scapula and that only the lower fibres of serratus anterior and lower trapezius form the lower force couple. It is well acknowledged in the literature that the actions of the scapular stabilisers, and especially the actions of the force couples around the scapula, have an impact on the positions of the scapula and the glenoid (Hébert *et al.,* 2002; Inman *et al.,* 1944).

EMG activity of the scapular stabiliser muscles has been explored by many researchers in numerous studies. Several authors agree that the emphasis of investigation into trapezius muscle activity is rather on the amount of activity present in the different parts of the trapezius muscle, than on the onset times and the order of recruitment of the different parts of the muscle (Ballantyne *et al*., 1993; Scovazzo *et al.,* 1991). In the scapulothoracic joint, where the dynamic stability of the joint is mostly dependent on the scapular stabilisers, subconscious muscle reaction is thought to be very important for optimal joint stability (Lephart *et al*., 1997). Temporal muscle recruitment in the glenohumeral joint has been examined (Auge *et al*., 2000; Brindle *et al*., 1999; Latimer *et al.,* 1998), but literature on the timing activity of the scapular stabilising muscles is still lacking (Wadsworth and Bullock–Saxton, 1997). Muscular balance of the scapular stabilisers is one of the criteria needed for proper neuromuscular control of the scapulohumeral complex. Thus, even with numerous studies done by many researchers, some questions on the ideal functioning of the scapular stabilising musculature remain unanswered.

Altered kinematics is a known cause of dysfunction of the scapulothoracic joint. Abnormal scapular positioning and an increased anterior-tilted scapula have been associated with a shortened pectoralis minor muscle (Borstad *et al*., 2008; Tate *et al.,* 2012). The scapular stabilisers are placed in a lengthened position by this kinematic alteration, leading to abnormal scapular and glenohumeral kinematics (Kibler *et al*., 2013; McClure *et al.,* 2001; Tate *et al*., 2012). Several studies have established scapular kinematic alteration in most pathological conditions affecting the shoulder, such as rotator cuff pathologies, shoulder instabilities and shoulder stiffness (Ludewig and Reynolds, 2009). Accordingly, disruption of the ideal functioning of the scapular stabilisers has been found to be present in shoulders with pathology.

In view of the prior evidence presented in the literature of the relevance of the force couple actions of the scapular stabilisers, the muscles selected for testing were: the upper, middle, and lower trapezius muscles; the upper and lower fibres of serratus anterior; and the rhomboid muscles. To my knowledge, there is no evidence in the literature of individual force measurement values, nor of force couple ratio values, of the scapulothoracic muscles. Health professional have used manual muscle testing since 1917, this however has been found lacking in reliability and validity, and Hislop and Montgomery (1995) concluded that a more measurable scientific objective tool is needed to record and measure force production. The handheld dynamometer was used to record measurements as its validity has been proved in test-retest documents (Andrews *et al*., 1996; Bohannon, 1986).

The literature presented in Chapter 2 was sourced from the following data bases: PubMed, Clinical Key and Science Direct. The search engine Google Scholar was used. Keywords used in the search were ‘scapula’, ‘scapulothoracic’, ‘force couples’, ‘isometric’, ‘isokinetic’, ‘electromyography studies, ‘kinematics’, ‘biomechanical analysis’, ’validity’, ‘reliability’. Literature from 1944 to 2016 was included in the literature review.

2.2 Anatomy and biomechanics of the scapula and scapulothoracic stabilisers

2.2.1 Scapulothoracic joint

The scapulothoracic joint is classified as a physiological joint between the anterior aspect of the scapula and the posterolateral aspect of the chest wall (Moore *et al*.,2014). It is not a true joint, but rather where the concave anterior surface of the scapula moves on the convex posterolateral surface of the thoracic cage (Williams, 1995). The scapulothoracic joint needs stability as well as mobility during elevation, so that the muscles moving the glenohumeral joint have a steady platform on which to position the arm (Mottram, 1997).

2.2.2 Scapular stabilising Muscles

The scapular stabilisers consist of the following muscles: the upper, middle, and the lower trapezius; the serratus anterior upper fibres, the serratus anterior lower fibres; and the rhomboids major and minor. A discussion of these muscles, according to the current literature, follows below.

a) Upper trapezius

The first muscle described is the trapezius. Even though the trapezius is anatomically one muscle, it consists of distinct parts, with different actions (Table 2.2). The primary action of the upper trapezius is elevation and retraction of the clavicle, as it does not have a direct attachment to the scapula, but rather attaches to the clavicle and acromioclavicular joint. The upper trapezius (Figure 2.1) is active mostly during scapular elevation, which it effects by means of clavicular elevation (Fey *et al.*, 2007; Johnson *et al*., 1994; Wiedenbauer and Mortenson, 1952).

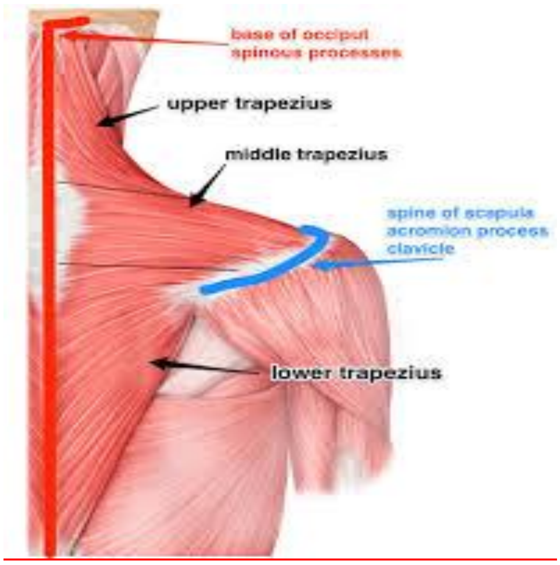

Figure 2. 1 The origin and insertion of the upper, middle and lower trapezius muscles.
https://www.yoganatomy.com/trapezius-muscle-yoga-anatomy/

b) Middle trapezius

The middle trapezius inserts from the root of the spine of the scapula to the acromion process of the scapula (Table 2.2). Due to the fibre arrangement of the middle trapezius, it is best aligned to offset the lateral movement of the scapula caused by the serratus anterior. It does not really contribute to upward rotation during activity, because of the small moment arm provided by the fibre alignment (Johnson *et al.*, 1994) (Figure 2.1).

It is known that the middle trapezius contributes to scapular stability (*ibid*). The centre of rotation of the scapula on the thorax moves from the root of the spine of the scapula towards the acromioclavicular joint during elevation. The rotation closely follows the insertion of the trapezius on the spine of the scapula (Bagg and Forrest, 1986).

c) Lower trapezius

The lower trapezius is the only part of the trapezius that can contribute overall to upwards rotation of the scapula (Figure 2.1). The moment arm of the trapezius changes across the range of movement for arm abduction and flexion (Johnson *et al.*, 1994). The activity of the lower trapezius is thought to be higher in abduction compared to in flexion (Inman *et al.*, 1944; Ludewig and Reynolds, 2009; McClure *et al.*, 2001; Wiedenbauer and Mortenson, 1952). When there is a lack of trapezius activity stabilising the scapula, an intact rhomboid and levator scapula may be greatly ineffective in their function of producing scapular rotation (Wiater *et al.*, 1999). It can thus clearly be seen that the various parts of the trapezius function both independently and as a unit to control the scapula (Table 2.2).

Table 2. 1 Scapular stabilisers, posterior axio-appendicular muscles, anatomy and function (Moore *et al*., 2014).

Muscle	**Proximal attachment**	**Distal attachment**	**Innervation**	**Muscle action**
Trapezius	Medial third of superior nuchal line; external occipital protuberance; nuchal ligament; and spinous processes of C7-T 12 vertebrae	Lateral third of clavicle; acromion; and spine of scapulae	Spinal accessory nerve (CVX1) Motor fibres, and C3, C4 spinal nerves (pain and proprioceptive fibres)	Descending part elevates; ascending part depresses; middle part (or all parts together) retract the scapula; descending and ascending parts act together to rotate the glenoid cavity.

d) Serratus anterior upper and lower fibres

The serratus anterior, which is primarily an upward rotator of the scapula and is considered by many to be the main stabilising muscle of the scapulothoracic joint, is highlighted below (Figure 2.2) (Ekstrom *et al*., 2003, 2004; Phadke *et al*., 2009). The serratus anterior is composed of the different sections, the upper, middle and lower fibres (Cuadros *et al.*, 1995; Norkin and Levangie, 1992; Ruland *et al.*, 1995; Simons *et al.*, 1999; Warwich *et al.*, 1998; Williams *et al.*, 1999). The serratus anterior is seen by most authors to be the prime stabiliser of the scapulothoracic articulation. It provides a steady platform for effective glenohumeral function (Ekstrom *et al.*, 2003, 2004; Moseley *et al.*, 1992; Pink *et al.*, 1991; Smith *et al.*, 2003; Townsend *et al.*, 1991). It has been described as a sheet of muscles situated between the ribs and the scapula (Smith *et al.*, 2003). The upper serratus anterior has been minimally investigated (Ekstrom *et al.*, 2004). The serratus anterior muscle has also been described as an abductor and upward rotator of the scapula. Distinct functions have been attributed to the various parts of the muscle (De Groot *et al.*, 2004; Ekstrom *et al.*, 2004). It was the conclusion of Ekstrom *et al.* (2004) that upward rotation and posterior tilt of the scapula on the thoracic wall, are only provided through the middle and lower serratus anterior muscle. Their simultaneous controlled actions provide stability to the articulation at the scapula-thoracic joint, which creates a stable base for the rotator cuff muscles. Improper functioning of the serratus anterior muscle results in decreased upward rotation and posterior tilt of the scapula, contributing to impingement symptoms at the glenohumeral joint (Ebaugh *et al.*, 2005; Karduna *et al.*, 2001).

In cadaveric dissections by Smith *et al.* (2003) the upper and lower portions of the serratus anterior were found to be clearly different and separate from each other. Figure 2.2. and Table 2.2, illustrate the anatomical representation of the origin and insertion of the serratus anterior. The superior four slips or upper fibres of the serratus anterior muscle formed a continuous sheet of muscle that inserts on the medial border of the scapula (*ibid*.). And the lower portion, consisting of the remaining inferior muscle slips, was found to insert on the inferior angle of the scapula (Smith *et al.*, 2003). Smith *et al.*

(2003) also found that each cadaver had seven to ten serrated or blade like muscle slips. The scapulothoracic joint space was found to be anatomically divided by the serratus anterior muscle into the subscapularis space posteriorly, and the serratus anterior space anteriorly (Ruland *et al.,* 1995; Smith *et al*., 2003). This is due to the remarkably large area it covers on the ribs (Cuadros *et al.,* 1995; Warwick and Williams, 1973). Serratus anterior originates from ribs one through to ribs seven (Cuadros *et al.,* 1995; Smith *et al.,* 2003; Williams *et al.,* 1999). It inserts along the medial scapular border, from the superior to the inferior angle on the anterior surface of the scapula (Smith *et al.,* 2003). The upper portion originates from ribs one and two and attaches to the superior angle of the scapula (Smith *et al*., 2003).

The serratus anterior upper portion is covered first. In the dissections by Smith *et al.* (2003), the serratus anterior upper fibres were found to be more superior and anterior, as well as separate, to the middle and lower portions of the muscle. The upper portion was found to have increased girth in comparison to the middle and lower portions of the serratus anterior. A further observation, in two cadaveric dissections by Smith *et al.* (2003), was that the posterior cord of the brachial plexus lay in close relationship to the axillary artery, and that both were imbedded in the upper portion of the serratus anterior. It was determined by dissection that the serratus anterior upper portion consistently inserts on a triangular area on the anterior superior angle of the scapula (Smith *et al.,* 2003). The levator scapular muscle attaches to the posterior superior angle of the scapula, in almost a mirror image of the attachment of the serratus anterior upper portion (Smith *et al.,* 2003). An intricate muscular arrangement is formed by the serratus anterior upper fibres and the levator scapula, where it attaches to the anterior, posterior and medial border of the superior angle of the scapula (Gregg *et al.,* 1979; Panegyres *et al.,* 1993; Smith *et al.,* 2003; Warwick and Williams, 1973; Williams *et al.,* 1999).

The overall conclusion reached by several researchers is that the most important function of the serratus anterior upper fibres is to anchor the scapula (Gregg *et al.,* 1979; Smith *et al.,* 2003). Scapular stability, provided by the compressive force of the serratus anterior upper fibres on the thorax, leads to a decrease of the sub-scapular space (Moore *et al.,* 2014)**.** Ekstrom *et al.* (2004) demonstrated that the serratus anterior upper fibres are best suited for abduction or protraction movements and that the serratus anterior lower fibres are best suited for upward rotation. This action in turn leads to scapular stability during humeral elevation (Smith *et al.*, 2003). Clearly, it can be seen that the upper serratus anterior fibres function in a very specific manner.

The lower fibres are anatomically arranged to produce both upward rotation and protraction, as well as posterior tilt, of the scapula (Ekstrom *et al.*, 2004). Progressive increased activity of the serratus anterior lower fibres has been demonstrated, in active elevation in the scapular plane (Ekstrom *et al.*, 2003; Moseley *et al.*, 1992). It was also concluded that the activity of serratus anterior lower fibres increases maximally in resisted arm elevation above 120°, in several movement planes (Ekstrom *et al.*, 2003; Moseley *et al.*, 1992). The serratus anterior lower fibre is the only muscle of the scapular stabilisers known to both upwardly rotate and posteriorly tilt the scapula (Ekstrom *et al.*, 2003; 2004). This is an important component for scapular stability and for maintaining the ideal width of the acromiohumeral joint space.

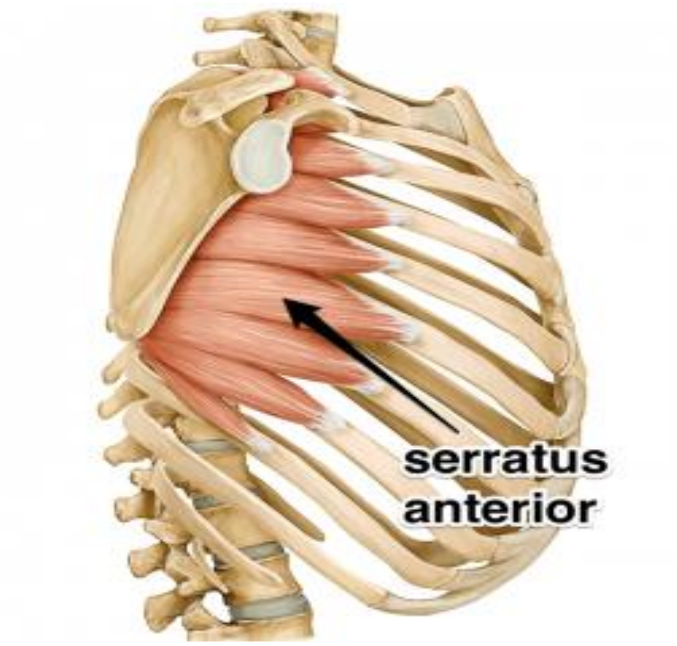

Figure 2. 2 Origin and insertion of serratus anterior, upper and lower fibres.

Taken from: https://www.yoganatomy.com/serratus-anterior-muscle/

Table 2. 2 Anterior axio-appendicular muscles of the scapula (Moore *et al*., 2014).

Muscle	Proximal attachment	Distal attachment	Innervation	Muscle action
Serratus anterior upper and lower fibres	External surface of the lateral parts of ribs 1 to 8	Anterior surface of the medial border of the scapula	Long thoracic nerve C5,6,7	Protracts the scapula and holds it against the thoracic wall; rotates the scapula upwards

e) Rhomboids minor and major

There is not always a clear division between the rhomboid minor and major fibres. Their main role is to cause retraction and downward rotation of the scapula, with resultant downward rotation of the glenoid cavity. Acting together with the serratus anterior, they cause a compressive force on the scapula, holding the scapula flush against the thoracic cage (Moore *et al.*, 2014). Based on anatomical considerations, the rhomboid muscles adduct (or draw medially) and elevate the scapula (Simons *et al.,* 1999) (Table 2.3). Figure 2.3 shows a graphic representation of the origin and insertion of the rhomboids minor and major muscles. Electromyographically, increased activity was displayed in rhomboids during abduction compared to flexion, during shoulder movements. (Basmajian and De Luca, 1985; Simons *et al*., 1999). Ito (1980) found that the rhomboid muscle exhibits steadily increasing activity throughout abduction and flexion. But in flexion the EMG activity reached only about two-thirds of the amplitude compared with abduction. In another study, the EMG activity of the rhomboids rapidly increased in intensity between 160° and 180° of either movement (Simons *et al*., 1999). The antagonistic roles of the serratus anterior lower fibres and of the rhomboids are an important function controlling upward and downward rotation of the scapula.

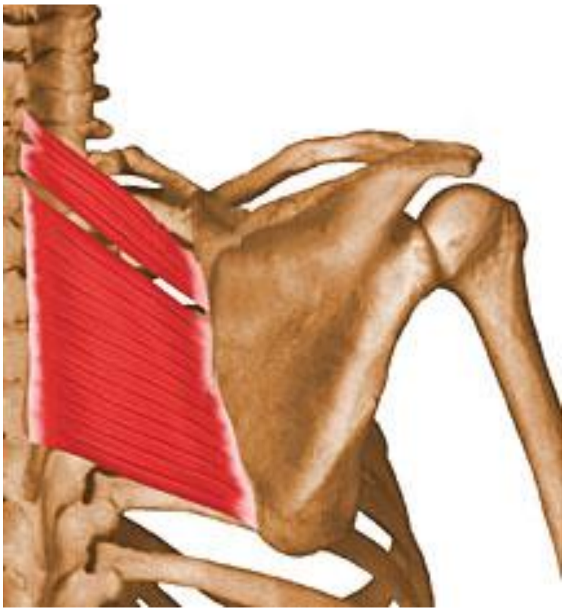

Figure 2. 3 Origin and insertion of rhomboids minor and major.

Reproduced from: http://www.letempledelaforme.com/anatomie/anatomie/rhomboide.htm

Table 2. 3 Scapular stabilisers, posterior axio-appendicular muscles, anatomy and function (Moore *et al*., 2014).

Muscle	Proximal attachment	Distal attachment	Innervation	Muscle action
Rhomboids Minor and Major	Nuchal ligament; spinous processes of C7-T1 vertebrae	Minor: Smooth triangular area at medial end of spine of scapula; major: medial border of the scapula from level of the spine to inferior angle	Dorsal scapular nerve C4,5	Retracts scapula and rotates glenoid cavity inferiorly; fixes scapula to the thoracic wall

2.3 Muscle Fibre Type

The scapular stabilising muscles act mainly in a stabilising role, keeping the scapula stable on the thorax. They act as dynamic stabilisers of the scapulothoracic joint. Even though in skeletal muscles varying amounts of type 1 and type 11 fibres are found, fibre type 1 is the predominant type found in all the scapular stabilisers muscles. (Table 2.4). This is due to the postural action that is required of the muscles. Muscles containing more of these type 1 fibres are also called slow-twitch oxidative (SO) muscles. They are able to sustain postural and tonic actions for lengthy periods of time (Norkin and Levangie, 1992).

Table 2. 4 The scapula's muscle fibre types and characteristics (Moore *et al.*, 2014; Norkin and Levangie, 1992; Warwick and Williams, 1973).

Muscle fibre types				
Muscle	Type of fibre present in the scapular stabilisers	Fibre type	Characteristics of type 1	Example of type 1
Trapezius, upper, middle and lower fibres; serratus anterior, upper and lower fibres; and rhomboids minor and major	Type 1 (mainly) but also type 11	Slow twitch, oxidative-type 1 Faster phasic twitch-type 11	Efficient use of oxygen and slow to fatigue	Postural muscles fibres high in proprioceptive nerve endings

2.4 Movements of the scapula

The key role of the scapula, and therefore scapular motion, lies in the biomechanical value it provides by increasing the elevation of the arm, and by positioning the glenoid for optimal and stable contact with the humeral head during motion (Norkin and Levangie, 1992). The scapulothoracic joint forms a primary example of dynamic stability in the body (Norkin and Levangie, 1992). In the normal resting position, the scapula lies approximately 5cm in from the midline and between the second to the seventh ribs (Steindler, 1955). De Groot (1999) describes the scapular position as being: 30^0 anterior to the frontal plane on the thoracic cage, with the medial border parallel to the spine, the upper edge lying between the 2^{nd} and 3^{rd} thoracic vertebrae, and the inferior angle lying between the 7^{th} to the 9^{th} thoracic vertebrae. Ideally, the inferior angle of the scapula should be flush against the thoracic wall, midway between medial and lateral rotation, and midway between elevation and depression (Mottram, 1997). The motions of the scapula are described from this reference point. They are described as elevation (cephalad motion), depression (caudad motion), abduction or protraction (internal rotation), and adduction or retraction (external rotation). These are all translatory motions

(Norkin and Levangie, 1992). (Figure 2.6). The upward and downward rotatory motions, tilts the glenoid fossa either upwards or downwards (Norkin and Levangie, 1992). (Figure 2.5). Anterior tilting, when the scapular superior surface approximates the thorax, and posterior tilting, when the inferior scapular surface approximates the thorax, and tipping of the scapula, are the other movements of the scapula (Karduna *et al.*, 2001). (Figure 2.5). In Figure 2.4 the movements of the scapula are graphically presented. With elevation of the arm, the scapula progressively rotates upwards, externally rotates and posterior tilts (Lukasiewicz *et al.*, 1999; McClure *et al.*, 2001).

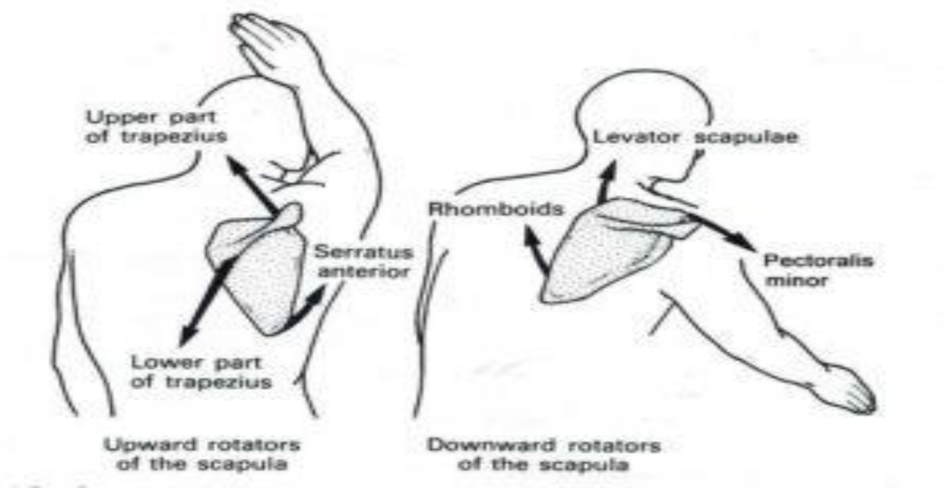

Figure 2. 4 The scapular movements, with resultant arm movements.

