The relationship between shoulder complex strength and throwing velocity in club cricketers

Rucia Vern-Clare November

2554024

UNIVERSITY *of the*
WESTERN CAPE

A thesis submitted in fulfilment of the requirements for the degree of Magister Scientiae in Biokinetics, in the Department of Sport, Recreation and Exercise Science University of the Western Cape

Supervisor: Dr. Lloyd Leach

January 2016

DECLARATION

I hereby declare that *"The relationship between shoulder complex strength and throwing velocity in club cricketers"* is my own work, that it has not been submitted before for any other degree in any other university, and that the sources I have used have been indicated and acknowledged as complete references.

Rucia Vern-Clare November   **January 2016**

Signed _____

DEDICATION

To my family, Ronald, Anacia, Verna (ma), Azni, Sergei and Berkeley who always supported me and believed in me. "Keep your feet firm on the ground and reach for the stars"- Roy (pa).

I never regretted a single moment of this academic journey. If it wasn't my destination, then, it surely was preparation.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

UNIVERSITY of the
WESTERN CAPE

ABSTRACT

Over the years, cricket has progressed into a game of immense physical prowess, and evolved from a traditional and conservative game into a professional sport requiring very high levels of fitness and skill. The ability to throw a ball at high velocity and with great accuracy is critical for successful performance in many ball sports, including cricket. The aim of this study focussed on examining the relationship between isokinetic strength of the shoulder complex and throwing velocity amongst club cricketers in the age group of 18-32 years. The study used a quantitative methodology with a cross-sectional research design. A convenient sample of 40 male cricketers from the University of the Western Cape was tested. Isokinetic strength of external rotators (ER), internal rotators (IR) and ratios were measured using the Biodex Pro System 4 isokinetic dynamometer at two speeds, namely, $60^{\circ} \cdot \sec^{-1}$ and $90^{\circ} \cdot \sec^{-1}$. Throwing velocity was measured using a calibrated Cordless Speed/Radar Gun. The major findings of this study were the significant correlations between IR at $60^{\circ} \cdot \sec^{-1}$ and throwing velocity for the first team ($r = 0.72$; $p = 0.01$), second team ($r = 0.67$; $p = 0.03$), third team ($r = 0.73$; $p = 0.01$) and fourth team ($r = 0.69$; $p = 0.02$). The correlation between the strength ratio at $60^{\circ} \cdot \sec^{-1}$ and throwing velocity was significant for the first team ($r = 0.76$; $p = 0.01$), second team ($r = 0.83$; $p = 0.002$), third team ($r = 0.70$; $p = 0.02$) and fourth team ($r = 0.94$; $p = 0.0001$). In conclusion, shoulder strength plays a significant role in the throwing velocity amongst club cricketers. Specifically, the shoulder internal rotators were found to be a major influence in throwing velocity. Furthermore, the shoulder strength ratio is a strong predictor of shoulder strength performance.

KEY WORDS: Cricket, throwing velocity, shoulder complex, isokinetics, peak torque, strength ratio, internal rotators, external rotators, muscle strength

LIST OF SYMBOLS, ACRONYMS AND ABBREVIATIONS

%	Percentage
AC	Acromioclavicular
CC	Coracoclavicular
cm	Centimetres
Con	Concentric
$°•sec^{-1}$	Degrees per second
Ecc	Eccentric
ER	External Rotators
GH	Glenohumeral
IR	Internal Rotators
Kg	Kilograms
$km•h^{-1}$	Kilometres per hour
m	Metres
Nm	Newton metres
PT	Peak Torque
ROM	Range of Motion
SC	Sternoclavicular
SD	Standard Deviation
SR	Strength Ratio
TEM	Technical error measurement
UWC	University of the Western Cape

CHAPTER ONE: STATEMENT OF THE PROBLEM

1.1 Introduction

Over the years, cricket has progressed into a game of immense physical prowess, and evolved from a traditional and conservative game into a professional sport requiring very high levels of fitness and skill (Bourdon et al., 2000). Cricket has become more demanding due to the limited number of overs played per innings, the fast rate of scoring, the quick speed or shorter duration per over (an average of fifteen over's bowled in less than an hour), and field restrictions that force players to field more athletically and in a wider variety of positions (Bourdon et al., 2000).
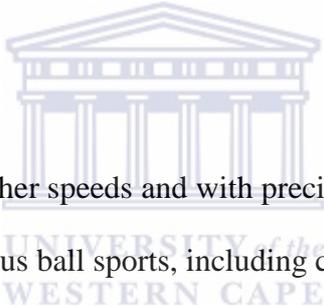
The capacity to throw a ball at higher speeds and with precision is of utmost importance for successful performance in numerous ball sports, including cricket (Cook & Strike, 2000). During throwing, balanced and coordinated action of the rotator cuff muscles of the shoulder is paramount in providing glenohumeral joint motion and stability (Wilk et al., 2002). Thus, in order to prevent injuries, the muscular stabilizers of the shoulder play a significant role (Levine & Flatow, 2000). In order to understand the role of the shoulder complex, it is imperative to quantify and qualify the muscular performance of the shoulder in overhead throwing.

Several studies have examined the isokinetic muscular performance of the shoulder muscles in baseball pitchers and tennis players (Mont et al., 1994; Ellenbeker & Mattalino, 1997; Kibler, 1998; Dale et al., 2007). Even though there is an abundance of research focusing on the effects of isokinetic strength on sporting performance (Mont et al., 1994; Sirota et al.,

1

1997; Cools et al., 2007; Cerrah et al., 2012), currently, to the best of the researcher's knowledge, no such studies have been conducted on cricket players.

1.2 Statement of Problem

The skill of throwing is of significance in cricket, and the quicker and greater the distance the ball travels the better the throw. Throwing velocity is essential for an efficient and successful throw, however, it is crucial when players attack, especially if their throwing velocity can be inculcated effectively within a team's attacking strategy (Derenne et al., 2001). Throwing imposes specific demands on the shoulder muscles, hence the magnitude of the shoulder complex strength directly increases throwing performance (Wooden et al., 1992). Previous research has proven that throwing velocity is affected by an increase in musculature strength (Fleisig et al., 1996).
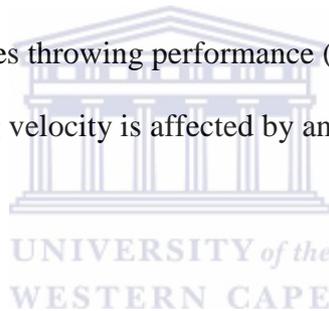
Given the foregoing, this study seeks to:

1. Assess the throwing velocity of the shoulder complex in a group of male club cricketers aged 18 to 32 years.

2. Assess the muscular strength of the shoulder complex in a group of male club cricketers aged 18 to 32 years.

3. Determine the relationship between the shoulder complex strength and throwing velocity in a group of male club cricketers aged 18 to 32 years.

1.3 Aim of the Study

The aim of this study is to measure the throwing velocity and muscular strength of the shoulder complex, and to examine the relationship between isokinetic muscular strength of the shoulder complex and throwing velocity amongst club cricketers aged 18 to 32 years.

1.4 Objectives of the Study

The objectives of the study are:

1. To measure the isokinetic muscular strength of the shoulder complex of the cricket players.
2. To assess the throwing velocity of the cricketer players (bowlers and fielders).
3. To determine the relationship between isokinetic muscular strength of the shoulder complex and throwing velocity.
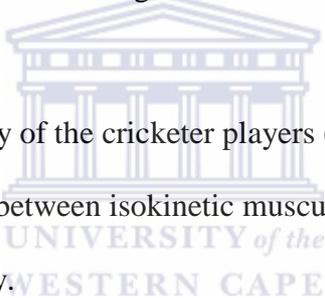
 1.5 Hypothesis

It is hypothesized that there will be a positive relationship between isokinetic muscular strength of the shoulder complex and throwing velocity.

1.6 Significance of the Study

No previous study has investigated the relationship between isokinetic muscular strength of the shoulder complex and throwing velocity, particularly in club cricket. The results yielded

from this study will assist numerous cricket clubs and associations, cricket players and coaches, as well as researchers in the field of cricket. The scientific investigation of the relationship between shoulder complex strength and throwing velocity will attempt to assist future sport science researchers to better understand the motor dynamics of sport performance, and so broaden the science of cricket. This study also intends to stimulate interest and ongoing research in the field of sport science and performance.

1.7 Limitations of the Study

In planning the study, every effort was made to reduce any serious limitations that could have a detrimental effect on the results obtained. However, despite strict control, the following limitations still remained. The subjects recruited for this study competed at amateur level cricket in the first division, therefore, the subjects were not representative of all cricketers, especially not professional cricketers. Also, this was a sample of convenience and not randomly obtained, therefore, the external validity of the study is compromised, so the results cannot be generalized to all cricketers. In addition, the availability of the subjects for testing was challenging and, consequently, the sample size in the study was limited, which substantially impacted the power of statistical significance. The sample is gender specific, since it comprised male cricketers only and, therefore, has limited application and relevance for female cricketers. Inclement environmental conditions were also a limitation. As a result, data collection on throwing velocity was frequently postponed to alternative dates pending favourable weather conditions.

1.8 Delimitations of the Study

The study delimitations consisted of inclusion and exclusion criteria.

1.8.1 Inclusion Criteria

The study inclusion criteria were the following:

- Participants must be currently registered players of the University of the Western Cape's Cricket Club.

- Participants should have played club cricket for a minimum of 3 years.

- Participants must be male.

- Participants must be free of musculoskeletal shoulder injuries.

1.8.2 Exclusion Criteria

The study exclusion criteria were the following:

- Participants younger than 18 years or older than 32 years.

- Participants currently presenting with acute or chronic shoulder pathology or pathology within the previous three (3) months.

- Participants with shoulder pain or discomfort during activity.

1.9 Definition of Terms

Concentric muscle action: refers to the production of muscle tension. When the muscle contracts (muscle shortening) (Ellenbecker et al., 1988).

Eccentric muscle action: refers to the production of muscle tension when the muscle elongates (muscle lengthening) (Luttgen & Hamilton, 1997; Ellenbecker et al., 1988; Derbyshire, 2007).

Eccentric/concentric ratio: refers to the reciprocal muscle group ratio and is calculated as a percentage of peak torque output. Muscular imbalance may influence joint injury, as agonist/antagonist muscle groups offer dynamic joint stability. The production of smooth muscle motion requires the concentric contraction of the agonist muscle group to accelerate the limb, while the antagonists generate eccentric work to decelerate the limb, and to control and prevent supraphysiological joint loading. In throwing, the shoulder internal rotators contract eccentrically to decelerate the limb during the cocking phase (Perrin, 1993).

Isokinetic: refers to the controlled exercise performed with a variable resistance at a constant speed of motion (Davies et al., 2000).

Peak torque: is displayed as the highest value produced at any point throughout the joint range of motion, e.g., the shoulder (Warner et al., 1990; Davies et al., 2000).

Peak torque to body weight ratio: refers to the ratio of the maximum torque produced relative to the participant's body weight presented as a percentage (Davies et al., 2000).

Torque: refers to a force that causes rotation about an axis, measured in units of Newton-metres (Davies et al., 2000).

1.10 Summary of the Chapter

Chapter one provides an overview of the background of cricket in general and various studies related to cricket, involving both throwing speeds and isokinetic performance. The chapter briefly examines the relevant research related to isokinetic strength and throwing velocity in cricket in order to formulate a clear research aim and hypothesis. The chapter ends by defining the terms related to isokinetics. The next chapter will provide and interrogate the literature related to the study.
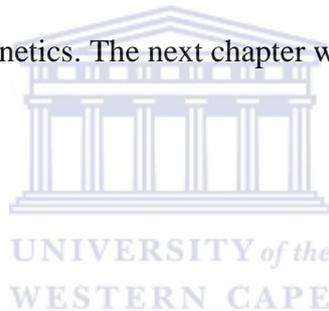
CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The focus of this chapter is to review the literature related to cricket as a sport, the anatomy and biomechanics of the shoulder during the overhead throw, and the importance of the correct muscle activation during throwing. The strength of the shoulder plays a significant role in throwing during cricket (Freeston et al., 2015).

Throwing speed is essential for an efficient and successful throw, however, it is crucial when players attack, especially if their throwing speed can be inculcated efficiently within a team's attacking strategy (Derenne et al., 2001). If the objective is to get the batsman out by a run-out, the fielder must be able to throw the ball with precision and speed (Freeston et al., 2007). This requirement may rely greatly on the throwing technique, as proposed by Elliott and Anderson (1990). Research in throwing technique serves as an important strategy in identifying the characteristics of throwing performance (Fleisig et al., 1996).

Previous research on the throwing movements produced by the shoulder has concentrated primarily on isokinetic testing and the ratio of the internal to external shoulder rotators in the generation of power (Marques et al., 2007; Andrade et al., 2010). One such study investigated throwing skill in youngsters to determine the physical adaptations that take place with repetitive throwing (Clements et al., 2001a). No significant differences were found in either the shoulder or elbow joint range of motion in the experimental group when compared to the control. It was reported that maximum throwing speeds may be attained in well-trained young

players without any modifications in their isokinetic muscle strength, (Clements et al., 2001b).

Wang et al. (2004) set out to determine if arm dominance or gender played a role in shoulder mobility and muscular strength in elite adolescent's volleyball players. The results from this study showed statistically significant effects of both arm dominance and gender on the range of internal shoulder rotation. In young men, the range of motion of internal shoulder rotation on the prevailing side was significantly lower than that of the non-prevailing side. The influence of gender was also demonstrated in the strength assessment. The young men demonstrated greater shoulder strength than the young ladies at both test speeds, except for internal shoulder rotation (measured as concentric and eccentric strength of the prevailing arm) at $180^{\circ} \cdot sec^{-1}$. The side-to-side (arm dominance) difference in mobility in the young men may show a mobility loss in these players (Wang et al., 2004).
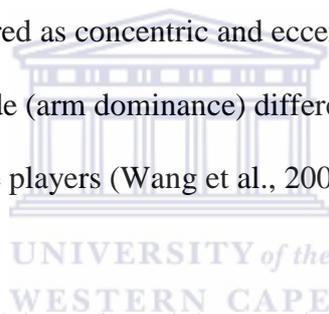
A study by Clements et al. (2001a) investigated the association between upper limb muscle strength and throwing speed in young baseball players. From the results, 71% of the variation in throwing speed was due to isometric internal shoulder rotation and concentric elbow extension. Clements et al. (2001a) found that both the elbow extensor and internal shoulder rotation strength had a crucial role on throwing speed. Hence, strength training for elbow extension and internal shoulder rotation in youngsters was suggested, without overlooking conditioning of the antagonistic muscle groups.

During throwing in cricket, the kinetic chain is most valuable. The mechanism involves neuromuscular co-ordination in such a way as to transfer energy to the upper body from the legs to the hips, trunk, upper arm, forearm, hand and lastly to the ball (Fleisig et al., 1994;

9

Fleisig et al., 1998; Kibler, 1998; Seroyer et al., 2010). The more the body segments contribute to the sequential movement, the greater the potential velocity of the distal end where the object is released. The shoulder plays a crucial role in this (kinetic) chain and the muscular forces developed in the shoulder are major factors of overall throwing performance (Fleisig et al., 1994; Fleisig et al., 1998; Kibler, 1998; Seroyer et al., 2010).

2.2 Cricket

Cricket is a sport that owes much of its distinctive appeal to the fact that it should be played not only within the laws, but also within the spirit of the game. The sport of cricket involves two teams of eleven players each. Depending on whether cricket is played as a one day international (ODI) or a test match, cricket has no specific time limit. One team bats, trying to score runs, while the other bowls and fields, trying to limit the scoring and dismiss the batsmen. The objective of the sport is for a team to score more runs than the opposition. During throwing in cricket, the movement of the shoulder represents a complex dynamic relationship of numerous muscle forces, ligament constraints, and joints. Therefore, it is important to understand the relevant anatomy and biomechanics of the shoulder in throwing.

2.3 Functional Anatomy

Understanding the function and structure of the shoulder complex is important, since it underpins the biomechanics of throwing velocity (Cook & Strike, 2000). The outline of the shoulder complex is associated precisely to the overall function of the upper limb. The joint mechanisms of the limb permit the placement, functioning, and control of the hand directly in front of the body where the functions can be observed easily.

The shoulder complex consists of the clavicle, scapula, humerus, glenohumeral (GH) acromioclavicular (AC) and the sternoclavicular (SC) joints (Anderson et al., 2009). In addition, the scapulothoracic and subacromial joints are often included in anatomical descriptions of the shoulder complex (Anderson et al., 2009). Together, these articulations offer the shoulder a range of motion that surpasses any other joint mechanism. Full mobility is reliant on coordinated, synchronous motion in all joints of the shoulder complex. This range of mobility, together with elbow motion, enables positioning of the hand anywhere within the visual work space (Anderson et al., 2009).

2.4 Shoulder Joint

2.4.1 Joints of the Shoulder Complex
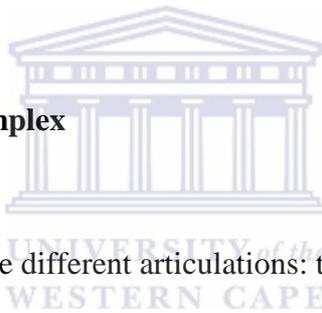
The shoulder region surrounds five different articulations: the sternoclavicular (SC) joint, the acromioclavicular (AC) joint, the coracoclavicular joint, the glenohumeral joint (GH), and the scapulothoracic joint (Anderson et al., 2009). The glenohumeral joint articulation commonly refers to the shoulder joint. The SC and AC joints are articulations that further improve motion of the clavicle and scapula, enabling the GH joint to supply a greater range of motion (Anderson et al., 2009).

2.4.1.1 Sternoclavicular Joint

The SC joint is comprised of the articulation of the medial aspect of the clavicle and the manubrium of the sternum (Levangie & Norkin, 2005).The joint is enclosed within a joint

capsule that is thickened anteriorly and posteriorly by four ligaments, including the interclavicular, costoclavicular, and anterior and posterior sternoclavicular ligaments. The anterior sternoclavicular ligament is a band supporting an anterior capsule, whereas the posterior strenoclavicular ligament is smaller and weaker, providing support to the posterior capsule. The costoclavicular (CC) ligament begins from the clavicle to the first rib and its adjacent cartilage. The interclavicular ligament provides minimal support to the joint, and also attaches to the manubrium. This connects both clavicles across the superior aspect of the sternum (Anderson et al., 2009). The sternoclavicular joint allows rotation of the clavicle with reference to the sternum (Anderson et al., 2009). This allows motion of the distal clavicle in superior, inferior, anterior, and posterior directions, along with some forward and backward rotation of the clavicle (Anderson et al., 2009).
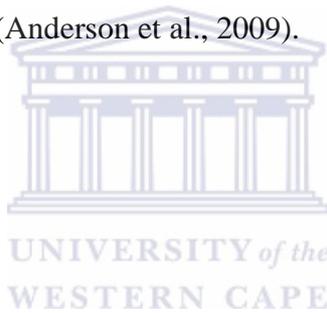
2.4.1.2 Acromioclavicular Joint

The acromioclavicular joint consists of the articulation of the medial facet of the acromion process of the scapula with the distal clavicle (Anderson et al., 2009). It acts as a "strut" between the thorax and shoulder around which the scapula rotates, giving one the ability to raise one's arms above the head. This is a generally unstable articulation (diarthrodial joint). The acromioclavicular joint capsule and the stable coracoclavicular (CC) ligaments, i.e., the conoid ligament medially and trazezoid ligament laterally, reinforce the joint and provide static stability (Johansen et al., 2011).

The strong superior and inferior acromioclavicular ligaments cross the joint, providing stability. The coracoacromial (CC) ligament, sometimes referred to as an 'arch' ligament, is attached to the inferior lip of the AC joint to serve as a buffer between the rotator cuff

muscles and the bony acromion process. A close-packed position of the AC joint occurs when the humerus is abducted at 90º (Anderson et al., 2009).

2.4.1.3 Coracoclavicular Joint

The coracoclavicluar joint is a syndesmosis to which the coracoid process of the scapula and the inferior surface of the clavicle are joined by the coracoclavicular ligament, with its conoid and trapezoid branches, that resist independent upward movement of the clavicle, downward movement of the scapula, and anteroposterior movement of the clavicle or scapula (Anderson et al., 2009).
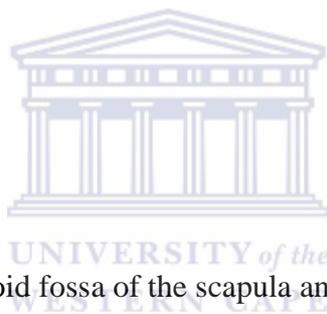
2.4.1.4 Glenohumeral Joint

The GH joint is between the glenoid fossa of the scapula and the head of the humerus. This joint lacks bony stability, whereas the joint enables a greater total range of motion (ROM) than any joint in the body. This occurs from the head of the humerus, which has three to four times the amount of surface area compared with the shallow glenoid fossa. Hence, the glenoid fossa is also less curved than the humeral head. The humerus not only rotates, but also moves linearly across the surface of the glenoid fossa when humeral motion occurs. Humeral head translation is limited by muscle tension during active positioning of the arm. The largest translations take place during passive movement of the arm at the extremes of the ROM.

The glenoid fossa is somewhat deepened around its perimeter by the glenoid labrum, a narrow rim of fibrocartilage around the edge of the fossa. The GH joint capsule is joined by the superior, middle, and inferior GH ligaments on the anterior side, and the coracohumeral ligment on the superior side. Although joint displacements can occur in the anterior, posterior, and inferior directions, the strong coracohumeral ligament protects against superior dislocations. The inferior glenohumeral ligament is the thickest of the ligaments and reinforces the inferior capsule. It is the main static stabilizer in the abducted arm.

The tendons of four muscles, including the supraspinatus, infraspinatus, teres minor, and subscapularis also join the joint capsule. These muscles, more commonly referred to as the rotator cuff muscles, because they act to rotate the humerus, and their tendons merge to form a collagenous cuff around the joint. Tension in the rotator cuff muscles help to hold the head of the humerus against the glenoid fossa, further supplying stability to the joint. The joint is most unstable in its close-packed position when the humerus is abducted and externally rotated (Anderson et al., 2009).

2.4.1.5 Scapulothoracic Joint

The scapulothoracic joint is described as the region where muscles attaching to the scapula permit its motion with respect to the trunk or thorax. Muscles attaching to the scapula comprise the levator scapula, rhomboids, serratus anterior, pectoralis minor, subclavius, deltoid, subscapularis, supraspinatus, infraspinatus, teres major, teres minor, coracobrachialis, the short head of the bicep brachii, the long head of triceps brachii, and the trapezius.

The scapula muscles perform two functions. The first is stabilization of the shoulder region. The second function is to facilitate movement of the upper extremity through appropriate positioning of the glenohumeral joint. For example, throughout the action of an overhand throw, the rhomboids contract to move the entire shoulder posteriorly as the arm and hand move backward during the preparatory phase. As the arm and hand then move forward to execute the throw, tension in the rhomboids is released to permit forward movement of the shoulder, enabling medial rotation of the humerus to occur (Anderson et al., 2009).

2.5 Shoulder Ligaments
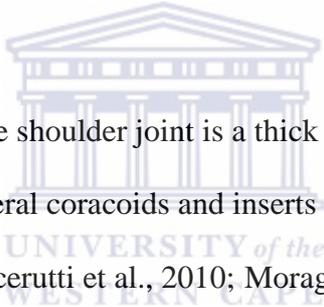
The coracohumeral ligament in the shoulder joint is a thick band of capsular tissue which originates from the base of the lateral coracoids and inserts into the lesser and greater tuberosities (Arai et al., 2010; Precerutti et al., 2010; Morag et al., 2012). The coracohumeral ligament is taut with the arm in the adducted position and inhibits the humeral head on the glenoid fossa (Petchprapa et al., 2010; Villasenor-Ovies et al., 2012).

The glenohumeral ligament has three parts: superior, middle and inferior ligaments. The superior glenohumeral ligament extends from the upper part of the glenohumeral labrum and crosses the superior aspect of the humeral neck. It parallels the course of the coracohumeral ligament, and these two structures in the shoulder are considered similar in function. Both ligaments constitute the rotator interval region between the anterior border of the supraspinatus and the superior border of the subscapularis (Terry and Chopp, 2000).