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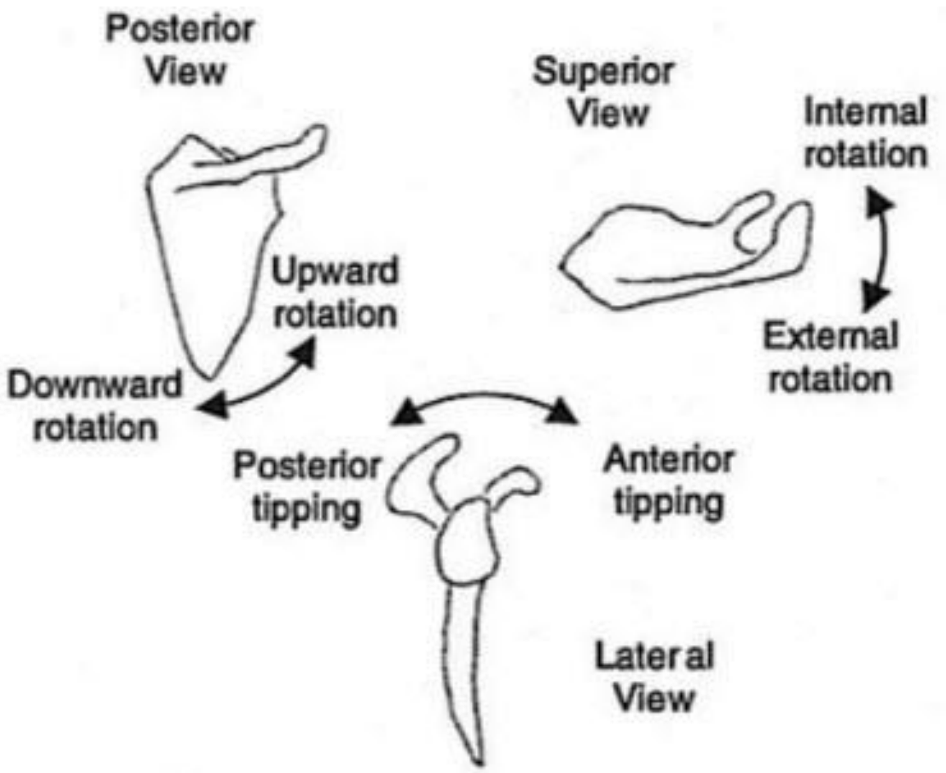

Figure 2. 5 The rotational motions of the scapula.

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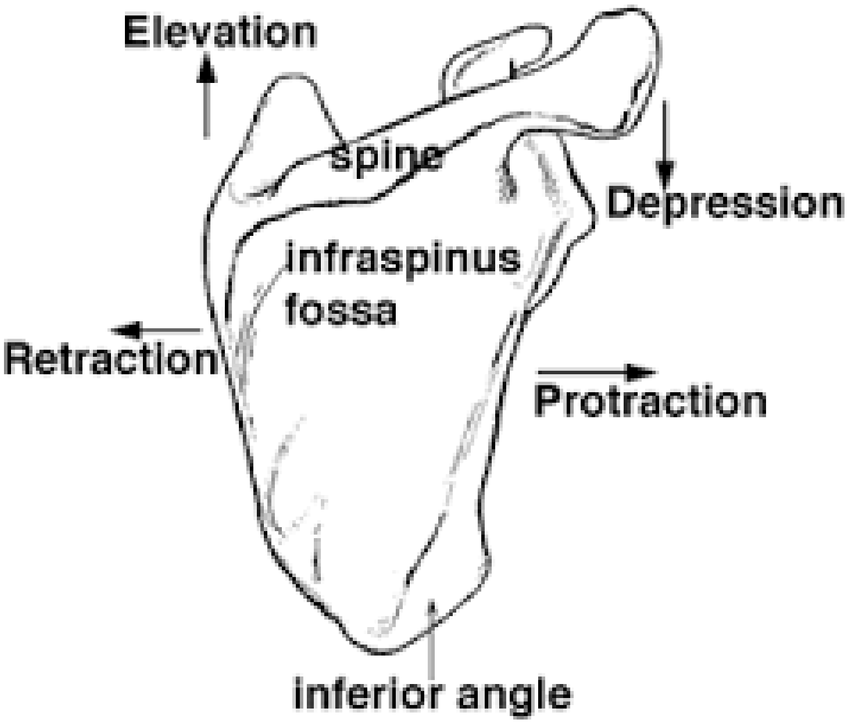

Figure 2. 6 The translatory motions of the scapula.

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Phadke *et al*. (2009) described the movements of the scapula around the known axes as follows: about a perpendicular axis to the scapula, upward and downward rotation of the scapula; about a vertically directed axis to the scapula, internal and external rotation; about a more horizontally directed axis, anterior and posterior tilting of the scapula (Figure 2.5). The movements of the scapula are presented in a table format in Table 2.4.

Table 2. 5 Movements of the scapula and the muscles providing the movements (Moore *et al*., 2014).

Movements of the scapula	Muscles producing movement	Range of movement, angular rotation, linear displacement
Elevation	Trapezius, descending part	10-12 cm
Depression	Trapezius, ascending part Serratus anterior, inferior part	
Protraction	Serratus anterior	40-45^{0}, 15 cm
Retraction	Trapezius middle part, Rhomboids	
Upward rotation	Trapezius, descending part Trapezius, ascending part	60° inferior angle, 10-12 cm
	Trapezius ascending part Serratus anterior inferior part	10-12 cm, Superior angle: 5 - 6 cm
Downward rotation	Rhomboids	

2.5 Scapulohumeral rhythm

The relative movement between the scapula and the humerus, during motion of the upper limb, has been described as the scapulohumeral rhythm (Struyf *et al*., 2014). The term scapulohumeral rhythm was first introduced by Codman in 1934 (Struyf *et al*., 2014). Cathcart (1884) was the first to observe and describe the simultaneous movement of the glenohumeral and the scapulothoracic joints in living subjects (Struyf *et al.*, 2014). Inman *et al.* (1944) concluded that glenohumeral and scapulothoracic rotations contribute a maximum of 120^0 and 60^0 respectively, of total arm movement. They identified a setting phase of the first 30^0 of abduction and the first 60^0 of flexion. Most of the motion at the glenohumeral joint occurs in this setting phase. The ratio of glenohumeral to scapulothoracic rotation was determined to be 2:1 (Inman *et al.*, 1944). However, more recent studies have challenged these findings. Bagg and Forrest (1988) and Doody *et al.* (1970) found that scapular rotation contributes 60^0 of arm movement and the glenohumeral joint contributes from 103^0 to 113^0 of arm movement, in a total range of 168° to 172^0 of arm movement. They also observed variability of the ratio of the glenohumeral and the scapulothoracic motion through range and between subjects. A glenohumeral to scapulothoracic ratio of up to 7.29:1 was reported by Doody *et al.* (1970) in the first 30^0 of elevation. Bagg and Forrest (1988) reported a ratio of 3.29:1 of glenohumeral to scapulothoracic motion, between 20^0 to 80^0 of elevation. They also found that during the middle phase of abduction (81.8^0 to 139.1^0) the ratio of scapulothoracic to glenohumeral rotation was 1.71:0.71. Glenohumeral to scapulothoracic motion, at a ratio of 3.49:1, was again dominant after or above 140^0 to 150^0 of elevation (Bagg and Forrest, 1988).

2.6 Scapular kinematics and dyskinesis

The scapular stabilisers consist of different muscles groups. Within these different muscle groups each fibre orientation displays distinct functions, functioning either in a synergistic or antagonistic force couple ratio orientation. Disruption in the force production of the scapular stabilisers, in particular increased upper trapezius activation and decreased middle trapezius, lower trapezius and serratus anterior muscle activation, has been implicated as a cause of decreased upward rotation of the scapula (Lucado, 2011).

The effect of dysfunction of the scapular stabilisers, as discussed, is summarised below. Imbalances between the upper trapezius and the lower trapezius may lead to the scapula's position leaning towards more elevation than upward rotation. Imbalances between rhomboids and serratus anterior lower fibres can lead to a downwardly rotated scapula, causing a decrease in the subacromial space and impingement of the supraspinatus tendon. The attachment of the rhomboid major fibres to the lower vertebral border of the scapula tends to rotate the scapula medially, turning the glenoid fossa downwards (Simons *et al.*, 1999). This in turn will lead to the development of potential subacromial impingement.

Imbalances between serratus anterior upper fibres versus middle trapezius, in the presence of a stronger serratus anterior, can lead to the position of the scapula favouring protraction, causing internal impingement of the neurovascular bundle (Smith *et al*., 2003). A possible relationship between thoracic outlet syndrome and hypertrophy of the upper serratus anterior might exist due to the proximity of the brachial plexus and the axillary vessels (Smith *et al.*, 2003).

Imbalances between the serratus anterior lower fibres and lower trapezius can cause a downwardly rotated glenoid, resulting in impingement even at rest. Disruption of the serratus anterior and the lower trapezius force couple allows the inferior-medial angle of the scapula to tilt in a posterior direction, away from the thoracic cage, this then causes the acromion process to tilt towards and closer to the greater tuberosity (Hébert *et al.*, 2002). The conclusion drawn by numerous researchers is that a downwardly rotated glenoid can cause a de-centring of the humeral head on the glenoid cavity (Karduna *et al.,* 2001; Lucado *et al.,* 2011). This can in turn lead to subacromial impingement.

The fine co-ordination between the rhomboids and the serratus anterior lower fibres, and the rhomboids and the lower trapezius, is important for the control of upward/ downward rotation of the scapula. EMG studies have shown that the rhomboids are active in both flexion and abduction, but more so in abduction (Ito, 1980).

As illustrated above, dysfunctions can all lead to the development of scapula dyskinesis (dys= alteration, kinesis= movement) and movement impairments. Figure 2.7 is a graphic illustration of the muscular forces of the scapular stabilisers. In light of the evidence provided previously, it can be concluded that the above dysfunctions can have a detrimental effect on functioning at the glenohumeral joint and can lead to altered arthokinematics at the scapulothoracic as well as the glenohumeral joint.

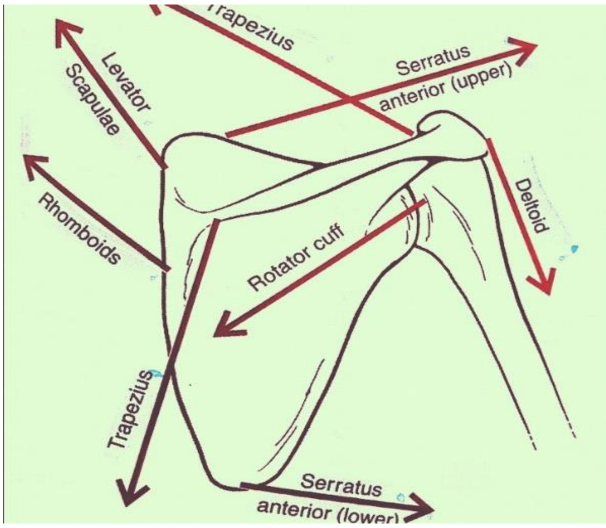

Figure 2. 7 Schematic representation of muscular forces acting on the scapula.
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https://i.pinimg.com/236x/bd/d9/6c/bdd96ced7eadb17117f7d05d27b59c1a--scapula-rotation.jpg

2.7 Subacromial impingement

Two types of subacromial impingement are identified in literature, structural (internal) and functional (external). Structural impingement is triggered by the presence of bony spurs, mainly on the inferior latero-anterior part of the acromion process, this causes a physical loss of subacromial space. The effect of this loss of subacromial space is increased pressure on the subacromial bursa, the supraspinatus tendon and the long head of biceps tendon (Page, 2011). Functional impingement is normally a secondary biomechanical alteration due to an imbalance in the scapular stabilising muscles. This biomechanical dysfunction causes a potential loss of subacromial space, causing increased pressure on the subacromial structures as well as glenohumeral instability (*ibid.*). The subacromial space between the coracoacromial arch and the humeral head is occupied by the rotator cuff tendons and the subacromial bursa (Culham *et al.*, 1993). When measured radiographically, the subacromial distance, from the inferior surface of the acromion to the humeral head, is on average 9-10 mm in normal shoulders (Petersson *et al.*, 1984). It is the conclusion of several researchers that a reduction in this distance can predispose the long head of biceps and the supraspinatus tendons to developing tears (Bigliani *et al.*, 1992; Petersson *et al.*, 1984; Weiner and Macnab, 1970). Studies by various researchers have shown that a 4° to 5° difference in scapular kinematics plays a role in subacromial impingement (Ludewig and Cook, 2000; Lukasiewicz *et al*., 1999). Normal subacromial space preservation therefore plays a key role in pain free functioning of the shoulder.

Any disruption or weakness of the scapular stabiliser muscles contributes to the development of functional (external) impingement. It is generally understood that with impingement, the subacromial structures, the subacromial bursa, supraspinatus tendon and the long head of biceps, is normally compressed beneath the anterior inferior part of the acromion (Neer, 1972; Phadke *et al*., 2009). Muscular changes around the scapulohumeral joint can lead to dysfunction of the shoulder complex, causing pain. Figure 2.9 depicts a graphic representation of the sequences that lead to subacromial impingement. Janda (1993) argued that weakness of lower trapezius, middle trapezius and serratus anterior, with tightness of upper trapezius, can lead to a functional subacromial impingement.

According to several authors the scapula plays a significant role in impingement syndrome, notably subacromial impingement syndrome. Furthermore, imbalances in the EMG ratios of lower trapezius, serratus anterior lower fibres and middle trapezius have been found in injured population groups (Cools *et al*., 2007; Karduna *et al*., 2005; Myers *et al*., 2005). An increased ratio in the activity of upper trapezius versus a decreased ratio in the activity of lower trapezius and middle trapezius was reported in the study by Cools *et al*. (2007). They compared the ratios of these muscles in a normal pain free group to a group with shoulder pain. Previous studies established that altered muscular activation patterns can be the result of scapular force couple imbalances (Kibler and McMullen, 2003; Ludewig and Cook, 2000; Michener *et al*., 2003). Altered kinematics has thus been one of the findings in patients with shoulder pain.

In patients with impingement, most researchers conclude that the EMG activation of upper trapezius is increased and the EMG activation of middle trapezius, lower trapezius and serratus anterior is decreased (Cools *et al*., 2003, 2007; Ludewig and Cook, 2000; Moraes *et al*., 2008; Wadsworth and Bullock- Saxon, 1997). Chester *et al.* (2010) determined that the coordinated action of the serratus anterior coupled with all the parts of the trapezius (upper, middle and lower), are needed for normal external rotation in the plane of the scapula. Altered synchronisation of these muscle groups results in a reduced upward rotation of the glenoid and thus a reduction in the size of the subacromial space (Ozaki *et al.*, 1987; Paletta *et al.*, 1997). This could contribute to the development of subacromial impingement. This finding of altered scapular stabiliser activity is deemed a major contributing factor to subacromial impingement. Figure 2.8 is a schematic representation of impingement in the subacromial space.

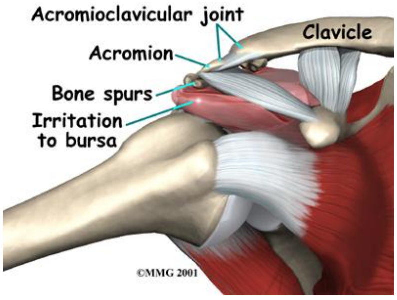

Figure 2. 8 Subacromial space. Reproduced from: http://www.eorthopod.com/images/ContentImages/shoulder/shoulder_impingement/shoulder_impingement_causes01.jpg

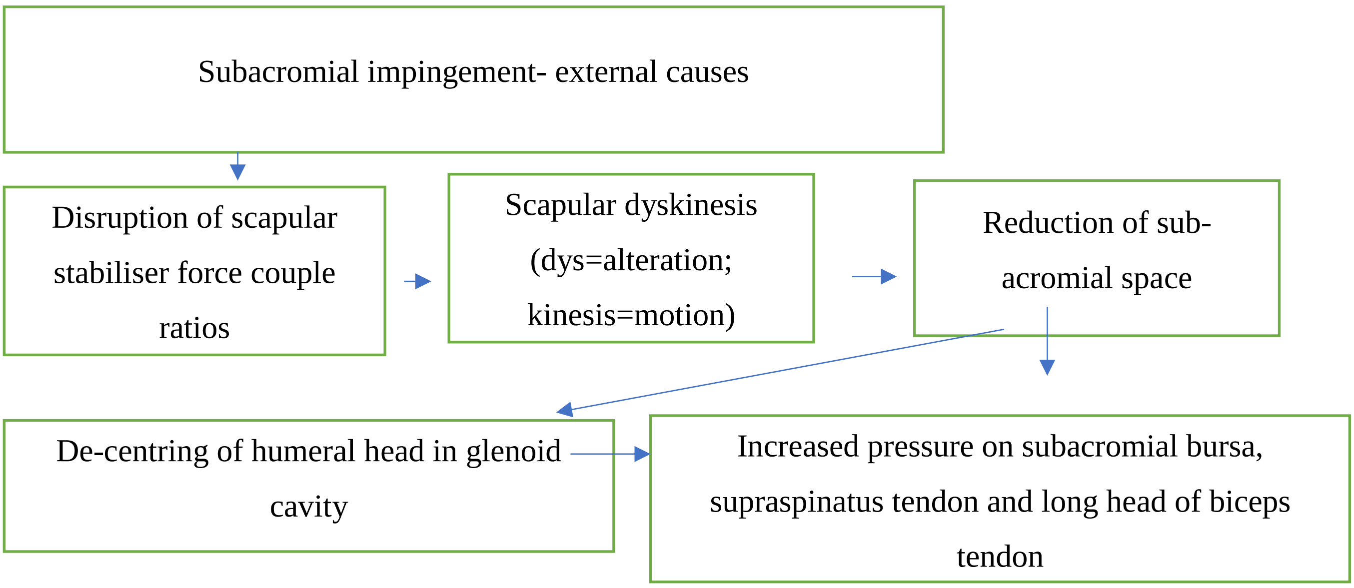

Figure 2. 9 Description of scapular dyskinesis and the effect on subacromial dysfunction.

2.8 Force measurements

The assessment of muscle strength or force in a measurable and repeatable manner is deemed a vital component of any assessment in movement dysfunction. Researchers and clinicians normally monitor patients over the rehabilitation period. The following reasons have been supplied by several researchers for monitoring the force production: (1) in the diagnosis of glenohumeral pathologies and dysfunctions (2) in evaluating the efficacy of treatment (3) in monitoring the change in muscle force with the resultant change in movement quality over time (Cools *et al*., 2014; Stark *et al.,* 2011; Van de Pol *et al.,* 2010). Accurate and reliable assessment tools are therefore a key factor in the objective evaluation of the functional status of the shoulder joint (Cools *et al.,* 2014; Roy and Doherty, 2004). Important assessment tools by clinicians are thus considered to be not only self-reported outcome scores, subjective examinations, but also strength assessments (Cools *et al.,* 2014). The assessment of muscle force is considered a key component of the patient's first clinical evaluation. Baseline figures should be established from the outset of treatment.

Currently there are two modalities available for the objective clinical measurement of muscle force. There is isokinetic testing, which is a computerised machine, and the handheld dynamometer, which is a handheld device. The isokinetic computerised machine has been used extensively in the practice setting and has been considered the gold standard of measuring muscle force. It has been used as a reference standard with which to compare other instruments (Burnham *et al*., 1994; Stark *et al*., 2011). Lovett and Martin in 1916, was the first to identify the handheld dynamometer in literature (Stark *et al.,* 2011). It is a suitable handheld instrument that can be used to test a patient's muscle strength. A quantifiable measurement of force can be provided by it.

The handheld dynamometer is therefore used for the assessment of muscle force because it has been found by various authors to be a measurable and reliable tool (Bohannon, 1986; Stark *et al*., 2011). In a study by Stark *et al.* (2011) it was found to be a reliable and valid instrument for the measurement of force when compared to isokinetic devices. Beasley, (1956), identified the need for a more objective and precise muscle testing tool, than the manual muscle tests used at the time. With the use of a manual force gauge he determined that a difference of 20% to 25% is not identified by manual muscle testing. This discrepancy clearly identified the need for a more measurable instrument for testing muscle force, than traditional muscle testing methods. Manual muscle testing done on the knee extensors muscles, frequently fails to identify a 50% decrease in strength (Beasley, 1956). Stark *et al.* (2011), concluded the handheld dynamometer to be a valid and reliable instrument for testing shoulder strength in a clinical setting. He found it to be compact, easily used and of relative low cost (Stark *et al.,* 2011). For monitoring and objectively evaluating the efficacy of the rehabilitation protocol, serial muscle force should be carried out routinely (May *et al*., 1997; Stark *et al*., 2011).

Chapter 3, section 3.3.2 covers methodology and provides more information on the reliability and validity of the handheld dynamometer.

2.9 Electromyography (EMG)

EMG is used for assessing the electrical activity of muscles. Basmajian and de Luca (1985), classified EMG as the study of muscle function, through analysis of the electrical signals produced by the muscles. EMG is used in the study of skeletal muscles (Reaz *et al.,* 2006). The EMG signal is formed in the following way: Activation of a motor neuron by the central nervous system, cause an electrical impulse to travel down to the motor endplate. Due to ionic changes across the resting muscle membrane, a muscle fibre action potential occurs (Barrett *et al.,* 2009). The functional unit of a muscle contraction is a motor unit. A single alpha motor neuron and all the muscle fibres innervated by it, is called a motor unit (Farina *et al.,* 2004). The activation of a single motor unit, as in a mild muscle contraction, is recorded on the skin's surface as a motor unit action potential (MUAP) (Robertson *et al.,* 2014*).* Depolarisation, which spreads along the membrane of a muscle, is called a muscle action potential. An electromagnetic field is caused by the depolarisation and is measured as a voltage. The normal resting voltage of a muscle membrane is -90mV (*ibid).* Electrodes used in surface EMG, can pick up the electrical activity of all the active motor units in the underlying muscles (Farina *et al.,* 2004). The effective area for the recording of the electrical activity in the muscle, is estimated to be 10-20mm from the skin's surface (Barkhaus and Nandekor, 1994). Action potentials are of a low amplitude and are measured in microvolts (µV) or millivolts (mV) (Farina *et al.,* 2004). Surface EMG is thus a reflection of both the central, as well as the peripheral properties of the neuromuscular system (Farina *et al.,* 2004; Robertson *et al.,* 2014).

2.9.1 The history of EMG

According to Redi's documentation, the development of EMG was started in 1666 when it was reported that the highly-specialised tissue of the electric ray fish generates electricity (Reaz *et al.,* 2006). It was followed by Walsh's statement in 1773 that the fish muscle tissue of the eel could generate a spark of electricity (*ibid*.). The publication in 1792 by Calvani, titled: 'De Viribus Electritatis in Motu Musculari Commentarius', showed that electricity could initiate muscle contractions (Reaz *et al*., 2006). The possibility of recording active voluntary muscle activity, was only made six decades later by Dubios-Raymond (*ibid*.). Marey in 1890 was the first person to record muscle activity and then subsequently introduced the term, electromyography (Reaz *et al*., 2006).

2.9.2 Typical benefits of EMG

EMG can be used either diagnostically or as a training aid. It can be used to more accurately determine and monitor electrical activity in the muscle than can mere visual observation of the muscle contraction. EMG can thus be beneficial to physiotherapists, surgeons and patients in the clinical setting (Konrad, 2005).

2.9.3 Approaches available

To determine the relationship between surface EMG and the characteristics of the neuromuscular system, two methods are normally employed: The Kinesiology approach and the Diagnostic approach. Kinesiological EMG, allows us to estimate the various physiological processes of the features of surface EMG (Farina *et al*., 2004; Soderberg *et al*., 2000). Diagnostic EMG, uses EMG to identify underlying physiology (Farina *et al*., 2004). Typically done by neurologists and physiatrists, diagnostic EMG is the study of the features of the motor unit action potential for duration and amplitude (Farina *et al.,* 2004). These are normally performed in the diagnosis of neuromuscular pathology. Kinesiological EMG, is most frequently used in movement analysis studies to evaluate the muscular activity with regards to movement (Farina *et al.,* 2004). For the purpose of the present study Kinesiology EMG was performed. This is described below.

2.9.4 Nature of the EMG signal

An unfiltered and unprocessed motor unit action potential (MUAP) is called a 'raw' EMG signal. A healthy, relaxed muscle, due to a lack of depolarisation and repolarisation, is seen as a relatively noise free baseline on the EMG monitor. Raw EMG spikes are random in nature and cannot be accurately reproduced. The exact set of recruited motor units is constantly changing, and this phenomenon causes the uneven EMG spikes (Konrad, 2005).

2.9.5 Factors influencing the EMG signal

Several factors can influence the quality of the EMG signal from where it originates in the muscle membrane to where it is monitored at the electrodes. These factors could be physiological, anatomical, geometrical or to do with the detection system.

They can be grouped as follows:

- Tissue characteristics: Electrical conductivity within tissue types varies. The thickness of subcutaneous tissue varies. The number of recruited motor units and the distribution of motor units varies. The spread of the innervation zones and the endplate zones varies (Farina *et al*., 2004; Halaki *et al.*, 2012; Konrad, 2005).
- Physiological crosstalk: The amount of EMG activity produced by neighbouring muscles might be detected at the local electrode site. Any change in the geometry between the muscle belly and the electrode site (or between the signal catching and the detection site) will alter the EMG recording (Farina *et al*., 2004; Halaki *et al.*, 2012; Konrad, 2005).
- External noise: Very noisy environments can influence the signal detection; therefore, particular care needs be taken to exclude any external noise. Incorrect grounding of external devices can cause direct interference by producing power hums (Farina *et al.*, 2004; Halaki *et al.*, 2012; Konrad, 2005).
- Electrodes and appliances: The selection and quality of the electrodes and the internal amplifier can significantly affect the EMG baseline (Farina *et al.*, 2004; Halaki *et al.*, 2012; Konrad, 2005).
- Skin preparation: The quality of the EMG signal can be affected by skin that is not properly prepared. The main criteria for good signal detection is a stable electrode position and low skin impedance. This requires the removal of hair and the cleaning of

the skin with pure alcohol. Clean skin will typically be light red in colour (Farina *et al.,* 2004; Halaki *et al.,* 2012; Konrad, 2005).

Certain factors are anatomical and physiological in nature and cannot be controlled. The following three factors can however be controlled; therefore, care should be taken with them.

2.9.6 Crosstalk

Neighbouring muscles may cause significant EMG disturbances; therefore, care must be taken to be precise in the electrode positioning (Farina *et al.,* 2004; Konrad, 2005).

2.9.7 Skin preparation

Skin preparation is a very important component in EMG studies. The main reason for skin preparation is to reduce skin resistance as much as possible. Modern EMG amplifiers are mostly intended for skin impedance levels between 5k and 50k Ohm (Konrad, 2005).
The following steps should be taken:

- Remove hair if present.
- Clean the skin with special abrasive pastes (commercially available) to remove dead skin cells. Dead cells provide high impedance levels.
- Fine sandpaper and alcohol swabs can also be used to clean the skin. Whichever method is used, the skin should turn a light red colour, as this is a sign of good skin impedance.

2.9.8 Electrode placement

The direction of the electrode should be parallel to the muscle fibres and the electrode size should not exceed 10mm (Stegeman and Hermens, 2007). The recommended position placement of the longitudinal electrode is halfway between the most distal motor endplate and the distal tendinous area. Not adhering to this may cause a reduction of up to 50% of the amplitude signal (Vigreux *et al.,* 1979). The recommended location of the transverse sensor is on the muscle surface away from the end of other subdivisions of the investigated muscle, or other muscles (Stegeman and Hermens, 2007). Stegeman and Hermens (2007) advised that the electrode should not be placed on the motor endplate zone. This suggestion was echoed by De Luca (1997), that stated that the preferred location of the EMG electrode is in the middle of the muscle belly between the nearest innervation zone and the myotendinous junction. This is the best position to detect the greatest amplitude of the EMG signal.

2.10 Normalisation

MVIC is the maximum voluntary isometric contraction of each muscle measured individually and of all the muscles being investigated. It is the suggestion of various researchers to normalise the EMG signal as this will allow for comparison between muscles activations, across time and between individuals (De Luca, 1997; Soderberg *et al.,* 1994*).* The MVIC obtained of the particular muscle (s) is then classified as the reference value (Halaki *et al.,* 2012). The recommendation is that the test must be performed for a minimum of three repetitions, with a two-minute rest period in between, to minimize any fatiguing (*ibid.).* Different techniques are then applied to the collected EMG signal, either high-pass filtering, rectifying and smoothing of the signal, or the root mean square of the signal is calculated (Halaki *et al.,* 2012). The main benefit of the MVIC normalisation process is that it provides an estimate of the neuromuscular effort needed by a muscle for a given task or exercise (*ibid.*). Factors such as electrode placement and skin preparation are similar during the MVIC procedure, and the EMG activity recording of a specific muscle(s) during a specific movement(s). The other main benefit is that it provides a reference standardised value to which comparisons can be made. With the EMG normalisation procedure, normative data and group statistics can be established and statistically confirmed (Konrad, 2005).

2.10.1 Maximum voluntary isometric contraction (MVIC)

Attention will be given only to MVIC, as it is the most popular normalisation method prior to the testing process (Arsenault *et al.,* 1986; Konrad, 2005; Yang and Winter, 1984). There are different normalising procedures available, but unfortunately no consensus exists in the literature on a ‘superior’ method for normalisation of EMG data (Halaki *et al*., 2012). A variety of methods exist for obtaining normalisation reference values:

a) Maximum (peak) activation levels obtained during maximum contraction,

b) Peak or mean activation levels obtained during the task under investigation,
c) Activation levels obtained during submaximal isometric contractions, and
d) Peak to peak amplitude of the maximum M- wave (M-max) (Halaki *et al.,* 2012).

A preference of reference values obtained from dynamic to reference values obtained from isometric contraction was voiced by Yang and Winter (1984), because with dynamic contraction MVIC's, lower inter-subject of coefficients of variance (CV) was produced. In a study of reliability and reproducibility by Knutson *et al.* (1994) with using intraclass correlation coefficient (ICC), the peak-d and mean-d were shown to be less reliable than that the MVIC test.

2.10.2 EMG amplitude parameters

EMG cannot determine the strength, or difference in strength of muscles or between muscles, it cannot determine if a muscle contraction is concentric or eccentric, also not if a muscle contraction is voluntary or induced (Konrad, 2005). However, valuable information can still be obtained from EMG data. Specialised techniques need to be employed to collect the EMG signal from muscles, as well as to process and decompose the acquired signal (Reaz *et al.,* 2006). The EMG signal collected from surface mounted electrodes, is a reflection of all the muscle fibre action potentials of the underlying muscles (Reaz *et al.,* 2006). The EMG signal can have either a positive or a negative charged voltage (*ibid*.). The EMG signal is collected at the electrode site and normally a differential amplifier is used as the first stage amplifier. The signals are processed before storing to eliminate low or high frequency noise or any additional artefacts (Reaz *et al*., 2006). The EMG amplitude is rectified and averaged to indicate the amplitude of the signal and make it more meaningful to a researcher (*ibid.*). Different parameters exist to help extract the data. (Figure 2.10) provides a schematic illustration of a raw EMG signal. An EMG parameter should provide applicable information and should be dependable in order to be used. Amplitude and frequency analysis are the two most common ways to interpret the EMG signal, the onset-offset analysis is also used quite frequently. These three methods will now be discussed.

EMG traces can be calculated by means of different tests. EMG amplitude reflects the extent of muscle activity caused by the number of active motor units (Robertson *et al*., 2014). With standard amplitude parameters the Mean, Peak, Minimum value, Area and slope can be calculated (Konrad, 2005). The usefulness of the EMG Peak values is only appropriate for averaged curves, due to its inconsistency. The gross innervation input of a muscle is best described by the Mean EMG value and is deemed to be the most important EMG amplitude calculation, because is more robust to changes in duration differences and analysis intervals (Konrad, 2005). The amplitude Mean EMG value works the best in comparison analysis (Konrad, 2005). EMG amplitude is normalised to allow comparisons between participants, days, muscles and studies (Mathiassen *et al*., 1995). Based on the average amplitude of the surface EMG, the degree of muscular activity can be determined (Basmajian and De Luca, 1985).

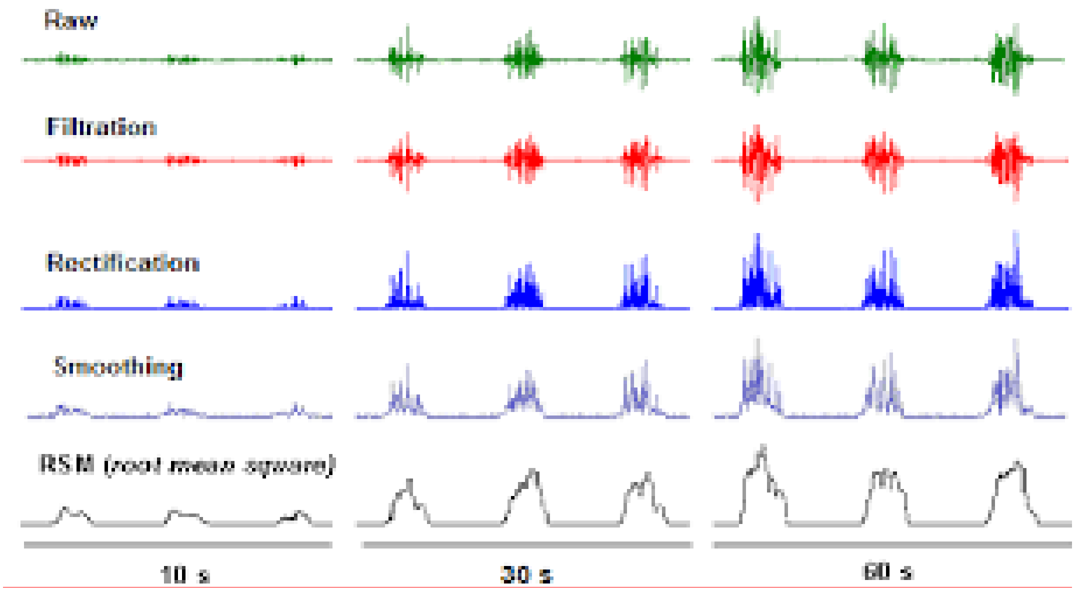

Figure 2. 10 Schematic illustration of the raw and rectified EMG signal.
Reproduced from: https://bretcontreras.com/wp-content/uploads/EMG.png

The technique of frequency analysis is applied to the EMG signal by means of computer technology (Basmajian and De Luca, 1985). Muscle fatigue is studied through the application of spectral analysis, to the acquired surface mounted EMG signals (Merletti *et al.,* 1990). The Mean Frequency, the Total Power and the Median Frequency parameters can be used to calculate the Total Power Spectrum (Konrad, 2005). The Mean and Median frequencies are the most important parameters used to study muscle fatigue during sustained isometric contractions (*ibid*). The Mean and Median frequency variables can often be seen as markers of peripheral muscle changes, as they can indicate changes occurring in the conduction of the muscle fibers (Robertson *et al.*, 2014). Because of the usage of the Power Spectrum of the EMG, the determination of signal shifting towards the lower band during prolonged contractions can be determined. With the calculation of the Power Spectrum of the EMG, muscular fatigue can be determined (Basmajian and De Luca, 1985).

2.11 Kinematics

Kinematics is the study of movement without taking the cause into consideration. Both the linear and angular positions of bodies are described and defined by it (Robertson *et al.*, 2014). Kinematics is the preferred analytical tool for researchers interested in how two motion patterns differ (*ibid.*). For meaningful clinical evaluation and effective rehabilitation of the shoulder complex, a comprehensive knowledge of the kinematics of the shoulder complex is needed (Sahrmann, 2001). Recent three dimensional (3-D) kinematic studies by various authors have confirmed that simultaneous rotation of the clavicle at the sternoclavicular joint occurs during scapulothoracic motion, and that this translates into full functional mobility of the arm (Ludewig and Reynolds, 2009; McClure *et al.*, 2001). Full details on the reliability and validity of kinematics is described in methodology, Chapter 3, section 3.3.4.

2.11.1 Kinematic data collection

3-D kinematics is the description of movement in a 3-D space without taking the cause, that provides the motion, into consideration. 3-D motion-capture systems use multiple input sensors for estimating 3-D data (Robertson *et al.*, 2014). The most common way of recording kinematic data is by obtaining the information from sensors fixed to the moving body. The information obtained is then digitised to extract the co-ordination of the markers (Robertson *et al.*, 2014). Inertial sensors are commonly used in biomechanical studies. Electronic and optical or camera-based systems are also used. The Xsens system used in this study consists of lightweight boxes, called MTxs. These incorporate a 3-D accelerometer, gyroscope and magnetometer. With the usage of sensor-fused algorithms, the 3-D real time orientation of every MTx is provided in reference to the global coordinate system, this is based on magnetic north, as well as on gravity (Cutti *et al.*, 2010).

The reporting and measurement of the velocity of an object is usually done with inertial sensors. The need for an external reference is thus eliminated. With inertial measurements units (IMUs), different inertial sensor technologies are incorporated, such as, accelerometers, gyroscopes and magnetometers. A precise estimation of location, referenced to a fixed frame are thus provided (Zhou *et al*., 2005).

The angular velocity applied to an object is measured with a gyroscope. The estimated rotated angle and the actual orientation of the object is thus provided. Unfortunately, the estimation of the orientation deteriorates over time, due to the different sources of dynamic drifts of the gyroscopes. Accelerometers and magnetometers are added to the system for the correction of these effects. External references, for the correction of drift, is provided with the use of data fusion algorithms (Zhou *et al*., 2005). The direction of the gravity vector is provided by the accelerometer and the direction of the earth's magnetic field is provided by the magnetometer. Using this technology IMUs can estimate their own location to a fixed frame very well. IMUs can thus be used very successfully in motion studies, providing the devices are correctly applied to a participant (Zhou *et al*., 2005). Human biomechanics can be monitored, and data collected fairly easily, regardless of the limb, or limbs, being used. This data collection can take place in real time.

2.11.2 Kinematic terminology

Kinematic terms permit description of human movements. Kinematic variables for a given movement may include: a) the type of motion that is occurring, b) the location of the movement, c) the magnitude of the movement, and d) the direction of the movement (Norkin and Levangie, 1992).

Type of motion:

- Rotatory (angular) – a motion or movement of an object or segment around a fixed axis in a curved path.
- Translator (linear) – a motion or movement of an object or segment in a straight line.

- Curvilinear – the combination of rotatory and translator motions of an object.
- General plane motion – where the object is segmented compared to being rigid (Norkin and Levangie, 1992).

With the availability and usage of the above variables, the following can be determined:

- Motion qualities of the human limb or limbs.
- Comparisons within or between movements can be analysed, and relationships between or within individuals can be determined.
- The effect of intervention on a motion can be illustrated.
- The movement plane(s) can be shown.

The anatomical position of the human body is normally used in the description of positions (Norkin and Levangie, 1992).

2.11.3 Calculation of 3-D joint angles

Biomechanical anatomical joints are described according to joint axes and degrees of freedom. The XYZ axes are used in kinematic description and are as follows:

- The universal X coordinate corresponds to the cardinal transverse (horizontal) plane.
- The Y coordinate corresponds to the frontal (coronal) plane.
- The Z coordinate corresponds to the sagittal plane and divides the body into right and left halves (Norkin and Levangie, 1992).

The Eulerian system is used to describe three-dimensional rotation. The specific joint position and the range of motion (ROM) of the joint position can be described using the Eulerian angle system. Cardan-Euler angles use the XYZ sequence to describe the anatomical joint angles. This particular system has been used effectively in lower limb calculations (Robertson *et al.,* 2014). However, if the Y-rotation is more than about 40° of abduction, the XYZ sequence does not have any anatomical meaning, and when gimbal lock occurs (when the second rotation equals ±90°) it has no meaning at all (Robertson *et al*., 2014). This often creates problems with calculations of the upper limb.

Helical angles are especially appropriate when rotations are very small and in addition can eliminate the gimbal lock problem (Robertson *et al*., 2014). These are often used in upper limb calculations.

2.11.4 Anthropometry

Anthropometry is the discipline concerned with the measurement of the physical characteristics of humans (Robertson *et al*., 2014). Biomechanics is concerned with the inertial properties of human movement and human movement segments This is a subfield of anthropometry called body segment parameters (*ibid.).* Before a study can commence the following inertial properties need to be determined: the segmental mass, the locations of the segmental centres of gravity and the segmental moments of inertia (Robertson *et al.,* 2014). These measurements are needed for the biomechanical analysis of human movement.

CHAPTER 3: METHODOLOGY

3.1 Type of study

This is a quantitative, cross sectional study.

3.2 Participants

3.2.1 Source of Participants

A sample of convenience was used. Participants were recruited from the Department of Physiotherapy at the University of the Witwatersrand, from the general public, from schools, church groups and from sport clubs in the Boksburg area.

3.2.2 Sample size calculation

Descriptive statistics were used, with the means and standard deviations of the upper trapezius and lower trapezius muscles as the variables. A Pearson correlation coefficient was calculated to determine the correlation between the variables of the upper trapezius and the lower trapezius, using existing data, which was collected from 354 patients. The data was from the primary researchers own data pool. Once the correlation coefficient was calculated, a priori sample size calculation was calculated using G*Power (version 3.1.9.2). Using an alpha of 0.05, a power level of 0.95 and a two-tailed design, it was determined that the sample size required under these conditions would be n=58.

3.2.3 Selection

A sample of 16 asymptomatic adults (eight females and eight males) was recruited from the student body of the physiotherapy department. The remaining 42 participants (21 females and 21 males) were recruited from the general public. A schematic illustration of the recruitment and testing process is presented in Figure 3.1.

3.2.4 Inclusion criteria

The inclusion criteria for this study were as follows:

- Participants between 18 and 35 years of age were chosen because in this age group underlying pathology is least likely to be present.
- Both female and male participants were included.

3.2.5 Exclusion criteria

The following exclusion criteria were adhered to:

- Participants with any cervical pain, either local pain or pain spreading down the arm.
- Participants with pins and needles spreading into the arm and hand.
- Participants with previous shoulder or cervical surgery.
- Participants with local pain or clicking in the shoulder joint.
- Participants with previous subluxation or complete dislocation of the shoulder joint.

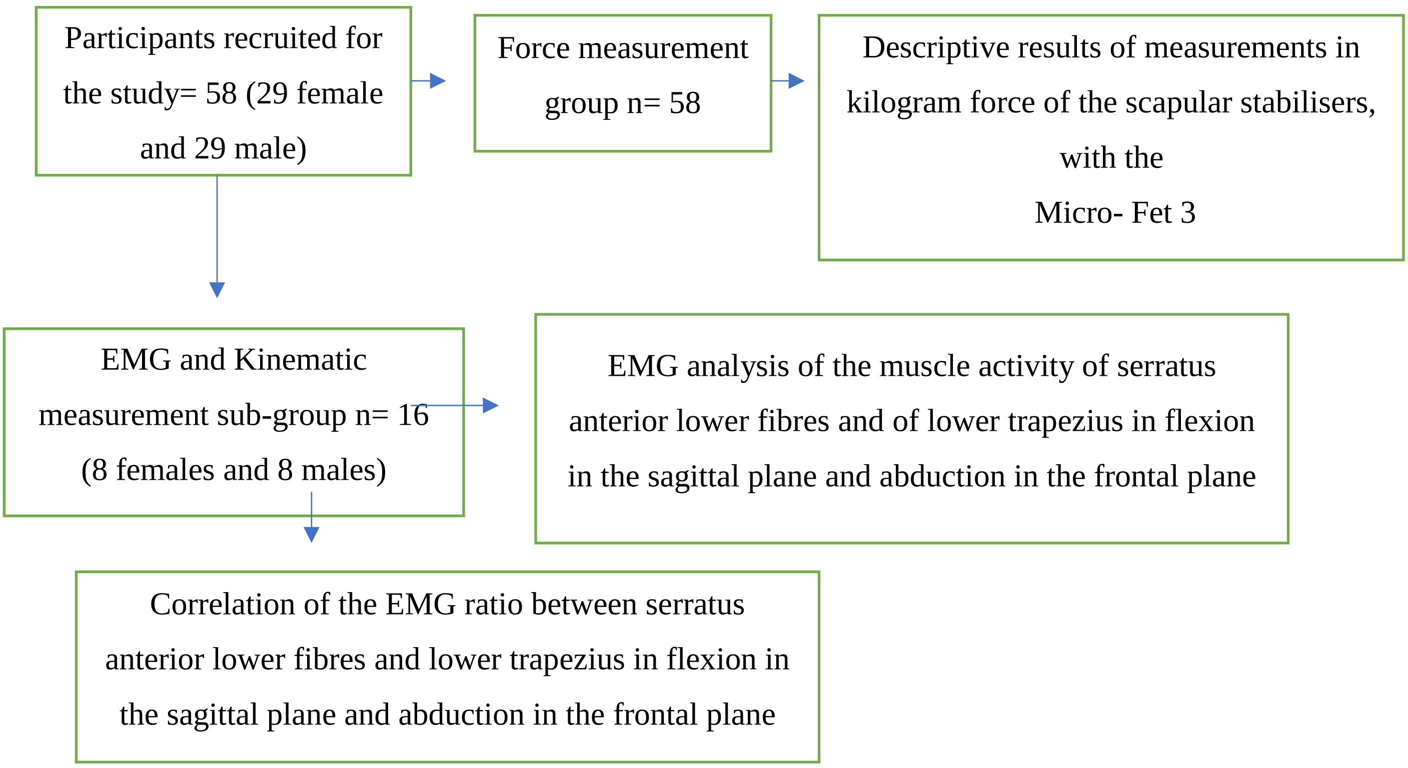

Figure 3. 1 The selection and testing procedures followed.