The middle glenohumeral ligament is the most variable of the three glenohumeral ligaments, being absent in 8% to 30% of patients. It derives from the supraglenoid tubercle, superior labrum, or scapular neck and inserts on the medial aspect of the lesser tuberosity. Its function is to restrain anterior translation of the humeral head in the lower ranges of abduction (60° to 90°) and inferior translation in the adducted position at the side (Terry & Chopp, 2000)

The inferior glenohumeral ligament is the thickest and most consistent of the three glenohumeral ligaments. It is often described as a complex, containing an anterior band, an axillary pouch, and a posterior band. The anterior band extends from the anteroinferior labrum and glenoid lip to the lesser tuberosity of the humerus and is the thickest portion and the primary stabilizer against anterior translation of the humeral head in the throwing position of abduction and external rotation (Terry & Chopp, 2000).
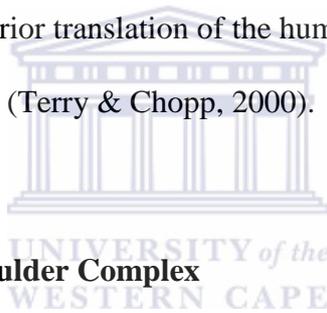
2.6 Muscles Involved in the Shoulder Complex

2.6.1 Rotator Cuff

Four of the scapulohumeral muscles (intrinsic muscles of the shoulder), the suprasinatus, infraspinatus, teres minor and subscapularis (referred to as SITS muscles), are also termed the rotator cuff muscles, because they form a muscluotendinous rotator cuff around the glenohumeral joint. Excluding the supraspinatus, all are rotators of the humerus. The supraspinatus, besides being part of the rotator cuff, initiates and aids the deltoid in the first 15^0 of abduction of the arm. The tendons of the four rotator cuff muscles blend with the articular capsule of the glenohumeral joint, reinforcing it as the rotator cuff, which secures the joint and gives it stability, with their tonic contraction holding the relatively large head of

the humerus in the small, shallow glenoid cavity of the scapula during arm movements (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.2 Supraspinatus

The supraspinatus occupies the supraspinatus fossa of the scapula. A bursa separates it from the lateral fourth of the muscle. The insertion is the superior facet on the greater tubercle of the humerus. The action of the supraspinatus is to initiate and assist the deltoid in abduction of the arm and rotates the humerus laterally (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.3 Infraspinatus
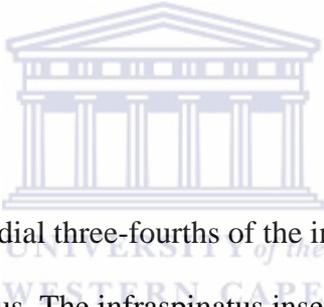
The infraspinatus occupies the medial three-fourths of the infraspinatus fossa and is partly covered by the deltoid and trapezius. The infraspinatus inserts in the middle facet on the greater tubercle of the humerus. In addition to helping to stabilize the shoulder joint, it aids to hold the humeral head in the glenoid cavity of the scapula. The infraspinatus is a powerful lateral rotator of the humerus (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.4 Teres Minor

The teres minor is a thin, elongated muscle that is completely hidden by the deltoid and is often not clearly delineated from the infraspinatus. The origin of the teres minor is the superior part of lateral border of the scapula with the insertion on the inferior facet of the

greater tubercle of the humerus. The teres minor rotates the arm and assists in its adduction (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.5 Subscapularis

The subscapularis is a broad triangular muscle that lies on the subscapular fossa. The scapula forms part of the posterior wall of the axilla, where its insertion is on the lesser tubercle of the humerus. It crosses the anterior aspect of the scapulohumeral joint on its way to the humerus. The subscapularis is the prime medial rotator of the arm and also adducts it. It also joins the other rotator cuff muscles (supraspinatus, infraspinatus and teres minor) in holding the head of the humerus in the glenoid cavity during all movements of the scapulohumeral joint (i.e., it helps stabilize the joint during movements of the elbow, wrist and hand) (Franklyn-Miller et al., 2010; Moore et al., 2013).
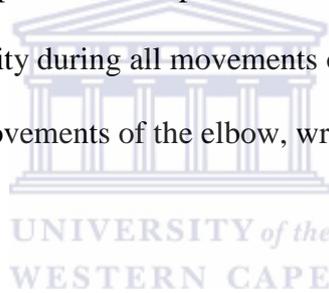
2.6.6 Coracobrachialis

The coracobrachialis helps to flex and abduct the arm and stabilize the glenohumeral joint. The proximal attachment of the coracobrachialis is the coracoid process of the scapula and the distal attachment of the medial anterior humerus. The coracobrachialis derives from the apex of the coracoid process, the same as the short head of the bicep brachii, and from the intermuscular septum between the two muscles, and inserts as a flat tendon between the triceps brachii and brachialis on the medial aspect of the shaft of the humerus. The coracobrachialis acts to flex and adduct the shoulder (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.7 Biceps Brachii

As its name suggests, the bicep brachii's proximal attachment has two heads. The origin of the long head is the supraglenoid tubercle of the glenoid fossa. The short head is the coracoid process of the scapula. The bellies of the two muscles unite on the distal attachment of the radial tuberosity of the humerus.

The two heads (long and short) both arise in and around the shoulder. The short head derives from the coracoid process of the scapula. The long head arises from the supraglenoid tubercle, with considerable anatomical variation described in its relationship with the glenoid labrum. The tendon is intra-articular, but extra-synovial (it lies within a reflection of the synovial sheath). As the tendon passes the joint, through the rotator interval and into the bicipital groove, it is stabilized proximally by the "biceps pulley" mechanism, composed of the coracohumeral ligament and superior glenohumeral ligament. Reinforcing fibres from the subscapularis and supraspinatus tendons surround the biceps tendon at its entrance to the bicipital groove.

The scapula origin of the biceps helps it stabilize the glenohumeral joint, depressing the humeral head when the arm is internally rotated. The short head is a weak adductor and, when the arm is externally rotated, the long head aids in adduction, while both heads contribute to flexion (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.8 Tricep Brachii

This large fusiform muscle is positioned in the posterior compartment of the arm. As suggested by the name, the triceps has three heads: long, lateral and medial. The proximal attachment of the long head is the infraglenoid tubercle of the scapula. The lateral head proximal attachment is the posterior surface of the humerus, superior to the radial groove. And the medial head proximal attachment is the posterior surface of humerus, inferior to the radial groove. The distal attachment of each is the proximal end of the olecranon of the ulna and fascia of the forearm. The triceps extends the elbow, also acting as an antagonist of the biceps and brachialis muscles. The triceps accounts for approximately 60% of the upper arm mass (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.9 Deltoid

The deltoid is the most obvious muscle of the shoulder. It derives from the anterior border of the lateral third of the clavicle, the lateral border of the acromion, and the lower lip of the scapula spine, as well as from the fascia over the infraspinatus muscle. The muscle's proximal attachment is the outer third of the clavicle, top of the acromion, and scapula spine. The distal attachment of the deltoid is the deltoid tuberosity of the humerus.

The deltoid is a powerful abductor of the shoulder (a motion which is commenced by the supraspinatus), while the posterior bundle of the deltoid is an extensor of the shoulder. The deltoid muscle is multipennate. Tendinous septa arising from the acromion and the deltoid

tuberosity interdigitate, with short muscle fibres extending between the septa. This gives the muscle a short, but powerful pull (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.10 Trapezius

The trapezius, which is divided into three parts, has distinct actions at the scapulothoracic joint between the scapula and the thoracic wall. The superior fibres elevate the scapula, the middle fibres retract the scapula, and the inferior fibres depress the scapula and lower the shoulder. The trapezius is a triangular muscle, with the occipital bone superior nuchal line at the base of the triangle and the ligamentum nuchae and the supraspinous ligaments to the twelfth throacic vertebrae serving as the origin of the trapezius. This muscle is situated along the vertebral column, and the apex is at the insertion of the lateral third of the clavicle, acromion, and the spine of the scapula. The trapezius also braces the shoulder by pulling the scapulae posteriorly and superiorly, fixing them in position on the thoracic wall with tonic contractions. The superior and inferior trapezius fibres act together in rotating the scapula on the thoracic wall (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.11 Levator Scapulae

The origin of the levator scapulae is the posterior tubercles of transverse processes of the first to the fourth cervical vertebrae. The levator scapulae inserts in the superior part of the medial border or scapula. The superior third of the strap-like levator scapulae lies deep to the sternocleidomastoid, and the inferior third is deep to the trapezius. From the transverse processes of the upper cervical vertebrae, the fibres of the levator scapulae pass inferiorly to

the superomedial border of the scapula. The levator scapulae elevates and rotates the scapula, depressing the glenoid cavity, as well as retracts the scapula and fixes it against the trunk, and flexes the neck laterally (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.12 Pectoral Major

The pectoral major is the most prominent muscle of the chest wall, deriving from the anterior surface of the sternal half of the clavicle, from the anterior surface of the sternum, the cartilages of the upper six ribs, and the aponeurosis of the abdominal external oblique muscle. The muscle fibres are divided into superficial and deep laminae. The lower fibres of the deep lamina insert higher up on the humerus, giving the appearance to the anterior border of the axilla. The upper insertions of the posterior lamina may contribute to the transverse humeral ligament. The sternal head medially rotates the humerus, and draws the scapula anteriorly and inferiorly. The clavicular head aids in flexion and adduction of the humerus (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.13 Pectoral Minor

The pectoral minor is confined in the anterior wall if the axilla, where it is largely enclosed by the much larger pectoralis major. The pectoral minor is triangular in shape which originates on the third to the fifth rib near the costal cartilage and inserts on the medial border and superior surface of coracoid process of the scapula. The muscle stabilizes the scapula by drawing it inferiorly and anteriorly against the thoracic wall (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.14 Serratus Anterior

The serratus anterior forms the medial wall of the axilla, along with the upper five ribs. It is a large muscle composed of a series of finger-like slips. The lower slips interdigitate with the origin of the external oblique. The muscle originates on the outer surfaces and superior borders of the upper eight or nine ribs and the fascia covering their intercostal space.

The muscle inserts into the entire length of the anterior aspect of the medial border of the scapula and inferior border angle of the scapula. It serves to protract the scapula and hold it against the thoracic wall. The serratus anterior aids in rotation of the scapula for abduction and flexion of the arm (Franklyn-Miller et al., 2010; Jarmey, 2013; Moore et al., 2013).
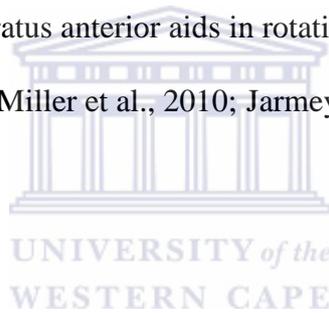
2.6.15 Teres Major

The teres major is a flattened scapulohumeral muscle originating from the dorsal surface of the inferior angle of the scapula, and from the fibrous septa which is found between the teres minor and infraspintaus. The teres major muscle inserts in the medial lip of the intertubercular sulcus (bicipital groove) of the humerus. The muscle aids in adduction and medial rotation of the arm (Franklyn-Miller et al., 2010; Jarmey, 2013; Moore et al., 2013).

2.6.16 Latissimus Dorsi

This broad, fan-shaped muscle passes from the trunk to the humerus and acts exactly on the glenohumeral joint. The muscle arises from the spinous processes of the inferior six thoracic vertebrae, the thoracolumbar fascia, the iliac crest and inferior three or four ribs, and the insertion is the floor of the intertubercular groove of the humerus. The muscle aids with extension and adduction, and medial rotation of the humerus (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.6.17 Rhomboids
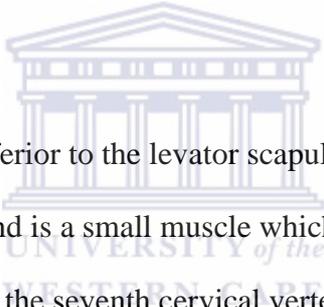
The two rhomboid muscles are inferior to the levator scapulae. The rhomboid minor is superior to the rhomboid major, and is a small muscle which originates from the nuchal ligament and spinous processes of the seventh cervical vertebrae and the first thoracic vertebrae. The large muscle arises from the spinous processes of the second to the fifth thoracic vertebrae. Both insert into the medial border of the scapula from the level of the spine to the inferior angle. Both muscles aid in retraction of the scapula towards the vertebral column (Franklyn-Miller et al., 2010; Moore et al., 2013).

2.7 Kinematics and Major Muscle Actions of the Shoulder Complex

The shoulder joint is the most freely movable joint in the body, with motion in all three planes, sagittal, frontal and transverse. In the sagittal plane, movements of the shoulder include shoulder flexion, extension and hyperextension. In the frontal plane, movements of

the shoulder include shoulder adduction and abduction. And in the transverse plane, movements include horizontal adduction and horizontal abduction. The humerus rotates medially and laterally. The scapula function is important to throwers. It serves as a stabilising base for glenohumeral articulation rapidly rotating the humerus and keeping the glenoid in position for the movement of the humeral head, which reduces stress on the shoulder capsule during the throwing action (Anderson et al., 2009).

2.8 Throwing

2.8.1 Throwing Performance
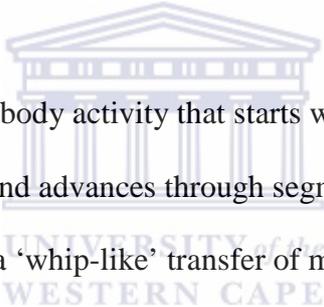
The action of throwing is a whole body activity that starts with a drive from the large leg muscles and rotation of the hips, and advances through segmental rotation of the trunk and shoulder girdle. It continues with a 'whip-like' transfer of momentum through elbow extension and through the small muscles of the forearm and hand, transferring propulsive force to the ball. This action results in a summated velocity at the end of the kinetic chain of the distal segment. The objective of throwing in cricket is to use the velocity of the ball to improve the success of the delivery (Kibler, 1998).

Although throwing kinematics and kinetics have been well documented in various studies, it is equally important to understand what amounts to good throwing performance (Linthorne and Everett, 2006). It is well accepted that good throwing performance has properties of greater distance, accuracy and higher velocity (Linthorne & Everett, 2006). The distance covered in turn has a strong relationship with speed, angle of the throw and height of release

(Linthorne & Everett, 2006). This release characteristic is altered by each athlete's skill during the throwing procedure (Linthorne & Everett, 2006). Effective technique maximizes the speed of release and optimizes the angle and height of release (Linthorne & Everett, 2006; Leigh & Yu, 2007).

The distance of a throw may be improved by launching the ball with a fast backspin, however, the ball must be launched at a slightly lower release angle (Linthorne & Everett, 2006). Throwing speed has been measured by many researchers using a radar gun which can be hand-held or fixed depending upon the type of measurements involved (Zapartidis et al., 2009; Alcaraz et al., 2011; Platanou & Varamenti , 2011; Zinner et al., 2015). It has been shown to be a reliable technique with an interclass correlation of 0.88 to 0.96 between repeated measurements using the same subjects (Van den Tillaar & Marques, 2013). It is evident that throwing speed is an important measure that has been used in the past as an objective tool to measure throwing performance (Van den Tillaar & Marques, 2013).

2.8.2 General Stages of the Throwing Action

It is essential to appreciate the actions that take place within the shoulder during a throw. This is a summated action of many muscles that are involved. The dynamics of the throwing motion calls for the athlete to have a sufficient range of motion, strength, endurance and neuromuscular control to dissipate the stresses placed on the body.

26

During throwing, neuromuscular timing of contractions occur through specific coordinated links for concentric and eccentric muscle actions. The series of actions cause the transfer of force, derived from the lower extremities and trunk, to the throwing arm, and through the shoulder and elbow, and ultimately to the ball at release (Reinoid et al., 2000). The throwing motion may be separated into four distinct phases, namely, the wind-up phase, the cocking phase, the acceleration phase, and the follow-through phase (Houghman, 2010).

2.8.2.1. Wind- up Phase

The wind up phase establishes the rhythm of the throw. In this phase, the muscles initially fire at low intensity. The wind-up begins from the initiation of movement. The intention of the phase is to position the body in a way to facilitate the rest of the throw. As such, there is large individual disparity in the kinematic pattern and velocity of movement during the wind up to accommodate differing throwing styles (Kibler, 1998).

During this phase, muscle activity of the rotator cuff is inactive. There is no constant pattern of muscle activation found in this stage of the throwing motion. When the shoulder is fully elevated, activity increases (Jobe et al, 1983). In this phase, athletes must use their momentum to assist in the acceleration of the ball. Muscles contract more forcefully when they are first put into a stretched position, without being overstretched. This stretch-shortening principle is suggested as the reason for the winding-up phase of initial movements before the ball is thrown (Kibler et al., 1998; Houghman, 2010).

2. 8.2.2 Cocking Phase

The second phase known as the cocking phase is often divided into early and late phases. These two phases, combined, account for nearly 80% of the time required for throwing, which equals 1500 milliseconds. The cocking begins when the hands separate, and ends when abduction and maximum lateral rotation of the shoulder is achieved (Pappas et al., 1985). The cocking movement positions the body to enable all body segments to contribute to ball release. During early cocking, the trunk rotates toward the side of the throwing arm and the lead leg positions the body toward the target. The scapula is retracted and the humerus is abducted, laterally rotated, and horizontally extended and then moves into maximal external rotation. The elbow then flexes which leads to the striding leg extending the knee. During this phase, the hip extends, abducts and medially rotates with plantar flexion at the ankle (Braatz and Gogia, 1987). The non-throwing shoulder is abducted and its elbow is extended. The body's centre of gravity is dropped, because the support knee and hip are flexing, and the hips and pelvis begin to rotate forward. The late cocking phase begins when the stride foot hits the ground (Jobe et al., 1984). At the moment of foot contact, both arms are elevated about 90° and in line with each other along the plane of the shoulders. There is stress in front of the GH joint which occurs at this point in the late cocking phase with the body in front of the arm.

As the phase terminates, the shoulder medially rotates and is maximally stretched, the shoulder is "loaded" with the anterior capsule coiled tightly in the apprehension position storing elastic energy, and the pelvis leads the shoulders to face the target, and the legs and trunk begin their acceleration for energy transfer to the arm. Right before the end of this

phase, the body laterally tilts to the non-throwing arm side. Shoulder rotation to the target and lateral trunk motion are facilitated by the non-throwing arm's motion from a position of abduction at the start of the late cocking to adduction and extension at the end (Braatz & Gogia, 1987; Houghman, 2010).

2.8.2.3. Acceleration Phase

The acceleration phase begins with maximal lateral shoulder rotation and abduction, and finishes when the ball leaves the fingers (Jobe et al., 1984). The actions in this phase involve scapular protraction, humeral horizontal flexion and medial rotation, and elbow extension. Immediately before ball release, the shoulder remains at about 90° of abduction. The glenohumeral joint's capsule is loaded tight to provide an elastic force release and the accelerator muscles are also maximally stretched (Perry, 1983). During the acceleration phase, the speed of the arm has increased significantly beginning from almost $0°\bullet sec^{-1}$ at the end of cocking to $7500°\bullet sec^{-1}$ by the end of acceleration, in a time of 50 msec (Pappas et al., 1985: Houghman, 2010).

2.8.2.4. Follow-Through Phase

The follow-through phase happens from the point of ball release to completion of the movement when the support leg moves forward and contacts the ground to stop forward body motion (Jobe et al, 1983). This phase is separated into early and late follow-through according to the point of maximal shoulder medial rotation. The early follow-through phase is completed swiftly, in less than 0.1 s (Jobe et al, 1983). Trunk rotation and scapula motions

occur and are diminished to a changeable amount, depending on the individual thrower. A few forces produced during acceleration are absorbed by the stride leg. The stride leg is stationed during acceleration and the flexed knee position absorbs some of the forces (Braatz & Gogia, 1987). Following the release of the ball, the throwing arm progresses to move across the body towards the opposite hip, with the scapula continuing to protract. This cross-body motion assists to minimize irritation to the rotator cuff, subsequently the scapula motion keeps the coracoacromial arch structures from impinging on the rotator cuff (Braatz & Gogia, 1987; Houghman, 2010).

2.9 Muscles Involved in Throwing
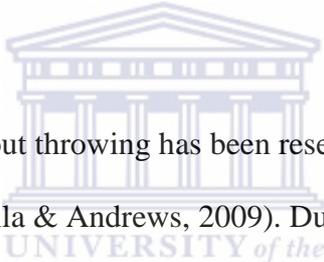
Shoulder muscle activity throughout throwing has been researched extensively by various authors (Jobe et al., 1984; Escamilla & Andrews, 2009). During the process of throwing, the first stage of the movement, known as the wind up phase, where the lead leg drives forward and both arms are abducted. The throwing arm externally rotates and the four rotator cuff muscles fire to hold the head of the humerus within the glenoid fossa. The scapula rotates upward as the head of the humerus is seated within the glenoid fossa. The supraspinatus is the most active of the rotator cuff muscles during the wind up phase (Jobe et al., 1984). There is a greater activation from the upper trapezius, serratus anterior and anterior deltoid in the stage. These muscles all contract concentrically to upwardly rotate and elevate the scapula and abduct the shoulder as the arm is initially brought overhead, and then contract eccentrically to control the downward scapula rotation and shoulder adduction, as the hands are lowered to approximately chest level. The rotator cuff muscles, which have a dual function as gleno-humeral joint compressors and rotators, have their lowest activity during

30

this phase. Because shoulder activity is low, it is not surprising that the shoulder forces and torques generated are also low (Fleisig et al., 1995).

The deltoid is strongly active throughout early cocking. When maximum shoulder lateral rotation and abduction to at least 90° occurs, the static stabilizers of the shoulder, the glenohumeral capsule and ligaments, serve to limit further movement. Active stabilizers, consist of the forward flexors, lateral rotators, the subscapularis, pectoralis major, and latissimus dorsi, which act as additional restraints to control movement. Scapula stabilizers, such as the pectoralis minor and serratus anterior, are also active in late cocking. The inhibition of the other rotator cuff muscles, the teres minor, supraspinatus, and infraspinatus, also take place as these muscles attempt to resist the superior subluxating forces that occur when the trunk is in a forward lean position and the shoulder is maximally rotated laterally (Jobe et al., 1984). At the end of late cocking, the lumbar spine hyperextends to include the shoulder's lateral rotation (Braatz & Gogia, 1987). The supraspinatus and infraspinatus are particularly active in late cocking.

During the acceleration phase, the serratus anterior and pectoralis major are strongly active, as the arm moves forward and the scapula protracts (Jobe et al., 1984). The subscapularis and latissimus dorsi contract concentrically as the arm moves into medial rotation during acceleration (Jobe et al., 1984). The glenohumeral internal rotators (subscapularis, pectoralis major and latissimus dorsi) have their highest activity during this phase, as they contract concentrically to help generate a peak internal rotation angular velocity of approximately $6500°•sec^{-1}$ near ball release (Escamilla et al., 2007). This rapid internal rotation, with a range of motion of approximately 80° from maximum external rotation to ball release, occurs in only 30–50 milliseconds (Escamilla et al., 1998). The very high activity from the

subscapularis occurs in part to help generate this rapid motion, but it also functions as a steering muscle to maintain the humeral head in the glenoid. The teres minor, infraspinatus and supraspinatus also demonstrate moderate to high activity during this phase to help properly position the humeral head within the glenoid.

In the follow-through phase, the deltoid is intensely active during the early follow-through (Jobe et al., 1984). The rotator cuff, particularly the lateral rotators, must decelerate the arm after ball release, and work against the distraction forces occurring at the shoulder. The biceps also work at high levels eccentrically to reduce the distraction forces at the elbow (Jobe et al., 1984).

2.10 Biomechanics of the Scapula in Throwing

In normal biomechanics of the scapula in throwing, the movement is coupled with coordination between the scapula and humerus, often termed scapulohumeral rhythm, for efficient arm movement and allows for glenohumeral alignment in order to maximize joint stability (Kibler et al., 2013). The scapula rhythm ratio is a two-to-one (2:1) relationship between glenohumeral elevation and scapula upward rotation. In a study by McClure et al. (2001), a relevant analysis of scapula motion has been conducted in numerous three dimensional studies. The study explored the use of surface markers and indwelling bone pins (Paine & Voight, 2013). The study found that during scapular plane elevation of the arm in normal subjects, there was a consistent pattern of scapula upward rotation, posterior tilting, and external rotation along with clavicular elevation and retraction (Paine & Voight, 2013). Scapula upward rotation is the predominant scapulothoracic motion.

2.11 Stability

2.11.1 Glenohumeral Stability

Stability of the glenohumeral joint is provided by the articulating surfaces, capsular and ligamentous structures, and synchronous activity of the rotator cuff, biceps, deltoid, and scapula muscles. Four structures are considered to be the main factors in stability of the shoulder articular surfaces, labrum, capsuloligamentous complex, and rotator cuff. The glenohumeral joint relies on the static and dynamic aid of the soft tissues to maintain joint stability. The dynamic stabilizers consist of the rotator cuff muscles (supraspinatus, subscapularis, infraspinatus and teres minor), whereas the static stabilizers include the glenoid labrum and associated capsuloligamentous components (Moore et al., 2013).
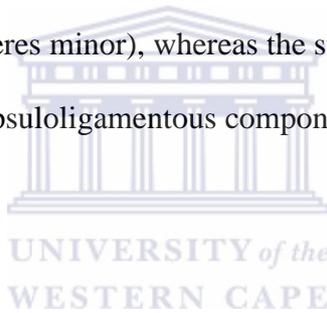
2.11.2 Dynamic Stability

The dynamic stability of the glenohumeral joint is the fourth line of defense against shoulder instability. The musculotendinous units surrounding the glenohumeral joint assist the static restraints in stabilizing responsibilities, while providing the power for motion.

Under normal circumstances, forces transmitted by the supraspinatus, infraspinatus, teres minor, and subscapularis provide significant stability to the glenohumeral joint. This is achieved in several ways: contraction of these muscles centralizes the humeral head in the glenoid by increasing the compressive forces. The tension developed across the cuff tendons during a contraction, squeezes the humeral head preventing anterior and posterior displacement. Passive tension of the tendons provides some stability (Graichen et al., 2000).

2.12 Measurement of Shoulder Muscle Function

Muscle function in athletes can be measured by a variety of methods such as isotonic, isokinetic and isometric testing procedures. Also the type of muscle activity (concentric, eccentric, or isometric) and the velocity may differ in testing. An isokinetic evaluation is a form of muscle testing to determine the strength of a given muscle or muscle group.

In this procedure, the angular velocity of the bony component is preset and kept constant by a mechanical device throughout the joint range of motion. This form of exercise has been thought to be a valuable tool for assessment and evaluation of muscular function and pathology. Extensive work has been done by various researchers on measurement of shoulder rotator muscles, specifically external and internal rotator strength in various forms of sport (Juneja et al., 2011). Various researcher's used isokinetic strength measurements to study performance, stability, injury patterns and strength differences between dominant and non-dominant upper extremities (Stickley et al., 2008; Andrade et al., 2010; Pontaga & Ziden, 2014).

There are exceptions in the strength testing procedures of the rotator muscles with regard to the position of the shoulder, test speeds and modes of contraction (Edouard et al., 2011; Forthomme et al., 2011).

Most research on shoulder strength in overhead athletes has been done using isokinetic type muscle work in the concentric and eccentric mode (Ellenbecker et al., 1988; Noffal, 2003). The reason is that isokinetic measurements allow high reproducibility and measurements at

high speeds with accommodating resistance, which was thought of as having more relevance to function (Caruso et al., 2012).

2.13 Role of Strength in Throwing

Throwing, which is considered as a highly coordinated neuromuscular activity, can be highly variable if strength has a role to play. Many research reports indicate that the strength of muscles play an important role, even in highly skilled coordinated techniques (Wilk et al., 1993; Bayios et al., 2001; Marques et al., 2007).

Gorostiaga et al. (2005) and Van den Tillaar and Ettema (2007) accounted for three factors which are crucial with respect to effectiveness of throwing: (1) mechanics, (2) coordination of consecutive actions of body segments and (3) upper and lower extremity muscle strength and power. It can be argued that maximum strength is the basic quality that affects power output.