3.3 Instrumentation and Outcome measures

3.3.1 Dynamometer

The Micro Fet 3 dynamometer (Hoggan Health Industries Inc., West Jordan, UT, USA) (http://www.hogganhealth.net/microfet3.php) device was used for the force production measurements. (Figure 3.2). This model is a wireless muscle testing dynamometer. It is an accurate, portable, force evaluation and testing device. Measurements can be taken in pounds-force (lbf), newtons (N) or kilogram-force (kgf). The validity and reliability of the dynamometer has been proven in the clinical setting by various clinicians.

Figure 3. 2 Micro Fet 3.

Intraclass correlations coefficient (ICC) values range between 0 and 1, values closer to 1 represents stronger reliability (Koo *et al.*, 2015). Values are deemed to be excellent if the value is greater than 0.90, if the value falls between 0.83-0.94 it can be regarded as good to excellent, if the value falls between 0.5-0.75 it indicates moderate reliability and if the value is less than 0.5 it indicates poor reliability (*ibid*). These concluded values can be applied to all the reported studies. In a study by Bohannon (1986) of the test-retest reliability of the handheld dynamometer the following results were expressed. He compared three dynamometer strength scores of 18 muscles, of 30 neurologically affected patients, using the Pearson product-moment correlation and a one-way analysis of variance. Measurements in kg. All correlations were found to be significant ($p<0.01$): the median and modal correlations were all (0.97 or 0.98). In a study by Cools *et al.* (2014), specifically using the handheld dynamometer manufactured by Hoggan Industries, the reliability of the handheld dynamometer was found to be excellent for inter-rater and intra-rater reliability, with an ICC of (0.85-0.99). Measurements in kg Cadogan *et al.* (2011) tested the reliability of the handheld dynamometer on 40 participants, with shoulder pain, between 18 and 77 years of age. Maximum isometric external rotation and abduction were tested by two physiotherapists. Measurements in kg. They found the intra-rater reliability to be from (0.91-0.99) ICCs and the inter-rater reliability to be (0.84) ICCs. Hayes *et al.* (2002) tested the reliability of the handheld dynamometer on 17 symptomatic participants. Shoulder strength was tested in isometric external rotation, internal rotation and elevation, utilising four raters. Measurements in kg. An inter-rater and intra-rater correlation coefficient (p) were performed. The intra-rater reliability test was found to be (p= 0.79-0.92). The inter-rater reliability test was (p=0.79-0.96). Sullivan *et al.* (1988) tested the isometric maximum external rotation strength of the shoulders of 14 healthy male participants, using the handheld dynamometer and the Cybex machine. Measurements in kg. He compared the reliability of the two machines and concluded that the intra-rater reliability for the handheld dynamometer was (r= 0.986) and for the Cybex was (r= 0.993). Concurrent validity is demonstrated due to the relationship with the variables at the same time as the testing of the instruments under investigation (Shumway-Cook et al., 2005). Trudelle-Jackson *et al.* (1994) tested the validity of the Nicholas handheld dynamometer. Thirty healthy females between ages 20 and 56 years of age were tested for hamstring strength. Three maximum hamstring contractions, to allow for peak force production, per session were collected. This procedure was repeated for two days. The correlations between the force values (averages across the three trials over two days), were .83 (p<.001, .95 CL=.92-.68). This finding indicated acceptable concurrent validity coefficients for the handheld dynamometer. The handheld dynamometer was thus found to be a valid evaluation tool for testing isometric shoulder muscle strength by the above-mentioned authors.

3.3.2 Electromyography

Muscle activity was captured using the Trigno™ Wireless EMG System manufactured by Delsys, Inc. In a study by De Witte *et al.* (2012) of Leiden University Medical Centre (LUMC) in the Netherlands, the reliability and validity of this system was proven. This study involved testing the EMG activation ratios of the pectoralis major, teres major, latissimus dorsi and the middle deltoid muscles during isometric abduction and adduction movements. Twenty of the participants had healthy shoulders and 20 had full rotator cuff tears. The ICC score for test-retest reliability was (0.60–0.74). Lee *et al.* (2012) studied the concurrent validity of EMG activity between manual muscle testing, handheld dynamometry and stationery dynamometry. He tested maximum voluntary isometric contractions (MVIC) of quadriceps (for 5 seconds, repeated three times). The EMG mean activity intra-trial reliability was (0.960-0.989) and the validity was found to be high ICC (0.980). The study consisted of 40 voluntary, healthy, adult participants, 17 men and 23 women. The conclusions thus reached reflected consistent EMG measurements between trials.

3.3.3 Kinematics

Kinematic data were collected by the Xsens MVN Biomech AW-A2 inertial motion capture system (Xsens Technologies B.V., Enschede, The Netherlands). The Euler rotational sequence of XZY for abduction in the frontal plane of movement and XYZ for the flexion in the sagittal plane of movement, was used to calculate the shoulder movements. Cuesta-Vargas *et al.* (2010) concluded that inertial sensors could successfully be mounted onto different body areas, to collect accurate and reliable data. Repetitive, precise motions in variable situations, can accurately and reliably be measured. Even though the degree of reliability is site dependent, it provides a feasible option in motion analysis studies (Zhou *et al.*, 2005). In experimental work done by Zhou *et al.* (2005) using the Xsens manufactured by Xsens Technologies B.V, the outcome yielded a less than 5% error in most motion manners, compared to a standard motion) concluded that inertial sensors could successfully be mounted onto different body areas, to collect accurate and reliable data. In the present study an inertial sensor was used to measure the 3-D shoulder angles during flexion in the sagittal plane of movement and abduction in the frontal plane of movement. The Xsens MVN Biomech AW-A2 (Xsens Technologies B.V., Enschede, The Netherlands) inertial motion capture system was utilised in the present study. The Euler rotational sequence of XZY for abduction in the frontal plane of movement and XYZ for the flexion in the sagittal plane of movement, was used to measure the joint angles. Increased interest in human biomechanics has made the usage of the inertial systems to study human motion very popular (Kontaxis *et al.*, 2009). There has been a call for standardisation by various researchers in the implementation of the inertial motion systems, of in particular the shoulder joint (Kontaxis *et al.,* 2009; Wu *et al.,* 2005). The International Society of Biomechanics (ISB), in 2005, has proposed a shoulder model based on the position of anatomical and bony landmarks (Jackson *et al.,* 2012), which is also the model used in the present study.

3.4 Procedure

3.4.1 Pilot study procedure

A total of eight participants (four females and four males) were included in the pilot study. The aim of the pilot study was:

- to calculate the time for the participants to complete the informed consent, to read the information leaflet, to weigh the participants, to measure their height and to collect the kinematic inertial measurement data from them,
- to familiarise participants with the equipment, and
- to address any unknown factors, for example: the endurance of the researcher and of the participants needed to be established. Participants were limited to a minimum of four and a maximum of six, per testing session.

The basic procedure as described under the main study was used. It was determined that a maximum of six participants could be tested on a particular day. No other problems were encountered during the pilot study. No tiring of the participants occurred during testing, the movements under investigation, were thus not randomized. No changes were needed, and the pilot study data was thus included in the main study.

3.4.2 Main study

Permission and recruitment: Ethical clearance was obtained from the Human research Ethics Committee (Medial). Clearance certificate no: M160515. Permission was obtained from the acting Head of the Department (Appendix A) and the Deputy Dean of Student Affairs of the Health Science Department (Appendix B). The participants were recruited enlisting the help of the class representatives, by posting a notice on the online learning management system, Moodle, and on the general advertisement board (Appendices C- D). The participants were also recruited from general sport clubs, churches and schools in the Boksburg area. Testing in Boksburg took place at the researchers' practise. Only the force measurements were collected from participants at the researchers' practise. When a participant contacted the researcher a time convenient for the participant, was scheduled for the testing. Testing at Wits medical school took place at the Wits Movement Analysis Laboratory at the School of Physiotherapy, on a Wednesday and on a Friday. When participants contacted the researcher a convenient time for the participant for the testing was arranged by the researcher. Collection of the force measurements and the EMG and kinematic data were collected from participants at the Wits Physiotherapy Movement Analysis Laboratory. When participants arrived at the respective venues, they were greeted, and the testing procedure was firstly explained to them. For the participants taking part in only the force measurements, a sports bra was supplied to the female participants. For more detail, the reader is referred to Section 3.4.2. They then read and completed the informed consent form. They were allowed to undress behind a closed door, the females changed into a sport bra, and the rest of their clothes was kept on. The males removed their tops only. It was explained that this was a necessary step to monitor the muscle contraction during the muscle force measurement collection process. Two sets of data were collected and recorded for the force measurements. For the EMG and kinematic data collection process, the participants were shown the Lycra Xsense suit manufactured by Xsens Technologies B.V., Enschede, The Netherlands, and it was explained that the Lycra suit is necessary for affixing the lightweight sensors of the Xsense to the suit. This was needed for the kinematic data to be transmitted to the computer. It was explained that a video recording would be made simultaneously as the EMG and kinematics data recordings taking place. The video recording was to monitor the movement of flexion and abduction in real time, this was recorded on the computer. Both the EMG and kinematic data collected were needed for the analysis of the respective movements.

- Step one: introductory procedure, participants read and filled in the informed consent form for the EMG (Appendix E) and the kinematic data collection form and video recording consent forms (Appendix E and H) prior to the start of the data collection process commencing. A detailed explanation of the EMG and kinematic data collection process can be found in Section 3.4.1. A second research assistant helped with the EMG and video recordings of the muscle activity during the EMG and kinematic analysis. The second research assistant was in the employment of the Wits Physiotherapy Movement Analysis Laboratory. She helped with the EMG and kinematic data collection process, since this is a technical process and falls outside the primary researchers' scope of training. She is in the possession of a Masters degree in Physiotherapy from the Wits university. She is acknowledged in the Acknowledge Section. The participants were made fully aware of the procedures to be used and the reason for the data collection. Their privacy was not violated. For the EMG and kinematic data collection, the participants were allowed to dress behind a closed screen, so as to not leave them exposed. They were not coerced into participating in the study. Informed consent was obtained for the photographs used (Appendices J and K). Models were used for the photographs and did not participate in the study. Table 3.1 outlines the process followed during the data collection sessions. The same sequence was followed for all the data collection sessions.

Table 3. 1 Steps followed in the data collection process.

Steps	Participants
Step one	Participants read the information leaflet and read and completed the informed consent form. They were weighed, measured and kinematic inertial measurements where applicable were collected by the primary researcher. Information was recorded by the primary researcher. For detail on the scale, stature meter and guidelines followed please consult the main study procedures (Section 3.4.2).
Step two	The force measurements procedures were collected and recorded by the primary researcher in all cases (Section 3.4.2).
Step three	The MVIC procedures were performed by both the primary researcher and the research's assistant in all instances (Section 3.4.2).
Step four	Kinematic data together with the EMG data were collected and recorded by the research's assistant in all instances (Section 3.4.2).

MVIC = maximum voluntary isometric contraction; EMG = electromyographic.

- Step two: force measurements procedure: In order to calibrate the handheld dynamometer, it was held down on an electronic domestic scale before each testing session. To calibrate the handheld dynamometer, it was held down on an electronic bath scale (Camry, Yuppiechef), if one kilogram was recorded on it, it had to correspond with 1kg on the handheld dynamometer. Following that, the testing positions for the force measurements tests were demonstrated to the participants. The explanation of the ‘break’ principle of the force measurement test is as follows: Resistance was slowly applied until the maximum force the muscle could hold before ‘giving’ Hislop and Montgomery (1995). That position was then held for a count of ten seconds. The explanation of the number of times and sequence of the force measurements is: each muscle was tested twice, and in the same order each time. The following sequence of testing positions was followed: upper trapezius was tested first in sitting, then serratus anterior lower fibres in sitting, followed by serratus anterior upper fibres in supine. The rhomboids, middle trapezius and lower trapezius were tested in prone. For the muscle force data collection sheet see Appendix F. For EMG sensors used see Figure 3.3.

Figure 3. 3 EMG sensors.

Testing positions used for upper trapezius, lower trapezius and serratus anterior were based on the descriptions of Hislop and Montgomery (1995).

- Upper trapezius: in sitting, the participant raised the shoulder towards their ear and held it against maximum resistance (Figure 3.4).
- Serratus anterior, lower fibres: in short sitting with the arm forward to approximately 130°, the participant protracted to end of range. Resistance to break point was applied (Figure 3.5).
- Serratus, anterior upper fibres: in supine, arm flexed with elbow bent to 90°, the participant protracted to end of range. Resistance to break point was applied (Figure 3.6).

For the middle trapezius and rhomboids, the muscle testing techniques by Kendall and McCreary (1993) were used.

- Rhomboids: in prone with arm straight, in the horizontal plane, abducted to approximately 60°, thumb pointing down to the floor. Resistance to break point was applied (Figure 3.7).
- Middle trapezius: in prone with arm straight, in the horizontal plane, at shoulder level to approximately 90° of abduction, thumb pointing up towards the ceiling. Resistance to break point was applied (Figure 3.8).
- Lower trapezius: in prone with arm straight, in the horizontal plane, to about 145° of abduction (in line with fibres of lower trapezius), thumb pointing up towards the ceiling. Resistance to break point was applied (Figure 3.9).

Each test was repeated twice, with a rest period of 60 seconds between measurements. Both tests measurements were recorded, but only the best of the two tests was used for the data analysis. An average of the two tests could not be used, as this would not be representative of a real participant. An "average score" would represent a fictitious participant.

Figure 3. 4 Force measurement of the upper trapezius.

Seated, shrug the shoulder. Maximum isometric hold for a count of 10. Position: on the lateral part of the shoulder over the acromio-clavicular joint.

Figure 3. 5 Force measurements for serratus anterior lower fibres.

Maximum protraction in 130° of anterior flexion in the sagittal plane. Force applied downward to 'break' hold of the scapula. Position: on the inferior radius, above the styloid process.

Figure 3. 6 Force measurements for serratus anterior upper fibres.

Maximum protraction in 90° of flexion. Downward pressure to 'break' hold of the scapula. Position: on the superior ulna, just below the elbow joint.

Figure 3. 7 Force measurements for rhomboids.

Arm in frontal plane, 45° of abduction, thumb pointing down. Maximum downward force applied to 'break' hold of the scapula. Position: on the inferior ulna, just above the styloid process.

Figure 3. 8 Force measurements for middle trapezius.

Arm in 90° of flexion in the frontal plane, thumb pointing up. Maximum isometric hold, and downward pressure applied to 'break' hold of the scapula. Position: on the inferior radius, just above the styloid process.

Figure 3. 9 Force measurements for lower trapezius.

Arm in 145° of flexion in the frontal plane, thumb pointing up. Maximum isometric hold, and downward pressure applied to 'break' hold of the scapula. Position: on the inferior radius, just above the styloid process.

- Step three: electromyographic Procedure. The procedure for obtaining MVIC is explained here in detail. For participants taking part in the EMG and kinematic analysis sessions, they first had to prepare for the EMG session and get suited up in the Xsense body suit, therefore a delay occurred after they participated in the dynanometer testing sessions, prior to the EMG sessions taking place. The skin was cleaned with a commercially available paste, Nuprep, to reduce skin impedance prior to the EMG electrodes being applied to the skin (skin impedance typically < 10 k Ohm), (Konrad, 2005). Tensospray, for improved adherence of the electrodes, was applied prior to the electrodes being attached. The muscles were tested, and normalisation with MVIC was done. MVIC, is usually the most widely used method of obtaining the reference value used in the normalisation of shoulder EMG data (Boettcher *et al.*, 2008). Electrode position: the preferred location is in the middle of the muscle belly, between the closest innervation zone and the myotendinous junction. The EMG signal with the highest amplitude can be detected in this location (De Luca, 1997). Participants performed a three-second MVIC hold against maximum manual resistance applied by the principal investigator (Table 3.2). A two-minute pause occurred between muscle contractions

(Ivey *et al.*, 1985). As a normalising reference, the EMG data was collected during a MVIC for each muscle. The participants were tested in the positions as described by Hislop and Montgomery (1995) for lower trapezius (Figure 3.10) and for serratus anterior lower fibres (Figure 3.11).

Figure 3. 10 MVIC for lower trapezius.

Arm in 145° of frontal plane flexion. MVIC = maximum voluntary isometric contraction. Maximum downward pressure was applied as illustrated, for the recording session. Position: on the inferior radius, just above the styloid process.

Figure 3. 11 MVIC for serratus anterior lower fibres.

Arm in 130° flexion in the sagittal plane, protracted to end of range and maximum downward pressure applied as illustrated. MVIC = maximum voluntary isometric contraction. Position: on the inferior radius, just above the styloid process.

- Choice of force couples

The following factors determined the choice of the muscle pairs of the force couples. In the literature, the upper force couple is said to consist of the upper trapezius and the serratus anterior upper fibres (Bagg and Forrest, 1986; Schenkman and Rugo de Cartaya, 1987). In the current study this was changed by coupling the upper trapezius with the lower trapezius, since the upper trapezius is active mainly during elevation of the scapula rather than upward rotation of the scapula (Fey *et al*., 2007; Johnson *et al*., 1994), and the lower trapezius is active during depression of the scapula (Johnson *et al*., 1994).

Serratus anterior upper fibres was coupled with the middle trapezius in the present study. Johnson *et al*. (1994) found that the middle trapezius is more active during retraction of the scapula, and Ekstrom *et al.* (2004) concluded that serratus anterior upper fibres is more involved during protraction of the scapula. These were the deciding factors for the proposed force couple of the middle trapezius versus serratus anterior upper fibres.

In the present study it was decided to divide the lower force couple of serratus anterior lower fibres and the lower trapezius further into force couples:

- Between the serratus anterior lower fibres and the lower trapezius muscles;
- between the rhomboids versus the serratus anterior lower fibres, and
- between the rhomboids and the lower trapezius.

This decision was reached because differences have been demonstrated in the EMG activity of serratus anterior lower fibres in abduction compared to flexion, and for the lower trapezius versus serratus anterior lower fibres in flexion (Basmajian and De Luca, 1985). The significance of the findings regarding the proposed force couples is discussed in the discussion section.

- Step four: kinematic procedure: the kinematic data was collected according to the guidelines by Xsens Technologies B.V. The scale used was an electronic bath scale (Camry, Yuppichef), the tape measure was a wall mounted stature meter (Milton.en. alibaba., model PHD-5011). The participants were verbally told about wearing the Xsense body suit, before the actual procedure of kinematic data collection was initiated. The participant was suited up in the Xsens body suit. The inertial sensors were placed on predetermined anatomical sites, recommended by Xsens Technologies B.V. These were on the thorax, sternum, spine of the scapula, humerus, hand, as well as on the pelvis, upper leg, lower leg and foot. A kinematic data collection sheet is shown in Appendix G. Next, the important process of calibration, which is described below, took place. For calibration with the computer, the following steps had to be taken. The participant was instructed to maintain the 'neutral pose' or position (the N-pose): standing tall, facing forwards with arms straight by the sides and thumbs facing forwards, until calibration was completed (Figure 3.12). This step is required for the sensor-to-segment calibration, which defines the anatomical coordinate system of the thorax, scapula and humerus, and relates them to the technical coordinate system of the corresponding MTx sensors (Cutti *et al.*, 2010).

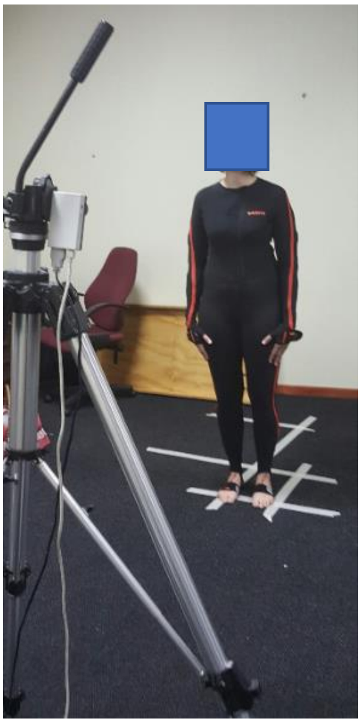

Figure 3. 12 Neutral pose (N-pose) for calibration.

Standing tall with arms by the sides.

On completion of the calibration, the kinematic and EMG movement testing started. The muscles chosen for EMG testing were identified as the lower trapezius and the serratus anterior lower fibres. These muscles form part of the lower force couple of the scapula. The starting position for the test was with the participants standing in a relaxed position, with feet comfortably apart and arms relaxed by their sides. Elbows were straight. Thumbs faced up and led the movement. The range of movement was from neutral to the end of range, with full range of movement being achieved. EMG and kinematic signals were triggered to occur simultaneously with the Trigno EMG trigger sensor at the start, after calibration had occurred, and before the actual movements took place. This was to ensure that EMG and kinematic data were collected simultaneously.

The movements were recorded in forward flexion in the sagittal plane and in abduction in the frontal plane. The movement of flexion in the sagittal plane was repeated three times, at the participants own pace (Figure 3.13). The next movement was abduction in the frontal plane, which was also repeated three times, at the participants own pace (Figure 3.14). This procedure was followed for all the participants taking part in the EMG and kinematic analysis procedures.

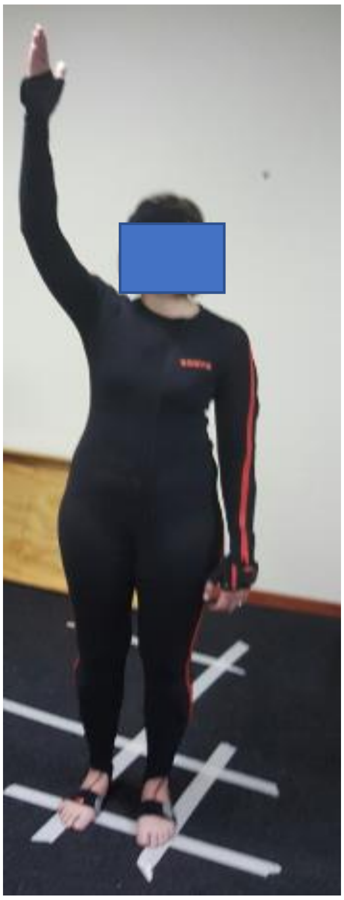

Figure 3. 13 Flexion in the sagittal plane.

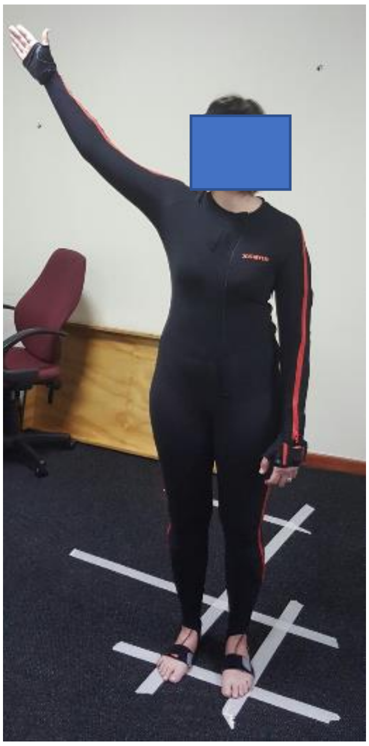

Figure 3. 14 Abduction in the frontal plane.

Table 3. 1 MVIC method used in the testing procedure (n=16).

Muscles assessed	Position	Repetitions	Electrode position
Serratus anterior lower fibres	Sitting, with the arm flexed to 130° in the sagittal plane. Maximum downward pressure applied to the arm, to just before the break-point of the hold of the scapula	Repeat three times, hold for a count of thirty, with a-minute break between recording sessions.	Just below the axilla at the level of the inferior angle of the scapula, medial to latissimus dorsi (Ekstrom *et al*., 2005).
Lower trapezius	Prone lying, with the arm in 145°abduction in the frontal plane. Maximum downward pressure applied to the arm, to just before the break-point of the hold of the scapula.	Repeat three times, hold for a count of thirty, with a two- minute break between recording sessions.	Positioned according to SENIAM, Stegeman and Hermens (2007) on the lower trapezius, 2/3rds down from the trigonum spine to the 8th thoracic vertebrae.

MVIC = maximum voluntary isometric contraction.

The raw EMG data was processed and smoothed, using a Butterworth 4 filter and a Broadband carrier frequency of 20. The data was normalised using the root mean square (RMS) and mean amplitudes were calculated for all data collected during the MVIC movements. Additionally, the RMS of the serratus anterior lower fibres and of lower trapezius was normalised to the MVIC of the corresponding muscles, which had been collected during the isometric holds in the described testing positions.

3.5 Ethical considerations

Written informed consent to take part in the study was obtained from all participants. Informed consent to perform the video recordings was also signed by all the participants who took part in the video recording during the kinematic sessions. Informed consent for the usage of the photographs was obtained. Participants were informed about the relevance of the study and about their right to withdraw at any time without having repercussions. Their anonymity was protected: participant’s names were not used, and they were allocated numbers, for example, participant ‘no one’, participant ‘no two’. Permission to invite the students to participate in the study was obtained from the Dean of Health Science Faculty of the University of the Witwatersrand. Ethical clearance was obtained from the University of the Witwatersrand Human Research Ethics Committee (Medical) (Appendix I). Data was kept on the researcher’s computer, protected by a password. Data was only available to the researcher, the researcher’s assistant, the statistician and the researcher’s supervisors.

3.6 Statistical analysis

Graph Pad 5 (Prism, San Diego, Ca, USA) was used for the statistical analysis. The confidence level (CL) was set at 95%, $p<0.05$. This study utilised largely descriptive analysis. The Shapiro-Wilk test was used to determine the normality of the data. For the force measurements, the data was found to be normally distributed and parametric tests were used to calculate the results. A paired-t test analysis was used for the comparison between the dominant and the non-dominant arm, and an independent t-test was used for the comparison between female and male participants. The means, standard deviations and ranges were calculated for all force measurements. The isometric force couple ratios were calculated between:

- the upper trapezius versus the lower trapezius,
- the serratus anterior lower fibres versus the rhomboids,
- the serratus anterior upper fibres versus the middle trapezius,
- the serratus anterior lower fibres versus the lower trapezius, and
- the lower trapezius versus the rhomboids.

Box and whisker plots, as well as tables, were used in the description of the statistical results. Because the EMG data was not normally distributed, the following non-parametric tests were used for the analysis. A repeated measure ANOVA with a Bonferroni post-hoc test was run for the variance of the serratus anterior lower fibres and the lower trapezius interaction over time, throughout the movement cycle. The variable measure was the serratus anterior and the lower trapezius. A Spearman’s test was run to determine the muscle activity of serratus anterior lower fibres versus the lower trapezius in both flexion and abduction. For the relationship of the ratio of serratus anterior lower fibres and lower trapezius in the two movement planes of flexion and abduction a Spearman’s test was also used. The variables were serratus anterior lower fibres and lower trapezius (Table 3.3). Tables and Figures were used in the EMG description of the results.

Table 3. 2 Statistical analysis used for independent variables, (n=16).

Objectives	Independent variables	Statistical tests used
To determine the forces of the individual scapular stabiliser muscles, as well as the ratios of the scapular muscles within and between the sexes, in the non-dominant versus the dominant arm	Continuous data, UT: LT; SAU: MT; SAL: LT; SAL: RH; LT: RH	Parametric tests and paired t-tests for the force couple ratios between the non-dominant versus the dominant arm within the same sex Independent t-tests for the ratios of the force couples between the female and the male sample groups
To determine the EMG (%MVIC) activity of SAL and IT in flexion in the sagittal plane of movement and abduction in the frontal plane of movement	Continuous data, SAL: LT ratios	Non-parametric tests and a repeated ANOVA with a Bonferroni-post hoc test
To determine the EMG (%MVIC) ratio correlation between SAL and LT, in the flexion in the sagittal plane of movement and abduction in the frontal plane of movement movements	Continuous data, EMG ratio of SAL: LT	Non-parametric tests and Spearman's paired t-test

UT = upper trapezius; LT = lower trapezius; MT = middle trapezius; SAU = serratus anterior upper fibres; SAL = serratus anterior lower fibres; RH = rhomboids. Normality of the data was determined using the Shapiro-Wilk test.

CHAPTER 4: RESULTS

4.1 Participants

Fifty-eight participants (29 females and 29 males) who took part in the study. All 58 participants took part in the force measurements study, while a subgroup of 16 participants took part in the EMG and kinematic analysis data collection sessions. For a full explanation of the smaller subgroup selection consult Chapter 5.2.1. None of the participants recruited dropped out or were excluded. Table 4.1 contains a detailed description of the demographical information of the participants. Most of the sample group was found to be right hand dominant.

Table 4. 1 Demographic and anthropometric information (n=58).

Variables	Combined group	Females	Males
Age (years)	25.4±4.6	24.9±4.7	25.9±4.7
Mass (kg)	80.2±25.1	69.0±11.9	91.1±29.6
Height (cm)	171.6±10.3	165.0±6.6	178.0±9.3
Arm dominance (L: R)	5:53	4:25	5:53

4.2 Force measurements

4.2.1 Absolute force measurements

Substantially significant differences in the mean force values were observed between the females and the males, for both the non-dominant and the dominant sides, in all the individual muscle mean force measurements (Table 4.2). The mean force values of the male participants reflected higher mean force values than those of the female participants for all comparisons ($p<0.001$). Statistical significance was only seen as significant if obtained results reflected a $p<0.001$.

Table 4. 2 A comparison between the force measurements in females (n=29) and males (n=29) (n=58). Measurements in Kg.

Muscles	Female		Male		
Non-dominant	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**p-value**
UT	9.75 (1.06)	7.60- 12.60	11.85 (1.74)	9.10- 16.40	<0.001
MT	2.85 (0.78)	1.80- 4.70	4.92 (1.49)	2.90- 6.80	<0.001
LT	2.85 (0.65)	1.80- 4.10	4.34 (0.97)	2.90- 6.80	<0.001
SAU	8.10 (1.51)	5.40- 11.10	10.98 (2.09)	6.90- 16.60	<0.001
SAL	5.39 (1.28)	3.50- 9.50	9.31 (1.98)	5.80- 13.10	<0.001
RH	3.74 (0.88)	2.50- 6.20	6.63 (1.84)	4.10- 11.70	<0.001
Dominant	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**p-value**
UT	9.53 (1.20)	7.40- 12.70	11.18 (1.32)	9.50- 15.80	<0.001
MT	3.05 (0.74)	2.00- 4.50	4.98 (1.55)	2.60- 9.70	<0.001
LT	2.76 (0.59)	1.50- 3.60	4.44 (1.38)	2.70- 8.80	<0.001
SAU	7.80 (1.51)	4.80- 10.30	10.56 (1.47)	7.30- 13.40	<0.001
SAL	5.33 (1.04)	3.50- 8.10	9.15 (1.71)	6.30- 12.20	<0.001
RH	3.85 (0.91)	2.10- 6.30	6.88 (2.31)	3.50- 15.00	<0.001

UT = upper trapezius, LT = lower trapezius, MT = middle trapezius, SAU = serratus anterior upper fibres, SAL = serratus anterior lower fibres, RH = rhomboids. SD = standard deviation.

No statistically significant difference was observed between the non-dominant and dominant sides for any of the muscles in the female group (Table 4.3). Statistical significance was only reported if $p<0.001$.

Table 4. 3 A comparison between non-dominant and dominant force measurements in the female group (n=29). Measurements in Kg.

Muscles	Non-dominant arm		Dominant arm		
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	**p-value**
UT	9.75 (1.06)	7.60- 12.60	9.53 (1.20)	7.40- 12.70	0.272
MT	2.85 (0.78)	1.80- 4.70	3.05 (0.74)	2.00- 4.50	0.058
LT	2.58 (0.65)	1.80- 4.10	2.76 (0.59)	1.50- 3.60	0.104
SAU	8.10 (1.51)	5.40- 11.10	7.80 (1.51)	4.80- 10.30	0.064
SAL	5.39 (1.28)	3.50- 9.50	5.33 (1.04)	3.50- 8.10	0.785
RH	3.74 (0.88)	2.50- 6.20	3.85 (0.91)	2.10- 6.30	0.315

No statistical significance was observed. UT = upper trapezius, LT = lower trapezius, MT = middle trapezius, SAU = serratus anterior upper fibres, SAL = serratus anterior lower fibres, RH = rhomboids. SD = standard deviation.

A significant difference was observed in the mean value of the upper trapezius mean force value between the non-dominant arm and the dominant arm in males (p=0.003) (Table 4.4). The mean force value in the non-dominant arm demonstrated a higher mean value than that of the dominant arm. Similar force measurements were found for all the other muscles when the non-dominant and dominant sides were compared.

Table 4. 4 A comparison between non-dominant and dominant force measurements in the male group (n=29). Measurements in Kg.

Muscles	Non-dominant arm		Dominant arm		
	Means (SD)	**Range**	**Means (SD)**	**Range**	**p-value**
UT	11.85 (1.74)	9.10- 16.40	11.18 (1.32)	9.50- 15.80	0.003*
MT	4.92 (1.49)	2.80- 9.90	4.98 (1.55)	2.60- 9.70	0.730
LT	4.34 (0.97)	2.90- 6.80	4.44 (1.38)	2.70- 8.80	0.536

Muscles	Non-dominant arm		Dominant arm		
SAU	10.98 (2.09)	6.90- 16.60	10.56 (1.47)	7.30- 13.40	0.079
SAL	9.31 (1.98)	5.80- 13.10	9.15 (1.71)	6.30- 12.20	0.404
RH	6.63 (1.84)	4.10- 11.70	6.8 (2.31)	3.50- 15.00	0.291

Statistical significance is denoted by an *. UT = upper trapezius, LT = lower trapezius, MT = middle trapezius, SAU = serratus anterior upper fibres, SAL = serratus anterior lower fibres, RH = rhomboids. SD = standard deviation.

4.2.2 Force couple ratios

Statistically significant differences were found to exist within the combined groups mean force couple ratios as shown in Table 4.5. The differences were found in the force couple ratios between the upper trapezius versus the lower trapezius and the middle trapezius versus serratus anterior upper fibres, in both the non-dominant and the dominant arm, and between the females and the males. The mean force couple ratio for upper trapezius versus lower trapezius was found to be higher at 3.97 in the non-dominant side in the females, compared to the lower 2.85 in the non-dominant side in the males ($p<0.001$). For the dominant side in the females the ratio between upper trapezius versus lower trapezius was also higher at 3.63, versus the lower ratio of 2.70 in the dominant side of the males ($p<0.001$). The ratio between the middle trapezius versus serratus anterior upper fibres in the non-dominant side of the females was lower at 0.35, compared to that of the males, which was higher at 0.45 ($p<0.001$). The ratio of the dominant side between the middle trapezius and serratus anterior upper fibres in the females was also lower, at 0.40, than the higher mean force ratio of 0.47 of the dominant side of the males ($p<0.001$).

Table 4. 5 A comparison between the force couple ratio measurements found in males (n=29) and females (n=29) (n= 58). Measurements in Kg.

Muscle ratios non-dominant	Female		Male		
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	**p-value**
UT: LT	3.97 (0.88)	2.24- 5.20	2.85 (0.73)	1.66- 4.42	<0.0001*
SAL: LT	2.15 (0.57)	1.21- 4.52	2.21 (0.53)	1.22- 3.54	0.6808
MT: SAU	0.35 (0.08)	0.23- 0.54	0.45 (0.08)	0.27- 0.60	<0.0001*
SAL: RH	1.48 (0.42)	1.12- 3.39	1.45 (0.26)	0.88- 1.90	0.7353
LT: RH	0.70 (0.16)	0.48- 1.00	0.69 (0.19)	0.36- 1.07	0.6934
Dominant	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**p-value**
UT: LT	3.63 (0.97)	2.34- 6.00	2.70 (0.72)	1.57- 4.15	<0.0001*
SAL: LT	1.97 (0.27)	1.46- 2.63	2.15 (0.45)	1.39- 3.29	0.0627
MT: SAU	0.40 (0.10)	0.23- 0.52	0.47 (0.12)	0.25- 0.72	0.0135*
SAL: RH	1.41 (0.21)	1.09- 1.87	1.40 (0.31)	0.81- 2.17	0.8923
LT: RH	0.74 (0.17)	0. 42- 1.10	0.17 (0.6)	0.30- 1.02	0.1073

Statistical significant differences are denoted by an *. UT = upper trapezius, LT = lower trapezius, MT = middle trapezius, SAU = serratus anterior upper fibres, SAL = serratus anterior lower fibres, RH = rhomboids. SD = standard deviation.

In the female sample group, no significant differences were found in the force couple ratio values between the non-dominant arm and the dominant arm (Table 4.6).

Table 4. 6 A comparison of the force couple ratios between the non-dominant and the dominant arm amongst females (n=29). Measurements in Kg.

Muscle ratios	Non-dominant arm		Dominant arm		
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	**p-value**
UT: LT	3.96 (0.88)	2.24- 5.20	3.63 (0.97)	2.34- 6.0	0.049
SAL: LT	2.14 (0.57)	1.46- 4.52	1.97 (0.27)	1.46- 2.63	0.120
MT: SAU	0.35 (0.08)	0.23- 0.54	0.40 (0.10)	0.23- 0.52	0.025
SAL: RH	1.47 (0.42)	1.12- 3.39	1.41 (0.21)	1.09- 1.87	0.360
LT: RH	0.70 (0.16)	0.48- 1. 0	0.74 (0.17)	0.42- 1.10	0.325

UT = upper trapezius, LT = lower trapezius, MT = middle trapezius, SAU = serratus anterior upper fibres, SAL = serratus anterior lower fibres, RH = rhomboids. SD = standard deviation.

In Figure 4.1 and Figure 4.2 the upper whisker represents the maximum value of the sample size, the bottom whisker represents the minimum value of the sample size, and the box represents the middle 50% of the sample size. The mean is represented by the X inside the box.

In Figure 4.1 the only difference seen is in the force couple ratio between serratus anterior lower fibres versus rhomboids on the dominant side, where more values are found in the upper statistical range than in the middle statistical range, with the box being smaller and the upper whisker being longer. Similar results are reflected in the ratio between the upper trapezius versus the lower trapezius on the dominant side, where more high-force values are found in the upper statistical range than in the middle statistical range, with the longer upper whisker and smaller box being present.

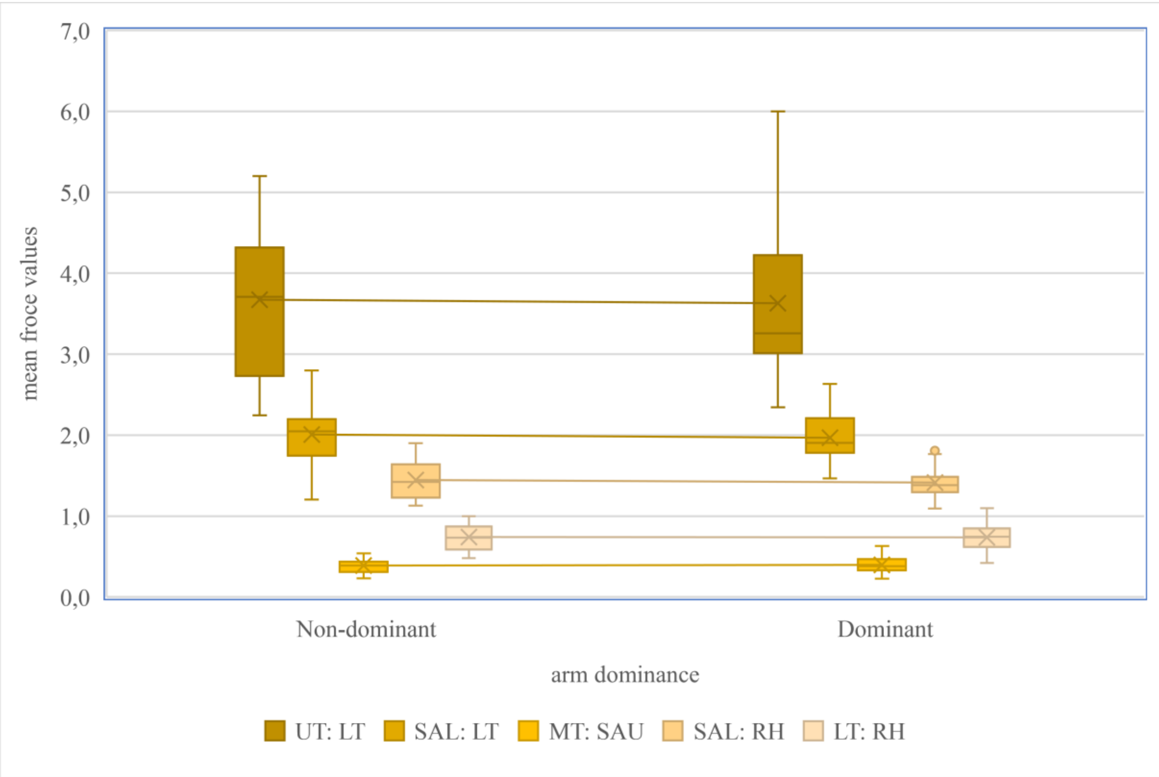

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Figure 4. 1 Mean and range of the force couple ratios of the non-dominant and dominant side in females (n=29).

UT = upper trapezius; LT = lower trapezius; MT = middle trapezius; SAU = serratus anterior upper fibres; SAL= serratus anterior lower fibres; RH = rhomboids.

No statistical significant differences were observed in the ratios between the non-dominant and the dominant sides of the males (Table 4.7).

Table 4. 7 A comparison between the non-dominant and the dominant arm force ratios within the male sample group (n=29). Measurements in Kg.

Muscle ratios	Non-dominant arm		Dominant arm		
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	**p-value**
UT: LT	2.85 (0.73)	1.66- 4.42	2.70 (0.72)	1.57- 4.15	0.158
SAL: LT	2.21 (0.53)	1.22- 3.54	2.15 (0.45)	1.39- 3.29	0.537
MT: SAU	0.45 (0.08)	0.27- 0.60	0.47 (0.12)	0.25- 0.72	0.537
SAL: RH	1.45 (0.26)	0.88- 1.90	1.40 (0.31)	0.81- 2.17	0.318
LT: RH	0.69 (0.19)	0.36- 1.07	0.67 (0.16)	0.30- 1.02	0.575

UT = upper traps; LT = lower trapezius; SAL = serratus anterior lower fibres; SAU = serratus anterior upper fibres; MT = middle trapezius; RH = rhomboids. SD = standard deviation.

Figure 4.2 displays a central tendency of the normally distributed data of the force couple ratios in the male sample group in the non-dominant versus the dominant arms, using the means as a centre value. In the ratio between serratus anterior lower fibres versus lower trapezius, there are more high-force values than middle-force values, with the upper whisker being longer and the box slightly smaller (Figure 4.2). Overall the mean force couple ratios were fairly symmetrically distributed between the non-dominant and dominant sides.

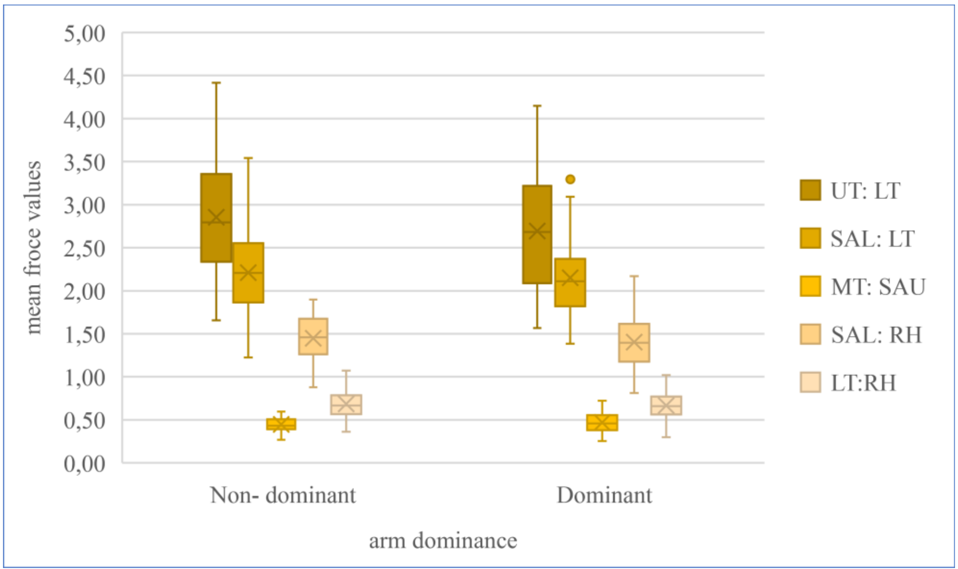

Figure 4. 2 Mean and range of the force couple ratios of the non-dominant and dominant side in males (n=29).