Toyoshima et al. (1974), Pedegana et al. (1982) and Bartlett et al. (1989) have shown that increasing dynamic muscle strength in the upper limb will increase the throwing velocity. Furthermore, the shoulder muscles in concentric adduction, wrist and elbow extension was shown to significantly predict throwing velocity in adult players. Toyoshima (1974) also found that 53.1 % of throwing speed can be attributed to upper limb involvement.

Clements et al. (2001a) in their review on muscle strength and its relationship with throwing speed in baseball players, reported that elbow extensor and shoulder internal rotation strength have a large influence on throwing speed (Cook, 2010). Therefore, potential strength training

for elbow extension and shoulder internal rotation muscle groups is recommended in adolescent players, without neglecting the antagonist muscle groups. They also reported that weakness in these muscles should be taken care of in the rehabilitation of these athletes. Marques et al. (2007) explored the relationship between ball throwing velocity during a three step running throw and dynamic strength, power, and bar velocity during a concentric-only bench-press exercise in team handball players. Participants power and bar velocity was measured during a concentric-only bench-press test, as well as one repetition maximum bench-press strength. Throwing velocity was assessed with a standard three step running throw using a radar gun. The results of this study showed that throwing velocity of elite team handball players is related to maximal dynamic strength, peak power, and peak bar velocity. Therefore, a training routine that is resigned to improve ball throwing velocity in elite male team handball players should include exercises that are aimed at increasing both strength and power in the upper body.

2.14 Isokinetic Testing

The isokinetic assessment provides useful evidence that can be used to diagnose weaknesses, imbalance and to quantify strength in muscular function (Davies et al., 2000). Isokinetic testing provides objective data to determine agonist and antagonist muscular strength around the glenohumeral joint (Cools et al., 2007). Isokinetic testing has shown to be a good indicator of shoulder internal and external rotator strength.

2.15 Isokinetic Muscular Strength of the Shoulder Complex.

In overhead sports, it is essential for the competitor to have an appropriate functional relationship between the internal and external rotators. The ratio between the internal and the external rotators is essential so that optimal functioning may take place without injury. One of the methods of measuring muscular torque is isokinetic dynamometry. Isokinetic strength assessment of the shoulder internal (IR) and external rotator (ER) muscles is often used by clinicians to objectively assess muscle performance and to guide diagnosis and rehabilitation (Edouard et al., 2013). Isokinetic dynamometers make it possible to evaluate muscle strength in the concentric (con) or eccentric (ecc) mode, across a broad range of speeds, and can be used to assess the agonist–antagonist strength balance as well (Edouard et al., 2013).
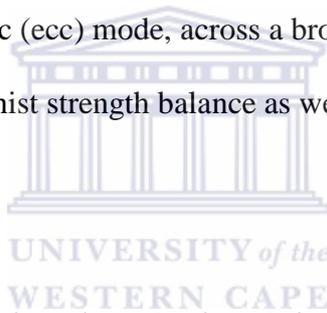
Agonist–antagonist strength ratios have been used to evaluate muscular balance during movement, specifically in sport, and have been used to identify possible risk factors for shoulder pathologies (Edouard et al., 2009). In addition to the agonist–antagonist ratios, bilateral strength asymmetry ratios of both internal rotator (IR) and external rotator (ER) muscles are used in sport medicine to quantify the functional deficits resulting from shoulder injury and or surgery, and to decide whether the athlete is ready to compete again (Stickley et al., 2008).

A study by Cools et al. (2002) has shown the relevance of the coordinated and synchronized action of the muscle groups that comprise the shoulder joint, as well as the importance of the

balanced relationship of the shoulder cuff muscles strength throughout the range of motion. Slight power imbalances in the relationship between the shoulder internal (IR) and external rotators (ER) may lead to joint dysfunction, and cause injury and prolong functional inactivity (MacDermid et al., 2004).

Dominant ratios or unilateral ratios, defined as the proportion between concentric strength values of the external rotators (ER) and internal rotators (IR), are used to describe the relationship between the muscle groups of the shoulder rotators, which characterize the quality of the muscle balance. The reliability of isokinetic assessment is fundamental in order to track small, but clinically relevant, changes.

2.16 Throwing Velocity of Cricketer Players

Overhead throwing is a skill commonly performed in cricket and is an efficient throwing skill, compared to the sidearm and underarm throw, when maximum velocity is required. A successful throw in cricket depends on the implement velocity and accuracy. Velocity and accuracy are two fundamental factors for the success of throwing performance (Van den Tillaar & Ettema, 2003). Throwing velocity depends essentially on four factors: (a) throwing technique, (b) temporal coordination of the actions of the different body segments, (c) the muscle strength and (d) power of the arms and legs (Van Muijen et al., 1991). The importance of the last two factors indicates the relevance in evaluating them.

Freeston et al. (2007) examined the throwing performance of 110 cricket players from six different populations, and found that sex, training volume (training time per week), and to a lesser extent training experience (training years) have a significant influence on maximal throwing velocity in cricketers. The results indicate that sex, playing experience, and training volume (muscle strength) may all contribute to throwing performance in cricket players.

2.17 Relationship Between Isokinetic Muscular Strength of the Shoulder Complex and Throwing Velocity

A study by Clements et al. (2001a) involving adult baseball players, demonstrated that the strength of the shoulder adductors, wrist extensors and elbow extensors predicted throwing speed. Throwing requires specific muscle actions, consequently, changes in muscle strength are essential for optimal performance when pitching and throwing (Pontaga & Ziden, 2014). It has been suggested, that increasing muscle strength in the upper limb will increase throwing speed (Bartlett et al., 1989). In a previous study, all three types of muscle contraction were tested, since upper limb muscles work isometrically, concentrically and eccentrically during pitching and throwing. The muscles work to accelerate and decelerate movements and to stabilize the upper limb joints, especially the shoulder joint (Jobe et al. 1984).

The results of the study by Clements et al. (2001a) on early adolescent, elite baseball players reinforces the findings from earlier studies on adults that elbow extensor strength has a large

influence on throwing speed. In comparison to the earlier studies on adults showed that shoulder internal rotators have a large influence on throwing speed.

A study by Pontaga and Ziden (2014) compared shoulder external/internal rotator muscles' evaluating peak torques, average power and ratios in the dominant and non-dominant arms. The study looked at the relationship between shoulder rotator muscles' peak torque, average power and ball-throwing speed in handball players. The results showed a positive correlation between the isokinetic characteristics of the shoulder rotator muscles and the ball throwing speed. This showed that the contribution to the shoulder internal and external rotator muscles peak torques and average power produced is similar at high ball throwing speed. The power produced by the internal rotator muscles during concentric contractions after eccentric contractions of the external rotator muscles was significantly greater in the dominant than in the non-dominant arm.
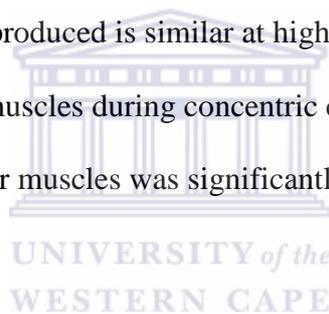
The correlation between the shoulder external rotator muscle peak torques and the ball throwing speed was higher (r = 0.69) than the correlation between the shoulder internal rotator muscle peak torques and the ball throwing speed (r = 0.61) at the fast velocity of movement ($240°•sec^{-1}$) (Pontaga & Ziden, 2014). Thus, it may be concluded that the shoulder eccentric external/concentric internal rotator muscle power ratio is significantly greater than this ratio in the concentric contractions of these muscles.

2.18 Summary of the Chapter

Several different muscles are involved in the throwing process, and they all have their distinctive role in the throwing movement, some in terms of acceleration or deceleration, while others in stabilisation. The kinetic chain plays an immensely important role in the throwing motion. This is observed in many different actions and characteristics involved in each sport. Cricket is played over a greater surface area and the ball has to travel much further and faster in the game situation. Players need to provide a powerful throw in such situations. The shoulder complex muscles are all crucial for certain functions in the shoulder, and throwing the ball optimally.
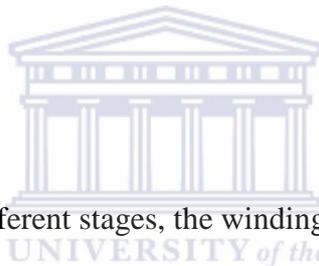
Throwing may be divided into different stages, the winding-up phase, the cocking phase, the acceleration phase, and the follow-through. All these phases have different biomechanical and functional demands that are paramount to the skill of throwing. It is of importance for sport and exercise scientists to appreciate these demands so that training is in context. The next chapter focuses on the methodological stance which was adopted in this study.

CHAPTER THREE: RESEARCH METHODS

3.1 Introduction

This chapter examines and describes the methodological approach adopted in this study. The chapter also describes the research setting of the study, followed by the study design, the sample size and participant selection, the tests performed and the methods of how the data was collected. The chapter concludes with a description of the methods used in the statistical analysis of the data and the ethical considerations.

3.2 Research Design

A cross-sectional quantitative experimental study design was used in this study. A cross-sectional sample of male cricketers was drawn from the cricket club at the University of the Western Cape for this study.

3.3 Participants

The sample group consisted of forty male cricketers whose age ranged from 18 to 32 years who were registered full-time students from the University of the Western Cape. The method of recruiting the cricketers was by convenient sampling.

The information about the study was shared, both verbally and orally, with the participants (Appendix A: Information Letter). All assessment procedures and risks involved in participation were explained to the participants. There was an opportunity for the participants to ask questions, in the possible event of participants being unsure of any aspects or needing to know more about the testing procedures. The participants agreed to all assessment requirements and procedures by giving their written consent (Appendix B: Consent Form).

3.4 Research Instruments

On the day of testing, the participants received a general purpose questionnaire (Appendix C). The participants were given a concise overview verbally of the procedures of testing, and they were guided through the questionnaire they had to complete.
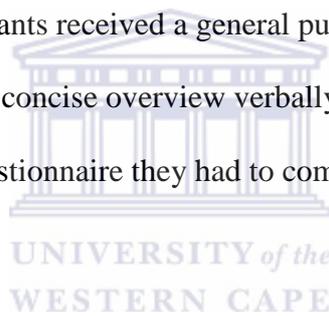
The general purpose questionnaire consisted of personal information, years of participating in cricket and the level of participation. The level of participation was used to rank the players in the various teams.

The instruments used in the research were used to assess physical profile, throwing velocity and isokinetic strength. The research instruments were as follows:

- Physical Profile

This comprised testing of stature, body mass, subcutaneous skinfold thickness, girth circumferences and limb lengths using the following anthropometric equipment: Seca

stadiometer and Seca 700 balance beam scale (Seca model 700, Gmbh & Co., Germany), Harpenden skinfold caliper (Harpenden, UK), Harpenden sliding caliper (Harpenden, UK), metal tape measure (Sanny Medical, HK) and a Harpenden anthropometer (Harpenden, UK).

- Throwing Velocity

This entailed measuring maximal throwing velocity of the dominant arm using the Bushnell velocity speed gun (Bushnell® Velocity™)

- Isokinetic Strength

Peak torque during external and internal rotation at the isokinetic angular velocity of $60^\circ \bullet sec^{-1}$ and $90^\circ \bullet sec^{-1}$ and the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60^\circ \bullet sec^{-1}$ and $90^\circ \bullet sec^{-1}$ was measured using the Biodex Pro System 4 isokinetic dynamometer (Biodex Medical Systems, Inc., Biodex Corp., Shirley, NY, USA)
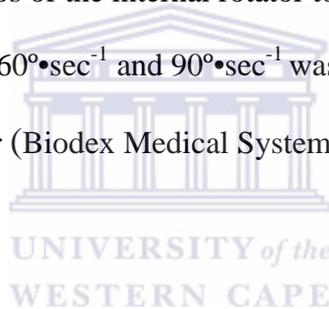
3.5 Testing Procedures

The tests were selected to determine the isokinetic muscular strength of the shoulder complex and the maximal throwing velocity of the dominant throwing arm. Each cricketer performed an isokinetic shoulder strength test, which was conducted at the University of the Western Cape's biokinetics practice, and a maximal throwing velocity test was conducted at the University of the Western Cape's cricket oval.

3.6 Physical Assessments

3.6.1   Stature

Stature (height) is defined as the perpendicular distance between the transverse plane of the vertex of the head and the inferior aspects of the feet, (Marfell-Jones, Olds, Stewart and Carter, 2006, p. 57). The stadiometer was calibrated against an anthropometric metal take measure.

Four general techniques exist for the measurement of stature: free standing, stature against the wall, stretch stature and recumbent length. For the purposes of this study, the stretch stature method was employed. The procedure is described as follows (Marfell-Jones et al., 2006).
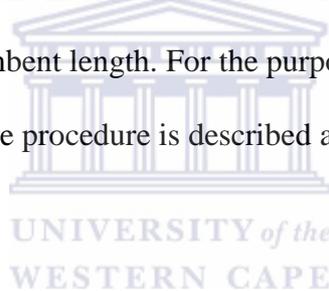
The participant was requested to remove his shoes and stand with the heels together, with the heels, buttocks and upper part of the back touching the stadiometer upright rod. The head was positioned in the Frankfort plane. The Frankfort plane was achieved when the orbitale (lower edge of the eye socket) was in the same horizontal plane as the tragion (the notch superior to the tragus of the ear). This was accomplished by placing the tips of the thumbs on each orbitale and the index fingers on each tragion, then horizontally aligning the two.

Figure 3.1: Stature measurement with a participant in the Frankfort plane.

Once the head was properly positioned, the thumbs were then repositioned posteriorly, towards the participant's ears, and far enough along the side of the jaw to ensure that upward pressure was transferred to the mastoid process. When the participant was correctly aligned, the vertex was identified as the highest point of the skull. While keeping the head in the Frankfurt plane, a gentle upward lift through the mastoid processes was applied. The participant was then instructed to take a deep breath and hold it. The head board of the anthropometer was then placed firmly down on the vertex, compressing the hair as much as possible. The measurement was taken before the participant exhaled and was measured to the nearest 0.01 cm. The average of two measures was used as the final measurement provided that the measures were within 5 mm of each other. If it was not, the standard protocol was observed. The technical error of measurement (TEM) for measuring stature was 1.0%

3.6.2 Body Mass

Body mass was measured to the nearest 50g using a beam balance scale (Seca model 700, Gmbh & Co., Germany) with a measurement range from 0 to 220 kg calibrated against standard low and high weights.

Body mass (weight) is defined as the quantity of matter in the body and is calculated through the measurement of weight (the force that matter exerts in a standard gravitational field) (Marfell-Jones et al., 2006). The scale was calibrated to ensure accuracy. This was accomplished by weighing standardised weights ranging from 0.5 to 50 kg on the scale. Adjustment of the scale was made until it was properly calibrated.

Ideally, body mass should be measured with the participant nude. However, it is accepted that the measurement be done with minimal clothing in order to produce sufficient accuracy. The measurement was carried out as follows (Marfell-Jones et al., 2006).

The participant was asked to remove all excess clothing as well as keys, cellular phones and any other objects. He then stood on the centre of the scale in minimal clothing (shorts only) without support, with the body weight evenly distributed on both feet. Using the balance beam scale, the 10 kg sliding weight indicator was firstly positioned, then the 1 kg sliding weight indicator. Once the movable beam settled voluntarily, the reading of the weight was taken. Body mass was measured to the nearest 0.1 kg. The average of two measurements was used as the final measurement, provided that the measurements were within 0.1 kg of each other. If not, additional measurements were taken until the appropriate limits were obtained. The TEM for measuring body mass 1.0%

Figure 3.2: Body mass measurement.

3.6.3 Skinfold Measurement

All skinfold measurements were taken using a calibrated Harpenden skinfold caliper to ensure accuracy. Skinfold caliper calibration was accomplished by opening the pivotal tips of the caliper jaws and placing the tips on a calibration (gauge) block. Calibration is accomplished by comparing the needle indication on the dial face to the gauge of the calibration block. If needed, adjustment of the caliper was made until it was properly calibrated.

Skinfold measurements were taken and body fat percentage determined using the three-site formula (according to Jackson and Pollock, 1985). The sites measured were the chest, triceps and subscapular skinfolds. All readings were measured on the right hand side of the participant's body in and in duplicate. Each skinfold test measurement was recorded to the nearest 0.01 mm. If measurements were not within 5% (usually 1-2 mm), they were retaken. The TEM for measuring skinfolds was 5.0%. Body fat percentage was derived from the three site formula: the chest, triceps and subscapular skinfolds (Jackson & Pollock, 1985).

Body density = 1.1125025 – 0.0008267 (Sum of three skinfolds) + 0.0000055 (sum of three skinfolds) ^{2} - 0.000244 (participant's age)

Percentage body fat (% body fat) = (495 / Body Density) – 450 (ACSM, 2010, p.68).
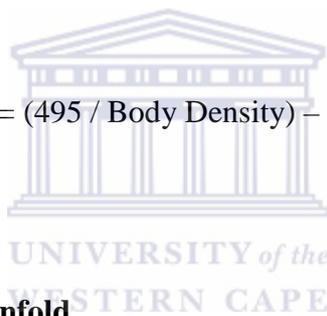
3.6.4 Measurement of Chest Skinfold

The participant assumed a relaxed standing position with the arms handing at the sides. This is a diagonal skinfold midway between the anterior axillary line and the nipple. The subject stood with the right arm relaxed (ACSM, 2010, p. 67).

3.6.5 Measurement of Triceps Skinfold

The participant assumed a relaxed standing position with the arms hanging by the sides. This is a vertical skinfold taken on the posterior midline of the upper arm. The right shoulder joint

was externally rotated slightly and the elbow held extended by the side of the body. First, the midpoint of the acromiale and radiale was measured perpendicularly to the long axis of the arm with a large sliding caliper (Holtain, UK) and marked on the lateral border of the arm with a felt pen. The triceps skinfold site was located by projecting mid-acromiale-radiale mark around to the back of the arm and intersecting the projected line with a vertical line in the middle of the arm when viewed from behind (Marfell-Jones et al., 2006, p. 67).

3.6.6 Measurement of Subscapular Skinfold

The participant assumed a relaxed standing position with the arms hanging by the sides. The undermost tip of the inferior angle of the scapula was palpated with the left thumb. If there is was difficulty locating the inferior angle of the scapula, the subject was instructed to slowly reach behind the back with the right arm. The inferior angle of the scapula could then be felt continuously, before the hand is again placed by the side of the body. A final check of the landmark should be made with the hand by the side in the relaxed position. The skinfold measurement was taken with the fold running obliquely downwards as the subscapular skinfold site. The site is 2 cm along a line running laterally and obliquely downward from the subscapulare landmark at a 45^0 angle (Marfell-Jones et al., 2006, p. 68).

3.7 Girth Measurement

The two girths or circumferences measured were the waist and hips.

3.7.1 Waist Circumference

Waist circumference (circumference of the abdomen) is defined as the narrowest point between the lower costal border (tenth rib) and the top of the iliac crest, perpendicular to the long axis of the trunk (Marfell-Jones et al., 2006, p.87).Waist circumference was measured as follows:

The participants were asked to stand in a relaxed position with the arms folded across the thorax (chest).The cross-hand technique was used for measuring and the reading was taken from the steel tape measure held at right angles to the body where the zero was located more lateral than medial on the participant. In order to position the tape measure correctly, the case was held in the right hand and the stub in the left hand. The stub was passed around and to the back of the waist and grasped in the right hand. The left hand was used to manipulate the tape to the correct level and then passed underneath the casing to grasp the stub again. The middle fingers of both hands were used to locate the tape at the landmark for measurement and to position the tape so that the zero was easily read. The participants were asked to breathe normally and the measurement was taken at the end of a normal expiration (end-tidal measurement). If there was no obvious narrowing of the waist, the measurement was taken at the mid-point between the lower costal border and the iliac crest. Measurement of the waist circumference was taken to the nearest 0.3 cm (Marfell-Jones et al., 2006, p.87). The average of two measures was used as the final measurement, provided that the measures were within 5 mm of each other. If not, then the standard protocol was observed. The TEM for measuring the circumferences was 1.0%.

3.7.2 Gluteal Circumference

The gluteal circumference is also referred to as the hip girth. This measurement is made at the level of the greatest protuberance of the gluteus maximus (buttock) muscle. Hip circumference was measured according to Marfell-Jones et al. (2006, p 88) as follows.

The participants were asked to stand in a relaxed position with the arms folded across the thorax. The participants' feet were positioned together and the gluteal muscles relaxed. The girth was taken at the level of the greatest posterior protuberance of the buttocks, which usually corresponds anteriorly to about the level of the symphysis pubis. With the tester standing on the right side of the participant s, the tape was passed around the participant's hips. The stub of the tape and the housing were then both held in the right hand, while the tester used the left hand to adjust the level of the tape to the greatest posterior protuberance of the buttocks. Measurement of the hip circumference was taken to the nearest 0.3 cm (Marfell-Jones et al., 2006, p 88). The average of two measures was used as the final measurement, provided that the measures were within 5 mm of each other. If not, then the standard protocol was observed. The TEM for measuring the circumferences was 1.0%.

3.8 Measurement of Limb Length

The purpose of this test was to measure the length of the various segments of the dominant throwing arm. The various segments measured were the acromiale-radiale length, radiale-stylion length, and the midstylion-dactylion length.

3.8.1 Acromiale-radiale Length

When measuring the acromiale-radiale length, the participant assumed a relaxed standing position with the arms hanging by the sides. The measurement was taken on the right forearm. The forearm should be pronated. The measurement represents the length. One branch of the sliding caliper was held on the acromiale, while the other branch was placed on the radiale. The caliper measurement scale should be parallel to the long axis of the arm. (Marfell-Jones et al., 2006, p.98).

3.8.2 Radiale-stylion Length

For the radiale -stylion measurement, the participant assumed a relaxed standing position with the arms hanging by the sides. This measurement was taken on the right side and represented the length of the forearm. This measurement was the distance between the radial and stylion landmarks. One sliding caliper branch was held against the radial and the other branch was placed on the stylion landmark, whereupon this distance was measured (Marfell-Jones et al., 2006, p.99). The TEM for measuring lengths was 1.0%.

3.8.3 Midstylion-dactylion Length

During the measurement of the midstylion-dactylion length, the participants assumed a relaxed standing position with the arms hanging by the sides. The right elbow was partially flexed, the forearm supinated, and the fingers extended but not hyper-extended. This measurement depicted the length of the hand, and was taken as the shortest distance from the marked midstylion line to the dactylion line. One branch of the caliper was placed on the

marked midstylion line, while the other branch was positioned on the most distal point of the third digit (Marfell-Jones et al., 2006, p.100).

3.9 Measurement of Isokinetic Shoulder Muscular Strength

The isokinetic test was done to measure the maximal muscular strength and to examine the ratio of internal and external rotator muscular strength in the dominant throwing shoulder. The Biodex dynamometer contains strain gauges and potentiometers that are capable of measuring torque in various shoulder positions (Myers et al., 2005). The Biodex isokinetic system is valid for shoulder torque measurements at speeds up to 300°•sec^{-1} and has been demonstrated to have a high degree of reliability (Drouin et al., 2004). The reliability of the testing equipment was assessed. A total of 10 participants were identified and tested. The isokinetic assessments consisted of two identical testing sessions seven days apart in order to evaluate test reliability.

Calibration of the Biodex was done for research purposes. The instrument was calibrated before and after the final performance test using the procedure suggested by the Biodex Medical System (Biodex, Corp., Shirley, NY). Verified calibration of the device was done according to the manufacturer's guidelines. Gravity correction of the torque measurements was accomplished through the Biodex software package (McCleary and Andersen, 1992).

Before the start of the isokinetic testing session, participants warmed up using an arm ergometer at a moderate intensity for approximately 5 minutes followed by static stretches (chest, shoulder and tricep stretches) which was held for 30 seconds.

The testing equipment was set up and the participants were positioned in the seated position and stabilized uniformly as described in the Biodex manual for Internal and External rotation with 45º of shoulder abduction in the scapular plane (Davies et al., 1992; Dvir, 2004;Edouard et al., 2013). The humerus was aligned with the rotational axis of the dynamometer. The elbow was supported in 90º flexion, and the forearm and wrist were in neutral pronation/supination.

Each participant received a concise explanation on what to expect when performing the isokinetic assessment. Prior to testing, the Biodex was positioned in shoulder external/ internal rotation in the modified neutral sitting position. The participant was strapped on the Biodex chair that was rotated to the neutral position (0º). The dynamometer head was rotated to 20º and tilted to 50º. The shoulder attachment was aligned with the shaft of the humerus and secured in position.

It is recommended to strap the participant's trunk and hips while testing (Wilk et al,. 1993; Ellenbecker et al,. 2000; Dvir, 2004). During the test, the chest straps were attached across the chest in a crossover position. The waist strap was applied over the upper thigh for stabilization of the trunk. This position allowed normal gravitational forces to act on the trunk and upper extremities and enhanced stabilization of the glenohumeral joint. Stabilization is important to prevent unnecessary accessory movements of the segments.

Accessory or compensatory movements may allow the subject to obtain incorrect higher torque values.

The dynamometer was raised to align it with the participant's axis of rotation. The axis of rotation refers to axis alignment which is longitudinal through the head of the humerus in a horizontal plane. If needed, the chair was raised or adjusted with a back tilt between 55-85° to accommodate the participant in term of comfort during the assessment. Each participant was tested through a 70° range of motion, composed of 30° internal rotation and 40 ° external rotation, from the reference position of the forearm held horizontal in the neutral position (0°).

The participants were assessed for both internal and external rotation at two speeds, namely, $60°•sec^{-1}$ and $90°•sec^{-1}$ for concentric/concentric shoulder contractions. Each participant was allowed three (3) sub-maximal efforts at pre-speed warm-ups, and one (1) maximal effort. This will allow the participant to get a feel for the speed of the lever arm and what it will feel like to apply submaximal and maximal effort at the various speeds.

Figure 3.3 : Isokinetic shoulder strength assessment.