UT = upper trapezius, LT = lower trapezius, MT = middle trapezius, SAU = serratus anterior upper fibres, SAL = serratus anterior lower fibres, RH = rhomboids.

4.3 Muscle activity and Kinematic analysis

Figures 4.3 and 4.4 depict the range of the movements in flexion in the sagittal plane of movement and abduction in the frontal plane of movement. Kinematic analysis of the shoulder angles during flexion in the sagittal plane and abduction in the frontal plane was used to determine the muscle activity in the various phases of each movement. The muscle activity ratios of serratus anterior lower fibres and lower trapezius are presented in this section.

4.3.1 Shoulder angles during flexion in the sagittal plane of movement and abduction in the frontal plane of movement

The abduction and flexion angles from the start (0%) to the end of the movement (100%) is shown in Figure 4.3 (abduction) and in Figure 4.4 (flexion). The right arm of all the participants was used for the collection of the kinematic data, in flexion and in abduction.

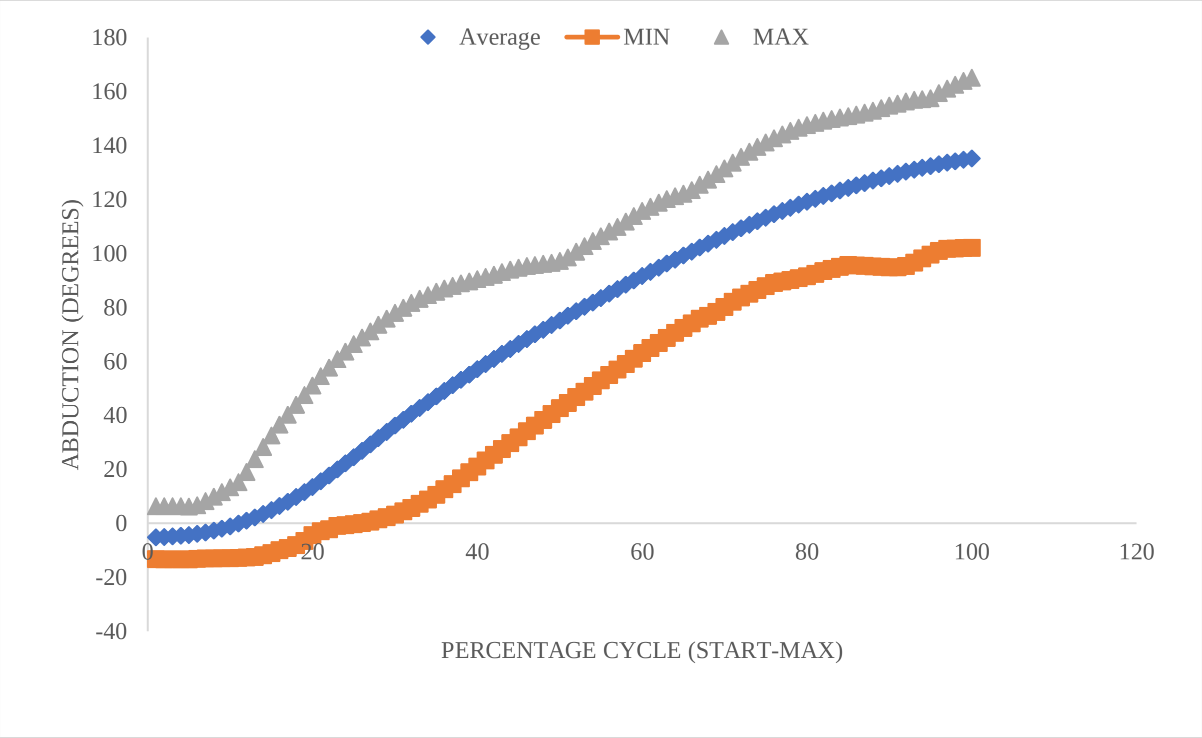

Figure 4. 3 Kinematic analysis in abduction, showing the range of the abduction movement of the participants (n=16).

The abduction arm movement from (±) -10°– (±) 170^{0}, converted to %, from 0%–100% of the movement cycle. Min = Minimum; Max = Maximum.

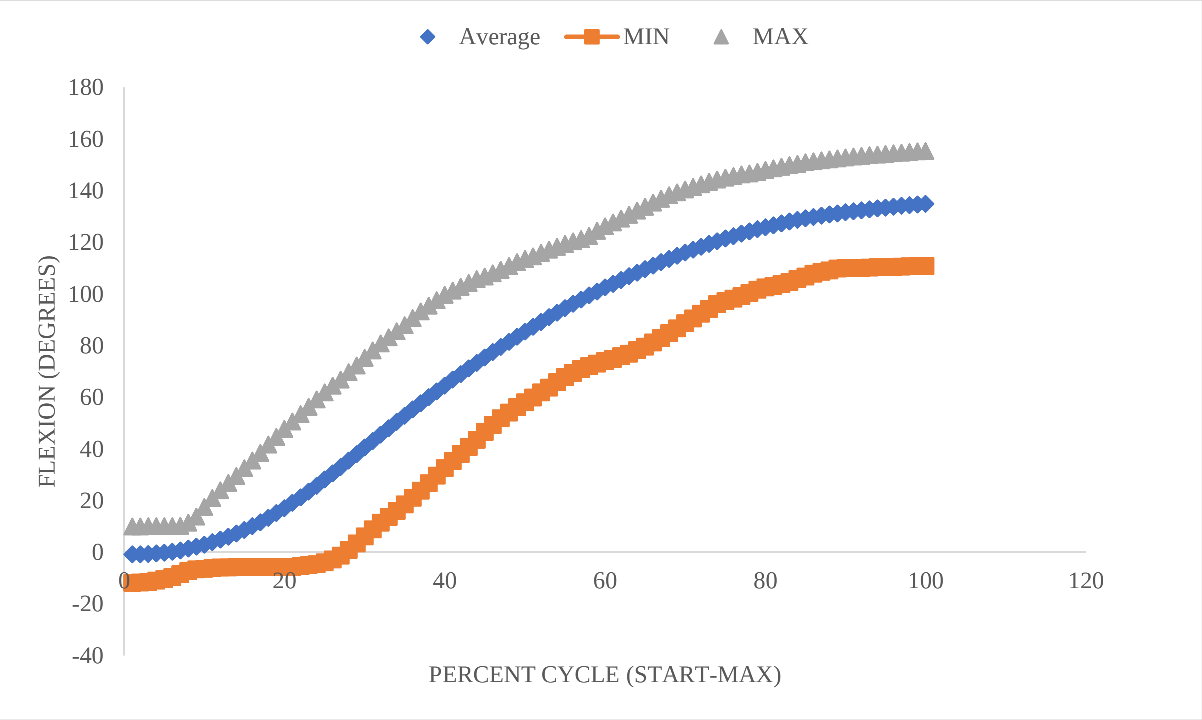

Figure 4. 4 Kinematic analysis in flexion, showing the range of the flexion movement of the participants (n=16).

The flexion arm movement from (±) -20˚– (±) 160^0, converted to %, from 0%–100%, of the movement cycle. Min = Minimum; Max = Maximum.

4.3.2 Muscle activity as measured through electromyography

The muscle activity was calculated as a percentage of the MVIC of the serratus anterior lower fibres and the lower trapezius. With the results obtained from the kinematic data, the flexion and abduction angles were recorded at every one percent of the movement cycle from the start (or neutral position) to the maximum angle (or end of range). The muscle activity was recorded at every 10% of the cycle, from the start (neutral position=0%) to the maximum angle (end of range=100%). The graphical representation of the combined muscle activity as a percentage of the MVIC in both the flexion in the sagittal plane of movement and abduction in the frontal plane of movement of serratus anterior lower fibres and of lower trapezius will now be presented.

A steady increase in muscle activity was reflected in both serratus anterior lower fibres and in the lower trapezius. From 50%-90%, a sharp increase in EMG activity in serratus anterior lower fibres and in the lower trapezius was observed in abduction in the frontal plane (Figure 4.3). A slight decrease in the activity of both serratus anterior lower fibres and the lower trapezius was seen between 90%–100% of movement in abduction in the frontal plane. The EMG activity of both serratus anterior lower fibres and the lower trapezius was less in flexion in the sagittal plane of movement. From 30%–40% of movement in both flexion in the sagittal plane and abduction in the frontal the EMG muscle activity of both serratus anterior lower fibres and of the lower trapezius was more or less equal.

Muscle activation ratios were calculated from the mean EMG amplitude. Figure 4.5 indicates more muscle activity as the cycle progressed, in both serratus anterior lower fibres and the lower trapezius. The data represented in Figure 4.5 also shows that there was no statistically significant difference between the levels of muscle activation in these muscles during the flexion movements ($p>0.05$). Serratus anterior lower fibres and lower trapezius were both active during flexion. Looking at the activation of these muscles during abduction, there was a steady increase in the activation of the lower trapezius from 50%– 90%, but there was a significantly greater activation of serratus anterior lower fibres at 70%, 80% and 90% ($p<0.05$), compared to the flexion movement cycle from 0%–100% (Figure 4.5).

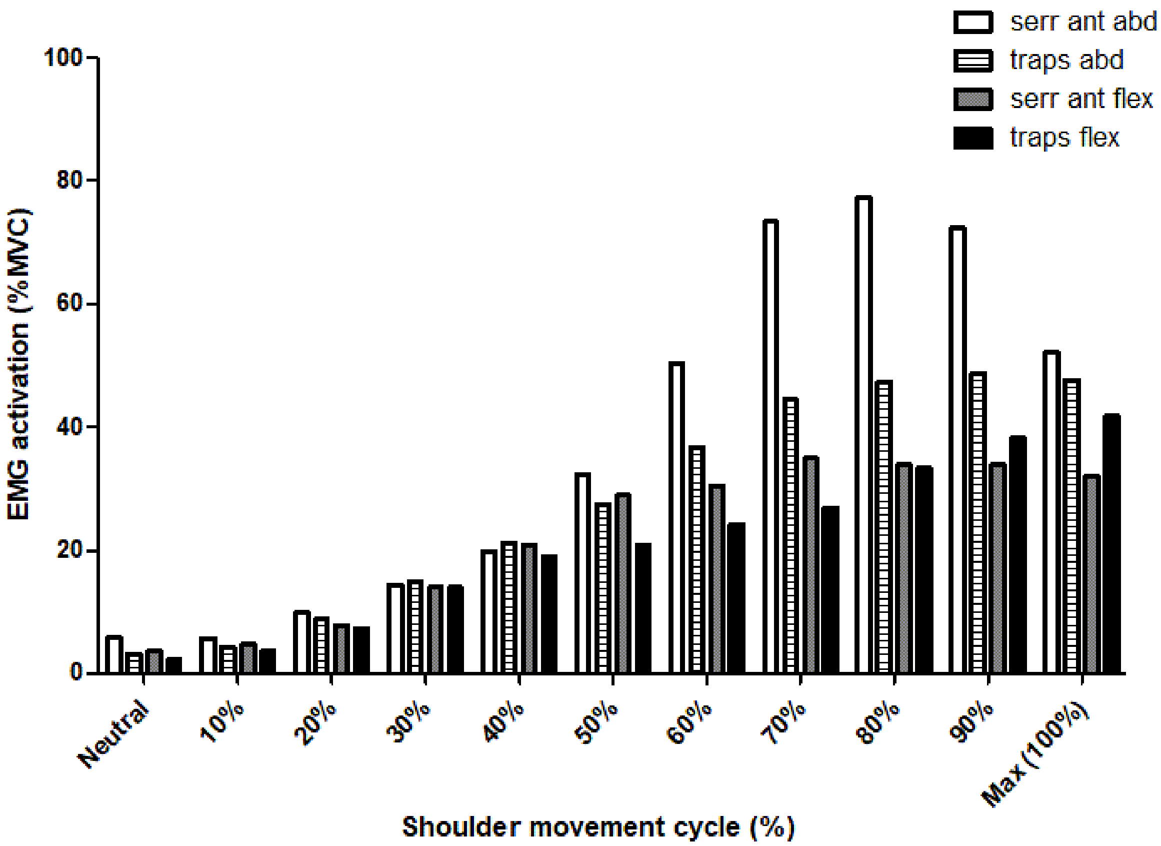

Figure 4. 5 A bar graph comparison of the mean EMG amplitude (%MVIC) of the serratus anterior lower fibres and the lower trapezius during flexion in the sagittal plane of movement and abduction in the frontal plane of movement (n=16).

MVIC = maximum voluntary isometric contraction. Serr ant = serratus anterior lower fibres; traps = lower trapezius; abd = abduction; flex = flexion.

A comparison of the EMG ratios of serratus anterior lower fibres and lower trapezius during flexion in the sagittal plane of movement and abduction in the frontal plane of movement is shown in Table 4.8. The only significant increase in the mean EMG ratio of serratus anterior lower fibres versus the lower trapezius in flexion versus abduction was present at 60% (from baseline) of abduction ($p=0.03$). For the rest of the movement cycle the differences were due to chance with ($p>0.05$).

Table 4. 8 A comparison between the EMG muscle activity ratios in flexion and abduction for serratus anterior lower fibres versus lower trapezius in the combined group (n=16).

Range	Flexion	Abduction	
	Mean (SD)	**Mean (SD)**	**p- value**
Neutral	3.37 (2.57)	3.60 (5.61)	0.82
10%	3.21 (3.26)	2.64 (2.46)	0.29
20%	3.59 (4.62)	2.98 (4.90)	0.42
30%	3.08 (3.52)	3.17 (6.72)	0.93
40%	2.96 (3.75)	3.20 (6.47)	0.84
50%	3.81 (4.56)	2.07 (3.87)	0.8
60%	3.52 (4.32)	1.76 (2.76)	0.03*
70%	3.74 (2.93)	1.61 (2.86)	0.07
80%	3.23 (0.79)	1.97 (3.58)	0.10
90%	2.70 (0.70)	2.41 (5.21)	0.69
Max	2.40 (0.59)	2.62 (5.14)	0.64

Statistical significant differences are denoted by an *. SAL:LT ratio differences between flexion and abduction determined with the paired t-test values. SAL= serratus anterior lower fibres, LT= lower trapezius. SD= standard deviation.

4.3.3 Correlation between EMG muscle ratio activity

Table 4.9 shows the correlation between the EMG ratios of serratus anterior lower fibres and the lower trapezius, in flexion and abduction. For the correlation between EMG (%MVIC) of serratus anterior lower fibres and the lower trapezius in abduction, there was a strong negative correlation at start of abduction ($p<0.01$) ($r= –0.623$) and at 10% of abduction ($p<0.004$) ($r= –0.675$). No correlation existed between the EMG (%MVIV) ratio of serratus anterior lower fibres versus lower trapezius in flexion at the start ($p>0.05$) ($r= –0.061$), nor at 10% ($p>0.05$) ($r= – 0.211$) of the movement. For the rest of the movement cycle of both flexion and abduction, a poor correlation existed between the EMG (%MVIC) ratio of serratus anterior lower fibres versus the lower trapezius ($p>0.05$) The ratios remained variable between serratus anterior lower fibres versus the lower trapezius, for the rest of the movement cycle from 20%–100%, in both flexion and abduction.

Table 4. 9 The correlation between the EMG ratios of serratus anterior lower fibres and the lower trapezius in flexion and abduction (n=16).

	Flexion		Abduction	
	r-values	**p-values**	**r-values**	**p-values**
Start	-0.061	0.823	-0.623	0.010*
10%	-0.211	0.433	-0.675	0.004*
20%	-0.333	0.208	-0.476	0.062
30%	-0.181	0.502	-0.300	0.258
40%	0.082	0.763	-0.186	0.491
50%	0.059	0.827	-0.238	0.375
60%	-0.006	0.983	-0.184	0.494
70%	-0.131	0.629	-0.162	0.549
80%	-0.147	0.587	-0.079	0.771
90%	-0.394	0.131	-0.098	0.717
Max	-0.282	0.289	-0.166	0.537

Statistical significance is denoted with an *.

CHAPTER 5: DISCUSSION

5.1 Introduction

The primary objective of this study was twofold:

- Firstly, to establish baseline figures for the force production values of the scapular stabilisers in terms of the ratios of the force couples (upper trapezius versus lower trapezius, middle trapezius versus serratus anterior upper fibres, serratus anterior lower fibres versus lower trapezius, serratus anterior lower fibres versus rhomboids and lower trapezius versus rhomboids). The investigation was done in the non-dominant versus the dominant arm, in both females and males.
- Secondly, to compare the force production values in healthy shoulders between the two sexes.

The second objective was to establish the muscle activity as measured through EMG (%MVIC) of serratus anterior lower fibres and the lower trapezius during flexion in the sagittal plane and abduction in the frontal plane. These two muscles form the lower force couple of the scapular stabilisers and are the two muscles which are easiest to measure by surface EMG because of their relatively superficial anatomical location.

The third and last objective was to determine the correlation between the EMG ratios of the lower force couple, namely the lower trapezius and the serratus anterior lower fibres.

5.2 Participants

5.2.1 Sample size

A total number of 58 participants took part in the force measurement data collection sessions. A subsample of 16 also participated in the EMG and kinematic data collection sessions. An equal number of females and males participated in the study. The researchers own data pool of 354 evaluated patients was utilized for the sample size calculation. It was necessary to use this data because at the time of the present study no other data for comparison existed in the literature. A smaller sample size was included in the EMG and kinematic data collection; the numbers used in EMG and kinematic studies are frequently smaller due to the complex nature of the collection and analysis processes. In a study by Wattanaprakornhul and Halakim (2011), which investigated the EMG activity of serratus anterior and the lower trapezius in normal shoulders, only 15 participants were used. Seven asymptomatic participants were used in a study by Hackett *et al.* (2014), which assessed the validity of surface EMG in the recording of serratus anterior. In their kinematic study, Forte *et al.* (2009) analysed 14 asymptomatic participants to assess scapulohumeral rhythm. The findings and conclusions made in the present study, as they relate to the topics below, will be discussed in the following sections. These topics are: the force measures of the individual muscles of the scapula; the force couple ratios of the scapular stabilising muscles; the muscle activity of the serratus anterior lower fibres and the lower trapezius in the different movement planes; and the correlation between the muscle activity of the serratus anterior lower fibres and the lower trapezius muscles.

5.3 Force measurements

5.3.1 Absolute force measurements

Different mean force measurements were found in the individual scapular stabilising muscles in both the female and male sample groups. Anatomically, the individual parts of the trapezius are one muscle, as are the individual parts of the serratus anterior muscle (Johnson *et al.*, 1994; Smith *et al*., 2003). However, biomechanically, the individual parts (upper, middle and lower trapezius and the upper and lower serratus anterior) display distinctive functions (Ekstrom *et al*., 2004; Fey *et al*., 2007; Wiedenbauer and Mortenson, 1952). Different force values in the different parts of the individual muscles were therefore anticipated. Subsequently, an important finding was that different mean force values were observed in all the individual force measurements of the scapular stabilisers, in both sexes.

The substantial difference in values found, for example, between upper trapezius and lower trapezius, in both the females and the males, might be attributed to the functioning of that particular muscle against gravity. The existence of different forces values in all the individual parts of the trapezius, the serratus anterior and the rhomboids was a thought-provoking result. A plausible explanation for the significant differences observed between the mean force values within the same muscle group might be found in the specific functioning of the individual parts of the muscles, as illustrated in the following two examples. In the first example, the upper trapezius functions as the main scapular elevator (Fey *et al*., 2007; Jonhson *et al*., 1994). This means it needs to overcome the downward pull of gravity and the force of the lower trapezius, to elevate the scapula. A higher mean force value was therefore expected in the upper trapezius versus the lower trapezius, and it was in fact a finding of the present study.

In the second example, the concluded mean force value of the serratus anterior lower fibres was higher than the mean force value of the lower trapezius, in both the non-dominant and the dominant sides, in both sexes. The higher force finding in the serratus anterior lower fibres versus the lower trapezius, in both sexes, can be found in the biomechanical functioning of the serratus anterior lower fibres. The serratus anterior lower fibres functions mainly as an upward rotator of the scapula, and also controls the posterior tilt of the scapula (Ekstrom *et al*., 2004; Phadke *et al*., 2009). Significant force is thus required of the serratus anterior lower fibres to overcome gravity and the downward pull of the strong antagonistic action of rhomboids, which counteracts the upward rotation and posterior tilt of the scapula exerted by serratus anterior lower fibres. The lower trapezius acts in synergy with the serratus anterior as an upward rotator of the scapula, and it can therefore be expected to exert a lower force (Johnson *et al*., 1994).

The mean force values of the present study were consistently higher in the males than in the females, in all the individual muscles of the scapular stabilisers. Miller *et al*. (1993) reached a similar conclusion, of higher strength values being present in men, compared to women. The fact that women tend to have lower proportions of lean muscle tissue distributed in their upper bodies, was the main conclusion reached and cited as the reason for greater differences in upper body strength between women and men in their study (Miller *et al.*, 1993). The same reason of less lean tissue present in the upper bodies of women might be responsible as to the lower mean force values present in the present study.

The serratus anterior upper fibres revealed higher mean values in both the non-dominant and the dominant sides in the males compared to the females. Similar higher mean force values were expressed in the upper trapezius, with the males yielding higher mean force values in the non-dominant and the dominant sides. The concluded results of higher mean force values of serratus anterior upper fibres and upper trapezius in men compared to women of the present study, might mean that the scapula is in a slightly more elevated and protracted position in males. Serratus anterior upper fibres were found to be more active in protraction of the scapula (Ekstrom *et al.*, 2004), and upper trapezius was found to be more involved in elevation of the scapula (Fey *et al.*, 2007). A further explanation for this occurrence of increased strength values present in serratus anterior upper fibres and upper trapezius in men, is that it might offset the presumably higher strength levels that would be present in the middle deltoid (Wickham *et al.*, 2010). Wickham *et al*. (2010), in a study investigating the EMG activity of several muscle groups, demonstrated the early activation of supraspinatus, middle deltoid, upper trapezius, middle trapezius and serratus anterior. A plausible explanation for the early activation of these muscles is that the middle trapezius provides stabilisation to the scapula, and the upper trapezius and serratus anterior counteract the downward rotation of deltoid (Wickham *et al*., 2010). The EMG findings of Wickham *et al.* (2010), might therefore be supportive of the finding, in the present study, of why higher strength levels in upper trapezius and serratus anterior upper fibres are present in males.