3.10 Measurement of Throwing Velocity

Testing of throwing velocity was conducted at the University of the Western Cape's cricket

oval. The reliability of the testing equipment was assessed. Testing the speed gun consisted of

matching a vehicle speed against which to calibrate the speed gun. The vehicle speed was

measured by the speedometer of the vehicle. The speed gun speed reading and the speedometer readings were compared for accuracy. Before participating in the throwing velocity test, the participants performed a general warm-up routine for 5 to 10 minutes, consisting of a moderate-intensity jog around the cricket oval. This was followed by 5 to10 minutes of general stretching (static and dynamic stretches) of the major muscle groups (Upper limb stretches), and 10 to 15 minutes of progressive light-to-heavy intensity overhead throwing with a standard cricket ball. Regulation, four-piece leather cricket balls weighing 156 g were thrown into a net with no specific target.

The participants performed maximal throws from behind a marked line at a distance of 20.12m from the target. This distance is equal to the length of a standard cricket pitch. A cordless Bushnell Velocity Speed Gun was positioned behind the net, to measure maximal throwing velocity. Participants were instructed to ''throw as hard as possible towards the radar gun''. Participants performed five throws at maximal intensity with an overarm throwing technique simulating the cricket throw.

The participants were permitted one stride forward with the front leg, while maintaining the front foot behind the line until ball release. This relatively stationary starting position was adopted to minimize the influence of outside factors on throwing performance, such as approach speed, approach angle, and ball pick-up.

The highest speed measured was recorded as the participant's peak throwing velocity, and the average of the five throws as the maximal throwing velocity and mean throwing velocity (Freeston et al., 2007).
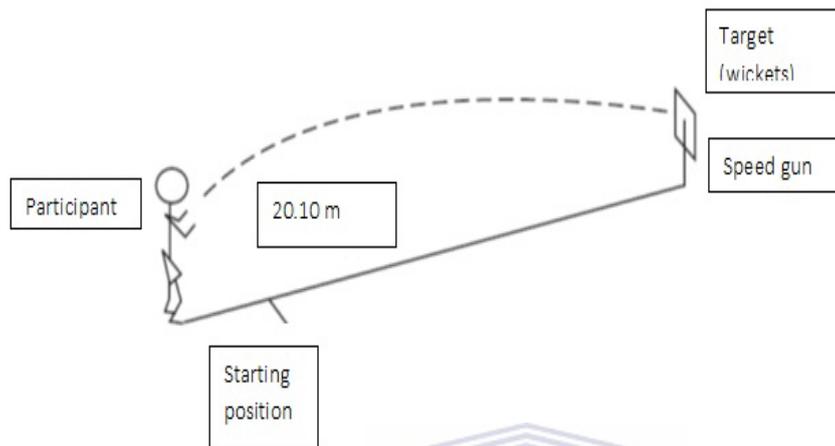
Figure 3.4: Maximal Throwing Velocity Test.

3.11 Instrument Validity and Reliability

The research instruments used to collect data in the study were the technical equipment for taking physical and performance measurements.

3.11.1 Clinical Equipment

The following clinical equipment was used, namely, a beam balance scale, stadiometer, skinfold caliper, tape measure, sliding caliper, speed gun and isokinetic dynamometer. All equipment used in the collection of research data was accurately calibrated and remained consistent throughout the study.

3.11.2 Inter-Rater (Tester) Reliability

The tester measuring the skinfolds was trained by a criterion tester according to the ISAK guidelines (Marfell-Jones et al., 2006), and the technical error of measurement (TEM) for the tester was established within acceptable limits for research. The requirements of tester accuracy with minimal error per test and consistency producing repeatable results from test to test were standardized across all measurements. The accepted anthropometric TEM for the tester was as follows (Pederson & Gore, 1996, pp. 77-95):

- Body mass 0.1 kg

- Height, 3 mm

- Skinfolds, 5%

- Girths, 3 mm

When taking skinfolds, the tester measured all measurements once, before repeating them a second or third time. This was done in order to allow the skin time to regain its normal tension and texture.

3.12 Statistical Analysis

Data was captured onto a Microsoft Office Excel spreadsheet by double entry to ensure accuracy. It was then exported to the Statistical Package for the Social Sciences (SPSS) version 22 for data analysis.

The study utilised two principle measurement variables, namely, maximal isokinetic shoulder muscular strength, maximal throwing velocity and average throwing velocity. Descriptive statistics (mean and standard deviation) and inferential statistics (Pearson product-moment correlation coefficient) and (one-way analysis of variance) were generated. Pearson correlation was conducted to assess the relationship between the two principle variables (isokinetic strength and throwing velocity). A p value of below 0.05 was considered to indicate statistical significance.
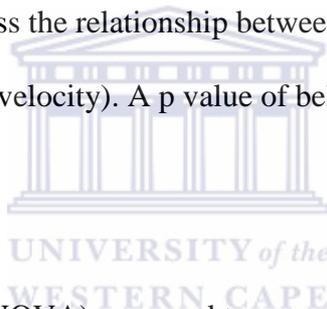
One-way analysis of variance (ANOVA) was used to examine whether there were statistically significant differences between the physical characteristics and performance variables. Where the results of the ANOVA indicated significant F-value between groups, a Tukey test was applied post hoc to determine in which groups the differences occurred.

3.13 Ethical Considerations

Ethical clearance and permission to conduct the study was granted by the Senate Research Committee of the University of the Western Cape. Permission was also granted by the management committee of the cricket team of the University of the Western Cape for the players to participate voluntarily in the study. During the recruitment phase of the study, an

information letter, including the background and purpose of the study, was given to all the cricket players and their consent to participate was requested in writing. The information letter also included the benefits and risks of the study. Participants were informed that participation in the study was voluntary and that they could refuse to perform the tests or withdraw from the tests at any stage without any negative consequences. In the instance where an injury could occur, the tester was trained with a level three (3) first aid qualification to provide emergency care.

Confidentiality and privacy were assured at all times. Each participants was allocated an identity code to protect their identity when capturing the data either on data sheets or on computer. Once the data was collected, only the researcher had access to the participant's files and database. All participant files were stored in a locked cabinet. The computer database containing the participant information was protected by a password to which only the researcher had access.
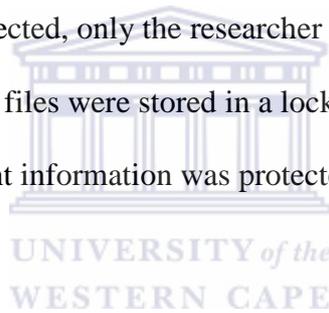
CHAPTER FOUR: RESULTS

4.1 Introduction

The purpose of this chapter is to present the results of the research. The overall aim of the research was to examine the relationship between isokinetic maximal muscular strength of the shoulder complex and maximal throwing velocity amongst club cricketers. The first objective was to measure the isokinetic muscular strength of the shoulder complex of the cricket participants. The second objective was to measure the maximal throwing velocity of the cricket participants (bowlers and fielders). And, the third objective was to determine the relationship between isokinetic muscular strength of the shoulder complex and maximal throwing velocity.
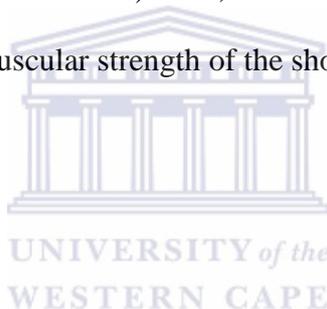
The chapter starts by presenting the descriptive statistics of the participants, namely, information from the general purpose questionnaire which included the years of participation in cricket, level of participation, age, stature, body mass (weight), lean body mass, body fat weight, body fat percentage, circumferences (waist and hip) and limb lengths (acromiale-radiale, radiale-stylion, and the midstylion-dactylion). The chapter then focuses on the results that address the objectives of the study, i.e., maximal throwing velocity, shoulder peak torque and the unilateral strength ratios at angular velocities of $60°•sec^{-1}$ and $90°•sec^{-1}$. The chapter concludes by determining the relationship between isokinetic muscular strength of the shoulder complex and maximal throwing velocity.

4.2 Physical Characteristics of the Participants

The physical characteristics of the participants comprised personal information, years of participation in cricket and the level of participation or competition. The level of player participation in cricket competition was used to rank the participants into the various teams. From the forty participants who participated in the study, ten participants were ranked into each of the four teams from first to fourth.

The results for age, stature, body mass, lean body mass, body fat mass, body fat percentage, waist circumference, hip circumference and arm limb lengths of the participants in the four teams are presented in Table 4.1 as mean ($\pm$SD), including the p values for statistical significance . The mean ages of the first, second, third and fourth team participants were 24.40 ± 2.91, 21.60 ± 2.79, 20.80 ± 3.55 and 21.50 ± 3.24 years, respectively. Even though the first team participants had a greater mean age than the other teams, none of the teams were significantly different in age ($p = 0.069$).

The mean statures of the first, second, third and fourth team participants were 1.76 ± 0.06, 1.78 ± 0.09, 1.76 ± 0.04 and 1.73 ± 0.06 m, respectively. The second team participants were the tallest, followed by the first and third teams who were of similar stature, with the fourth team being the shortest, but none were significantly different ($p = 0.508$).

In terms of the mean body masses of the first, second, third and fourth team cricket participants, the results were 78.59 ± 10.78, 72.70 ± 7.29, 76.52 ± 9.09 and 69.89 ± 9.06 kg, respectively. The first team participants were the heaviest followed by the third, second, and fourth teams, but these differences were not statistically significant ($p = 0.163$).

The mean lean body masses of the first, second, third and fourth team cricket participants were 68.26 ± 6.91, 65.81 ± 6.01, 65.62 ± 5.60 and 57.64 ± 8.99 kg, respectively. There was a statistically significant difference in lean body mass ($p = 0.009$) between the four cricket teams. The post-hoc analysis showed that the first team had a significantly higher lean body mass ($p = 0.000$) than the fourth team. Thus, the results for lean body mass showed the first team to have a significantly greater muscularity than the fourth team, with the second and third teams having a similar muscularity.

The mean body fat masses of the first, second, third and fourth team cricket participants were 10.30 ± 5.03, 6.80 ± 2.13, 10.90 ± 5.88 and 10.70 ± 5.18 kg, respectively. The third team participants had the highest body fat mass, followed by the fourth, first and second teams. A one- way analysis of variance test showed that these differences were not statistically significant ($p = 0.203$).
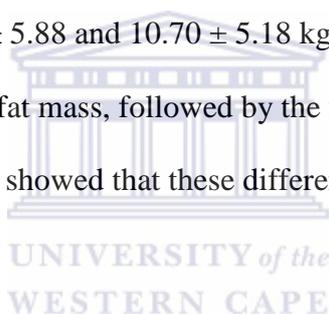
The mean body fat percentages of the first, second, third and fourth team cricket participants were 12.72 ± 4.80, 9.28 ± 2.29, 13.69 ± 6.64 and 14.28 ± 6.38 %, respectively. The fourth teams participants had the highest body fat percentage followed by the third, first and second teams. A one- way analysis of variance test showed that these differences were not statistically significant ($p = 0.171$).

The mean waist circumferences of the first, second, third and fourth team cricket participants were 82.34 ± 7.54, 81.66 ± 3.94, 82.39 ± 5.65 and 81.79 ± 5.77 cm, respectively. There were no statistically significant differences between teams ($p = 0.989$). In terms of mean hip circumferences, the first, second, third and fourth team cricket participants were 99.75 ± 8.25,

98.74 ± 4.47, 100.21 ± 5.19 and 100.52 ± 8.25 cm, respectively. Similarly, there were no statistically significant differences between teams (p = 0.940).

Segmental arm lengths were taken as physical measurements to determine if limb length contributed to throwing velocity. The mean total arm lengths displayed by the first, second, third and fourth team cricket participants were 79.52 ± 2.29, 80.14 ± 3.64, 76.59 ± 2.22 and 71.60 ± 1.77 cm, respectively. There was a statistically significant difference between the four cricket teams for arm length (p = 0.000), with the post-hoc analysis revealing that the first, second and third teams all had significantly greater arm lengths than the fourth team (p = 0.000, p = 0.000 and p = 0.001, respectively). In addition, the second team had a significantly greater arm length than the third team (p = 0.02).

The mean number of years of cricket playing experience of the participants in the first, second, third and fourth teams were 14.00 ± 3.40, 10.00 ± 1.30, 10.00 ± 2.40, and 10.00 ± 1.30 years, respectively. The participants in the first team had the longest playing experience that was significantly different compared to the participants in the other three teams (p = 0.000), each of which had a similar number of playing years.

Table 4.1: Physical characteristics of the participants per team.

Variable	First team (n = 10) (X±SD)	Second team (n = 10) (X±SD)	Third team (n = 10) (X±SD)	Fourth team (n = 10) (X±SD)	P value
Age (years)	24.40 ± 2.91	21.60 ± 2.76	20.80 ± 3.55	21.50 ± 3.24	0.069
Stature (m)	1.76 ± 0.06	1.78 ± 0.09	1.76 ± 0.04	1.73 ± 0.06	0.508
Body mass (kg)	78.59 ± 10.78	72.70 ± 7.29	76.52 ± 9.09	69.89 ± 9.06	0.163
Lean body mass (kg)	68.26 ± 6.91	65.81 ± 6.01	65.62 ± 5.60	57.46 ± 8.99	0.009*

Body fat mass (kg)	10.30 ± 5.03	6.81 ± 2.13	10.88 ± 5.88	10.67 ± 5.18	0.203
Body fat percentage (%)	12.72 ± 4.80	9.28 ± 2.29	13.69 ± 6.64	14.28 ± 6.38	0.171
Waist circumference (cm)	82.34 ± 7.54	81.66 ± 3.94	82.39 ± 5.65	81.79 ± 5.77	0.989
Hip circumference (cm)	99.75 ± 8.25	98.74 ± 4.47	100.21 ± 5.19	100.52 ± 8.25	0.940
Total arm length (cm)	79.52 ± 2.29	80.14 ± 3.64	76.59 ± 2.22	71.60 ± 1.77	0.000*
Players experience (years)	14.00 ± 3.40	10.00 ± 1.33	10.00 ± 2.40	10.00 ± 1.33	0.000*

Note:

* indicates statistically significant difference between groups (*p*< 0.05)

4.3 Performance Measurements

The results of the performance measurements of the participants per team for throwing velocity, peak torque (PT) during external (ER) and internal rotation (IR) at $60°•sec^{-1}$ and $90°•sec^{-1}$, and the strength ratios of the internal rotators compared to the external rotators at $60°•sec^{-1}$ and $90°•sec^{-1}$ are presented in Table 4.2 as mean (±SD).
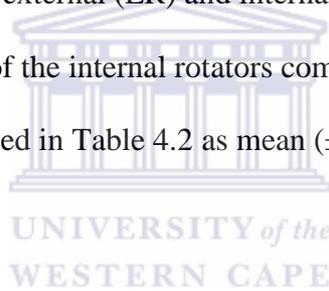
The mean maximal throwing velocities for the first, second, third and fourth team cricket participants were 108.90 ± 6.17, 105.80 ± 3.19, 97.70 ± 8.41 and 95.70 ± 8.85 $km•h^{-1}$, respectively. There was a statistically significant difference between the four cricket teams for throwing velocity (p = 0.000). Figure 4.1 displays the statistical significance between the teams for maximal throwing velocity. The post-hoc analysis revealed that the first team had a significantly greater throwing velocity than the third (p = 0.006) and fourth teams (p = 0.001), and the second team had a significantly greater throwing velocity than the fourth team (p = 0.014).

The mean average throwing velocities for the first, second, third and fourth team cricket participants were 106.64 ± 5.48, 104.32 ± 3.00, 96.50 ± 8.23 and 94.18 ± 8.94 $km•h^{-1}$,

respectively. There was a statistically significant difference between the cricket teams for average throwing velocity ($p = 0.000$). Figure 4.2 displays the statistical significance between the teams for average throwing velocity. The post-hoc analysis revealed that the first team was significantly greater than both the third ($p = 0.011$) and fourth ($p = 0.0001$) teams. Also, that the second team had a significantly greater mean average throwing velocity than the fourth team ($p = 0.011$).

The mean peak torques during external rotation at an isokinetic angular velocity of $60^{\circ} \bullet sec^{-1}$ for the first, second, third and fourth team cricket participants were 35.70 ± 3.84, 33.99 ± 2.69, 31.16 ± 2.20 and 30.71 ± 2.33 Nm, respectively. There was a statistically significant difference between the cricket teams for mean peak torque during external rotation at $60^{\circ} \bullet sec^{-1}$ ($p = 0.001$). Figure 4.3 displays the statistical significance between the four teams for mean peak torque during external rotation at $60^{\circ} \bullet sec^{-1}$. The post-hoc analysis showed that the first team had a significantly greater throwing velocity than the third ($p = 0.005$) and fourth teams ($p = 0.002$).

The mean peak torques during internal rotation at an isokinetic angular velocity of $60^{\circ} \bullet sec^{-1}$ for the first, second, third and fourth team cricket participants were 42.59 ± 2.88, 42.87 ± 2.70, 41.30 ± 3.11 and 40.23 ± 2.67 Nm, respectively. There were no statistically significant differences between the various teams ($p = 0.157$).

The mean strength (agonist/antagonist) ratios of the internal rotators compared to the external rotators at an isokinetic angular velocity of $60^{\circ} \bullet sec^{-1}$ for the first, second, third and fourth team cricket participants were 79.03 ± 2.35, 78.34 ± 2.20, 75.40 ± 1.55, and 75.25 ± 1.12 %, respectively. There was a statistically significant difference between the cricket teams for

strength ratios at $60°•sec^{-1}$ (p = 0.000), with the post-hoc analysis revealing the first team having a significantly greater strength ratio than the third (p = 0.001) and fourth (p = 0.000) teams, and the second team having a significantly greater strength ratio than the third (p = 0.006) and fourth (p = 0.004) teams. Figure 4.4 displays the statistical significance between the teams for the mean strength ratio at $60°•sec^{-1}$.

The mean peak torques during external rotation at the isokinetic angular velocity of $90°•sec^{-1}$ for the first, second, third and fourth team cricket participants were 33.84 ± 3.92, 33.13 ± 3.27, 31.77 ± 3.68 and 29.96 ± 2.45 Nm, respectively. There were no statistically significant differences between the teams (p = 0.070).

The mean peak torques during internal rotation at the isokinetic angular velocity of $90°•sec^{-1}$ of the first, second, third and fourth team cricket participants were 38.85 ± 5.12, 39.96 ± 3.38, 35.76 ± 4.70 and 33.31 ± 3.24 Nm, respectively. There was a statistically significant difference between the cricket teams for peak torque during internal rotation at $90°•sec^{-1}$ (p = 0.004). Figure 4.5 displays the statistical significance between the teams for mean peak torques during internal rotation at $90°•sec^{-1}$. The first team participants had a significantly greater peak torque during internal rotation at $90°•sec^{-1}$ than the fourth team (p = 0.027). Similarly, the second team participants had a significantly greater peak torque than the fourth team (p = 0.006).

The mean strength (agonist/antagonist) ratio of the internal rotators compared to the external rotators at the isokinetic angular velocity of $90°•sec^{-1}$ for the first, second, third and fourth team cricket participants were 82.81 ± 1.65, 82.40 ± 1.47, 81.63 ± 1.47, and 81.17 ± 0.92 %,

respectively. There were no statistically significant differences between the teams (p = 0.051).

Table 4.2: Throwing velocity, isokinetic peak torque and strength ratio measurements per team.

Variable	First team (n = 10) (X±SD)	Second team (n = 10) (X±SD)	Third team (n = 10) (X±SD)	Fourth team (n = 10) (X±SD)	P value
Maximal throwing velocity (km•h^{-1})	108.90 ± 6.17	105.80 ± 3.19	97.70 ± 8.41	95.70 ± 8.85	0.0003*
Average throwing velocity (km•h^{-1})	106.64 ± 5.48	104.32 ± 3.00	96.50 ± 8.23	94.18 ± 8.94	0.000*
PT-ER at 60º•sec^{-1} (Nm)	35.70 ± 3.84	33.99 ± 2.69	31.16 ± 2.20	30.71 ± 2.33	0.001*
PT-IR at 60º•sec^{-1} (Nm)	42.59 ± 2.88	42.87 ± 2.70	41.30 ± 3.11	40.23 ± 2.67	0.157
SR at 60º•sec^{-1} (%)	79.03 ± 2.35	78.34 ± 2.20	75.40 ± 1.55	75.25 ± 1.12	0.0000*
PT-ER at 90º•sec^{-1} (Nm)	33.84 ± 3.92	33.13 ± 3.27	31.77 ± 3.68	29.96 ± 2.45	0.070
PT-IR at 90º•sec^{-1} (Nm)	38.85 ± 5.12	39.96 ± 3.38	35.76 ± 4.70	33.31 ± 3.24	0.004*
SR at 90º•sec^{-1} (%)	82.81 ± 1.65	82.40 ± 1.47	81.63 ± 1.39	81.17 ± 0.92	0.0502

Note:
PT-ER= Peak torque of external rotation; PT-IR= Peak torque of internal rotation; SR= Strength ratio.
* indicates significant difference between groups ($p< 0.05$).
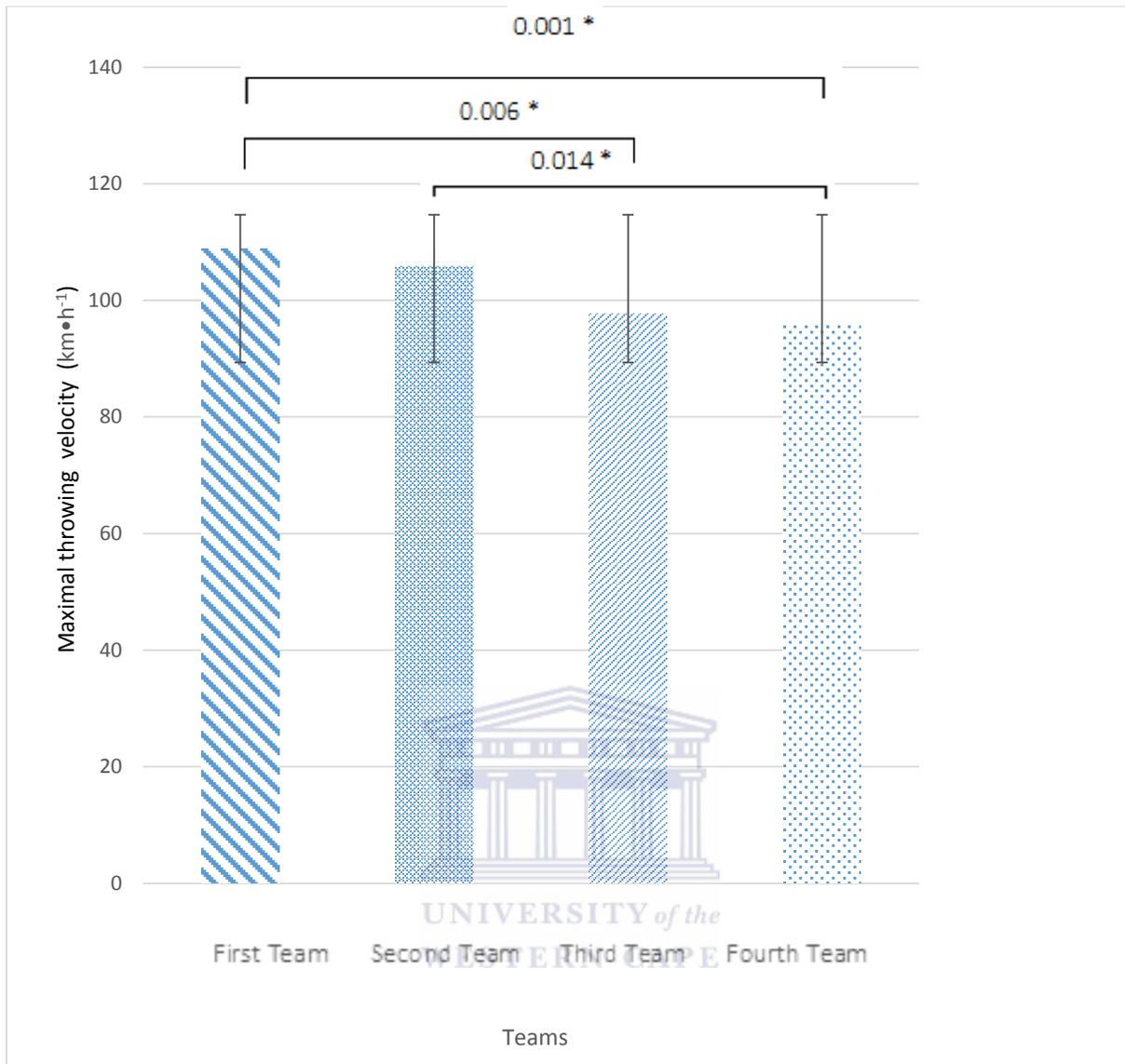
Figure 4.1: Maximal throwing velocity per team.
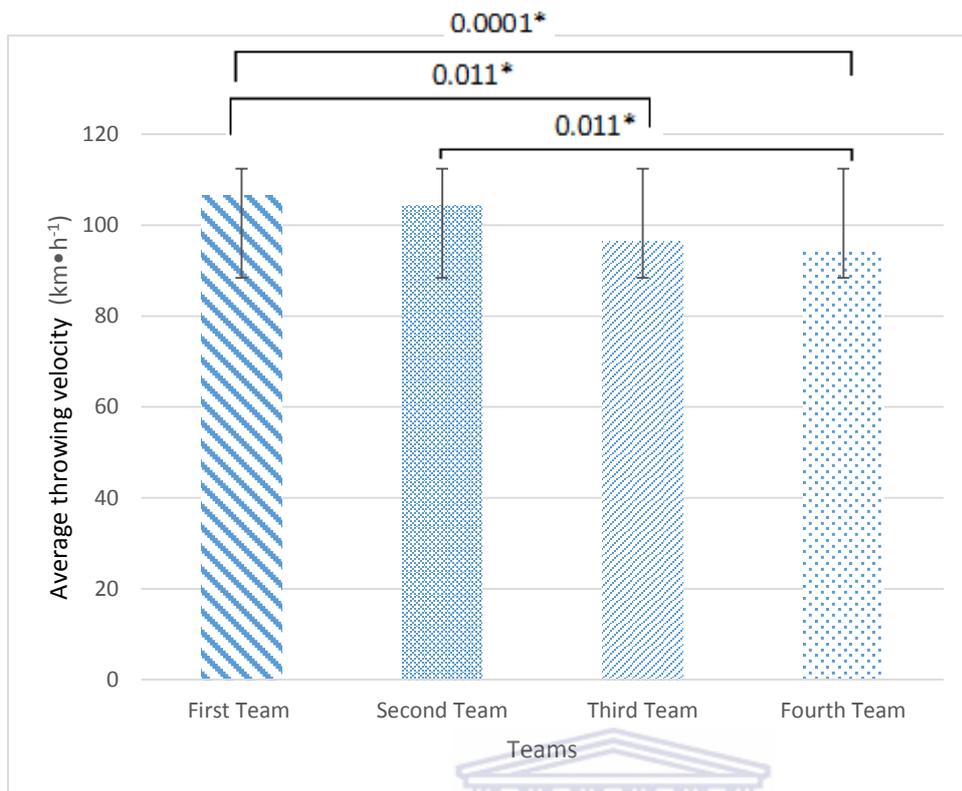
Figure 4.2: Average throwing velocity per team.
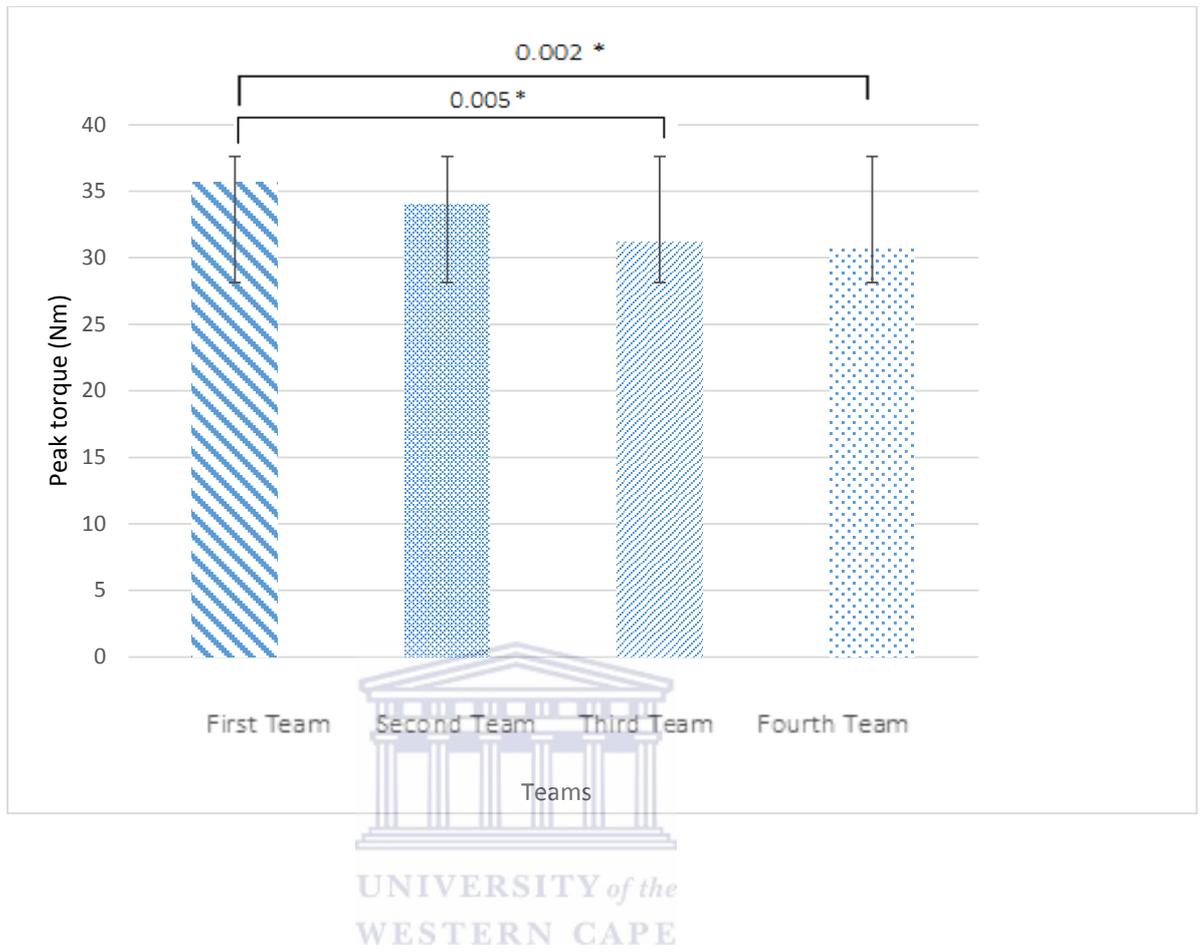
Figure 4.3: Isokinetic peak torque per team during external rotation at 60 °•sec^{-1}.
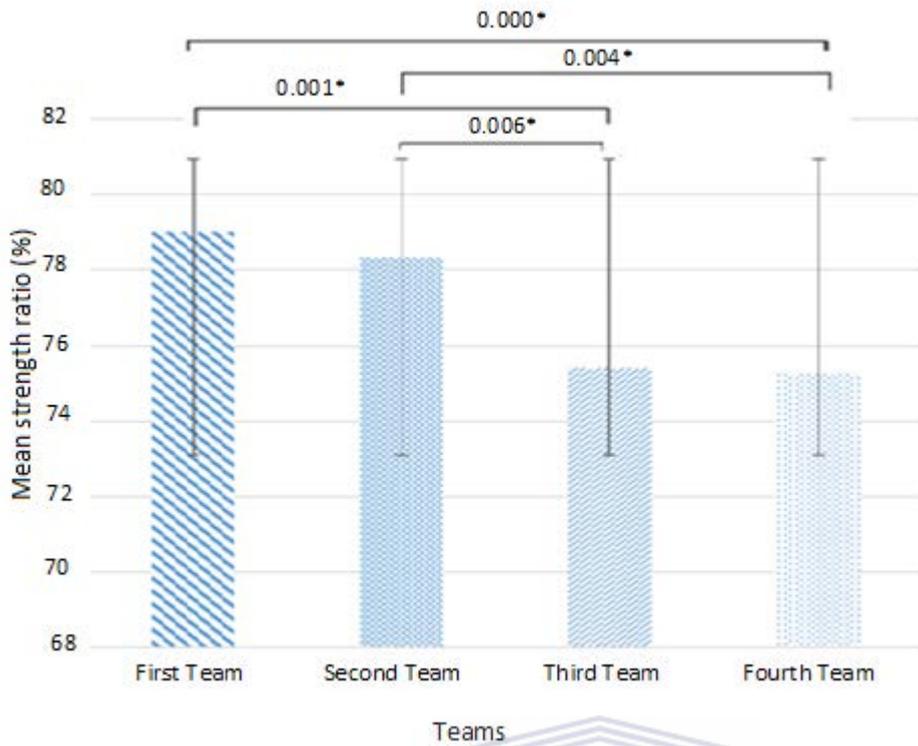
Figure 4.4: Strength ratios of the teams at 60 $^\circ \bullet sec^{-1}$.
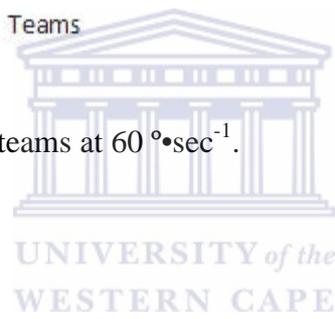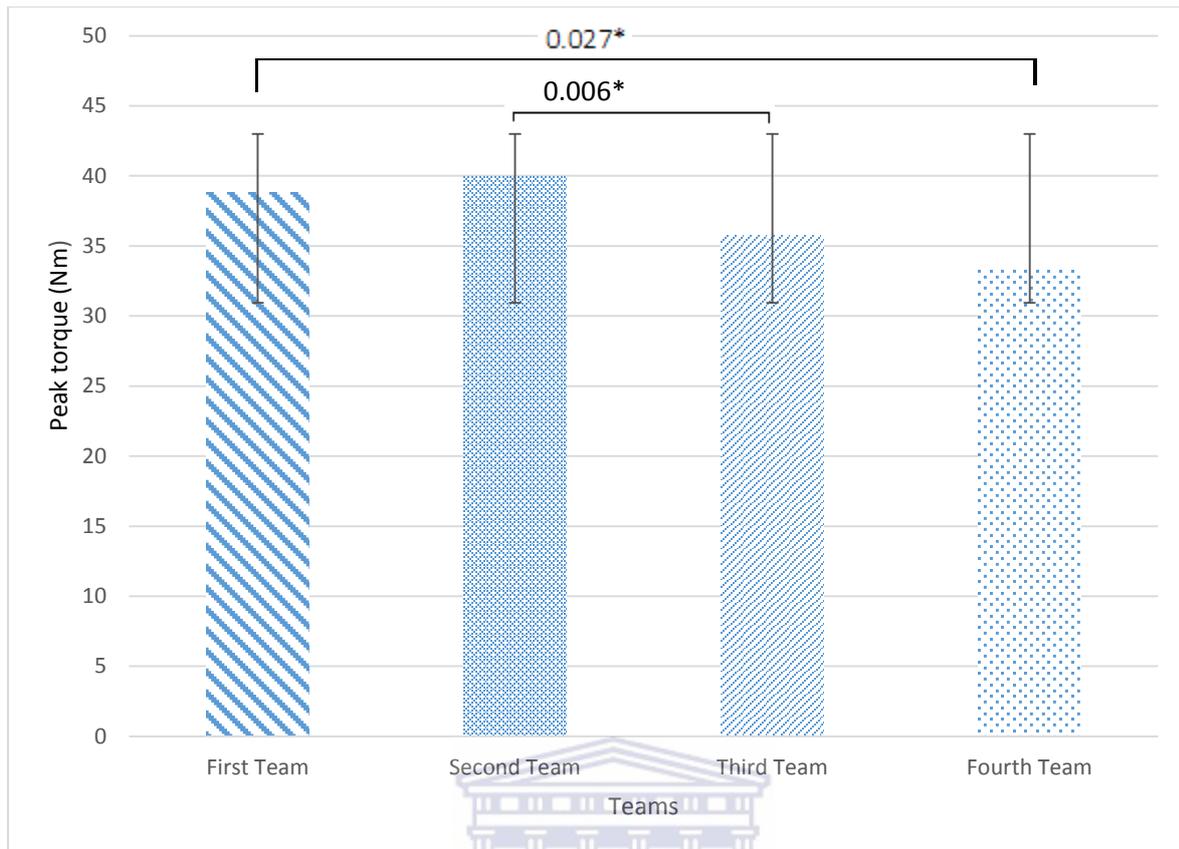
Figure 4.5: Mean isokinetic peak torque per team during internal rotation at 90°•sec^{-1}.

4.4 Relationship Between Shoulder Strength and Throwing Velocity

Table 4.3 displays the correlation matrix for the variables of maximal throwing velocity and the physical characteristics of each team. The relationship between maximal throwing velocity and age showed a moderate positive correlation for the first team ($r = 0.69$) that was statistically significant ($p = 0.03$), but weak negative correlations for the second and third teams, and the fourth team displayed a very weak negative correlation, with none being statistically significant ($r = -0.41$, $p = 0.23$; $r = -0.45$, $p = 0.19$ and $r = -0.02$, $p = 0.95$, respectively). Body fat percentage showed moderate positive correlations for the first and fourth teams ($r = 0.66$, $p = 0.04$ and $r = 0.61$, $p = 0.06$, respectively), and the third team had a very weak positive correlation ($r = 0.06$, $p = 0.87$), but only the first team was statistically significant. The second team showed a very weak negative correlation that was not statistically significant ($r = -0.20$, $p = 0.58$).
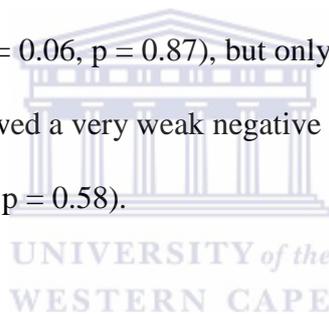
The following physical characteristics did not show a statistically significant relationship with maximal throwing velocity. The relationship between maximal throwing velocity and lean body mass showed weak negative correlations for the second team and very weak negative correlations in the third and fourth teams (second team: $r = -0.39$, $p = 0.27$; third team: $r = -0.18$, $p = 0.61$ and fourth team: $r = -0.15$, $p = 0.60$). A very weak positive correlation was shown for the first team participants ($r = 0.02$, $p = 0.96$). Stature showed very weak negative correlations for the first three teams (first team: $r = -0.24$, $p = 0.51$; second team: $r = -0.24$, $p = 0.50$ and third team: $r = -0.05$, $p = 0.88$). The fourth team showed a weak positive correlation ($r = 0.39$, $p = 0.27$). Body mass showed weak negative correlations for the second team and a very weak negative correlation for the third team (second team: $r = -0.39$, $p = 0.27$ and third team: $r = -0.09$, $p = 0.80$). A very weak positive

76

correlation was shown for the first and fourth teams (r = 0. 29, p = 0.42 and r = 0.03, p = 0.94, respectively).

Body fat mass showed moderate positive correlations for the first team, and very weak correlations for the third and fourth teams (first team: r = 0.58, p = 0.08; third team: r = 0.04, p = 0.92 and fourth team: r = 0.08, p = 0.83). The second team showed a very weak negative correlation (r = -0.27, p = 0.46).

The relationship between throwing velocity and total arm length showed moderate positive correlations for the first, second and fourth teams, and the third team displayed a very weak positive correlation, with none being statistically significant (first team: r = 0.63, p = 0.053; second team: r = 0.55, p = 0.10; third team: r = 0.03, p = 0.93 and fourth team: r = 0.63, p = 0.052).

Hip circumference showed a weak positive correlation for the first team, and very weak correlations for the third and fourth teams (first team: r = 0.35, p = 0.32; third team: r = 0.10, p = 0.78 and fourth team: r = 0.28, p = 0.43). The second team showed a weak negative correlation (r = -0.31, p = 0.38). Waist circumference showed very weak negative correlations for the second and third teams (second team: r = -0.22, p = 0.54 and third team: r = -0.07, p = 0.84). The first team and fourth teams displayed weak positive correlations (first team: r = 0.44, p = 0.21 and fourth team: r = 0.49, p = 0.16).
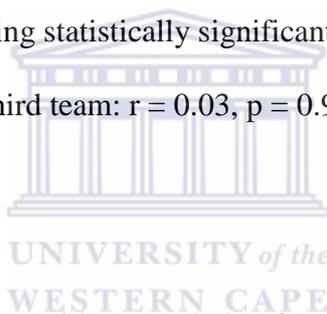
Table 4.3: Relationship between physical characteristics per team and maximal throwing velocity.

Physical Characteristics	First team	Second team	Third team	Fourth team
	Maximal throwing velocity			
Age	0.69*	-0.41	-0.45	-0.02
Lean body mass	0.02	-0.39	-0.18	-0.15
Stature	-0.24	-0.24	-0.05	0.39
Body mass	0.29	-0.39	-0.09	0.03
Body fat mass	0.58	-0.27	0.04	0.08
Body fat percentage	0.66*	-0.20	0.06	0.61
Total arm length	0.63	0.55	0.03	0.63
Hip circumference	0.35	-0.31	0.10	0.28
Waist circumference	0.44	-0.22	-0.07	0.49

Note:
* indicates significant correlation ($p < 0.05$).

Table 4.4 displays the correlation matrix for the variables of average throwing velocity and the physical characteristics of each team. The relationship between average throwing velocity and age showed weak negative correlations for the second and third teams. The fourth team displayed a very weak negative correlation, and none were statistically significant (second team: $r = -0.41$, $p = 0.24$; third team: $r = -0.43$, $p = 0.22$ and fourth team: $r = -0.16$, $p = 0.65$). A strong positive correlation was shown for the first team that was statistically significant ($r = 0.70$, $p = 0.03$). Body fat percentage showed a moderate positive correlation-that was statistically significant for first team, with the third and fourth teams displaying very weak correlations, that were not statistically significant (first team: $r = 0.66$, $p = 0.04$; third team: $r = 0.06$, $p = 0.87$ and fourth team: $r = 0.04$, $p = 0.92$). A non-significant very weak negative

correlation was displayed by the second team ($r = -0.20$, $p = 0.56$). Total arm length showed moderate positive correlations for the first, second, and fourth teams, but only the first team was statistically significant (first team: $r = 0.69$, $p = 0.03$; second team: $r = 0.50$, $p = 0.14$ and fourth team: $r = 0.61$, $p = 0.06$). The third team displayed a very weak negative correlation ($r = -0.00$, $p = 0.98$). Waist circumference showed very weak negative correlations for the second and third teams, with neither being statistically significant (second team: $r = -0.24$, $p = 0.51$ and third team: $r = -0.05$, $p = 0.89$, respectively). The first team displayed a weak positive correlation, and the fourth team showed a moderate positive correlation, with only the fourth team being statistically significant (first team: $r = 0.41$, $p = 0.24$ and fourth team: $r = 0.64$, $p = 0.05$).
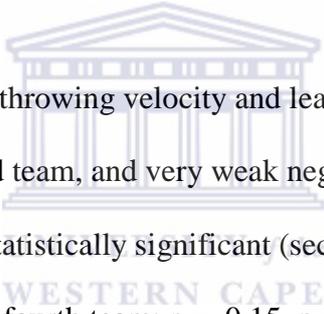
The relationship between average throwing velocity and lean body mass showed a weak negative correlation for the second team, and very weak negative correlations for the third and fourth teams, but none were statistically significant (second team: $r = -0.42$, $p = 0.23$; third team: $r = -0.16$, $p = 0.66$ and fourth team: $r = -0.15$, $p = 0.67$). A very weak positive correlation was shown for the first team with no statistical significance ($r = 0.03$, $p = 0.94$).

Stature showed very weak negative correlations for the first three teams, and none were statistically significant (first team: $r = -0.20$, $p = 0.57$; second team: $r = -0.28$, $p = 0.43$ and third team: $r = -0.05$, $p = 0.89$). The fourth team showed a weak positive correlation (fourth team: $r = 0.39$, $p = 0.27$). Body mass showed a weak negative correlation for the second team and a very weak negative correlation for third team, and none were statistically significant (second team: $r = -0.41$, $p = 0.24$ and third team: $r = -0.08$, $p = 0.84$). Very weak positive correlations were shown for the first and fourth teams (first team: $r = 0.29$, $p = 0.42$ and fourth team: $r = 0.05$, $p = 0.88$), with neither being statistically significant. Body fat mass

showed a moderate positive correlation for the first team, while the third and fourth teams displayed very weak positive correlations, but none were statistically significant (first team: r = 0.59, p = 0.08; third team: r = 0.04, p = 0.92 and fourth team: r = 0.04, p = 0.88). The second team displayed a very weak negative correlation (r = -0.27, p = 0.45) with no statistical significance. Hip circumference showed a weak positive correlation for the first team, and very weak positive correlations for the third and fourth teams, and none were statistically significant (first team: r = 0.34, p = 0.33; third team: r = 0.16, p = 0.75 and fourth team: r = 0.23, p = 0.40). A very weak negative correlation was displayed by the second team (r = -0.29, p = 0.42) that was not statistically significant.

Table 4.4: Relationship between physical characteristics and average throwing velocity per team.

	First team	Second team	Third team	Fourth team
Physical Characteristics	Average throwing velocity			
Age	0.70*	-0.41	-0.43	-0.16
Lean body mass	0.03	-0.42	-0.16	-0.15
Stature	-0.20	-0.28	-0.05	0.39
Body mass	0.29	-0.41	-0.08	0.05
Body fat mass	0.59	-0.27	0.04	-0.04
Body fat percentage	0.66*	-0.20	0.06	0.09
Total arm length	0.69*	0.50	-0.00	0.61
Hip circumference	0.34	-0.29	0.12	0.23
Waist circumference	0.41	-0.24	-0.05	0.64*

Note:
* indicates significant correlation ($p < 0.05$).

Table 4.5 displays the relationship between the physical characteristics of the participants, isokinetic peak torques and the strength ratios. The relationship between the strength ratios of the internal rotator to the external rotator peak torque and age at the isokinetic angular velocity of $60°•sec^{-1}$ had a weak negative correlation for the second team, and very weak negative correlations in the third and fourth teams, with none being statistically significant (second team: r = -0.45, p = 0.19; third team: r = -0.17, p = 0.64 and fourth team: r = -0.14, p = 0.70). The first team had a moderate positive correlation that was statistically significant (r = 0.67, p = 0.03).

The relationship between the strength ratios of the internal rotator to the external rotator peak torque and age at the isokinetic angular velocity of $90°•sec^{-1}$ showed a moderate positive correlation in the first team and a weak positive correlation in the fourth team, but only the first team was statistically significant (first team: r = 0.67, p = 0.03 and fourth team: r = 0.43, p = 0.22). A very weak negative correlation was displayed in the second team, while the third team showed a weak negative correlation, with neither being statistically significant (second team: r = -0.28, p = 0.43 and third team: r =-0.40, p = 0.26). The relationship between the external rotator peak torques during concentric/concentric contraction at the isokinetic angular velocity of $60°•sec^{-1}$ and lean body mass showed very weak negative correlations for the first, third and fourth teams, while the second team showed a moderate negative correlation, with only the second team being statistically significant (first team: r = -0.23, p = 0.52; second team: r = -0.64, p = 0.05; third team: r = -0.19, p = 0.61and fourth team: r = -0.13, p = 0.72).

The relationship between the strength ratios and lean body mass at the isokinetic angular velocity of $90°•sec^{-1}$ showed very weak negative correlations in both the first and second

teams, with neither being statistically significant (first team: r = -0.19, p = 0.60 and second team: r = -0.05, p = 0.89). A moderate positive correlation was displayed in the third team, and fourth teams displayed a weak positive correlation, with only the third team being statistically significant (third team: r = 0.68, p = 0.03 and fourth team: r = 0.26, p = 0.48).

The relationship between peak torque during internal rotation generated at the isokinetic angular velocity of $60°•sec^{-1}$ and body fat mass showed a very weak positive correlation for the first team that was not statistically significant (r = 0.12, p = 0.73). The second and fourth teams displayed weak negative correlations, and the third team displayed a moderate negative correlation, with only the third team being statistically significant (second team: r = -0.39, p = 0.27; third team: r = -0.65, p = 0.04 and fourth team: r = -0.26, p = 0.46). The relationship between peak torque during external rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and body fat mass showed a strong positive correlation for the first team and a very weak positive correlation for the third team, but only the first team was statistically significant (first team: r = 0. 72, p = 0.02 and third team: r = 0.10, p = 0.78). There were very weak negative correlations in the second and fourth teams (second team: r = -0.14, p = 0.69 and fourth team: r = -0.03, p = 0.93).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and body fat percentage showed a strong positive correlation for the first team and very weak positive correlations in the third and fourth teams, with only the first team being statistically significant (first team: r = 0. 74, p = 0.01; third team: r = 0.11, p = 0.76 and fourth team: r = 0.06, p = 0.87). There was a very weak negative correlation in the second team that was not statistically significant (r = -0.03, p = 0.93).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $60°•sec^{-1}$ and total arm length showed a weak positive correlation in the first team, and the second and third teams displayed very weak positive correlations. The fourth team displayed a moderate positive correlation, with only the fourth team being statistically significant (first team: $r = 0.34$, $p = 0.34$; second team: $r = 0.29$, $p = 0.41$; third team: $r = 0.08$, $p = 0.82$ and fourth team: $r = 0.67$, $p = 0.03$).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60°•sec^{-1}$ and total arm length had moderate positive correlations for the first and fourth teams. The second team displayed a strong positive correlation, with the first and second teams showing statistical significance (first team: $r = 0.69$, $p = 0.03$; second team: $r = 0.81$, $p = 0.00$ and fourth team: $r = 0.57$, $p = 0.08$). The third team had a weak negative correlation that was not statistically significant ($r = -0.39$, $p = 0.26$). The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $90°•sec^{-1}$ and total arm length showed moderate positive correlations for the first, second and fourth teams. The third team displayed a very weak positive correlation, with only the fourth team being statistically significant (first team: $r = 0.53$, $p = 0.11$; second team: $r = 0.59$, $p = 0.07$; third team: $r = 0.03$, $p = 0.92$ and fourth team: $r = 0.64$, $p = 0.04$).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and hip circumference displayed weak positive correlations in the first and third teams. The fourth team displayed a very weak positive correlation, with none being statistically significant (first team: $r = 0.38$, $p = 0.28$; third team: $r = 0.30$, $p = 0.39$ and fourth

team: r = 0.06, p = 0.88). A moderate negative correlation was displayed in the second team that was statistically significant (r = -0.74, p = 0.01).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $90^{\circ} \cdot \sec^{-1}$ and waist circumference showed a strong positive correlation in the first team. The fourth team showed a very weak positive correlation, with only the first team being statistically significant (first team: r = 0.76, p = 0.01 and fourth team: r = 0.17, p = 0.64). There were very weak negative correlations in the second and third teams (r = -0.20, p = 0.58 and r = -0.29, p = 0.42, respectively).

The relationship between the following physical characteristics of the participants, isokinetic peak torques and strength ratios did not display any statistical significance. The relationship between the peak torque during external rotation for concentric/concentric contraction at the isokinetic angular velocity of $60^{\circ} \cdot \sec^{-1}$ and age showed a moderate positive correlation in the first team and a weak positive correlation in the fourth team, but none were statistically significant (first team: r =0.53, p = 0.11and fourth team: r = 0.31, p = 0.38). A moderate negative correlation was shown in the second team and a very weak negative correlation in the third team, but neither were statistically significant (second team: r = -0.57, p = 0.08 and third team: r = -0.08, p = 0.83).

The relationship between peak torque during internal rotation generated at the isokinetic angular velocity of $60^{\circ} \cdot \sec^{-1}$ and age had a moderate negative correlation for the second team, with a weak negative correlation in the third team and a very weak correlation in the fourth team, with none being statistically significant (second team: r = -0.51, p = 0.13; third team: r

= -0.33, p = 0.35 and fourth team: r = -0.17, p = 0.64). The first team had a weak positive

correlation (r = 0.46, p = 0.18).