Therefore, a difference in the resting position of the scapula between the female and male sample group can be expected, due to the increased mean strength levels observed in the mean force of the upper trapezius and serratus anterior upper fibres in males. The proposed difference in the resting position of the scapula in the male group is supported by the findings of Culham and Peat (1993), who found that the scapular resting position in females was different to that of males. It could therefore be proposed from these findings of the present study, that a difference would exist in the resting position of the male's scapula. This is just a hypothetical proposition based on the direct functioning of the stabilising muscles on the scapula. The resting position was not directly measured but, based on the findings of the present study, it could be postulated to be different.

5.3.2 Force couple ratios

Large differences in the mean values in some force couple ratios of the females versus the males were displayed. Similarly, the findings for the non-dominant and the dominant sides reflected a higher ratio in females than in males for the upper trapezius versus the lower trapezius. On the dominant side in the females, the ratio between upper trapezius versus lower trapezius was also higher in the males. The difference in the force couple ratios in both the non-dominant and the dominant sides of the females was due to the mean force value of the upper trapezius muscle. The upper trapezius of the non-dominant side had a significant higher mean force value in the males, compared to in the females. It was concluded that there was a big difference in the force values of the upper trapezius in the dominant sides between the males and the females; the males displayed a higher mean force value.

The findings expressed in the non-dominant and the dominant sides of the females versus the males reflected the higher ratio present in the middle trapezius versus the serratus anterior in the male sample group. The ratio between middle trapezius versus serratus anterior upper fibres in the non-dominant side of the males was confirmed as being higher in the females. The ratio of the dominant side between middle trapezius and serratus anterior upper fibres in the males was found to be higher in the females. The serratus anterior upper fibre is the muscle responsible for the difference in the force couple ratio of serratus anterior upper fibres versus the middle trapezius, in both the non-dominant and the dominant sides. The serratus anterior upper fibres in the non-dominant side tested at a higher mean force in the males, versus the lower mean force in the females. In the dominant side, the mean force was also found to be higher in the males, compared to the lower mean force in the females.

Kibler and McMullen (2003) stated that scapular asymmetry is often considered, without proof, to be problematic. Taking the specific functioning of the serratus anterior upper fibres and the upper trapezius on the scapula into account the following is proposed: One of the proposals of the present study is the hypothesis of a different resting position of the scapula in males compared to females. This was concluded because of a significant difference in some of the proposed force couple ratios, between the females and males sample groups, and also due to the increased mean force values in the individual values of the upper trapezius and the serratus anterior upper fibres, in males, as discussed previously. Because the present study was conducted on healthy, normal shoulders, it can be seen as supportive of Kibler and McMullen's (2003) statement that scapular asymmetry can exist in non-pathological, normal shoulders.

Definitive force couple ratios were found to exist in all the scapular stabilisers in both sexes. Earlier in the study, it was alluded to by Margery and Jones (2003) that testing a muscle out of context could be misleading. This is particularly true in the scapular stabilisers, where it can be deceptive if only the individual muscles are tested, and the force couple ratios are ignored. In the present study it was shown that even though higher mean force values existed in all the individual forces between sexes, only certain force couple ratios were found to be different. Large differences were found between the female and the male sample groups in the mean force couple ratios of the upper trapezius versus the lower trapezius, and the serratus anterior upper fibres versus the middle trapezius. However, these differences do not indicate the presence of dyskinesis (or dyskinesia). The disruption of the above force couples would be required to cause dyskinesis (or dyskinesia). The scapula is stabilised both statically and dynamically by the scapular stabilising muscles. Therefore, it is deemed important to know the values of the force couple ratios for rehabilitation and evaluation purposes. The simultaneous action of two opposing muscular force couples is considered important for the effective functioning of that particular joint motion. This is especially true regarding scapular stability during glenohumeral movement (Oatis, 2009; Schory *et al*., 2016).

The force couple ratios, as researched in the present study, are discussed below, with respect to the potential dyskinesis and impingement syndromes that could develop if they are disrupted. Various authors have suggested that abnormal scapular movement (dyskinesia) has a role to play in impingement syndrome, rotator cuff dysfunction and even cervical pain (Cools *et al*., 2007; Huang e*t al*., 2013).

The first hypothetical example covered is the force couple ratio of the upper versus the lower trapezius. One of the results of the present study is the finding of a major difference in the mean force couple ratio of the upper trapezius versus the lower trapezius, with the ratio of females found to be higher in value than that of males. However, this does not indicate the existence of dyskinesis in either the female or the male sample group. Delayed recruitment of the lower trapezius compared to the upper trapezius was concluded by Cools *et al.* (2003), in a study on muscle recruitment patterns in painful shoulders. Muscle weakness may theoretically develop in a muscle that exhibit delayed recruitment (Janda, 1986). If known values of upper trapezius and lower trapezius is not available at the outset of the rehabilitation process, and the same amount of strengthening is applied to both upper and lower trapezius, a ratio imbalance will continue to exist. This will lead to the persistence and not the correction of a potentially stronger upper trapezius compared to the potentially weaker lower trapezius. In everyday life it is easy to inadvertently strengthen the upper trapezius disproportionately in relation to the lower trapezius. If the upper trapezius is disproportionately strengthened in relation to the lower trapezius, it could have a compromising effect on the lower trapezius, resulting in the force couple of upper trapezius versus lower trapezius being disrupted. In a study by Smith *et al.* (2002), they theoretically concluded that imbalances between the upper trapezius and the lower trapezius could be a contributing factor in subacromial impingement syndrome. It has been established that the key role of the upper trapezius is mainly one of elevation of the clavicle. This is due to the anatomical arrangement of the fibres which attach to the lateral one third of the clavicle, rather than directly on to the scapula (Fey *et al*., 2007; Johnson *et al*., 1994; Smith *et al*., 2003). Johnson *et al*. (1994) found that the lower trapezius assists with depression of the scapula due the arrangement of its fibres on the spine of the scapula. Disruption of the force couple ratio between the upper trapezius and the lower trapezius could therefore lead to alteration in the scapula's position, and subsequently to dyskinesis. Disruption of this upper trapezius versus the lower trapezius force couple could lead to a relatively stronger upper trapezius muscle (agonist), rendering the antagonistic action of the lower trapezius muscle inefficient. With a weaker lower trapezius, the force couple ratio between the lower trapezius and the serratus anterior lower fibres could be next in line to be compromised.

The following discussion focusses on the serratus anterior lower fibres versus the lower trapezius force couple ratio. No significant differences were found between the females and the males in the serratus anterior lower fibres versus the lower trapezius force couple ratio. The force couple of serratus anterior lower fibres versus the lower trapezius stabilises the inferior-medial border of the scapula and prevents winging at its medial border (Perry, 1978). According to Perry (1978), if the trapezius is not properly aligned, scapular winging (or posterior tilting of the inferior-medial corner of the scapula) can occur during shoulder flexion, because of the weight of the arm. The malalignment of the lower trapezius can have a counterproductive effect on the stabilising ability of the serratus anterior lower fibres (Perry, 1978). The synergistic action of serratus anterior lower fibres and the lower trapezius is important for the control of upward rotation of the scapula, in both the sagittal and the frontal plane of elevation (Bagg and Forrest, 1986; Johnson *et a1*., 1994). The disruption of this force couple, in which the lower trapezius and the serratus anterior lower fibres play a significant role, could have a negative knock-on effect on upward rotation of the scapula (Ebaugh *et al.*, 2005; Johnson *et al*., 1994; Phadke *et al*., 2009).

No substantial difference was found between the sexes in the force couple ratio of the serratus anterior lower fibres versus the rhomboids, nor in the force couple ratio between the lower trapezius versus the rhomboids. In the hypothetical scenario of the disruption of the force couples previously suggested, the next force couples to be compromised could be the serratus anterior lower fibres versus the rhomboids, and the lower trapezius versus the rhomboids. The agonistic/antagonistic action of serratus anterior lower fibres versus the rhomboids, and the lower trapezius versus the rhomboids, is important for the control of the upward/downward rotation of the scapula (Ito, 1980). Therefore, the effective execution of this motion is important for the maintenance of an ideal force couple relationship. Disruption of this force couple would have a detrimental effect on the upward rotation of the scapula.

The disruption of these force couples found in the scapula could therefore lead to dyskinesis and dyskinesia, with a resultant impingement syndrome developing. Potentially, the delayed and disrupted upward rotation of the scapula could worsen the subacromial impingement effect at the acromioclavicular and the glenohumeral joints (Michener *et al*., 2003). In this case the compromised upper trapezius versus lower trapezius force couple could be seen as the catalyst in a biomechanical snowball effect, resulting in disruption of the other force couples, and subsequent dyskinesis.

5.3.3 Difference in ratios in non-dominant versus dominant sides

No significant difference was observed in the mean force couple ratio between the non-dominant arm and the dominant arm in the female group. Neither was any difference observed between the non-dominant arm and dominant arm in the male sample group. In a scapular kinematic study, Yoshizaki *et al.* (2009) concluded that no statistically significant differences exist between the sides in healthy adults. The study was conducted on 14 healthy men and 14 healthy women, with a mean age of 24 years. It required the participants to elevate and lower their arms. In their study, Yoshizaki *et al.* (2009)) concluded that no strength differences existed between the non-dominant and the dominant sides of the participants. Even though this was a kinematic study and the present study is an isometric force comparison of the scapular stabilisers, the matching results seemed appropriate because of the involvement of scapular stabilisers in both studies. The next study, McCurdy and Langford (2005) was conducted on young healthy adults with a mean age of 21.7 years in men, and 21.9 years in women. They tested the unilateral squat strength of the participants' legs. Although this study was conducted on the lower limb, the age group is similar to the current study, and it also found no difference in strength between the non-dominant and the dominant sides. This echoes the finding of the current study, mainly that no significant differences exist in the force couple ratios between sides, in females and in males. The reason to no difference present in the different sides in sexes, might lie in the fact that the participants had healthy and unimpaired shoulders. The presence of pain might be an attributing factor to strength differences developing in different sides in the same individual.

5.4 EMG activity and kinematics

The results of the kinematic and electromyography analysis are discussed below. The EMG data was analysed comparing the muscle activity in the two movement planes of flexion in the sagittal plane and abduction in the frontal plane. Correlation of the EMG muscle activity of the lower force couple was also determined. The results obtained from the kinematic analysis are discussed first.

5.4.1 Kinematics

The rotational sequence used in the present study was (XZY) for the abduction movement in the frontal plane, and for the flexion movement in the sagittal plane. This rotational sequence was decided on because it is recommended by Xsens. The decision regarding the rotational sequence was based on the recommendations by Xsense and several researchers ((Bonnefoy–Mazure *et al*., 2010; Šenk and Chěze, 2006). A more detailed discussion follows. A limitation of the ISB recommendation is that the reference position of the shoulder joint is not standardized. The ISB recommended that the (YXY) rotation order be used in shoulder kinematics (Jackson *et al*., 2012). However, usage of this particular rotation sequence most frequently presents gimbal locks (GL). This particular phenomenon occurs most commonly in the shoulder joint as the second rotation equals or nears 0^0, with the arm by the side (Bonnefoy–Mazure *et al*., 2010; Rundquist *et al*., 2003). Clinically meaningful data can therefore not be collected in certain positions (Rundquist *et al*., 2003). From a biomechanical point of view, the large range of motion in the shoulder joint does not allow for a unique standard of 3-D kinematic analysis (Bonnefoy–Mazure *et al*., 2010). To avoid possible gimbal lock occurrences, several researchers have proposed the usage of a (XZY) rotational sequence in the shoulder (Bonnefoy–Mazure *et al*., 2010; Šenk and Chěze, 2006). For this reason, usage of the joint sequence (XZY) was decided upon as better choice for the present study.

The shoulder model used in the Xsens package does not calculate angles in flexion and extension the way a clinician would normally measure them with a goniometer, for example from 0^0 to 180^0. The total movement in flexion and abduction was converted to a percentage. So neutral, or 0^0, would equal 0%. And full range of movement, or 180^0, would equal 100%. I refer the reader to Figure 4.3–4.4. This conversion allowed for participants who did not start exactly in neutral (0^0) or did not end exactly in full range of movement (180^0), as is usually the case in a clinical setting. Flexion and abduction angles were recorded every 1% of the movement cycle from the start, or neutral position, to the maximum angle, or full range. By reporting the joint angles at different percentages, comparisons could be drawn between the EMGs (MVIC%) of the two muscles under investigation (serratus anterior lower fibres and the lower trapezius) at specific joint angles. For example, the specific MVIC% of serratus anterior lower fibres could be determined at 60% of the movement cycle. A comparison could then be made to the specific MVIC% of the lower trapezius at the exact same joint angle of 60%. The minimum, average and maximum percentages of the ranges in abduction and flexion are represented in the two graphs (Figure 4.3–4.4). Range is represented in percentages on the horizontal axis (0%–100%), and in degrees on the vertical axis (0^0–180^0). This allows for a conversion to be made on the graph from percentage ROM (0º–100%) to degrees ROM (0º–180^0). For example, when looking at the abduction graph (Figure 4.3), 60% of movement on the horizontal axis correlates with 110^0 on the vertical axis. The same example applies to Figure 4.4. This conversion from percentages to degrees makes comparisons to present literature studies easier.

The calculation of the angles at the shoulder joint was needed to determine the muscle activity (%MVIC) of the serratus anterior lower fibres and the lower trapezius at specific points in the range of flexion in the sagittal plane and abduction in the frontal plane. Without the use of the kinematics, irrespective of whether or not the muscle activity was monitored at the start of the movement, during the full excursion of the movement, or at specific points of the movement cycle, the MVIC% would have yielded the same value. When EMG electrodes are applied to the skin, electrical activity from the muscle is picked up at the electrode site. However, EMG cannot determine what angle a is joint at; it can only monitor muscle activity and whether or not the activity is increasing or decreasing. Refer to section on EMG parameters (Section 2.10.1—2.10.2). For the determination of joint angles, as in the present study, kinematics needs to be included. The calculation of the joint angles is done via kinematics and the determination of the EMG activity is monitored via EMG. In combining the two methods, activity present can be determined as well as the specific joint angle, the percentage of EMG (%MVIC) activity present, and the specific joint angle at which it occurs. Comparisons to the current literature would have been impossible if kinematics was not included in the current study.

In scapulohumeral movement, the range (0º–180°) is divided into three distinct phases (Section 2.5 Scapulohumeral rhythm) (Bagg and Forrest, 1988; Inman *et al*., 1944). The first setting phase is 0º–30° (in abduction) and 0º–60° (in flexion) (Bagg and Forrest, 1988; Inman *et al.,* 1944;). Most of the movement during this phase takes place at the glenohumeral joint (Inman *et al.,* 1944). During the middle phase (81.8º–139.1°) the movement is mostly at the scapulothoracic joint (Bagg and Forrest, 1988). In the final phase (140º-180°) most of the movement takes place at the glenohumeral joint (Bagg and Forrest, 1988). Scapular kinematics has been used successfully, by numerous researchers, during studies investigating the movement in normal shoulders (Bonnefoy–Mazure, *et al*., 2010; Šenk and Chěze, 2006) and pathological shoulders (Ludewig and Cook, 2000; Rundquist *et al*., 2003). Converting the range of movement from percentages to degrees allows for the following conclusions to be drawn (Figure 4.3–4.4). In the present study of glenohumeral abduction, an increase in EMG activity in serratus anterior lower fibres was noted from 60%–80%, which correlates to 100º–140°, or mid-range, of the movement cycle. This correlates with the results obtained from studies by Ludewig and Cook (2000), who found an increase in serratus anterior muscle EMG activity from 61º–120° (mid-range) of glenohumeral abduction. In a study by Wickham *et al.* (2010), conducted in the frontal abduction plane from 120º–135°, serratus anterior fibres reached 85% (MVIC%) of muscle activity compared to the lower trapezius, which reached 80% (MVIC%) of muscle activity. Similar results were achieved in the present study, which indicates higher serratus anterior lower fibre muscle EMG activity versus the lower trapezius in abduction. Results of the present study showed that at 80%–90% (120°–160°) of the movement cycle, serratus anterior lower fibres reached 80% of MVIC compared to the lower trapezius, which reached 50% of MVIC.

5.4.2 Muscle activity of serratus anterior lower fibres versus lower trapezius

The key role of the serratus anterior lower fibres and the lower trapezius in the biomechanics of the scapula was the motivation for closer investigation of this particular force couple. The serratus anterior lower fibres and the lower trapezius are seen by many as the only true upward rotators of the scapula (Ekstrom *et al*., 2004; Phadke *et al*., 2009). The upward rotation of the scapula by the serratus anterior lower fibres is counteracted by the synchronous activity of the lower trapezius (Perry, 1978). Serratus anterior lower fibres and the lower trapezius are the main stabilisers of the inferior-medial corner of the scapula. It follows that prominence of the inferior-medial corner of the scapula could indicate disruption of this force couple (Hébert *et al*., 2002). The findings of the present study are discussed below.

The increased activity of serratus anterior lower fibres displayed at 70%–90 % (120º–160°) of the movement cycle in abduction might be explained by the fact that posterior tilt of the scapula occurs near the end of range of abduction in the frontal plane. Serratus anterior lower fibres is the main muscle involved in the posterior tilt action of the scapula (Ekstrom *et al*., 2004).

External rotation (or posterior tilt) of the scapula occurs at the end of range of humeral elevation (Ludewig and Reynolds, 2009; McClure *et al*., 2001). The finding of increased muscle activity of the serratus anterior in the frontal plane of abduction in the higher ranges 70%–90% (120º–160^0) of the movement cycle, is therefore supported by the findings of the researchers mentioned above.

The results from the present study demonstrated greater muscle activity of serratus anterior lower fibres and the lower trapezius as the movement cycle increased, in both flexion in the sagittal plane and of abduction in the frontal plane of movement (Figure 4.5). The muscle activity of serratus anterior lower fibres and the lower trapezius was similar during flexion (Figure 4.5). Significantly more activity of serratus anterior lower fibres was found in frontal abduction. In the present study there was an increased EMG activity of serratus anterior lower fibres and the lower trapezius in the mid-range, from 60%–90% (100°–140°) of the movement cycle. This correlates with the results of the study by Bagg and Forrest (1988). They found that during the middle phase of abduction (81.8º–139.1°) the ratio of scapulothoracic to glenohumeral rotation was 1.71° of scapular rotation to 0.71° of glenohumeral rotation. An explanation of the higher scapular to glenohumeral rotation, offered by Freedman and Munro (1966) and Doody *et al.* (1970), was that the moment arms of the scapular rotators exceeded the moment arm strength of the supraspinatus and the deltoid in this range of movement. The scapulothoracic movement of upward rotation of the scapula is mainly executed by serratus anterior lower fibres and the lower trapezius.

The results of the present study led to the conclusion that there is increased EMG activity of serratus anterior lower fibres and lower trapezius, in the higher movement planes of abduction and flexion. The detailed results are shown in section 4.3.2. The conclusion was reached that both serratus anterior lower fibres and the lower trapezius are active throughout the flexion movement. This supports the findings of Wattanaprakornhul and Halakim (2011). They investigated the muscle activity of serratus anterior and the lower trapezius and concluded that both lower trapezius and serratus anterior are active in flexion throughout the range of movement. Their study was similar to the present study in that: the participants were of a similar age (19 years to 47 years); the sample number was 15; and normal shoulders were studied. Many other EMG studies have looked at the EMG activity of the scapular stabilisers in different movement planes. In EMG investigations conducted by different researchers, the age groups studied varied from 19-year-olds to 40-year-olds, there were normal and impaired shoulders, and females as well as males. The overall conclusion reached in these studies was that both serratus anterior and the lower trapezius, in normal shoulders, are active during flexion, especially in the higher ranges. In impaired shoulders, decreased activity of both serratus anterior lower fibres and the lower trapezius was demonstrated in the higher ranges of movement (Cools *et al*., 2002; Ekstrom *et al*., 2003; Karduna *et al*., 2001). The increased EMG activity of both serratus anterior lower fibres and the lower trapezius was also found in the present study (Figure 4.5). More information is provided on these findings in the literature review chapter (Section 2.1).

A major finding in the present study was the increased EMG activity of serratus anterior lower fibres compared with the lower trapezius in the 70%–90% of the abduction movement (Figure 4.5). Wadsworth and Bullock-Saxton (1997) observed conflicting evidence of the recruitment of serratus anterior lower fibres and the lower trapezius in flexion and in abduction. Closer inspection of the differences was warranted. Moseley *et al*. (1992) found that the EMG activity of serratus anterior lower part progressively increased during active elevation of the scapula, in the plane of the scapula (30° anterior to the frontal plane). The serratus anterior was also considered to be more active in forward flexion (Inman *et al*., 1944). The movements, in the study by Inman *et al*. (1944), were also conducted in the plane of the scapula. There were similarities between the present study and those by Cools *et al*. (2007) and Decker *et al.* (1999). The participants were similar: the mean age was the same, between 20.7 years and 30.4 years; the sample sizes were between 20 and 45 participants; both studies focussed on normal shoulders; and in both studies the conclusion reached was that serratus anterior was active mostly in scaption (30° anterior to coronal plane).

The increased activity of serratus anterior lower fibres in the present study, found in frontal abduction, and by the preceding authors in the plane of the scapula, might be due to the small difference in the movement planes. Scaption is abduction in the plane of the scapula, that is, 30° anterior to the coronal/ frontal plane. Pure abduction, on the other hand, is in the coronal, or frontal plane. The findings that serratus anterior lower fibres are more active in the abduction plane, regardless of the movement being in pure abduction in the coronal plane or abduction in 30° anterior to the frontal plane (scaption), might thus be supportive rather than contradictory.

In the present study, results yielded increased activity for serratus anterior lower fibres in the higher planes of movement, in both flexion and abduction. These results were supported by those of Ekstrom *et al.* (2003), who concluded that the maximum activity in serratus anterior lower fibres was reached in arm elevation above 120°, in various planes. In EMG studies by various authors, it was found that the trapezius is more active in abduction (Bagg and Forrest, 1986; Inman *et al.*, 1944). This is not supported by the findings in the present study, which concluded that both the lower trapezius and serratus anterior were active in flexion, but that serratus anterior lower fibres were more active in abduction in the frontal plane.

5.4.3. Correlation between EMG muscle activity.

The present study investigated the EMG muscle activity between serratus anterior lower fibres and the lower trapezius in the two movement planes: flexion in the sagittal plane and abduction in the frontal plane. Correlation of the EMG muscle activity of the lower force couple was also determined.

The results yielded in the correlation between the EMG muscle activity of the lower force couple (n=16) found a significant negative relationship at the start of abduction ($p<0.01$) ($r= -0.623$) and at 10% of the abduction movement ($p<0.05$) ($r= -0.675$) For the rest of the movement the muscle activity of serratus anterior lower fibres and the lower trapezius provided a correlation ($r=0$).