The relationship between peak torque during external rotation at the isokinetic angular

velocity of $90º•sec^{-1}$ and age showed a weak positive correlation in first team, with a very

weak correlation in the second team, but none were statistically significant (first team: r =

0.41, p = 0.25 and second team: r = 0.02, p = 0.96). There were weak negative correlations in

the third and fourth teams (third team: r = - 0.31, p = 0.38 and fourth team: r = -0.34, p =

0.33).

The relationship between peak torque during internal rotation generated at the isokinetic

angular velocity of $90º•sec^{-1}$ and age displayed moderate positive correlation in the first and

weak positive correlation fourth team (first team: r = 0.57, p = 0.09; fourth team: r = 0.42, p =

0.23). A moderate negative correlations displayed in the second team, with a very weak

negative correlation for the third team (second team: r = -0.52, p = 0.12; third team r = -0.25,

p = 0.49) with none being statistically significant.

The relationship between peak torque during internal rotation generated at the isokinetic

angular velocity of $60º•sec^{-1}$ and lean body mass showed very weak negative correlations for

the first and fourth teams, with a weak negative correlation in the second and third teams,

with none being statistically significant (first team: r = -0.08, p = 0.83; second team: r = -

0.48, p = 0.16; third team: r = -0.46, p = 0.18 and fourth team: r = -0.13, p = 0.73).

The relationship between the strength ratios of the internal rotator to external rotator peak

torque at the isokinetic angular velocity of $60º•sec^{-1}$and lean body mass showed very weak

negative correlations for the second, third and fourth teams, with none being statistically significant (second team: r = -0.06, p = 0.88; third team: r = -0.16, p = 0.66 and fourth team: r = -0.14, p = 0.71). The first team had a very weak positive correlation with no statistical significance (first team: r = 0.24, p = 0.51).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $90^\circ \bullet sec^{-1}$ and lean body mass showed a moderate negative correlation in second team, while the third and fourth teams displayed very weak correlations, but none were statistically significant (second team: r = -0.51, p = 0.13; third team: r = -0.26, p = 0.48 and fourth team: r = -0.11, p = 0.75). The first team displayed a very weak positive correlation (r = 0.28, p = 0.43), but no statistical significance.

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90^\circ \bullet sec^{-1}$ and lean body mass showed a very weak positive correlation in the first team no statistical significance (r = 0.15, p = 0.69). Weak negative correlations were shown in the second, third and fourth teams, with none being statistically significant (second team: r = -0.34, p = 0.33; third team: r = -0.45, p = 0.19 and fourth team: r = -0.36, p = 0.31).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $60^\circ \bullet sec^{-1}$ and stature showed a weak negative correlation for the first team, with a very weak negative correlations for the second and fourth teams, with none being statistically significant (first team: r =-0.32, p = 0.37; second team: r = -0.27, p = 0.46 and fourth team: r = -0.22, p = 0.54). The third team displayed a very weak positive correlation with no statistical significance (r = 0.03, p = 0.94).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $60^{\circ} \cdot sec^{-1}$ and stature showed a very weak negative correlation for the first team, with the second and third teams displaying very weak negative correlations, with none being statistically significant (first team: r = -0.13, p = 0.72; second team: r = -0.21, p = 0.55 and third team: r = -0.34, p = 0.34). The fourth team showed a weak positive correlation with no statistical significance (r = 0.39, p = 0.26).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60^{\circ} \cdot sec^{-1}$ and stature showed very weak negative correlations for the first and third teams, with none being statistically significant (first team: r = -0.08, p = 0.83 and third team: r = -0.08, p = 0.83). The second team displayed a very weak positive correlation, and the fourth team showed a moderate positive correlation, with neither having statistical significance (second team: r = 0.04, p = 0.92 and fourth team: r = 0.53, p = 0.11).
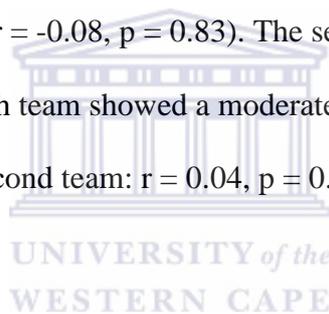
The relationship between peak torque during external rotation at the isokinetic angular velocity of $90^{\circ} \cdot sec^{-1}$ and stature showed very weak negative correlations in first and fourth teams, with the second team displaying a weak negative correlation, but none were statistically significant (first team: r = -0.22, p = 0.54; second team: r = -0.47, p = 0.17 and fourth team: r = -0.10, p = 0.79). There was a very weak positive correlation in the third team with no statistical significance (r = 0.09, p = 0.81).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90^{\circ} \cdot sec^{-1}$ and stature showed very weak negative correlations in the first and third teams, with no statistical significance (first team: r = -0.18, p = 0.62 and third team: r = -0.01,

p = 0.97). Very weak positive correlations were shown in the second and fourth teams, with no statistical significance (second team: r = 0.04, p = 0.92 and fourth team: r = 0.05, p = 0.90).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $90º\bullet sec^{-1}$ and stature showed a very weak negative correlation in the first team with a weak negative correlation in the third team (first team: r = -0.09, p = 0.80 and third team: r = -0.31, p = 0.38). Very weak positive correlations was displayed in the second and fourth teams, with no statistical significance respectively (second team: r = 0.14 and p = 0.70; fourth team: r = 0.24, p = 0.51).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $60º\bullet sec^{-1}$ and body mass showed very weak negative correlations for the first, third and fourth teams. The second team displayed a moderate negative correlation, but none were statistically significant (first team: r = -0.13, p = 0.72; second team: r = -0.58, p = 0.08; third team: r = -0.15, p = 0.68 and fourth team: r = -0.09, p = 0.81).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60º\bullet sec^{-1}$ and body mass showed a weak positive correlation for the first team, and the third and fourth teams displayed very weak positive correlations, with none being statistically significant (first team: r =0.34, p = 0.33; third team r = 0.01,: p = 0.98 and fourth team: r = 0.01, p = 0.99). The second team had a very weak negative correlation with no statistical significance (r = -0.06, p = 0.86).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and body mass showed a moderate positive correlation in the first team, but no statistical significance (first team: r = 0. 52, p = 0.12). There were weak negative correlations in the second and fourth teams, with the third team displaying a very weak positive correlation (second team: r = -0.47, p = 0.17; third team: r = -0.09, p = 0.80 and fourth team: r = -0.30, p = 0.39).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and body fat mass showed a very weak positive correlation in the first team with no statistical significance (first team: r = 0.27, p = 0.44). A weak negative correlation was displayed in the second team, and the third and fourth teams displayed very weak negative correlations (second team: r = -0.43, p = 0.21; third team: r = -0.03, p = 0.93 and fourth team: r = -0.07, p = 0.84).
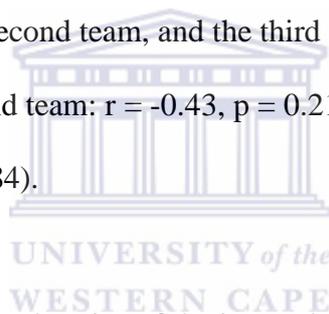
The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $90°•sec^{-1}$ and body mass showed very weak negative correlations in first and second teams, with the third team displaying a weak negative correlation (first team: r = -0.10, p = 0.78; second team: r = -0.17, p = 0.63 and third team: r = -0.39, p = 0.26), with none being statistically significant. A very weak positive correlation was displayed in the fourth team with no statistical significance (fourth team: r = 0.16, p = 0.65).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $60°•sec^{-1}$ and body fat mass showed very weak positive correlations in both the first and fourth teams, with none being statistically significant (first team: r = 0.04, p = 0.92

and fourth team: r = 0.21, p = 0.56). The second and third teams had very weak negative correlations, with no statistical significance (second team: r = -0.18, p = 0.62 and third team: r = -0.06, p = 0.87).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $60°•sec^{-1}$ and body fat mass showed a weak positive correlation for the first team and a very weak positive correlation for the second team, with none being statistically significant (first teams; r = 0.37, p = 0.29 and second team: r = 0.04, p = 0.91). The third team displayed a moderate negative correlation and the fourth team displayed a very weak negative correlation, but none were statistically significant (third team: r = -0.56, p = 0.09 and fourth team: r = -0.08, p = 0.83).
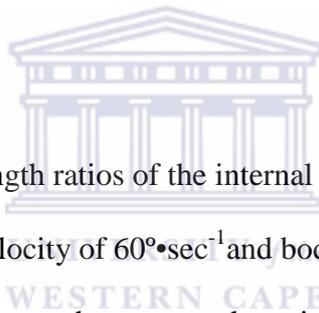
The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60°•sec^{-1}$ and body fat mass showed a weak positive correlation in the first team, and a very weak positive correlation in the third team , with no statistical significance (first team: r = 0.41, p = 0.24 and third team: r = 0.17, p = 0.65). The second and the fourth teams both had very weak negative correlations, and none were statistically significant (second team: r = -0.12, p = 0.75 and fourth team: r = -0.20, p = 0.57).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and body fat mass showed weak positive correlations in the first and third teams, with none being statistically significant (first team: r = 0.38, p = 0.27 and third team: r = 0.38, p = 0.28). A moderate negative correlation was displayed in the second team,

with the fourth team displaying a weak negative correlation, but none were statistically significant (second team: r = -0.55, p = 0.10 and fourth team: r = -0.30, p = 0.41).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $90^\circ \cdot sec^{-1}$ and body fat mass showed very weak positive correlations in both the first and third teams (first team: r = 0.05, p = 0.89 and third team: r = 0.04, p = 0.90), but no statistical significance was found. A moderate negative correlation was displayed in the second team, with the fourth team displaying a very weak negative correlation, both none were statistically significant (second team: r = -0.52, p = 0.12 and fourth team: r = -0.06, p = 0.86).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $60^\circ \cdot sec^{-1}$ and body fat percentage showed a very weak positive correlation for the first team, and the fourth team displayed a weak positive correlation, with none being statistically significant (first team: r = 0.12, p = 0.74 and fourth team: r = 0.30, p = 0.41). Both the second and the third teams had very weak negative correlations, with no statistical significance (second team: r = -0.03, p = 0.94 and third team: r = -0.03, p = 0.94).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $60^\circ \cdot sec^{-1}$ and body fat percentage showed a weak positive correlation for the first team, and very weak positive correlations for the second and fourth teams, with none being statistically significant (first team: r = 0.47, p = 0.17; second team: r = 0.14, p = 0.69 and fourth team: r = 0.05, p = 0.89). The third team displayed a moderate negative correlation with no statistical significance (third team: r = -0.51, p = 0.13).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60º•sec^{-1}$ and body fat percentage showed a weak positive correlation for the first team, and a very weak negative correlation for the third team, with none being statistically significant (first team: r = 0.39, p = 0.27 and third team: r = 0.18, p = 0.61). The second and fourth teams displayed very weak negative correlations with no statistical significance (second team: r = -0.12, p = 0.74 and fourth team: r = -0.08, p = 0.84).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90º•sec^{-1}$ and body fat percentage showed weak positive correlations in both the first and third teams with no statistical significance (first team: r = 0.37, p = 0.29 and third team: r = 0.44, p = 0.20). The second team displayed a moderate negative correlation and the fourth team displayed a very weak negative correlation, with no statistical significance (second team: r = -0.53, p = 0.11 and fourth team: r = -0.21, p = 0.57).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $90º•sec^{-1}$ and body fat percentage showed very weak positive correlations in both the first and third teams (first team: r = 0.09, p = 0.80 and third team: r = 0.10, p = 0.79), with no statistical significance. The second team displayed a moderate negative correlation and the fourth team displayed a very weak negative correlation with no statistical significance (second team: r = -0.56, p = 0.09 and fourth team: r = -0.01, p = 0.97).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $60º•sec^{-1}$ and total arm length showed weak positive correlations for the first and fourth teams, with no statistical significance (first team: r = 0.43, p = 0.21and fourth team: r =

0.48, p = 0.16). The second and third teams both had very weak negative correlations, with no statistical significance (r = -0.01, p = 0.98 and r = -0.05, p = 0.89, respectively).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and total arm length showed weak positive correlations in the first and fourth teams. The second and third teams displayed very weak positive correlations, with none being statistically significant (first team: r = 0.47, p = 0.17; second team: r = 0.07, p = 0.86; third team: r = 0.27, p = 0.45 and fourth team: r = 0.47, p = 0.17).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and total arm length showed a moderate positive correlation for the first team, with a weak positive correlation for the second team and a very weak positive correlation for the fourth team, with none being statistically significant (first team: r = 0.54, p = 0.11; second team: r = 0.44, p = 0.20 and fourth team: r = 0.29, p = 0.42). The third team showed a very weak negative correlation with no statistical significance (r = -0.09, p = 0.81).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $60°•sec^{-1}$ and hip circumference showed very weak negative correlations for the first and third teams. The second team displayed a weak negative correlation, with none being statistically significant (first team: r = -0.27, p = 0.45; second team: r = -0.46, p = 0.18 and third team: r = -0.09, p = 0.80). The fourth team had a very weak positive correlation with no statistical significance (r = 0.25, p = 0.48).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $60°•sec^{-1}$ and hip circumference showed very weak positive correlations for the

first, second and fourth teams, with none being statistically significant (first team: r = 0.07, p = 0.84; second team: r = 0.02, p = 0.95 and fourth team: r = 0.21, p = 0.55). The third team had weak negative correlation with no statistical significance (r = -0.46, p = 0.18).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of 60°•sec[-1] and hip circumference showed a weak positive correlation for the first team, and very weak positive correlations for the third and fourth teams, with none being statistically significant (first team: r = 0.38, p = 0.28; third team: r = 0.28, p = 0.43 and fourth team: r = 0.21, p = 0.56). The second team had a very weak negative correlation with no statistical significance (r = -0.01, p = 0.98.
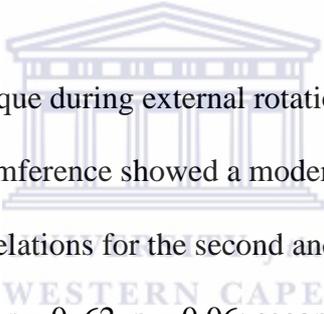
The relationship between peak torque during external rotation at the isokinetic angular velocity of 90°•sec[-1] and hip circumference showed a moderate positive correlation in the first team, and very weak positive correlations for the second and fourth teams, but none were statistically significant (first team: r = 0. 62, p = 0.06; second team: r = 0.00, p = 1.00 and fourth team: r = 0.11, p =0.77). The third team had a very weak negative correlation with no statistical significance (r = -0.02, p = 0.96).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of 90°•sec[-1] and hip circumference showed very weak negative correlations in the first and third teams, and the second team displayed a weak negative correlation (first team: r = -0.12, p = 0.75; second team: r = -0.47, p = 0.17 and third team: r = -0.03, p = 0.93), with none being statistically significant. Very weak positive correlation was displayed in the fourth team with no statistical significance (r = 0.07, p = 0.84).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $60^\circ\bullet\text{sec}^{-1}$ and waist circumference showed very weak negative correlations in the first and third teams, and the second team displayed a weak negative correlation, with none being statistically significant (first team: r = -0.24, p = 0.50; second team: r = -0.37, p = 0.29 and third team: r = -0.28, p = 0.43). A weak positive correlation with no statistical significance was shown in the fourth team (r = 0.34, p = 0.34).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $60^\circ\bullet\text{sec}^{-1}$ and waist circumference showed very weak positive correlations for the first and second teams, and the fourth team displayed a weak positive correlation, with none being statistically significant (first team; r = 0.15, p = 0.69; second team: r = 0.05, p = 0.89 and fourth team: r = 0.49, p = 0.15). The third team showed a weak negative correlation with no statistical significance (r = -0.33, p = 0.35).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60^\circ\bullet\text{sec}^{-1}$and lean body mass showed very weak positive correlations for the first and third teams, and the fourth team showed a moderate positive correlation, with none being statistically significant (first team: r = 0.33, p = 0.35; third team: r = 0.15, p = 0.68 and fourth team: r = 0.58, p = 0.08). The second team had a very weak negative correlation with no statistical significance (r = -0.08, p = 0.83).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90^\circ\bullet\text{sec}^{-1}$ and waist circumference showed a weak positive correlation in the first team, and very weak positive correlations for third and fourth teams, with none being

statistically significant (first team: r = 0.44, p = 0.21; third team: r = 0.04, p = 0.92 and fourth

team: r = 0.23, p = 0.52). A weak negative correlation was displayed in the second team, with

no statistical significance (r = -0.47, p = 0.17).

The relationship between the strength ratios of the internal rotator to external rotator peak

torque at the isokinetic angular velocity of $90°•sec^{-1}$ and waist circumference showed very

weak negative correlations in the first and third teams, and a weak negative correlation for the

second team, with none being statistically significant (first team: r = -0.15, p = 0.68; second

team: r = -0.35, p = 0.33 and third team: r = -0.15, p = 0.67). A weak positive correlation was

displayed in the fourth team with no statistical significance (r = 0.40, p = 0.25).
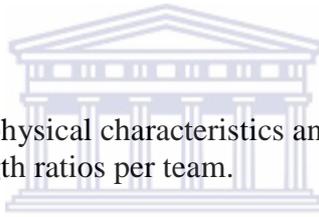
Table 4.5: Relationship between physical characteristics and isokinetic peak torque, and physical characteristics and strength ratios per team.

		Isokinetic peak torque				Strength ratios	
Physical characteristics	Teams	PT-ER @ $60°•sec^{-1}$	PT-IR @ $60°•sec^{-1}$	PT-ER@ $90°•sec^{-1}$	PT-IR @ $90°•sec^{-1}$	SR @ $60°•sec^{-1}$	SR @ $90°•sec^{-1}$
Age	First team	0.53	0.46	0.41	0,57	0.67*	0.67*
	Second team	-0.57	-0.51	0.02	-0.52	-0.45	-0.28
	Third team	-0.08	-0.33	-0.31	-0.25	-0.17	-0.40
	Fourth team	0.31	-0.17	-0.34	0.42	-0.14	0.43
Lean body mass	First team	-0.23	-0.08	0.28	0.15	0.24	-0.19
	Second team	-0.64*	-0.48	-0.51	-0.34	-0.06	-0.05
	Third team	-0.19	-0.46	-0.26	-0.45	-0.16	0.68*
	Fourth team	-0.13	-0.13	-0.11	-0.36	-0.14	0.26
Stature	First team	-0.32	-0.13	-0.22	-0.18	-0.08	-0.09
	Second team	-0.27	-0.21	-0.47	0.04	0.04	0.14
	Third team	0.03	-0.34	0.09	-0.01	-0.08	-0.31
	Fourth team	-0.22	0.39	-0.10	0.05	0.53	0.24
Body mass	First team	-0.13	0.12	0.52	0.27	0.34	-0.10
	Second team	-0.58	-0.39	-0.47	-0.43	-0.06	-0.17
	Third team	-0.15	-0.65*	-0.09	-0.03	0.01	-0.39

	Fourth team	-0.09	-0.26	-0.30	-0.07	0.01	0.16
Body fat mass	First team	0.04	0.37	0.72*	0.38	0.41	0.05
	Second team	-0.18	0.04	-0.14	-0.55	-0.12	-0.52
	Third team	-0.06	-0.56	0.10	0.38	0.17	0.04
	Fourth team	0.21	-0.08	-0.03	-0.30	-0.20	-0.06
Body fat percentage	First team	0.12	0.47	0.74*	0.37	0.39	0.09
	Second team	-0.03	0.14	-0.03	-0.53	-0.12	-0.56
	Third team	-0.03	-0.51	0.11	0.44	0.18	0.10
	Fourth team	0.30	0.05	0.06	-0.21	-0.08	-0.01
Total arm length	First team	0.43	0.34	0.47	0.54	0.69*	0.53
	Second team	-0.01	0.29	0.07	0.44	0.81*	0.59
	Third team	-0.05	0.08	0.27	-0.09	-0.39	0.03
	Fourth team	0.48	0.67*	0.47	0.29	0.57	0.64*
Hip circumference	First team	-0.27	0.07	0.62	0.38	0.38	-0.12
	Second team	-0.46	0.02	0.00	-0.74*	-0.01	-0.47
	Third team	-0.09	-0.46	-0.02	0.30	0.28	-0.03
	Fourth team	0.25	0.21	0.11	0.06	0.21	0.07
Waist circumference	First team	-0.24	0.15	0.76*	0.44	0.33	-0.15
	Second team	-0.37	0.05	-0.20	-0.47	-0.08	-0.35
	Third team	-0.28	-0.33	-0.29	0.04	0.15	-0.15
	Fourth team	0.34	0.49	0.17	0.23	0.58	0.40

Note:
PT-ER= Peak torque of external rotation; PT-IR= Peak torque of internal rotation; SR= Strength ratio.
* indicates significant correlation ($p < 0.05$).

Table 4.6 displays the correlation matrix of the variables for isokinetic peak torque, maximal throwing velocity and strength ratio for each team. The relationship between peak torque during external rotation at the isokinetic angular velocity of $60°•sec^{-1}$ and maximal throwing velocity showed moderately positive correlations for the first three teams, but none were statistically significant (first team: r = 0. 60, p = 0.07; second team: r = 0.61, p = 0.06 and third team: r = 0.60, p = 0.07). The fourth team had a weak positive correlation with no statistical significance (r = 0.47, p = 0.17).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $60°•sec^{-1}$ and maximal throwing velocity had positive correlations for all four teams, and all were statistically significant. The first and third teams both had a strong positive correlations (first team: r = 0.72, p = 0.01 and third team: r = 0.73, p = 0.01). The second and fourth teams both had a moderate positive correlations (second team: r = 0.67, p = 0.03 and fourth team: r = 0.69, p = 0.02).

The relationship between peak torque during external rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and maximal throwing velocity showed moderate positive correlations in all teams, but none were statistically significant (first team: r = 0. 63, p = 0.05; second team: r = 0.60, p = 0.07; third team: r = 0.62, p = 0.06 and fourth team: r = 0.61, p = 0.17). The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90°•sec^{-1}$ and maximal throwing velocity displayed moderate positive correlations for all four teams, with none being statistically significant (first team: r = 0.63, p = 0.051; second team: r = 0.62, p = 0.056; third team: r = 0.61, p = 0.06 and fourth team: r = 0.61, p = 0.06).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60°•sec^{-1}$ and maximal throwing velocity showed statistically significant strong positive correlations in the first, second and third teams, with the fourth team displaying a very strong positive correlation (first team: r = 0.76, p = 0.01; second team: r = 0.83, p = 0.002; third team: r = 0.70, p = 0.02; and fourth team: r = 0.94, p = 0.0001).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $90°•sec^{-1}$ and maximal throwing velocity showed

strong positive correlations that were statistically significant in both the first (r = 0.72, p = 0.01) and second teams (r = 0.75, p = 0.01). The fourth team displayed a moderate positive correlation (r = 0.57, p = 0.08), and the third team displayed a weak positive correlation, both of which were not statistically significant(r = 0.39, p = 0.26).

Table 4.6: Relationship between isokinetic peak torque, strength ratios and maximal throwing velocity per team.

		First team	Second team	Third team	Fourth team
		Maximal throwing velocity			
Isokinetic peak torque	PT-ER @ 60°•sec^{-1}	0.60	0.61	0.60	0.47
	PT-IR @ 60°•sec^{-1}	0.72*	0.67*	0.73*	0.69*
	PT-ER @ 90°•sec^{-1}	0.63	0.60	0.62	0.61
	PT-IR @ 90°•sec^{-1}	0.63	0.62	0.61	0.61
Strength ratios	SR @ 60°•sec^{-1}	0.76*	0.83*	0.70*	0.94*
	SR @ 90°•sec^{-1}	0.72*	0.75*	0.39	0.57

Note:
PT-ER= Peak torque of external rotation; PT-IR= Peak torque of internal rotation; SR= Strength ratio.
* indicates significant correlation ($p < 0.05$).

Table 4.7 displays the correlation matrix of the variables for isokinetic peak torque, average throwing velocity and strength ratio for each team. The relationship between peak torque during external rotation at the isokinetic angular velocity of 60°•sec^{-1} and average throwing velocity showed strong positive correlations in the first and second teams that were both statistically significant (first team; r = 0. 76, p = 0.01 and second team: r = 0.73, p = 0.02) .The third team had a weak positive correlation (r = 0.38, p = 0.28), and the fourth team had a moderate positive correlation, but none were statistically significant (r = 0.55, p = 0.09).

The relationship between peak torque during internal rotation at the isokinetic angular velocity of $60^\circ \cdot sec^{-1}$ and average throwing velocity showed moderate positive correlations in the first three teams, but only the first team displayed statistical significance (first team: r = 0.64, p = 0.04; second team: r = 0.60, p = 0.07 and third team: r = 0.60, p = 0.07).The fourth team had a weak positive correlation with no statistical significance (r = 0.45, p = 0.19). The relationship between peak torque during external rotation at the isokinetic angular velocity of $90^\circ \cdot sec^{-1}$ and average throwing velocity showed moderate positive correlations in all teams, but only the second team showed statistical significance (first team: r = 0. 59, p = 0.07; second team: r = 0.65, p = 0.05; third team: r = 0.60, p = 0.07 and fourth team: r = 0.61, p = 0.06).
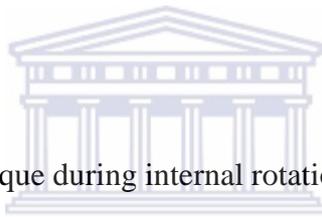
The relationship between peak torque during internal rotation at the isokinetic angular velocity of $90^\circ \cdot sec^{-1}$ and average throwing velocity displayed moderate positive correlations in all teams, with none being statistically significant (first team: r = 0.59, p = 0.07; second team: r = 0.58, p = 0.08; third team: r = 0.60, p = 0.07 and fourth team: r = 0.61, p = 0.06). The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60^\circ \cdot sec^{-1}$ and average throwing velocity showed statistically significant strong positive correlations in the first three teams, while the fourth team displayed a very strong positive correlation (first team: r = 0.77, p = 0.01; second team: r = 0.85, p = 0.002; third team: r = 0.73, p = 0.02; and fourth team: r=0.94, p=0.0001).

The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $90^\circ \cdot sec^{-1}$ and average throwing velocity showed significantly strong positive correlations in the first three teams (r = 0.77, p = 0.01; r = 0.72, p

= 0.02; and r = 0.73, p = 0.02 in the first, second and third teams, respectively). The fourth

team displayed a moderate positive correlation that was also significant (r = 0.66, p = 0.04).

Table 4.7: Relationship between isokinetic peak torque, strength ratios and average throwing velocity per team.

|		First team	Second team	Third team	Fourth team
		Average throwing velocity			
Isokinetic peak torque	PT-ER @ $60°•sec^{-1}$	0.76*	0.73*	0.38	0.55
	PT-IR @ $60°•sec^{-1}$	0.64*	0.60	0.60	0.45
	PT-ER @ $90°•sec^{-1}$	0.59	0.65*	0.60	0.61
	PT-IR @ $90°•sec^{-1}$	0.59	0.58	0.60	0.61
Strength ratios	SR @ $60°•sec^{-1}$	0.77*	0.85*	0.71*	0.94*
	SR @ $90°•sec^{-1}$	0.77*	0.72*	0.73*	0.66*

Note:
PT-ER= Peak torque of external rotation; PT-IR= Peak torque of internal rotation; SR= Strength ratio.
* indicates significant correlation ($p< 0.05$).

4.5 Summary of the Chapter

In summary, the main findings in this study are that the physical characteristics showed a

significant difference in lean body mass and total arm length between the first and fourth

teams. Player experience also showed a significant difference between the first team and the

other three teams. The relationship between maximal throwing velocity and physical

characteristics indicated that age and body fat percentage had significant effects on maximal

throwing velocity, but in the first team only. Similarly, age, body fat percentage and total arm length had significant effects on average throwing velocity in the first team only.

The relationship between the physical characteristics, isokinetic peak torque and strength ratios indicated significant correlations between age and peak torque during internal rotation at the isokinetic angular velocity of $90°•sec^{-1}$, and age and the strength ratios of the internal rotator to external rotator peak torque at isokinetic angular velocity of $90°•sec^{-1}$ in the first team.

Lean body mass and peak torque during external rotation at the isokinetic angular velocity of $60°•sec^{-1}$ displayed significant correlations in both the second and third teams. Weight and peak torque during internal rotation at the isokinetic angular velocity of $60°•sec^{-1}$ showed a significant correlation in the third team. Body fat mass and peak torque during external rotation at the isokinetic angular velocity of $90°•sec^{-1}$, and body fat percentage and peak torque during external rotation at the isokinetic angular velocity of $90°•sec^{-1}$ displayed significant correlations in the first team. Significant results were displayed for the relationship between total arm length and the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60°•sec^{-1}$ in the first and second teams. The relationship between Total arm length and peak torque during internal rotation at the isokinetic angular velocity of $60°•sec^{-1}$ and total arm length and peak torque during external rotation at the isokinetic angular velocity of $90°•sec^{-1}$ displayed significant results in the fourth team. The relationship between hip circumference and the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60°•sec^{-1}$ showed a significant result in the second team. Waist circumference and peak torque during

external rotation at the isokinetic angular velocity of $90º•sec^{-1}$ showed a significant result in the first team.

The performance data indicated that the first team had a significantly greater maximal and average throwing velocity than the other teams. The results also showed that the first team yielded greater peak torques during external rotation at the isokinetic angular velocity of $60º•sec^{-1}$, and greater strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60º•sec^{-1}$ then the other teams. The first and second teams also displayed greater peak torques during internal rotation at the isokinetic angular velocity of $90º•sec^{-1}$.
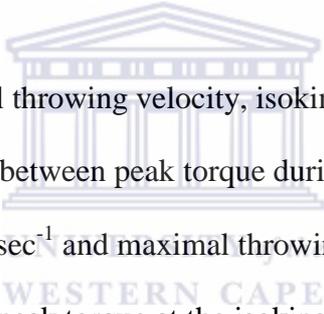
The relationship between maximal throwing velocity, isokinetic peak toque and strength ratios indicated significant results between peak torque during internal rotation at the isokinetic angular velocity of $60º•sec^{-1}$ and maximal throwing, and the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $60º•sec^{-1}$ and maximal throwing in all four teams. The relationship between the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of $90º•sec^{-1}$ and maximal throwing velocity displayed significant results in the first and second teams only.

The relationship between average throwing velocity, isokinetic peak toque and strength ratios displayed significant results between peak torque during external rotation at the isokinetic angular velocity of $60º•sec^{-1}$ and average throwing velocity in the first and second teams only. The relationship between peak torque during internal rotation at the isokinetic angular velocity of $60º•sec^{-1}$ and average throwing velocity displayed significant results in the first

team only. The relationship between peak torque during external rotation at the isokinetic angular velocity of 90º•sec^{-1} and average throwing velocity showed significant results in the third team only.

The relationship between the strength ratios of the internal rotator to external rotator peak torque at isokinetic angular velocity of 60º•sec^{-1}and average throwing velocity, and the strength ratios of the internal rotator to external rotator peak torque at the isokinetic angular velocity of 90º•sec^{-1} and average throwing velocity displayed significant results in all four teams.

CHAPTER FIVE: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The ability to execute a powerful throw is an essential skill in sport. The aim of the study was to measure the throwing velocity and muscular strength of the shoulder complex, and to examine the relationship between isokinetic muscular strength of the shoulder complex and throwing velocity amongst club cricketers aged 18 to 32 years.

This chapter discusses the main findings that have emerged in chapter four with reference to the research aim. It discusses the relationship between isokinetic strength of the shoulder complex and throwing velocity relative to the level of participation or competition in cricket. Lastly, it provides a conclusion, and ends with recommendations for future research, which summarize the important points of the study.

This study was conducted with the primary goal of examining the relationship between Isokinetic strength of shoulder complex and throwing velocity in club cricketers. Significant differences were found in lean body mass and arm length in all four teams. The ages of the club cricket players in the present study were older than those reported previously in university student cricket players (Koley, 2011), but was similar to the ages reported in senior club cricketers (Pyne et al., 2006).

In the study by Pyne et al. (2006), the mean stature of the club cricket players was shorter than that reported in senior cricketers, but was not statistically significant. In a similar study

which profiled the anthropometric characteristics of Indian interuniversity male cricketers, no significant difference was found between the height and body composition among batsmen, bowlers and all-rounders (Koley, 2011).

The results obtained from the current study showed that body mass in club cricketers was greater than that of other university student cricket players (Koley, 2011), but less than that of senior cricketers (Pyne et al., 2006). The results for height, body mass, arm length, and body composition (skinfold) in this study are consistent with results reported by Choudhary (2012) which indicated that morphological differences exist between cricketers playing in different competition levels.
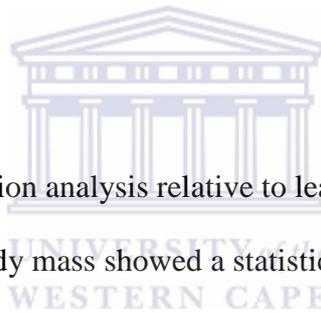
When considering body composition analysis relative to lean body mass, body fat mass and body fat percentage, only lean body mass showed a statistically significant difference between the teams. These results are in contrast with a study where body fat percentage was found to be significantly different between the three groups (Koley, 2011). In the current study, arm length in club cricketers was significantly different between the groups. The concept that arm length influences bowling speed and throwing is supported by Stuelcken et al. (2007). They found that the length of the bowling arm influenced the bowling speed, because for any given angular velocity, the linear speed of a segment's endpoint is proportional to the length of its radius (Pyne et al., 2006).

Similarly, Portus et al. (2000) investigating cricket fast bowling performance and technique and the influence of selected physical factors, found that abdominal strength, trunk stability, selected girth and skinfold measures, as opposed to the upper body strength alone, played a

role in ball speed. A tall stature could be perceived as a positive characteristic in terms of delivery release angle and force production (Glazier et al., 2000). Analysis of these characteristics provides useful references for investigations focusing on player selection and athlete development (Stuelcken et al., 2007).

5.2 Performance Characteristics

5.2.1 Throwing velocity

Throwing velocity in cricket is essential for an effective throw, but it also plays a crucial role in a players' attacking performance, especially if their throwing speed can be enhanced and applied effectively within the team's offensive play (Derenne et al., 2001). In the current study, maximal throwing velocity obtained in club cricket players was statistically significant between the various teams. The first team achieved greater speeds than both the third and fourth teams. The second team also achieved a greater speed than the fourth team. The greatest throwing velocity was achieved by the first team, the team shown to have more playing experience.

It is considered that playing experience (years of participation and level of participation) has a significant influence on maximal throwing velocity in cricket (Freeston et al., 2007). Freeston et al., 2007, examined the throwing performance of 110 cricket players from six different populations and found that gender, training volume (training time per week) and, to a lesser extent, experience (playing training experience) have a significant influence on

maximal throwing velocity in cricketers. The results indicate that gender, playing experience, and training volume (muscle strength) may all contribute to throwing performance in cricket players.

Bayios (2001) reported ball velocity to be positively correlated with body size, and the upper and lower extremities' length. In the current study, the relationship between maximal throwing velocity correlated with age and body fat percentage which displayed statistical significance. The current study also showed that average throwing velocity correlated well with age, body fat percentage and total arm length, which all displayed statistical significance.

5.2.2 Isokinetic Peak Torque

Muscle strength and endurance of the shoulder rotators are essential physical characteristics for success in overhead throwing performance and dynamic glenohumeral stability (Dale et al., 2007). The results obtained for peak torque during external rotation at $60^{\circ} \bullet sec^{-1}$ were significantly different between the teams. The first team displayed greater external rotation peak torque than both the third and fourth teams. In a study exploring the strength of the shoulder internal and external rotators in cricket bowlers, the concentric external rotator strength of the dominant shoulder showed no significant difference in mean torque values (Mabasa et al., 2002). Hurd et al. (2011) reported significant weakness in the external rotator muscles, and that throwing activity imposes tremendous demands on the external rotators which can lead to overuse and, consequently, weakness.

In the current study, peak torque during internal rotation at $60°•sec^{-1}$ showed no significant difference between the teams. In contrast with Mabasa (2002), the current study showed the concentric internal rotator muscle strength decreased at $60°•sec^{-1}$. These results are opposite with other studies that reported significant increases in internal rotator muscle strength in the dominant shoulders of high school pitchers (Alderink & Kuck, 1986; Sirota et al., 1993).

In the present study, peak torque during external rotation at $90°•sec^{-1}$ showed no statistically significant difference between the teams. The concentric external rotational strength of the dominant shoulder rotators showed a decrease in lower cricket teams, and no significant difference in mean torque values (Mabasa et al., 2002).
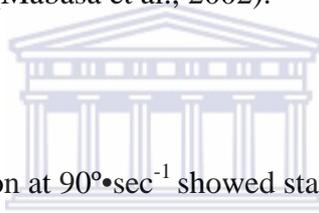
Peak torque during internal rotation at $90°•sec^{-1}$ showed statistically significant differences between the teams. The first team had a greater peak torque then the fourth team, and the second team had a greater peak torque then the third team. The concentric internal rotator muscle strength showed no significant differences in mean torque in the dominant shoulder for cricket bowlers (Mabasa et al., 2002). The power produced by the internal rotator muscles during concentric contractions after eccentric contractions of the external rotator muscles was significantly greater in the dominant shoulder (Pontaga & Ziden, 2014).

Several researchers used isokinetic devices which calculated the ratio of the external to internal rotator muscle strength for concentric muscular action in an attempt to assess muscular strength imbalances of the shoulder complex (Aldenrink & Kuck, 1986; Cook et al., 1987; Brown et al., 1988; Warner et al., 1990; Ellenbecker, 1991; Ellenbeckert et al., 1992; Codine et al., 1997; Noffal, 2003; Wang et al., 2004; Dale et al., 2007; Pontaga & Ziden,

2014; Cha et al., 2014). In the current study, the strength ratio of the internal rotators compared to the external rotators at 60 $°\bullet sec^{-1}$ showed significant differences between the teams. The first team had greater strength ratios than both the third and fourth teams. Furthermore, the second team also had a greater strength ratio than the third and four teams. Then strength ratio of the internal rotators compared to the external rotators at 90 $°\bullet sec^{-1}$ showed no significant differences between the teams. Mabasa et al., (2002) reported a decreased strength ratio at both speeds of 60 $°\bullet sec^{-1}$ and 90 $°\bullet sec^{-1}$. Their findings indicated it could have been due to an increase in internal rotation peak torque and a decrease in external rotational peak torque.

Sport that requires overhead throwing (baseball, cricket, tennis, volleyball and handball) requires a delicate balance between shoulder strength, mobility and stability in order to meet the functional demands of performance and competition (Bigliani et al., 1997; Crockett et al., 2002; Dale et al., 2007; Borsa et al., 2008; Cha et al., 2014). Such integration involves muscular strength, endurance, flexibility and neuromuscular control (Dillman et al., 1993; Escamilla et al., 2001; Murray et al., 2001; Cha et al., 2014). If any one of these factors becomes impaired, functional instability would occur and performance is likely to deteriorate (Dale et al., 2007; Cha et al., 2014).

Shedlarski's (2011) aim of the study was to determine how strength characteristics associated with jumping are affected by percent body fat, lean body mass and free fat mass. The findings of the study display the relationship between body fat percentage and strength measured by a countermovement jump. Similar to findings in the current study, the physical

characteristics, namely, age, lean body mass, weight, fat mass, body fat percentage, total arm length, hip circumference and waist circumference all correlated with the strength variables.

5.2.3 Relationship Between Throwing Velocity and Isokinetic Strength

The relationship between external rotation at an isokinetic angular velocity for a concentric/concentric contraction at $60°•sec^{-1}$ and maximal throwing velocity showed a positive correlation in all teams, but none were statistically significant. Similarly, a study by Clements et al. (2001a) who correlated upper limb muscle strength with throwing speed in adolescent baseball players showed a moderate correlation between the shoulder strength and throwing speed, but it was not significant. The researchers indicated that shoulder internal rotational strength had a large influence on throwing speed. In contrast to the study by Bayios et al. (2001), the aim of the study was to examine the relationship between the rotational strength of shoulder and ball velocity in team handball players. The main finding in the study showed that the peak torque of internal and external rotation of the shoulder was not related to ball velocity. The study concluded that peak torque of internal and external rotators of the shoulder was not a good indicator of throwing velocity. Other studies have reported that there was a poor correlation between throwing velocity and maximal muscle strength (Perrin, 1993; Yildiz et al., 2003; Goharpey et al., 2007; Jones & Bampouras, 2010; Çetin & Balcı, 2015). A correlation between internal rotation peak torque generated at $60°•sec^{-1}$ and throwing velocity had a positive correlation for all teams and was statistically significant. In comparison, a study from Degache et al. (2012) who investigated the relationship between shoulder muscle strength and smash velocity in volleyball players, found that ball velocity performance during a smash test correlated significantly with strength performance of the

dominant shoulder in the concentric mode of contraction at $60^\circ \cdot sec^{-1}$ of internal and external rotators.

A comparison of external rotation peak torque during concentric/concentric contraction at $90^\circ \cdot sec^{-1}$ and throwing velocity showed a moderately positive correlation in all teams, but none were statistically significant. A study by Bayios et al. (2001) that examined the relationship between the rotational strength of the shoulder and ball velocity in handball players, found that the peak torque of internal and external rotation of the shoulder was not associated with ball velocity.
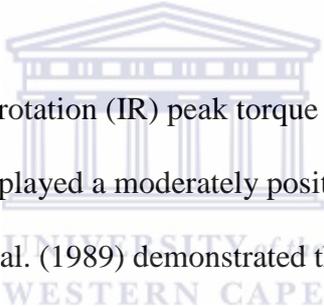
The relationship between internal rotation (IR) peak torque during the isokinetic speed at $90^\circ \cdot sec^{-1}$ and throwing velocity displayed a moderately positive correlation, but was not statistically significant. Bartlett et al. (1989) demonstrated that there was a strong positive relationship between the peak torque production of the presiding arm's shoulder adduction and throwing speed. Dershyshire, (2007) reported that both peak torque for a concentric/concentric contraction at $90^\circ \cdot sec^{-1}$ during external rotation and the peak torque for a concentric/concentric contraction at $90^\circ \cdot sec^{-1}$ during internal rotation correlated with throwing velocity, but were not statistically significant.

A statistically significant positive relationship was found between the agonist/antagonist ratios at $60^\circ \cdot sec^{-1}$ and throwing velocity in all four teams. Similarly, the study by Pontaga and Ziden (2014) compared shoulder external/internal rotator muscles' peak torques and average power values and their ratios in the presiding and non-presiding arm. The authors also sought to determine the relationship between the shoulder rotator muscles' peak torques, average

power and ball throwing speed in handball players. Their results showed positive correlations between the isokinetic characteristics of the shoulder rotator muscles and the ball throwing speed. This finding indicated that the contribution of the shoulder internal and external rotator muscles peak torques and average power production is at least similar in achieving high ball speeds when throwing. The power produced by the internal rotator muscles during concentric contractions after eccentric contractions of the external rotator muscles was significantly greater in the presiding arm (Pontaga & Ziden, 2014).

The relationship of the strength ratio and throwing velocity at $90°•sec^{-1}$ showed a statistically significant positive correlation in both the first and second teams. Derbyshire (2007) reported that strength ratio and throwing at $90°•sec^{-1}$ had a very weak correlation with throwing. The researcher concluded that it was evident cricket players, energy generated in the torso, and not merely the torque generated in the shoulder joint. This emphasised the kinetic chain and the energy that transferred from the lower extremities.
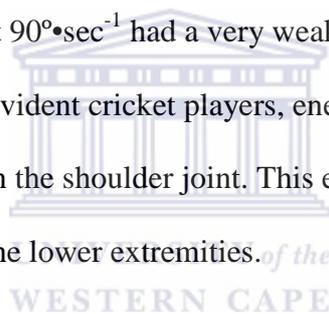
5.2.4 Strengths of the Study

The most important strength of this study relates to the rigorous methodological approach that was used to address the research questions. The aspects of shoulder strength and throwing velocity were also investigated, with the careful selection of participants at various levels of cricket competition. The study design provides credible results particularly in this relatively poorly researched area of cricket. To the author's knowledge, no previous study has addressed this topic, especially in the local setting.

5.2.5 Conclusion

The major findings of this study were the significant positive correlations between isokinetic peak torque internal rotation at $60°•sec^{-1}$ and throwing velocity. The relationship between the strength ratio at $60°•sec^{-1}$ and throwing velocity also showed significant positive correlations amongst club cricketers. Therefore, shoulder rotator strength plays a significant role in throwing velocity. Consequently, an increase in shoulder internal rotator muscle strength contributes to an increase in throwing velocity.

5.2.6 Recommendations
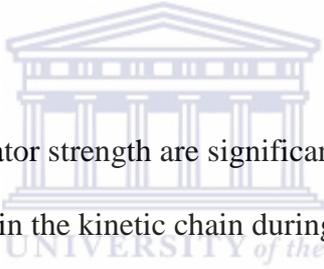
Shoulder external and internal rotator strength are significant components of the shoulder complex. They play a crucial role in the kinetic chain during the throwing process. Muscle imbalances between the two rotators are common in overhead sport. Therefore, the shoulder rotators should be assessed to evaluate muscle imbalances which could limit throwing velocity. It is also recommended that future researchers use a larger sample size in order to improve statistical power of the data. Also, the inclusion of randomized sampling greatly benefits external validity.

References

Alcaraz, P. E., Abraldes, J. A., Ferragut, C., Rodríguez, N., Argudo, F. M., & Vila, H. (2011). Throwing velocities, anthropometric characteristics, and efficacy indices of women's European water polo subchampions. *Journal of Strength and Conditioning Research*, *25*(11), 3051-3058.

Alderink, G. J., & Kuck, D. J. (1986). Isokinetic Shoulder Strength of High School and College-Aged Pitchers. *Journal of Orthopaedic and Sports Physical Therapy*, *7*(4), 163-172.

American College of Sports Medicine. (2010). *ACSM's guidelines for exercise testing and prescription*. Lippincott, Williams & Wilkins, New York, USA.

Anderson, M. K., Hall, S. J., & Martin, M. (2009). *Foundations of athletic training: prevention, assessment, and management*. Lippincott, Williams & Wilkins, New York, USA.

Andrade, M. D. S., Fleury, A. M., de Lira, C. A. B., Dubas, J. P., & da Silva, A. C. (2010). Profile of isokinetic eccentric-to-concentric strength ratios of shoulder rotator muscles in elite female team handball players. *Journal of Sports Sciences*, *28*(7), 743-749.

Arai, R., Mochizuki, T., Yamaguchi, K., Sugaya, H., Kobayashi, M., Nakamura, T., & Akita, K. (2010). Functional anatomy of the superior glenohumeral and coracohumeral ligaments and the subscapularis tendon in view of stabilization of the long head of the biceps tendon. *Journal of Shoulder and Elbow Surgery*, *19*(1), 58-64.

Bartlett, L. R., Storey, M. D., & Simons, B. D. (1989). Measurement of upper extremity torque production and its relationship to throwing speed in the competitive athlete. *American Journal of Sports Medicine*, *17*(1), 89-91.

Bayios, I. A., Anastasopoulou, E. M., Sioudris, D. S., & Boudolos, K. D. (2001). Relationship between isokinetic strength of the internal and external shoulder rotators and ball velocity in team handball. *Journal of Sports Medicine and Physical Fitness*, *41*(2), 229.

Bigliani, L. U., Codd, T. P., Connor, P. M., Levine, W. N., Littlefield, M. A., & Hershon, S. J. (1997). Shoulder motion and laxity in the professional baseball player. *American Journal of Sports Medicine*, *25*(5), 609-613.

Borsa, P. A., Laudner, K. G., & Sauers, E. L. (2008). Mobility and stability adaptations in the shoulder of the overhead athlete. *Sports medicine*, *38*(1), 17-36.

Bourdon, P., Savage, B., & Done, R. (2000). *Physiological Tests for Elite Athletes.* Human Kinetics, Champaign, Illinois,USA.

Braatz, J. H., & Gogia, P. P. (1987). The mechanics of pitching. *Journal of Orthopaedic and Sports Physical Therapy*, *9*(2), 56-69.

Brown, L. P., Niehues, S. L., Harrah, A., Yavorsky, P., & Hirshman, H. P. (1988). Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. *American Journal of Sports Medicine*, *16*(6), 577-585.

Caruso, J. F., Brown, L. E., & Tufano, J. J. (2012). The reproducibility of isokinetic dynamometry data. *Isokinetics and Exercise Science*, *20*(4), 239-253.

Cerrah, A. O., Onarici Gungor, E., & Yılmaz, İ. (2012). Relationship between isokinetic strength parameters and soccer throw-in performance. *Isokinetics and Exercise Science,* 4, 139-145

Çetin, E., & Balcı, N. (2015). The Effects of Isokinetic Performance on Accurate Throwing in Team Handball. *Procedia-Social and Behavioral Sciences*, *174*, 1872-1877.

Cha, J. Y., Kim, J. H., Hong, J., Choi, Y. T., Kim, M. H., Cho, J. H., & Jee, Y. S. (2014). A 12-week rehabilitation program improves body composition, pain sensation, and internal/external torques of baseball pitchers with shoulder impingement symptom. *Journal of Exercise Rehabilitation*, *10*(1), 35-44.

Choudhary, R., Tiwari, S., Kumar, S. & Rai, V. (2011). Comparison of Selected Anthropometric Measurements and Body Composition of Fast and Spin Bowlers of Uttar Pradesh U-19 Cricket. *Indian Journal of Movement Education and Exercises Sciences,* II, 1, 345-352.

Clements, A. S., Ginn, K. A., & Henley, E. (2001a). Correlation between muscle strength and throwing speed in adolescent baseball players. *Physical Therapy in Sport*, *2*(3), 123-131.

Clements, A. S., Ginn, K. A., & Henley, E. C. (2001b). Comparison of upper limb musculoskeletal function and throwing performance in adolescent baseball players and matched controls. *Physical Therapy in Sport*, *2*(1), 4-14.

Codine, P., Bernard, P. L., Pocholle, M., Benaim, C., & Brun, V. (1997). Influence of sports discipline on shoulder rotator cuff balance. *Medicine and Science in Sports and Exercise*, *29*(11), 1400-1405.

Cook, E. E., Gray, V. L., Savinar-Nogue, E., & Medeiros, J. (1987). Shoulder antagonistic strength ratios: a comparison between college-level baseball pitchers and nonpitchers. *Journal of Orthopaedic and Sports Physical Therapy*, *8*(9), 451-461.

Cook, D. P., & Strike, S. C. (2000). Throwing in cricket. *Journal of Sports Sciences*, *18*(12), 965-973.

Cook, L. (2010). *Shoulders, Core and Legs: Keys to Great Throwing and Striking Sports Performance in Female Athletes.* Retrieved on March 17, 2014 from http://www.mygroupfit.com/printeducationarticle.aspx?article=3264

Cools, A. M., Witvrouw, E. E., De Clercq, G. A., Danneels, L. A., Willems, T. M., Cambier, D. C., & Voight, M. L. (2002). Scapular muscle recruitment pattern: electromyographic response of the trapezius muscle to sudden shoulder movement before and after a fatiguing exercise. *Journal of Orthopaedic and Sports Physical Therapy*, *32*(5), 221-229.

Cools, A. M., Geerooms, E., Van den Berghe, D. F., Cambier, D. C., & Witvrouw, E. E. (2007). Isokinetic scapular muscle performance in young elite gymnasts. *Journal of Athletic Training*, *42*(4), 458.

Crockett, H. C., Gross, L. B., Wilk, K. E., Schwartz, M. L., Reed, J., O'Mara, J., & Andrews, J. R. (2002). Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *American Journal of Sports Medicine*, *30*(1), 20-26.

Dale, R. B., Kovaleski, J. E., Ogletree, T., Heitman, R. J., Norrell, P. M., Shelbourne, K. D., & McHugh, M. M. P. (2007). The effects of repetitive overhead throwing on shoulder rotator isokinetic work-fatigue. *North American Journal Sports Physical Therapy*, *2*(2), 74-80.

Davies, G. J., Heiderscheit, B., & Brinks, K. (2000). Test interpretation. *Isokinetics in Human Performance*, 3-24.

Degache, F., Minchev, G., Genty, M., & Edouard, P. (2012). Shoulder muscle strength is correlated with volleyball smash velocity. *Annals of Physical and Rehabilitation Medicine*, *55*, e258.