Just because the two independent variables of serratus anterior lower fibres and the lower trapezius in the movement planes of flexion in the sagittal plane and abduction in the frontal plane bear no linear relationship, it does not mean that they are unrelated. The results yielded the finding that serratus anterior lower fibres displayed consistently more activity at 70%, 80%

and 90% in the movement cycle, compared to the lower trapezius. Wickham *et al.* (2010) also found variable EMG muscle activity ratios. They concluded that EMG muscle activity remains variable in the middle and higher ranges of movement in flexion and abduction. The EMG muscle activity variability might be due to studies conducted in different movement planes, or different descriptions of movement planes, either frontal abduction, abduction/ flexion in the plane of the scapula or sagittal flexion.

Another conclusion that could be drawn is that the negative correlation of the EMG ratio activity at the start and at 10% of movement is not a reflection of the static stability of the scapula. Variability of muscle recruitment of the said scapular stabilisers at start of movement is therefore not a true reflection of scapular stability. No data on the EMG ratio correlation of serratus anterior lower fibres and the lower trapezius could be found in the literature relating to the scapular muscles. The study could therefore not be compared.

5.5 Conclusion

The main result found in the force measurement section was that different force values exist in the individual scapular stabiliser muscles. Significant differences in the mean force values were observed between the sexes in all the individual muscles. Substantial differences were also found in some of the mean force couple ratios between the sexes. To my knowledge, no other data on the individual force measurements and on the force couple ratios within the scapular muscles currently exists in literature. The results support the conclusion that different mean force couple ratios exist in some scapular muscles, and that this can be applied to clinical practice.

Collected normative measured values from shoulders in unimpaired individuals can be used as a reference base to ascertain the extent of a patient's impairments, by comparing them to the values obtained from the patient (Roy and Doherty, 2004). Determining the extent of a patient's impairment requires knowledge and the availability of a reference value for comparison (Andrews *et al*., 1996).

Therefore, the determining of baseline figures for the individual muscles, and for the proposed force couple ratios, can lead to a good starting point for evaluation. To effectively evaluate and rehabilitate the scapulohumeral complex, it is thus deemed important to pay closer attention to the force couple ratio balance of all the proposed force couples. By paying closer attention to the force couple ratios in the assessment process of scapular dyskinesis, impairments could be identified and addressed more efficiently. The benefit of knowing the known values of the scapular stabiliser ratios lies in their application in clinical practice.

The results of the EMG activity of serratus anterior lower fibres and of the lower trapezius, in flexion in the sagittal plane and abduction in the frontal plane, are supported in the current literature. This is important in clinical practice, when a patient presents with decreased movement in abduction but not in flexion, or vice versa, it can establish without the use of sophisticated equipment, which muscle is more affected – serratus anterior lower fibres or the lower trapezius? The specific muscle can then be rehabilitated accordingly.

Hypothetically if the obtained force couple ratio, as described in this study, is present, then this ideal isometric force couple ratio should in theory lead to consistency in the EMG activity in serratus anterior lower fibres in flexion and abduction, and also to consistency in the EMG activity in the lower trapezius in flexion and abduction.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The conclusion reached in the first objective of the force production investigation, is that significantly different mean force production ratios exist in healthy shoulders:

- within the upper trapezius versus the lower trapezius,
- within the middle trapezius versus the serratus anterior upper fibres,
- between the sexes, in both the non-dominant and the dominant arm.

No difference existed between the non-dominant and the dominant force couple ratios within the female and male groups.

The second objective of the study was to determine the muscle activity of the lower force couple, namely the serratus anterior lower fibres and the lower trapezius muscles, both in flexion in the sagittal plane and in abduction in the frontal plane. It was determined that serratus anterior lower fibres were significantly more active than the lower trapezius, in the frontal plane of abduction at 70%, 80% and 90 % with ($p<0.05$) and n=16.

The last objective of the study was to determine the EMG ratio correlation of the lower force couple (serratus anterior lower fibres versus the lower trapezius) of the scapular stabilisers. The conclusion reached was that no correlation existed, except for ($p<0.01$) ($r= –0.623$) at the start, and ($p<0.05$) ($r= –0.675$) at 10% of the movement cycle, n=16. The relationship between the two variables, however, showed a consistent increase in serratus anterior lower fibres muscle activity in the frontal abduction plane.

In a time where the call is for more objective, more sensitive and measurable evaluation methods, the results obtained in this study could aid in creating a data base for force measurements of the scapular muscles. The ideal position of the scapula is maintained by the optimal force couple ratios of its muscles. This ideal position should in theory lead to normal articulation at the glenohumeral joint, as well as the maintenance of the normal width of the subacromial space, which should translate into pain free arthrokinematics at the glenohumeral joint, preventing impingement of the supraspinatus tendon and other subacromial structures. The results obtained in the present study could assist to develop a more objective and quantifiable method of evaluating the scapulohumeral complex. The results could also assist in developing a more objective screening tool for the evaluation and monitoring of progress in the rehabilitation process. It might be worthwhile to pay attention to the different force couple ratios of the stabilising muscles when conceptualising a rehabilitation program. The differences found between female and male participants should serve as a reminder to individualise and tailor exercise regimes to the different sexes.

If no attention is given to the force couple ratios of the scapular stabilisers, imbalances could easily be created in the rehabilitation process. In order to approach the rehabilitation process in a scientific and objective manner, the force couple ratios should be evaluated at the outset, and the final rehabilitation should be based on the restoration of the normative values of the force couple ratios. It might be worthwhile to use the results obtained in the present study as reference points, both at the start and at the conclusion of the rehabilitation process.

6.2 Clinical recommendations

The recommendation is to implement more measurable and objective tools for evaluation purposes in the shoulder. Baseline force figures should be collected at the outset of the examination process. It could be beneficial to pay closer attention to force couple ratios as a starting point for rehabilitation, in addition to utilising the known values to identify minor imbalances (scapular dyskinesis). Further comparisons could then be made to the data determined in the present study. Progress could be monitored by collecting regular force measurements. The data collected during the present study could serve as a guideline to identify the stage of rehabilitation, and in the final evaluation, to determine if full strength has been obtained. As results of the present study indicated more muscle activity of serratus anterior in abduction in the frontal plane and of lower trapezius in the sagittal flexion plane of movement, the evaluation and identification of scapular dyskinesis in the respective movement planes can be applied to the rehabilitation process.

6.3 Limitation of the study

Although the sample size used in this study was large enough to add sufficient power to this study and to the inferential statistics used, using larger sample sizes from a healthy population would add to the data base of normative figures for the scapula. The data collected could be used a reference for patients in the same age group, 19 years to 35 years of age, but cannot necessarily be applied to the general population.

6.4 Recommendation for future studies

The establishment of normative figures for scapular stabilising muscles, including comparisons to EMG and kinematic studies, in all ranges of shoulder movements, in both normal, healthy and pathological shoulders, is recommended. Comparisons should be drawn between manual muscle testing values obtained and values obtained using the handheld dynamometer. A measurable and scientific data pool can be created for the scapular stabilising muscles. All of the scapular stabilising muscles should be investigated with EMG and kinematic studies in functional positions, and comparisons should be made to the ideal force couple ratios present in the scapular stabilisers. It should be determined in which of the force couple's disruption first occurs, and the resultant effect that that has on movement impairments of the scapulohumeral complex should be sought. Further understanding of scapular motion and muscle activity in functional positions, and in asymptomatic individuals, is needed to aid in the understanding of complex scapulohumeral biomechanics.

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APPENDICES

Appendix A Request for permission from Head of the Department of Physiotherapy to use participants.

Dear Prof. Mudzi

My name is Sonia Briel; I am currently completing my Masters by Dissertation in Physiotherapy at the University of the Witwatersrand.

The title of my study is “A descriptive Study of Force Production and Muscle Recruitment Ratios in Healthy Shoulders”. As there is currently no data available to the researchers’ knowledge, this particular study will aim to determine and add baseline figures of the scapula stabiliser musculature to the literature. This can then be applied to the clinical practise and might help in better evaluation and treatment strategies.

In order for me to commence and complete my study I need a sample size of 58 participants. Female and male participants will be required. Ages will range from 18 to 35 years of age. I herewith ask for your consent to recruit 20 participants from the physiotherapy student body. The remainder of the sample size will be recruited from the public. The only requirements from the students will be to show up at testing sessions to be tested for muscle force production measurements of the scapula musculature, and to be investigated with surface electromyographical of the said musculature.

If my request is met successfully I will abide with your guidelines, regards times and manner of recruitment. I am aware that the student’s priority is to their studies and I won’t in any matter want to disrupt this. I have attached my proposed protocol for your attention. For any further information regarding the study or any questions you may have prior to granting consent in this matter please feel free to contact me. Otherwise I am looking forward to hearing from you.

Regards

Sonia Briel

Appendix B Request for permission to Dean of students Prof. Parbhoo

Dear Prof., Parbhoo

My name is Sonia Briel; I am currently completing my Master by Dissertation in Physiotherapy at the University of the Witwatersrand.

The title of my study is: “A descriptive Study of Force Production and Muscle Recruitment Ratios in Healthy Shoulders”. This particular study will aim to determine baseline figures of the scapula stabiliser musculature. The outcome of this particular study will add new data to the evaluation and rehabilitation of the scapula complex. This will then be applied to the clinical practise and might help in better evaluation and treatment strategies.

In order for me to commence and complete my study I need to make use of the facilities as well as recruiting a part of my required sample size from the student body at the Physiotherapy Department. I am aware that the student’s first priority is to their studies and I won’t in any matter want to disrupt this. The only requirements from the students will be to show up at testing sessions to be tested for muscle force production measurements of the scapula musculature, and to be investigated with surface electromyographical of the said musculature. For any further information regarding the study or any questions you may have prior to granting consent in this matter please feel free to contact me. Otherwise I am looking forward to hearing from you.

Regards

Sonia Briel

Appendix C Participant information sheet

Title of Study: A Descriptive Study of Force Production and Muscle Recruitment Ratios in Healthy Shoulders Introduction:

Good day and welcome to you. My name is Sonia Briel, and I am a student in the Department of Physiotherapy. I am completing my Masters Degree at the University of the Witwatersrand. Research is just the process to learn the answer to a question. In this study, I would like to find out what the ideal muscle force ratios in the muscles of the shoulder blade are.

I would like to invite you to participate in the following study which is considering the muscle force ratios of the shoulder blade musculature. You have been chosen due to the fact that you are in the age range between 18 and 30 years of age and the fact that you have healthy shoulders. In a shoulder, the muscle forces of the shoulder blade muscles are very important to the optimal functioning of the shoulder. In this proposed study, I will test the muscle forces of all the muscles of your shoulder blade with a handheld machine, measuring the muscle forces in KG. This particular procedure has not been done before, the results expressed will thus add new data to the field of Physiotherapy. This data will be used in the field of Physiotherapy to better examine and treat patients with shoulder pathology.

58 participants will be needed for the study. Female and male participants will be needed. Participants must be between 18 and 30 years of age.

You will only be required to attend one data collection session. No translator will be present, English and Afrikaans will be the spoken languages and every effort will be made to convey the correct testing information to you. The sessions will consist of collecting data from taking force measurements of the shoulder blade muscles. Both shoulders will be tested. Force measurements will be taken with a handheld machine that tests muscle force. The shoulder blade muscles will be tested, six muscles will be tested. This testing session will take 30 minutes. For the electromyographical testing the muscle activity of two muscles will be tested as well, this session will take 45 minutes. The dominant arm will be tested. No risk is involved in participating in the study. All efforts will be made not to harm you during the testing procedure.

All data collected will be kept confident, no names will be mentioned in the study, numbers will be allocated to participants. Absolute confidentiality can-not be guaranteed, personal information might be disclosed if required by law. The data collected will be stored on the researcher’s computer that will be password protected. The data will be stored on the researcher's computer for the duration of the study, for more or less 12 months. Data will only be available to the researcher, the researcher's assistant and the researcher's supervisor. Raw data collected will be analysed with the help of a statistician. Results expressed from the data collected will be made known and published in Physiotherapy and Medical Journals. The data collected will be used to evaluate and treat shoulders more effectively. Should you wish to know the results of the study, it will be made available to you. You are free to withdraw from the study at any stage, without any repercussions to you. No benefits or penalty is associated with participation in the study. No monetary value is payable to you for partaking in the study. You must not have the following present. Any history of shoulder or neck surgery. Any history of sub or total dislocation of the shoulder. Any history of pain or pins and needles in the shoulder or down the arm in the last six months.

More pertinent information will be given while partaking in the study.

Your participation will be highly appreciated.

Contact details of Researcher: Sonia Briel Cell 0833793726 or 0119130405 e-mail sonia@miphysio.co.za.

You can leave your details (SMS me or e-mail or what's up me) and I will contact you.

Contact details of the Researcher's Supervisor for any queries regards the proposed study: Dr Benita Olivier tel. no 011 7173729

Contact details of the Human Research Ethics Committee(Medical) HREC Chair for any queries, complaints or concerns regards participation in the proposed study:

HREC (MEDICAL) Prof P Cleaton Jones Tel No: 011 7172301, email peter.cleatonjones@wits.ac.za

Ms Z Ndlovu/ Mr Rhulani Mkansi/Mr Lebo Moeng Administrative Officers 011 7172700/2656/1234/1252 zanele.ndlovu@wits.ac.za; Rhulani.mkansi@wits.ac.za; and lebo.moeng@wits.moeng@wits.ac.za

Thank you for taking the time to read this information sheet.

Appendix D Consent description sheet

Consent form

THIS STUDY WILL BE CONDUCTED TO COLLECT DATA ON THE SHOULDER BLADE MUSCULATURE

It will be required of you to remove your top (blouse/shirt). This is needed to visually monitor the area of muscle contraction. This is also necessarily for attachments of electrode for the electromyographical testing session. Female participants will be required to wear a sports bra. The shoulder area will be cleaned with an alcohol swab.

The procedure of the actual test will be explained step by step. You will be taken through the testing positions. All watches, bangles and chains will need to be removed. All possible steps will be taken to ensure that you are not harmed at any stage.

You are free to withdraw at any stage during the testing procedure.

Appendix E Participant consent form

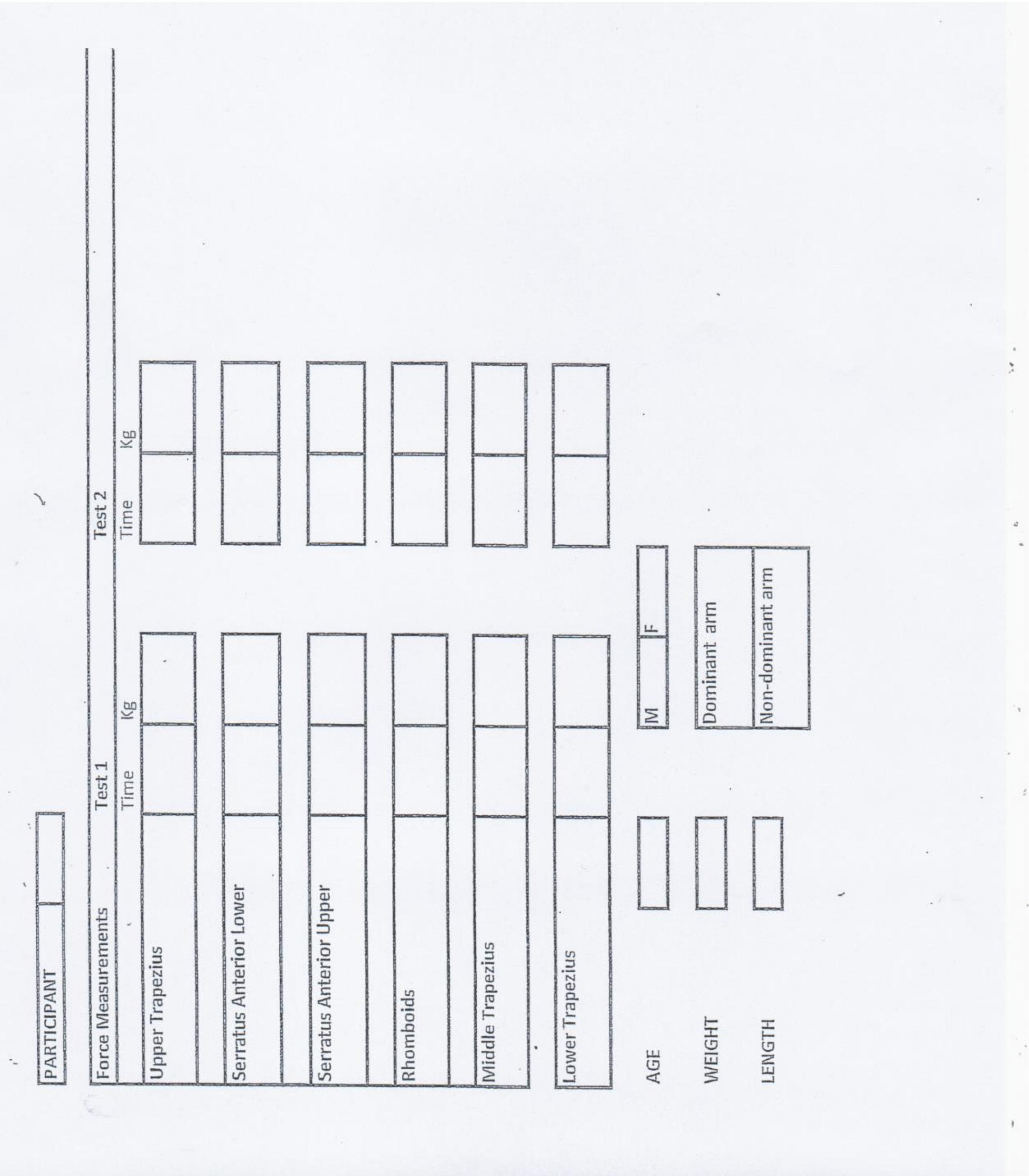
I___________________________________ e-mail address: ________________________ and cell phone number: ____________________, hereby agree to participate in the study as described to me and consent to participating in the muscle force evaluations and as well as the electromyographical testing of the scapula muscles.

I am aware that I will not be exposed to any additional risks, other than the collecting of the data, and that I can withdraw from the study at any time without suffering any repercussions. I understand that there are no monetary rewards for my participation, and that participation is voluntary, and I am not in any way obliged to take part.

Signature of participant: _________________________
Date _____________________________

Signature of researcher _______________________

Appendix F Force measurement data collection sheet



PARTICIPANT	

Force Measurements	Test 1		Test 2	
	Time	Kg	Time	Kg
Upper Trapezius				
Serratus Anterior Lower				
Serratus Anterior Upper				
Rhomboids				
Middle Trapezius				
Lower Trapezius				

AGE		M	F
WEIGHT		Dominant arm	
LENGTH		Non-dominant arm	

Appendix G Kinematic data collection sheet

Wits Physiotherapy Movement Analysis Laboratory

Data collection sheet: Xsens	Date:	Part no.
Variable (kinematics)	Detail	Measurement
Weight (kg)		
Height (cm)	head to toe	
Foot size (cm)	heel to toe	
Arm span (cm)	finger to finger	
Ankle height (cm)	floor to med mall	
Hip height (cm)	floor to great troch	
Hip width	ASIS to ASIS	
Knee height (cm)	floor to lat epicond	
Shoulder width (cm)	left to right acromion	
Sole height (cm)	inner sole middle of foot	

Variables (kinetics)	Measurements	
	L	R
Shoulder (SHO) – Half the distance between shoulder joint center and lateral border of the upper arm segment at the shoulder height		
Elbow (EJC) – Half the distance between mediolateral epicondyles of the humerus		
Wrist (WRIST) – Half the distance between the mediolateral border of the wrist		
Distal end of the Hand (HAND) – Half the distance between the 1st and 5th metacarpophalangeal joints		
Knee (KNE) – Half the distance between the mediolateral femoral epicondyles		
Ankle (ANK) – Half the distance between the mediolateral malleoli		
Distal end of the Foot (FT_Dist) –Half the distance between the 1st and 5th metatarsus		

Appendix H Video recording consent form

Video Recording Consent Form

Study title: A descriptive study of force production and muscle recruitment ratios in healthy shoulders

Dear Sir/ madam

Please will you complete the following consent form if you are willing to participate in this study.

I am willing to participate in the study (please circle)

- Yes
- No

I………………………………………… . (e-mail)
Address………………………………… and cell phone
Number…………………………………. hereby agree to participate in the study as
Described to me in the information sheet. I hereby agree to the video recording of my
arm movements.
I understand that the video recording will be used to analyse my shoulder movement
And will only be accessible to the researcher and the research assistants involved in the
Study The videos will be stored on an external hard drive, which will be password protected and the videos will be labelled with the study number only. Video recordings will be stored for a minimum of two years and a maximum of six years in the absence of publication.
I am aware that I will not be exposed to any additional risks other than usually experienced during my daily activities and that I can withdraw from the study at any time without suffering any repercussions. I understand that there are no monetary rewards for my participation and that participation is voluntary and I am not in any way obligated to take part.
Signature of the participant……………….
Date ………………………….

Appendix I Clearance certificate

R14/49 Mrs Sonia Briel

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M160515

NAME: (Principal Investigator) Mrs Sonia Briel

DEPARTMENT: Physiotherapy
University of the Witwatersrand, Physiotherapy department
(Private Practice of Sonia Briel)

PROJECT TITLE: A Descriptive Study of Force Production and Muscle Recruitment Ratios in Healthy Shoulders

DATE CONSIDERED: 27/05/2016

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Dr Benita Olivier and Prof Witness Mudzi

APPROVED BY:
Professor P. Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 27/06/2016

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004,10th floor, Senate House/2nd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated,from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially review in May and will therefore be due in the month of May each year.

Principal Investigator Signature ____________ Date ____________

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix J Photographic consent form-force measurements

CONSENT FORM FOR PHOTOGRAPHS USED IN THE STUDY:

A DESCRIPTIVE STUDY OF FORCE PRODUCTION AND MUSCLE RECRUITMENT RATIOS IN HEALTHY SHOULDERS

I, Christo Janse Van Rensburg herewith give permission for my photographs to be used in the above- mentioned study, and any subsequent publication (s) that may flow from this.

Name ..CJvan Rensburg.................Place..Alberton...........................

Date.......30/07/2017.......................Signed...[signature].........

Appendix K Kinematics photographic consent form

I.....Elandie Elizabeth Immelman.. cell......0828395153...........

Herewith give consent for my photograph to be used in the study:

"A Descriptive Study of Force Production and Muscle Recruitment Ratios in healthy Shoulders"

Signature..Date.........................18/03/2017

Researcher...