Derbyshire, D. (2007). Physical factors influencing the throwing action in netball and cricket players. Unpublished Master's thesis. *Stellenbosch University*.

Derenne, C., Ho, K. W., & Murphy, J. C. (2001). Effects of general, special, and specific resistance training on throwing velocity in baseball: a brief review. *Journal of Strength and Conditioning Research*, *15*(1), 148-156.

Dillman, C. J., Fleisig, G. S., & Andrews, J. R. (1993). Biomechanics of pitching with emphasis upon shoulder kinematics. *Journal of Orthopaedic and Sports Physical Therapy*, *18*(2), 402-408.

Drouin, J. M., Valovich-mcLeod, T. C., Shultz, S. J., Gansneder, B. M., & Perrin, D. H. (2004). Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *European Journal of Applied Physiology*, *91*(1), 22-29.

Dvir, Z. (2004). *Isokinetics: muscle testing, interpretation, and clinical applications*. Second edition, Churchill Livingstone, New York.

Edouard, P., Calmels, P., & Degache, F. (2009). The effect of gravitational correction on shoulder internal and external rotation strength. *Isokinetics and Exercise Science*, *17*(1), 35-39.

Edouard, P., Samozino, P., Julia, M., Gleizes Cervera, S., Vanbiervliet, W., Calmels, P., & Gremeaux, V. (2011). Reliability of isokinetic assessment of shoulder-rotator strength: a systematic review of the effect of position. *Journal of Sport Rehabilitation*, *20*(3), 367-383.

Edouard, P., Codine, P., Samozino, P., Bernard, P. L., Hérisson, C., & Gremeaux, V. (2013). Reliability of shoulder rotators isokinetic strength imbalance measured using the Biodex dynamometer. *Journal of Science and Medicine in Sport*, *16*(2), 162-165.

Ellenbecker, T. S., & Davies, G. J. (2000). The application of isokinetics in testing and rehabilitation of the shoulder complex. *Journal of Athletic Training*, *35*(3), 338.

Ellenbecker, T. S. (1991). A total arm strength isokinetic profile of highly skilled tennis players. *Isokinetics and Exercise Science*, *1*(1), 9-21.

Ellenbecker, T. S., Davies, G. J., & Rowinski, M. J. (1988). Concentric versus eccentric isokinetic strengthening of the rotator cuff objective data versus functional test. *The American Journal of Sports Medicine*, *16*(1), 64-69.

Ellenbeckert, T. S. (1992). Shoulder internal and external rotation strength and range of motion of highly skilled junior tennis players. *Isokinetics and Exercise Science*, *2*(2), 65-72.

Elliott, B., & Anderson, G. (1990). Age-related differences in high-performance overarm throwing patterns. *Journal of Human Movement Studies*, *18*(1), 1-24.

Escamilla, R. F., Fleisig, G. S., Barrentine, S. W., Zheng, N., & Andrews, J. R. (1998). Kinematic comparisons of throwing different types of baseball pitches. *Journal of Applied Biomechanics*, *14*, 1-23.

Escamilla, R. F., Fleisig, G. S., Zheng, N., Barrentine, S. W., & Andrews, J. R. (2001). Kinematic comparisons of 1996 Olympic baseball pitchers. *Journal of Sports Sciences*, *19*(9), 665-676.

Escamilla, R. F., Barrentine, S. W., Fleisig, G. S., Zheng, N., Takada, Y., Kingsley, D., & Andrews, J. R. (2007). Pitching biomechanics as a pitcher approaches muscular fatigue during a simulated baseball game. *American Journal of Sports Medicine*, *35*(1), 23-33.

Escamilla, R. F., & Andrews, J. R. (2009). Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. *Sports Medicine*, *39*(7), 569-590.

Fleisig, G. S., Dillman, C. J., & Andrews, J. R. (1994). Biomechanics of the shoulder during throwing. *The Athlete's Shoulder. Churchill Livingstone,* New York.

Fleisig, G. S., Escamilla, R. F., & Barrentine, S. W. (1998). Biomechanics of pitching: mechanism and motion analysis. *Injuries in Baseball.* Lippincott-Raven, Philadelphia.

Fleisig, C. S., Escamilla, R. F., Andrews, J. R., Matsuo, T., & Barrentine, S. W. (1996). Kinematic and Kinetic Comparison Between Baseball Pitching and Football Passing. *Journal of Applied Biomechanics*, *12*(2), 124-129.

Fleisig, G. S., Andrews, J. R., Dillman, C. J., & Escamilla, R. F. (1995). Kinetics of baseball pitching with implications about injury mechanisms. *American Journal of Sports Medicine*, *23*(2), 233-239.

Forthomme, B., Dvir, Z., Crielaard, J. M., & Croisier, J. L. (2011). Isokinetic assessment of the shoulder rotators: a study of optimal test position. *Clinical Physiology and Functional Imaging*, *31*(3), 227-232.

Franklyn-Miller, A., Falvey, E., McCrory, P., & Brukner, P. (2010). *Clinical Sports Anatomy*. McGraw-Hill, Sydney, Australia.

Freeston, J., Ferdinands, R., & Rooney, K. (2007). Throwing velocity and accuracy in elite and sub-elite cricket players: A descriptive study. *European Journal of Sport Science*, *7*(4), 231-237.

Freeston, J., Carter, T., Whitaker, G., Nicholls, O., & Rooney, K. (2015). Strength and power correlates of throwing velocity in sub-elite male cricket players. *Journal of Strength and Conditioning Research, 5,* 457-462.

Glazier, P.S, Paradisis, G. P., & Cooper, S. M. (2000). Anthropometric and kinematic influences on release speed in men's fast-medium bowling. *Journal of Sports Sciences*, *18*(12), 1013-1021.

Goharpey, S. H., Shaterzadeh, M. J., Emrani, A., & Khalesi, V. (2007). Relationship between functional tests and knee muscular isokinetic parameters in patients with patellofemoral pain syndrome. *Journal of Medical Sciences*, *7*(8), 1315-9.

Gorostiaga, E. M., Granados, C., Ibanez, J., & Izquierdo, M. (2005). Differences in physical fitness and throwing velocity among elite and amateur male handball players. *International Journal of Sports Medicine*, *26*(3), 225-232.

Graichen, H., Stammberger, T., Bonel, H., Englmeier, K. H., Reiser, M., & Eckstein, F. (2000). Glenohumeral translation during active and passive elevation of the shoulder—a 3D open-MRI study. *Journal of biomechanics*, *33*(5), 609-613.

Houghman, P. A. (2010). *An analysis of the biomechanics of pitching in baseball*. Retrieved on March 30, 2014 from http://www.humankinetics.com/excerpts/excerpts/an-analysis-of-the-biomechanics-of-pitching-in-baseball

Hurd, W. J., Kaplan, K. M., ElAttrache, N. S., Jobe, F. W., Morrey, B. F., & Kaufman, K. R. (2011). A profile of glenohumeral internal and external rotation motion in the uninjured high school baseball pitcher, part II: strength. *Journal of Athletic Training*, *46*(3), 289-295.

Jackson, A. S., & Pollock, M. L. (1985). A practical approach for assessing body composition of men, women, and athletes. *Physician and Sports Medicine*, *13*, 195-206.

Jarmey, C. (2013). *The concise book of muscles*. North Atlantic Books, New York.

Jobe, F. W., Tibone, J. E., Perry, J., & Moynes, D. (1983). An EMG analysis of the shoulder in throwing and pitching a preliminary report. *American Journal of Sports Medicine*, *11*(1), 3-5.

Jobe, F. W., Moynes, D. R., Tibone, J. E., & Perry, J. (1984). An EMG analysis of the shoulder in pitching A second report. *American Journal of Sports Medicine*, *12*(3), 218-220.

Johansen, J. A., Grutter, P. W., McFarland, E. G., & Petersen, S. A. (2011).

    Acromioclavicular joint injuries: indications for treatment and treatment options.

    Journal of Shoulder and Elbow Surgery, *20*(2), S70-S82.

Jones, P. A., & Bampouras, T. M. (2010). A comparison of isokinetic and functional methods

    of assessing bilateral strength imbalance. *Journal of Strength and Conditioning*

    Research, *24*(6), 1553-1558.

Juneja, H., Verma, S. K., & Khanna, G. L. (2011). Isometric peak force of shoulder rotators

    in cricketers with and without history of shoulder pain. *Journal of Exercise Science*

    and Physiotherapy, *7*(1), 42.

Kibler, W. B. (1998). The role of the scapula in athletic shoulder function. *American Journal*

    of Sports Medicine, *26*(2), 325-337.

Kibler, W. B., Ludewig, P. M., McClure, P. W., Michener, L. A., Bak, K., Sciascia, A. D., &

    Cote, M. (2013). Clinical implications of scapular dyskinesis in shoulder injury: the

    2013 consensus statement from the 'scapular summit'. *British Journal of Sports*

    Medicine, *47*(14), 877-885.

Koley, S. (2011). A study of anthropometric profile of indian inter-university male cricketers.

    Journal of Human Sport and Exercise, *6*(2), 427-435.

Leigh, S., & Yu, B. (2007). The associations of selected technical parameters with discus

    throwing performance: A cross-sectional study. *Sports Biomechanics*, *6*(3), 269-284.

Levangie, P., & Norkin, C. (2005). *Joint structure and function: a comprehensive analysis*.

    FA Davis.

Levine, W. N., & Flatow, E. L. (2000). The pathophysiology of shoulder instability.

    American Journal of Sports Medicine, *28*(6), 910-917.

Linthorne, N. P., & Everett, D. J. (2006). Soccer: Release angle for attaining maximum

    distance in the soccer throw-in. *Sports Biomechanics*, *5*(2), 243-260.

Luttgens, L and Hamilton N. (1997). *Kinesiology. Scientific basis of human motion (ninth edition).* McGraw-Hill: Boston.Kinesiology.

Mabasa, X. M., Stewart, A., & Fleishman, C. (2002). Isokinetic strength of shoulder internal and external rotators in cricket bowlers. *South African Journal of Physiotherapy*, *58*(2), 35-39.

MacDermid, J. C., Ramos, J., Drosdowech, D., Faber, K., & Patterson, S. (2004). The impact of rotator cuff pathology on isometric and isokinetic strength, function, and quality of life. *Journal of Shoulder and Elbow Surgery*, *13*(6), 593-598.

Marfell-Jones, M., Olds, T., Stewart, A., and Carter, J.E.L. (2006). *International standards for anthropometric assessment*. International Society for the Advancement of Kinanthropometry Publishers, Adelaide, Australia.

Marques, M. C., Van Den Tillaar, R., Vescovi, J. D., & González-Badillo, J. J. (2007). Relationship between throwing velocity, muscle power, and bar velocity during bench press in elite handball players. *International Journal of Sports Physiology and Performance*, *2*(4), 414.

McCleary, R. W., & Andersen, J. C. (1992). Test-retest reliability of reciprocal isokinetic knee extension and flexion peak torque measurements. *Journal of Athletic Training*, *27*(4), 362.

McClure, P. W., Michener, L. A., Sennett, B. J., & Karduna, A. R. (2001). Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *Journal of Shoulder and Elbow Surgery*, *10*(3), 269-277.

Mont, M. A., Cohen, D. B., Campbell, K. R., Gravare, K., & Mathur, S. K. (1994). Isokinetic concentric versus eccentric training of shoulder rotators with functional evaluation of performance enhancement in elite tennis players. *American Journal of Sports Medicine*, *22*(4), 513-517.

Moore, K. L., Dalley, A. F., & Agur, A. M. (2013). *Clinically oriented anatomy*. Lippincott,
    Williams & Wilkins, New York, USA.

Morag, Y., Bedi, A., & Jamadar, D. A. (2012). The rotator interval and long head biceps
    tendon: anatomy, function, pathology, and magnetic resonance imaging. *Magnetic
    Resonance Imaging Clinics of North America*, *20*(2), 229-259.

Murray, T. A., Cook, T. D., Werner, S. L., Schlegel, T. F., & Hawkins, R. J. (2001). The
    effects of extended play on professional baseball pitchers. *American Journal of
    Sports Medicine*, *29*(2), 137-142.

Myers, J. B., Laudner, K. G., Pasquale, M. R., Bradley, J. P., & Lephart, S. M. (2005).
    Scapular position and orientation in throwing athletes. *American Journal of Sports
    Medicine*, *33*(2), 263-271.

Noffal, G. J. (2003). Isokinetic eccentric-to-concentric strength ratios of the shoulder rotator
    muscles in throwers and nonthrowers. *American Journal of Sports Medicine*, *31*(4),
    537-541.

Paine, R., & Voight, M. L. (2013). Invited clinical commentary. The role of the scapula.
    International Journal of Sports Physical Therapy, *8*(5),617.

Pedegana, L. R., Elsner, R. C., Roberts, D., Lang, J., & Farewell, V. (1982). The relationship
    of upper extremity strength to throwing speed. *American Journal of Sports
    Medicine*, *10*(6), 352-354.

Pappas, A. M., Zawacki, R. M., & Sullivan, T. J. (1985). Biomechanics of baseball pitching
    A preliminary report. *American Journal of Sports Medicine*, *13*(4), 216-222.

Pederson, D. and Gore, C. (1996). Anthropometry Measurement Error (Chapter 3). In K.
    Norton and T. Olds (eds.). *Anthropometrica*. University of New South Wales Press,
    Sydney.

Perrin, D. H. (1993). *Isokinetic exercise and assessment*. Human Kinetics, Champaign, Illinois, USA.

Perry, J. A. C. Q. U. E. L. I. N. (1983). Anatomy and biomechanics of the shoulder in throwing, swimming, gymnastics, and tennis. *Clinics in Sports Medicine*, *2*(2), 247-270.

Petchprapa, C. N., Beltran, L. S., Jazrawi, L. M., Kwon, Y. W., Babb, J. S., & Recht, M. P. (2010). The rotator interval: a review of anatomy, function, and normal and abnormal MRI appearance. *American Journal of Roentgenology*, *195*(3), 567-576.

Platanou, T., & Varamenti, E. (2011). Relationships between anthropometric and physiological characteristics with throwing velocity and on water jump of female water polo players. *Journal of Sports Medicine and Physical Fitness*, *51*(2), 185.

Pontaga, I., & Zidens, J. (2014). Shoulder Rotator Muscle Dynamometry Characteristics: Side Asymmetry and Correlations with Ball-Throwing Speed in Adolescent Handball Players. *Journal of Human Kinetics*, *42*(1), 41-50.

Portus, M.R., Sinclair, P.J., Burke, S.T., Moore, D.J.A. & Farhart, P.J. (2000). Cricket fast bowling performance and technique and the influence of selected physical factors during an 8-over spell. *Journal of Sports Sciences*, *18*(12), 999-1011.

Precerutti, M., Garioni, E., Madonia, L., & Draghi, F. (2010). US anatomy of the shoulder: Pictorial essay. *Journal of Ultrasound*, *13*(4), 179-187.

Pyne, D. B., Duthie, G. M., Saunders, P. U., Petersen, C. A., & Portus, M. R. (2006). Anthropometric and strength correlates of fast bowling speed in junior and senior cricketers. *Journal of Strength and Conditioning Research*, *20*(3), 620-626.

Reinold, M.M.; Fleisig, G.S. & Andrews, J.R. (2000). Biomechanics and Rehabilitation of Elbow Injuries during Throwing. *Athletic Therapy Today, 5*(3), 12-18.

Seroyer, S. T., Nho, S. J., Bach, B. R., Bush-Joseph, C. A., Nicholson, G. P., & Romeo, A. A. (2010). The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports Health: A Multidisciplinary Approach*, *2*(2), 135-146.

Shedlarski, A. (2011). The Relationship of Strength and Body Composition to Vertical Jump Ability in Division 1 Female Volleyball Players. *American Journal of Sports Medicine*, *55*(1), 159-164.

Sirota, S. C., Malanga, G. A., Eischen, J. J., & Laskowski, E. R. (1997). An eccentric-and concentric-strength profile of shoulder external and internal rotator muscles in professional baseball pitchers. *American Journal of Sports Medicine*, *25*(1), 59-64.

Stickley, C. D., Hetzler, R. K., Freemyer, B. G., & Kimura, I. F. (2008). Isokinetic peak torque ratios and shoulder injury history in adolescent female volleyball athletes. *Journal of Athletic Training*, *43*(6), 571-577.

Stuelcken, M., Pyne, D., & Sinclair, P. (2007). Anthropometric characteristics of elite cricket fast bowlers. *Journal of Sports Sciences*, *25*(14), 1587-1597.

Terry, G. C., & Chopp, T. M. (2000). Functional anatomy of the shoulder. *Journal of Athletic Training*, *35*(3), 248.

Toyoshima, S., Hoshikawa, T., Miyashita, M., & Oguri, T. (1974). Contribution of the body parts to throwing performance. *Biomechanics IV*, 1, 169-174.

Van den Tillaar, R., & Ettema, G. (2003). Instructions emphasizing velocity, accuracy, or both in performance and kinematics of overarm throwing by experienced team handball players. *Perceptual and Motor Skills*, *97*(3), 731-742.

Van den Tillaar, R., & Ettema, G. (2007). A three-dimensional analysis of overarm throwing in experienced handball players. *Journal of Applied Biomechanics*, *23*(1), 12.

Van den Tillaar, R., & Marques, M. C. (2013). Reliability of seated and standing throwing velocity using differently weighted medicine balls. *Journal of Strength and Conditioning Research*, *27*(5), 1234-1238.

Van Muijen, A. E., Joris, H., Kemper, H. C., & Van Ingen Schenau, G. J. (1991). Throwing practice with different ball weights: Effects on throwing velocity and muscle strength in female handball players. *Sports Medicine, Training and Rehabilitation*, *2*(2), 103-113.

Villasenor-Ovies, P., Vargas, A., Chiapas-Gasca, K., Canoso, J. J., Hernández-Díaz, C., Saavedra, M. Á., & Kalish, R. A. (2012). Clinical anatomy of the elbow and shoulder. *Rheumatología Clínica*, *8*, 13-24.

Wang, H. K., Juang, L. G., Lin, J. J., Wang, T. G., & Jan, M. H. (2004). Isokinetic performance and shoulder mobility in Taiwanese elite junior volleyball players. *Isokinetics and Exercise Science*, *12*(2), 135-141.

Warner, J. J., Micheli, L. J., Arslanian, L. E., Kennedy, J., & Kennedy, R. (1990). Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *American Journal of Sports Medicine*, *18*(4), 366-375.

Wilk, K. E., Andrews, J. R., Arrigo, C. A., Keirns, M. A., & Erber, D. J. (1993). The strength characteristics of internal and external rotator muscles in professional baseball pitchers. *American Journal of Sports Medicine*, *21*(1), 61-66.

Wilk, K. E., Arrigo, C. A., & Andrews, J. R. (1997). Current concepts: the stabilizing structures of the glenohumeral joint. *Journal of Orthopaedic and Sports Physical Therapy*, *25*(6), 364-379.

Wooden, M. J., Greenfield, B., Johanson, M., Litzelman, L., Mundrane, M., & Donatelli, R. A. (1992). Effects of strength training on throwing velocity and shoulder muscle

performance in teenage baseball players. *Journal of Orthopaedic and Sports Physical Therapy*, *15*(5), 223-228.

Yildiz, Y. (2003). Relation between isokinetic muscle strength and functional capacity in recreational athletes with chondromalacia patellae. *British Journal of Sports Medicine*, *37*(6), 475-479.

Zapartidis, I., Skoufas, D., Vareltzis, I., Christodoulidis, T., Toganidis, T., & Kororos, P. (2009). Factors influencing ball throwing velocity in young female handball players. *Open Sports Medicine Journal*, *3*(1), 39-43.

Zinner, C., Sperlich, B., Krueger, M., Focke, T., Reed, J., & Mester, J. (2015). Strength, Endurance, Throwing Velocity and in-Water Jump Performance of Elite German Water Polo Players. *Journal of Human Kinetics*, *45*(1), 149-156.

Appendix A: INFORMATION SHEET

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

Tel: +27 21-959 2350, Fax: 27 21-959 3688

E-mail: ntsoli@uwc.ac.za

INFORMATION SHEET

Project Title: *The relationship between shoulder complex strength and throwing velocity in club cricketers*

What is this study about?

This research project is conducted by Rucia November, a Master's student in Biokinetics from the Department of Sport, Recreation and Exercise Science at the University of the Western Cape. The study will be investigating the relationship between isokinetic strength of the shoulder complex and throwing velocity of cricket bowlers and fielders. You may participate in this study if:

- you are willing to provide consent

- you a male club cricketer at UWC

- you are within the age group of 18-32 years

What will I be asked to do if I agree to participate?

You will be asked to come to the Biokinetics practice as well as the U.W.C cricket oval which are situated on the University of the Western Cape's campus. Isokinetic assessments will be performed at a scheduled time. Maximal throwing velocity tests would be performed at the U.W.C cricket oval. During the isokinetic assessment, it is necessary to wear appropriate sportswear. The tests will be performed using various pieces of exercise

equipment for evaluating, but not only limited to, your work capacity, muscular strength, muscular endurance, flexibility, and body composition. The exercise intensity is variable, but it usually begins at a level you can accomplish and will advance in stages depending on your fitness level. You or we may stop the test at any time, because of signs of distress. All testing is done privately, and the information is kept strictly confidential.

Confidentiality

We will keep your personal information confidential by keeping your identity and data anonymous and secured in a locked filing cabinet in our supervisors office. Furthermore, any information received from this testing will only be used for the purpose of this research study and no identities will be disclosed at any time. No names or personal information is required for this study, other than medically relevant information that may determine your ability to participate in this study. If we write a report or article about this research project, your identity will not be divulged at any time.

Risks and Discomforts

The possibility exists that certain abnormal changes can occur during the tests. These might include abnormal blood pressure, disorder of heart beat, and in rare instances, heart attack, stroke, or death. Every effort will be made to minimize these risks by evaluating preliminary information related to your health and fitness and by observations during testing. If this situation should arise, there will be trained personal with level three first aid qualifications available to assist.

Responsibilities of the Participant

Information you possess about your health status or previous experiences of unusual feelings with physical effort may affect the safety and value of your test. Your prompt reporting of how you feel during the exercise test is also important. You are responsible for fully disclosing such information when requested to do so by the testing staff.

Expected Benefits from the Test

The results obtained from the isokinetic assessment will be used to evaluate the strength of the shoulder complex. Maximal throwing velocity tests will evaluate the throwing speed.

Freedom of Consent

Your permission or participation in this research is completely voluntary. You are free to deny consent or stop the test at any point. You may choose not to take part at all. If you decide to participate in this research, you may choose to withdraw at any time.

Any questions?

This research is being conducted by Rucia November of the Department of Sport, Recreation and Exercise Science at the University of the Western Cape. If you have any questions about the research study, please contact the following

Rucia November

Cell: 073 2037 429

Email: www.rucia.november@gmail.com

Address: see departmental address above

I encourage you to ask any questions about either the tests or the procedures used in the research project. If you have doubts or questions regarding this study and your rights as a research participant or if you wish to report any problems you have experienced related to the study, please contact:

Supervisor: Dr L. Leach

Department of Sport, Recreation and Exercise Science, UWC

Telephone: (021) 959-2653

Fax: (021) 959-3688

Email: lleach@uwc.ac.za

Dean of the Faculty of Community and Health Sciences: Prof Jose Frantz

University of the Western Cape

Private Bag X17

Bellville

Tel: (021) 959-2631

Email: jfrantz@uwc.ac.za

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

Tel: +27 21-959 2350, Fax: 27 21-959 3688

E-mail: ntsoli@uwc.ac.za

CONSENT FORM

Title of Research Project: The relationship between shoulder complex strength and

throwing velocity in club cricketers

The study has been described to me in language that I understand and I freely and voluntarily agree to participate. My questions about the study have been answered. I understand that my identity will not be disclosed and that I may withdraw from the study at any time without giving a reason, and this will not negatively affect me in any way.

Participant's name: ………………………………………………………………….

Participant's signature: …………………………….... Date: ……/……/2014…

Witness Name: …………………………………………………………………….

Witness Signature: …………………………….. Date: ……/……/2014…

Should you have any questions regarding this study or wish to report any problems you have experienced related to the study, please contact the study supervisor:

Study Supervisor Name: Dr. Lloyd Leach

Telephone: (021) 959-2653

Cell: 082 200 6987

Fax: (021) 959-2653   Email: lleach@uwc.ac.za

Appendix C: DEMOGRAPHIC QUESTIONNAIRE

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

Tel: +27 21-959 2350, Fax: 27 21-959 3688

E-mail: ntsoli@uwc.ac.za

QUESTIONNAIRE

Date: _____

Name: _____

ID number: _____

D.O.B: _____

Contact no.: _____

Sport: _____

Level of participation: **Club**   **Provincial**   **National**

Level of participation: **First Team**   **Second Team**   **Third Team**   **Four Team**

Years Playing: _____

Injury: _____ **Year/Month:** _____

Specify: _____

Involved side: R   L   **Treatment received:** _____

Onset: Trauma   **Gradual**   **Other** _____

Other Medical problems: Yes   No   _____

Contra-indications to exercise: Yes   No   _____

**Other orthopaedic problems:**   Yes   No   _____

Appendix D: DATA RECORDING SHEET

Participants	Cricketer ID number	
Information	Participant number	
	Country	
	Ethnicity (B, C, I, W)	
	Sex (Male=1, female=2)	
	Sport	
	Date of Birth	

TEST	Date of Measurement:				
	Time of Measurement:	Measure	Measure	Measure	Final
	Measurements	1	2	3	Measures
	Body mass (kg)				
	Stretch stature (cm)				
	Circumferences (cm)				
	Waist circumference				
	Hip circumference				
	Skinfolds (mm)				
	Chest				
	Abdomen				
	Thigh				
	Length (cm)				
	Acromiale-Radiale				
	Radiale-Stylion				

Midstylion-Dactylion				

Isokinetic Testing				
Shoulder Joint	Left		Right	
60 $^{o} \cdot sec^{-1}$ con/con				
90 $^{o} \cdot sec^{-1}$ con/con				

Maximal Throwing Velocity Test		
Dominant Arm	Left	Right
Speed km/h		
Speed km/h		
Speed km/h		
Speed km/h		
Speed km/h		